NASA Technical Memorandum 100 468

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September 1988

National Aeronautics and
Space Administration

NASA Technical Memorandum 100 468

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ABSTRACT

Unpaced voluntary horizontal head oscillation was used to study the Vestibulo-Ocular Reflex (VOR) on Shuttle flights STS 7 and 8. Ten subjects performed head oscillations at 0.33 Hz and ± 30° amplitude under the following conditions: VVOR (visual VOR), eyes open and fixed on a stationary target; VOR-EC, with eyes closed and fixed on the same target in imagination; VOR-ES, with eyes open but shaded by opaque goggles and fixed on the same target in imagination; and VOR-S (VOR suppression), with eyes open and fixed on a head-synchronized target. Effects of weightlessness, flight phase, and Space Motion Sickness (SMS) on head oscillation characteristics were examined. A significant increase in head oscillation frequency was noted inflight in subjects free from SMS. In subjects susceptible to SMS, frequency was reduced during their symptomatic period. The data also suggest that the amplitude and peak velocity of head oscillation were reduced early inflight.

No significant changes were noted in reflex gain or phase in any of the test conditions; however, there was a suggestion of an increase in VVOR and VOR-ES gain early inflight in asymptomatic subjects. A significant difference in VOR-S was found between SMS susceptible and non-susceptible subjects. There is no evidence that any changes in VOR characteristics contributed to SMS.

INTRODUCTION

A complex spatial reference system essential for interaction with the external environment is constantly maintained in the human nervous system. It is referenced to the head, and two of its three major sensors are located there; i.e., eyes and vestibular organs. Input from the body (somatosensory) is the third major source of reference information. A large portion of this reference system is devoted to visual and ocular control. While primary control of eye position is derived from vision itself (Optokinetic Reflex [OKR]), both amplitude and frequency response of the visual tracking loop during head motion are improved by the inertial input from the semicircular canals with lesser input from the otolith organs and cervical somatosensory neurons(1). This Vestibulo-Ocular Reflex (VOR) operates in both vertical and horizontal planes(2) and its characteristics may be measured by recording eye and head motions under controlled conditions(3).

There are both theoretical and operational reasons for study of the VOR in spaceflight. Effects of weightlessness, an environment unavailable on Earth, may provide additional insight into interaction of semicircular canals and gravity sensing otolith organs and possibly other elements of the greater vestibular system. At one time it seemed possible or even likely that a disturbed VOR which upset visual imagery could be a cause or significant contributor to Space Motion Sickness (SMS)(4). Such a disturbance could arise from physical changes secondary to weightlessness; e.g., transient labyrinthine hydrops from the fluid shifts which are known to occur over roughly the same time period as SMS(5), or from anomalous sensory inputs in a weightless environment.

For these reasons, there has been a continuing interest in VOR studies in weightlessness, beginning with a number of studies in parabolic flight. Such studies, which must be done in brief periods (seconds) of weightlessness preceded and followed by increased G loads, have yielded inconsistent results. Jackson(6), Oosterveld(7), Bludworth(8), and Vesterhauge(9) found no changes in horizontal VOR gains with passive oscillation, while Lackner(4) and Vesterhauge(10) found a decrease. A psychophysiological study of detection threshold of horizontal angular acceleration was done by Graybiel(11) during spaceflight on Skylab and showed no consistent changes.

In 1982, we began a series of inflight studies of VOR on Shuttle missions STS 4-8 and have reported the clinical findings(12) and quantitative results from STS 4-6(13). On STS-6, using active head oscillation as the stimulus, a small increase in the mean horizontal VOR gain of 4 subjects was seen on Mission Day (MD) 4. Small increases in phase shift with vision blocked were also found on MD 2 and 4. The subjects denied any visual symptoms under test and operating conditions. Single head turns were used in a second experiment(14), and results showed an increased VOR gain in 2 subjects early inflight, up to 1.8 in one subject.

In November 1983, Benson(15) devised an ad hoc experiment on STS 9/Spacelab 1 to study changes in horizontal and vertical VOR gain using voluntary head oscillation at 1 Hz with eyes closed. A measurement from one subject on MD 5 showed a gain of 0.6, while a second subject had a gain of 0.4 on MD 7. Preflight data were not available, but mean postflight gains of the two subjects were 0.65 and 0.6, respectively.

Watt(16) designed a psychophysiological study of VOR gain in two subjects on Shuttle mission STS 41-G (1984) using voluntary head oscillations of increasing frequency until oscillopsia occurred. No changes were observed between pre-, in- and postflight periods.

In 1985, Viéville(17) studied VOR gain and VOR suppression of one subject on STS 51-G. The methods used were in principle similar to ours. They assumed a mean VOR horizontal gain of 1.0 preflight and found gains of 0.7, 0.75, and 0.9 on MD 1, 4, and 7, respectively, with no change in VOR suppression inflight or postflight.

Soviet investigators measured VOR gain in head turns during changes in gaze fixation in human subjects before and after spaceflight(18), and in 1985, Kozlovskaya reported on eye and head motions of a primate during gaze fixation on Kosmos-1514(19). Sirota repeated the experiment on two monkeys on Kosmos-1667(20). Both primate studies showed a 1.5-2.0 fold increase in the VOR gain for a portion of the flight, based on measurements from single head turns.

This report presents results from voluntary head oscillation and horizontal VOR studies from STS 7 and 8, June and August 1983, which were part of a Johnson Space Center (JSC) program to investigate neurological adaptation to spaceflight. Its purpose is to present the findings and their analysis as well as to archive the reduced data such that others may use them as desired; hence the extensive appendix. Major differences from previous studies in this experimental series were the extent of the investigations, participation of all crewmembers, and presence of onboard physicians trained in the experimental techniques.

Although standard procedures and techniques were used, methods of this study were constrained by operational flight conditions. These constraints included minimum time and complexity, and minimal subject (i.e., flight crew) impact. This necessitated the use of active head oscillation at a single frequency as the stimulus. In addition to examining VOR gain, it was also possible to examine the effects that experimental variables (such as weightlessness, flight duration, presence or absence of SMS, susceptibility to SMS, and return to 1-G) had on the characteristics of voluntary head oscillation.

MATERIALS AND METHODS

All subjects were astronauts with no known visual or vestibular defects and included the entire crews of STS 7 and 8. They comprised 9 males and one female, with ages from 32 to 54 years old. Six of the male subjects were high performance jet pilots, and two had prior spaceflight experience.

Preflight measurements were recorded by the crewmember physicians as part of the training of the crew, and were made in Shuttle simulators using locations and dimensions equivalent to those inflight. Inflight studies were administered on the orbiter middeck by the onboard physician and postflight by the principal investigator in laboratory space dimensionally equivalent to flight configuration. The same flight hardware was used in all studies and a checklist was used to standardize the protocol.

Eye position recording. Eye movement was recorded by standard electrooculography (EOG). Ag-AgCl 1 cm diameter electrodes were placed at the outer canthus of each eye with a ground electrode mid-forehead. A DC to 120 Hz amplifier was used except when manual drift correction was not practical, and then an AC amplifier (0.05 to 100 Hz) was employed. Phase and gain characteristics of both units were measured (Table II-1). A miniature two-channel FM magnetic tape recording system, DC-100 Hz, was developed and used, as well as the Shuttle Operational Bio-instrumentation System (OBS). The latter is a digital telemetry system sampled at 400 Hz with 8 bit sample resolution. The graphic record was made at 10 mm/sec using a Brush model ECP-2400 strip chart recorder with 100 mm record width and DC to >60 Hz response. Overall system response was >30 Hz with a reliable resolution of <2° eye motion. All recordings met or exceeded the clinical standards established for EOG work(21).

Head position recording. A 360° low torque potentiometer with 0.1% linearity was driven by 2:1 precision gearing such that head motion was effectively doubled and worst case accuracy became 0.05% of 180°. Calibration was done prior to each recording by rotating the potentiometer through its full range of motion, subtracting the measured dead band (7°) of each unit, then using the effective angle turned and resulting recorded deflection to calculate a scale factor.

The potentiometer was coupled to the center of head rotation through a short flexible drive and a closely fitting elastic cap. Error from inadvertant translational head movements was avoided by mounting the potentiometer on a pantograph which allowed ±5 cm linear motion from center in any horizontal direction without inducing measurable angular motion in the potentiometer. The flexible drive plus a vertical swivel mounting allowed for small changes in height without inducing angular errors. Zero angle was taken as that with the eyes and head fixated on the center calibration light. Power source of the potentiometer was a Hg battery, Zener regulated. Output was recorded by the same DC systems described under EOG. Measured worst case overall accuracy was 2°.

Protocol. Methodology was the same on both flights. Measurement of eye and head motions were made during voluntary horizontal head oscillaton under the following designated conditions: VVOR (Visual Vestibulo-Ocular Reflex), eyes open and fixed on an external stationary target; VOR-EC, eyes closed but fixed on the same target in imagination; VOR-ES, eyes open but shaded by opaque goggles and fixed on the same target in imagination; and VOR-S (VOR suppression), eyes open but fixed on a head synchronized target. Subjects were trained to make a minimum of 5 horizontal oscillations of the head for each condition at a frequency of 0.33 Hz and an amplitude of 30° right and left of center. Nominal test sequence began with calibrations of the potentiometer and EOG, then a sequence of VVOR followed immediately by VOR-EC. Goggles were donned and a sequence of VOR-ES performed. The goggles were removed, the head synchronized target positioned and a sequence of VOR-S completed, followed by a second calibration of the EOG. The entire test run required approximately 2 minutes. Dark adaptation was not practical because of time constraints.

Subjects were seated pre- and postflight in an upright Shuttle crew seat with its restraint harness fastened (shoulder straps and lap belt), or equivalent. Inflight, the seat was attached back down to the deck, with subjects restrained by the harness. The target LEDs were mounted on the overhead at a fixed distance of 1.5 m. They were 4.5×7 mm red LEDs with an emission area of <1 mm^2, located at horizontal visual angles of zero and 10° and 20° right and left. They were switched at a period of 1.0 sec^{-1} in a pseudo-random fashion for calibration of the EOG. The head synchronized target was a 5 mm white sphere on the axis of the eyes and coupled to a head cap by a light, rigid 42 cm long bar.

Data reduction. Data were manually derived from graphic records after semi-automated computer techniques were found to be unsatisfactory. All records were analyzed by the following methods for the features shown in figure 1. Head oscillation amplitude was measured peak to peak using the scale factors derived from the potentiometer calibration of each study. Head oscillation frequency is the reciprocal of the periods of each cycle measured, using the recorder time calibration. Waveforms of head oscillations were qualitatively assessed and recorded. Symmetry of oscillation amplitude, right vs. left, was measured.

EOG records were calibrated by taking the mean of the deflections for the ±20° calibration lights. The first EOG calibration was used for the VVOR and VOR-EC sequences and the second one for VOR-ES and VOR-S. Eye oscillation amplitudes and frequencies were derived using the techniques for head amplitudes and frequencies. Changes in eye amplitude induced by the finite target distance were corrected by Mansson's techniques(22) using measured head and target dimensions.

VVOR, VOR-EC and VOR-ES gains were derived by dividing means of eye amplitudes by head amplitudes for each sequence. Phase shift was measured by taking the time difference between eye and head oscillation peaks (ϕ in figure 1), dividing by the period of the cycle of the head oscillation and converting to degrees.

VOR-S gains were too small to allow reliable

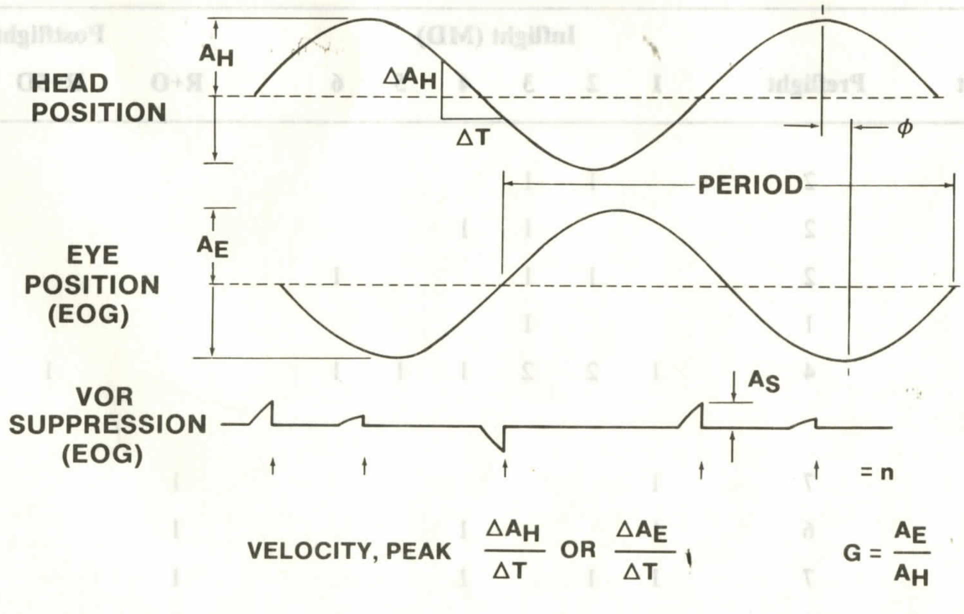

Figure 1.— Schematic of graphic record to illustrate data reduction methods. A_H, A_E, and A_S: amplitude of head, eye, and nystagmus slips; frequency = period^{-1} of head and eye oscillation; ϕ, phase shift between head and eye position; G, gain; n, number of nystagmus slips; EOG, electrooculogram.

comparisons. The number and mean amplitude of nystagmoid eye movements (designated "slips") per 2 head cycles were used instead as figures of merit.

Statistical analysis. Variability of data sampling times caused by operational constraints made it necessary to combine inflight data into two epochs, MD 1-2 and MD 3-6. Since the first epoch corresponds to the period of SMS symptoms for all those affected, this division allows not only a comparison between early and late flight phases but also between SMS susceptible and non-susceptible populations.

For some of the variables, statistical analysis was carried out on 7 of the 10 participating subjects who had consistent sampling times, i.e., preflight and the two inflight epochs. For other parameters, this sample size was reduced to four subjects. The General Linear Models procedure in the Statistical Analysis System (SAS) software package was used to determine statistical relations(23). Multivariate analysis of variance(24) and analysis of variance of contrast variables allowed comparisons among the three experimental conditions, as well as between preflight and inflight measurements. Independent t-tests were used to compare SMS susceptible and non-susceptible populations at each sampling period.

In addition, for descriptive analysis, graphs were prepared presenting the data for all individuals as a function of flight phase.

RESULTS

Table 1 summarizes the records and times they were made. There were combined totals of 54 preflight, 27 inflight and 14 postflight records from 10 subjects. Accurate head amplitude data were lost inflight after MD 1 on STS 7 due to technical problems. This eliminated all subsequent inflight VOR gain measurements on STS 7, but frequency and number of head turns derived from EOG tracings remain valid. All unprocessed data appear in the Appendix.

Head oscillation parameters. Individually, most of the subjects tended to increase the frequency of head oscillation inflight compared to preflight, regardless of whether vision was present (fig. 2). As a group (n=7), this increase reached statistical significance during the second inflight epoch for all three test conditions (fig. 3). However, individuals with SMS (n=3) reduced the frequency during the first inflight epoch. The difference in frequency between susceptible and

Table 1.— Schedule of Records Obtained

		Inflight (MD)						Postflight		
Flight/Subject	Preflight	1	2	3	4	5	6	R+O	R+5D	R+10D
STS-7										
1	2		1	1						
2	2			1	1					3
3	2		1	1			1			
4	1			1						
5	4	1	2	2	1	1	1		1	1
STS-8										
6	7	1						1		1
7	6	1			1			1		1
8	7	1	1		1			1		1
9	8	1				1		1		
10	15		1		1	1		1		1

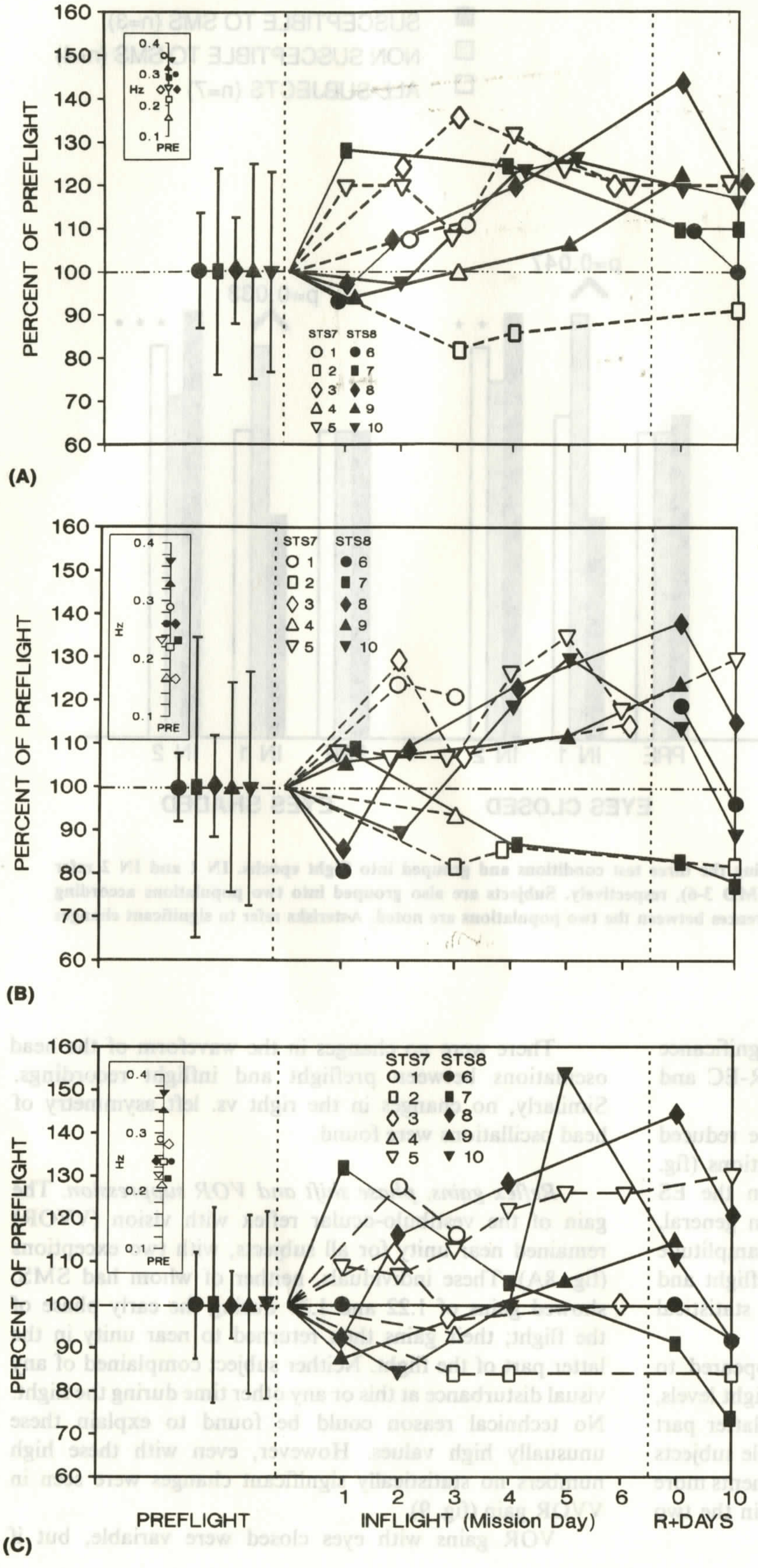

Figure 2.— Frequency of head oscillation of individual subjects as a function of flight phase, expressed as percent of preflight frequency. Absolute preflight values are represented in the insets. (A) VVOR with eyes open; (B) VOR with eyes closed; and (C) VOR with eyes shaded.

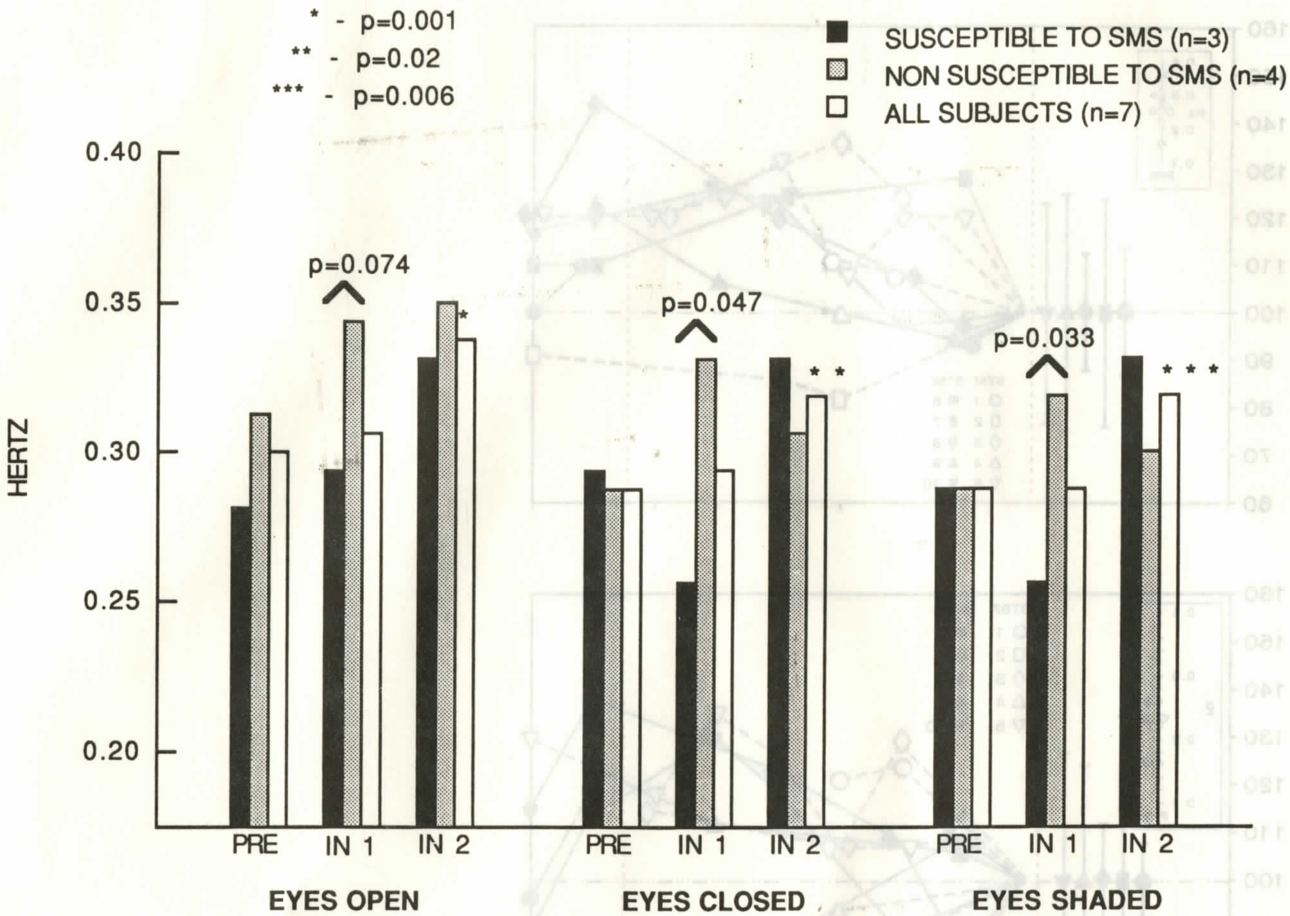

Figure 3.— Means of head oscillation frequency during the three test conditions and grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjects are also grouped into two populations according to susceptibility to SMS. Statistically significant differences between the two populations are noted. Asterisks refer to significant changes in the mean of all subjects from preflight values.

non-susceptible populations reached statistical significance in the two test conditions without vision (VOR-EC and VOR-ES).

Amplitude of head oscillation tended to be reduced inflight for most subjects under all three conditions (fig. 4). This reached statistical significance only in the ES condition in the early inflight epoch (fig. 5). In general, the SMS susceptible population made smaller amplitude oscillations than the non-susceptible group, preflight and inflight. The small size of the groups precluded statistical tests to support these trends

Maximum velocity of head oscillation appeared to decrease early inflight, but then returned to preflight levels, or even exceeded them in some cases, by the latter part of the flight (fig. 6). As a group, SMS susceptible subjects tended to reduce the velocity of their head movements more than the non-susceptible individuals, especially in the two conditions when vision was blocked (fig.7).

There were no changes in the waveform of the head oscillations between preflight and inflight recordings. Similarly, no changes in the right vs. left asymmetry of head oscillations were found.

Reflex gains, phase shift and VOR suppression. The gain of the vestibulo-ocular reflex with vision (VVOR) remained near unity for all subjects, with two exceptions (fig. 8A). These individuals, neither of whom had SMS, showed gains of 1.22 and 1.39 during the early phase of the flight; their gains then returned to near unity in the latter part of the flight. Neither subject complained of any visual disturbance at this or any other time during the flight. No technical reason could be found to explain these unusually high values. However, even with these high numbers no statistically significant changes were seen in VVOR gain (fig. 9).

VOR gains with eyes closed were variable, but if

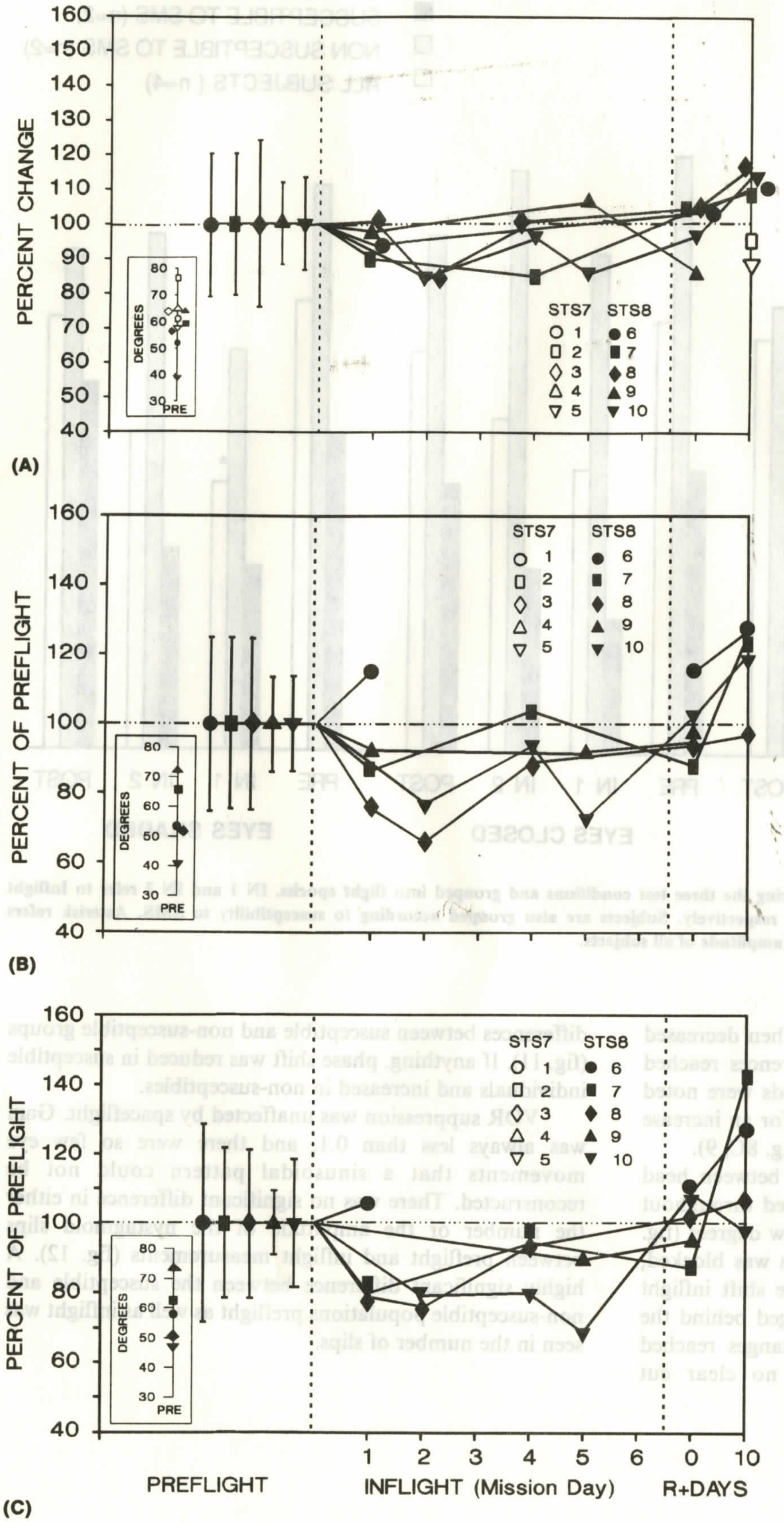

Figure 4.— Amplitude of head oscillation of individual subjects as a function of flight phase, expressed as percent of preflight amplitude. Absolute preflight values are represented in the insets. (A) VVOR with eyes open; (B) VOR with eyes closed; and (C) VOR with eyes shaded.

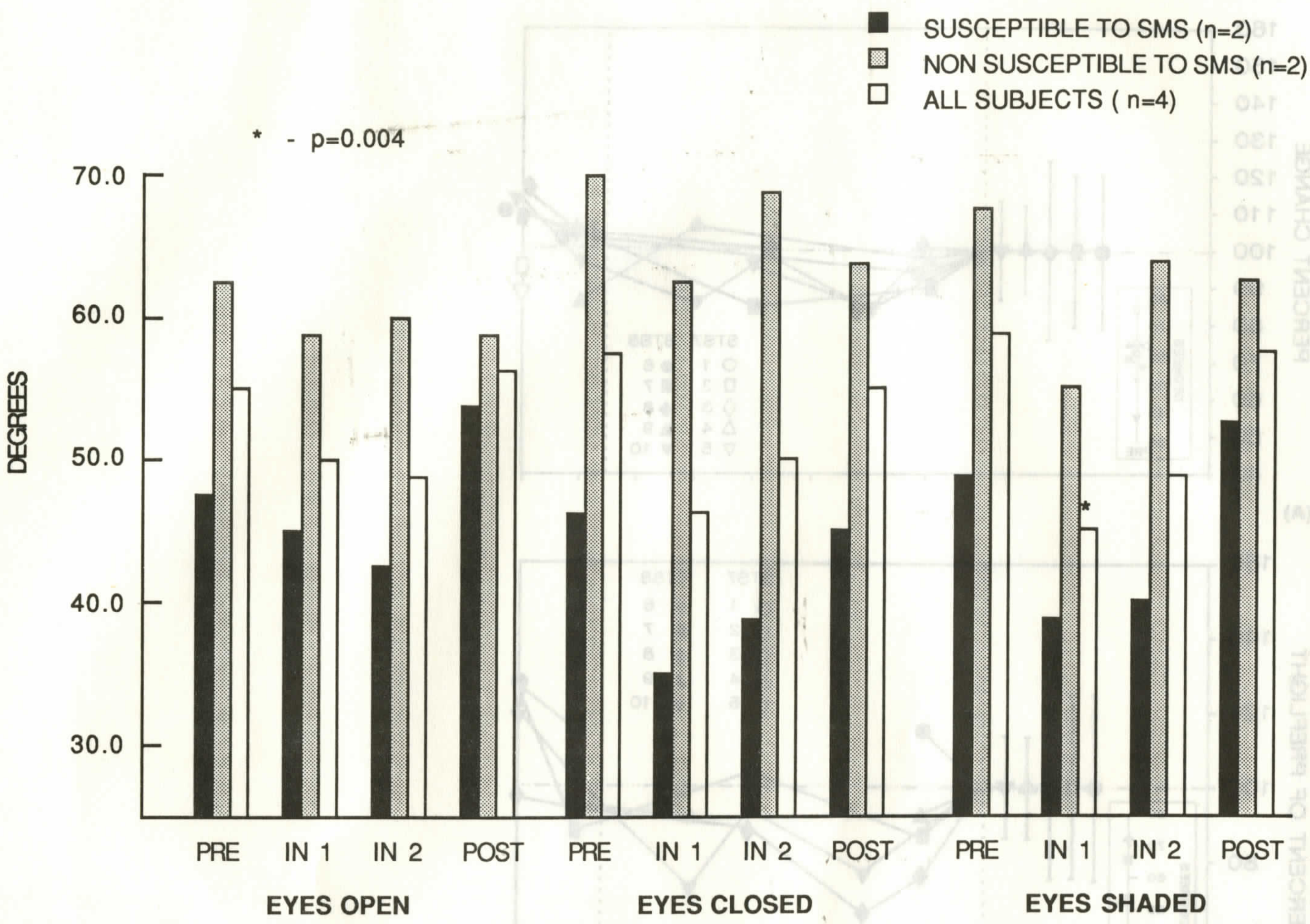

Figure 5.— Means of head oscillation amplitude during the three test conditions and grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjects are also grouped according to susceptibility to SMS. Asterisk refers to significant change from preflight value in the mean amplitude of all subjects.

anything were slightly increased early and then decreased later inflight (fig. 8B). None of these differences reached statistical significance (fig. 9). No clear trends were noted in gains with eyes open but shaded, except for an increase in the non-susceptible group early inflight (fig. 8C, 9).

With eyes open, the phase difference between head and eye movement was essentially unchanged throughout the flight, the eyes leading the head by a few degrees (fig. 10A). More variation was seen when vision was blocked, with a slight trend toward decreased phase shift inflight (fig. 10B, C). In several cases, the eyes lagged behind the head by a few degrees. None of these changes reached statistical significance, and there were no clear cut differences between susceptible and non-susceptible groups (fig. 11). If anything, phase shift was reduced in susceptible individuals and increased in non-susceptibles.

VOR suppression was unaffected by spaceflight. Gain was always less than 0.1, and there were so few eye movements that a sinusoidal pattern could not be reconsructed. There was no significant difference in either the number or the amplitude of the nystagmoid slips between preflight and inflight measurements (fig. 12). A highly significant difference between the susceptible and non-susceptible populations preflight as well as inflight was seen in the number of slips.

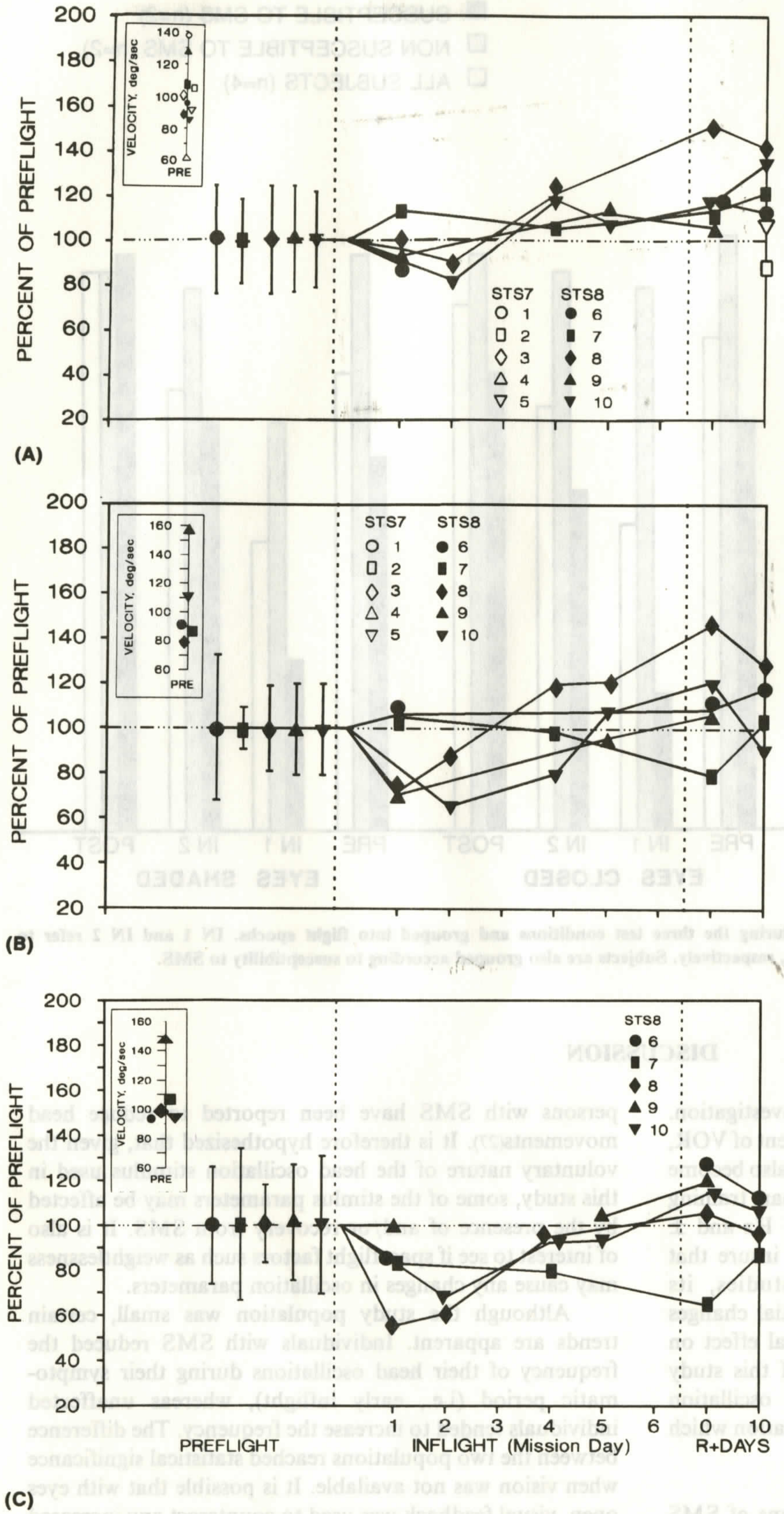

Figure 6.— Peak velocity of head oscillation of individual subjects as a function of flight phase, expressed as percent of preflight velocity. Absolute preflight values are represented in the insets. (A) VVOR with eyes open; (B) VOR with eyes closed; and (C) VOR with eyes shaded.

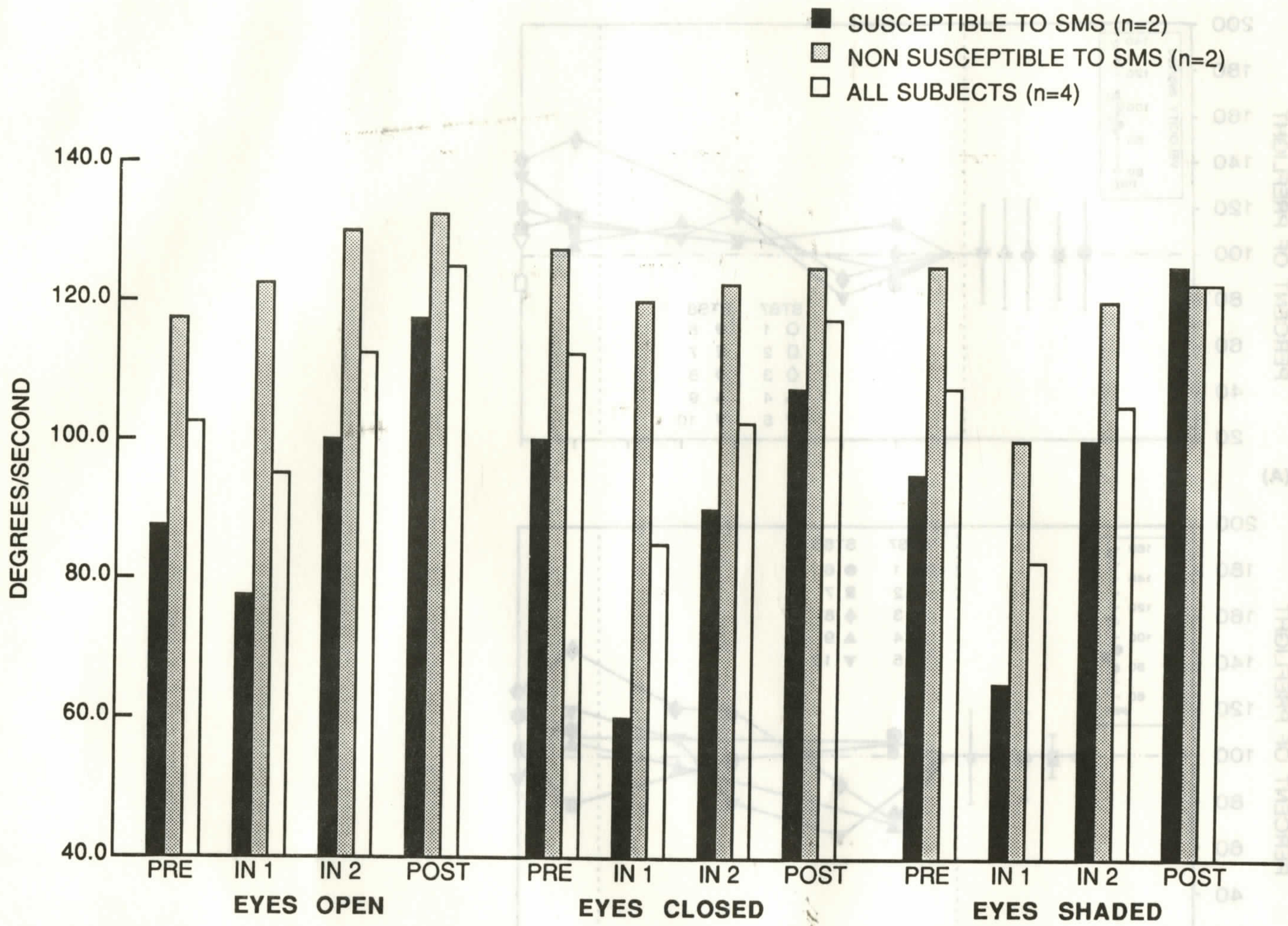

Figure 7.— Means of head oscillation peak velocity during the three test conditions and grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjects are also grouped according to susceptibility to SMS.

DISCUSSION

Study of SMS was a major concern of this investigation. Head oscillation, the stimulus used in measurement of VOR, was deliberately not constrained so that it could also become an indicator of the effects of SMS. Other than training the subjects to make head oscillations at 0.33 Hz and ± 30° amplitude, no pacers were employed. To insure that the stimulus would be valid for VOR studies, its characteristics were chosen so that any potential changes in frequency or amplitude would have minimal effect on reflex gain(25, 26). Evaluation of the results of this study must begin with examination of the head oscillation stimulus for any effects of SMS and for any variation which might have affected VOR results.

Head oscillation. One of the first symptoms of SMS is increased sensitivity to angular head motions(5) and persons with SMS have been reported to reduce head movements(27). It is therefore hypothesized that, given the voluntary nature of the head oscillation stimulus used in this study, some of the stimlus parameters may be affected by the presence of and/or recovery from SMS. It is also of interest to see if spaceflight factors such as weightlessness may cause any changes in oscillation parameters.

Although the study population was small, certain trends are apparent. Individuals with SMS reduced the frequency of their head oscillations during their symptomatic period (i.e., early inflight), whereas unaffected individuals tended to increase the frequency. The difference between the two populations reached statistical significance when vision was not available. It is possible that with eyes open, visual feedback was used to counteract any increased sensitivity to head motion. Later inflight, all subjects showed

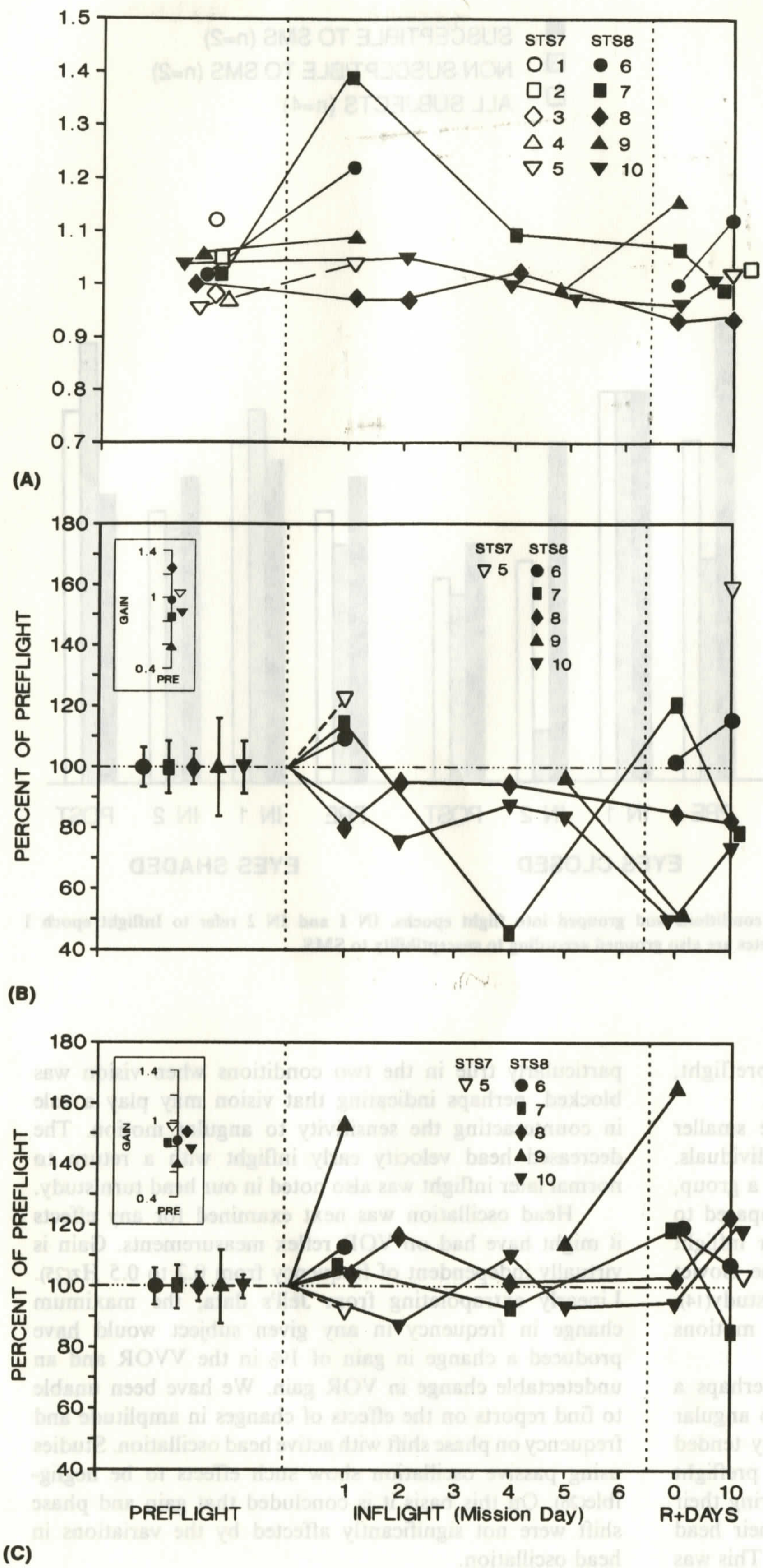

Figure 8.— Reflex gains of individual subjects as a function of flight phase. Expressed as absolute values in (A) VVOR gain with eyes, and as percent of preflight in (B) VOR gain with eyes closed and (C) VOR gain with eyes shaded.

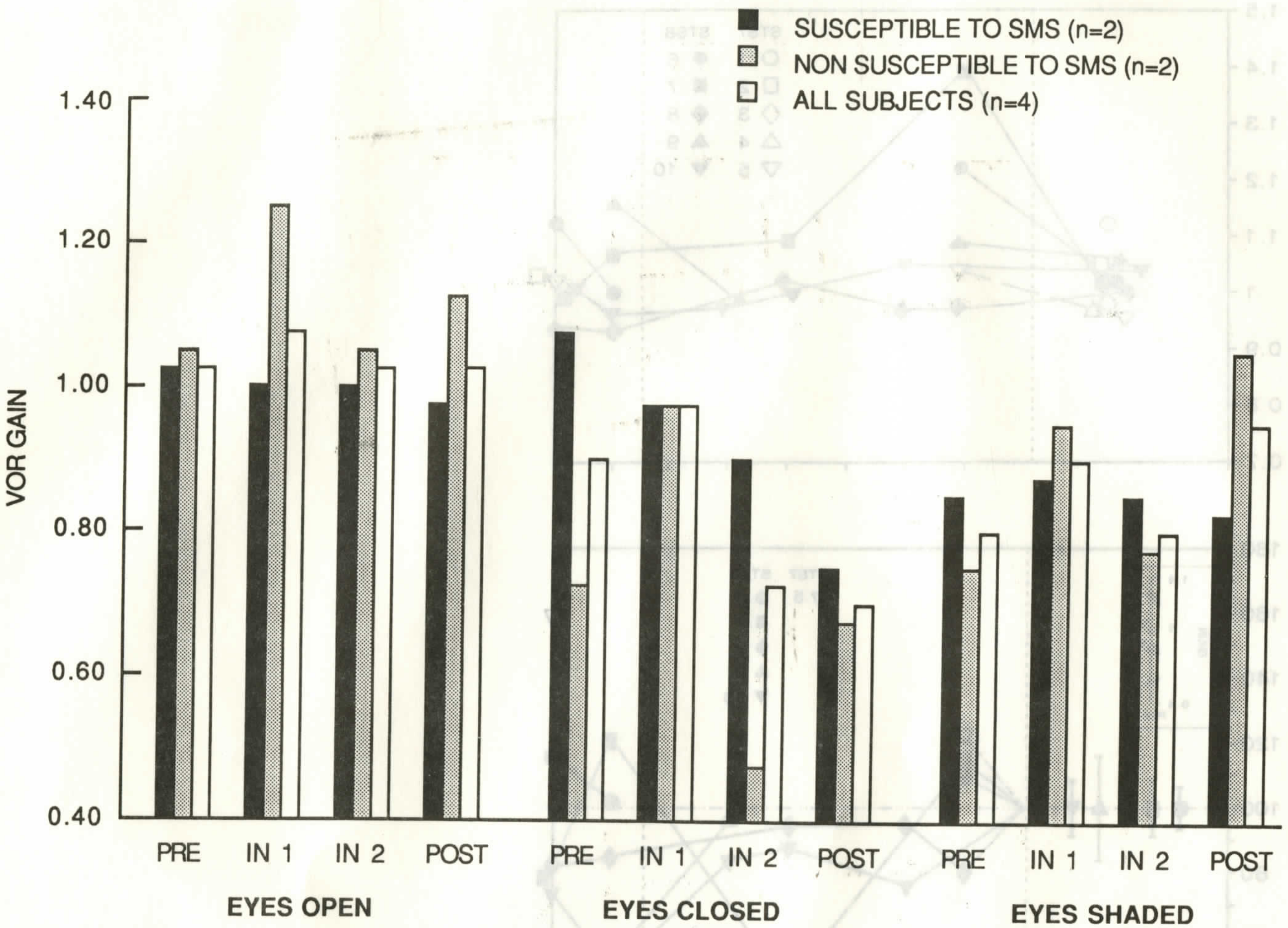

Figure 9.— Means of reflex gains during the three test conditions and grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjetcs are also grouped according to susceptibility to SMS.

higher frequency oscillations compared to preflight, including the ones who had recovered from SMS.

Subjects who had SMS consistently made smaller amplitude head oscillations than non-affected individuals. This was the case preflight as well as inflight. As a group, all subjects decreased the amplitude inflight compared to preflight. This finding is consistent with similar inflight decreases in head amplitude noted in both the Soviet primate studies(19, 20) and our human head turn study(14). Oman also found a reduction in angular head motions during SMS on Spacelab 1(27).

Maximum velocity of head oscillation is perhaps a more specific indicator of increased sensitivity to angular head motion. As we have seen, the peak velocity tended to be decreased early inflight, then returned to preflight levels (or even exceeded them) later inflight. During their period of illness, subjects with SMS reduced their head velocities more than the non-affected individuals. This was particularly true in the two conditions when vision was blocked, perhaps indicating that vision may play a role in counteracting the sensitivity to angular motion. The decreased head velocity early inflight with a return to normal later inflight was also noted in our head turn study.

Head oscillation was next examined for any effects it might have had on VOR reflex measurements. Gain is virtually independent of frequency from 0.2 to 0.5 Hz(25). Linearly extrapolating from Jell's data, the maximum change in frequency in any given subject would have produced a change in gain of 1% in the VVOR and an undetectable change in VOR gain. We have been unable to find reports on the effects of changes in amplitude and frequency on phase shift with active head oscillation. Studies using passive oscillation show such effects to be negligible(26). On this basis it is concluded that gain and phase shift were not significantly affected by the variations in head oscillation.

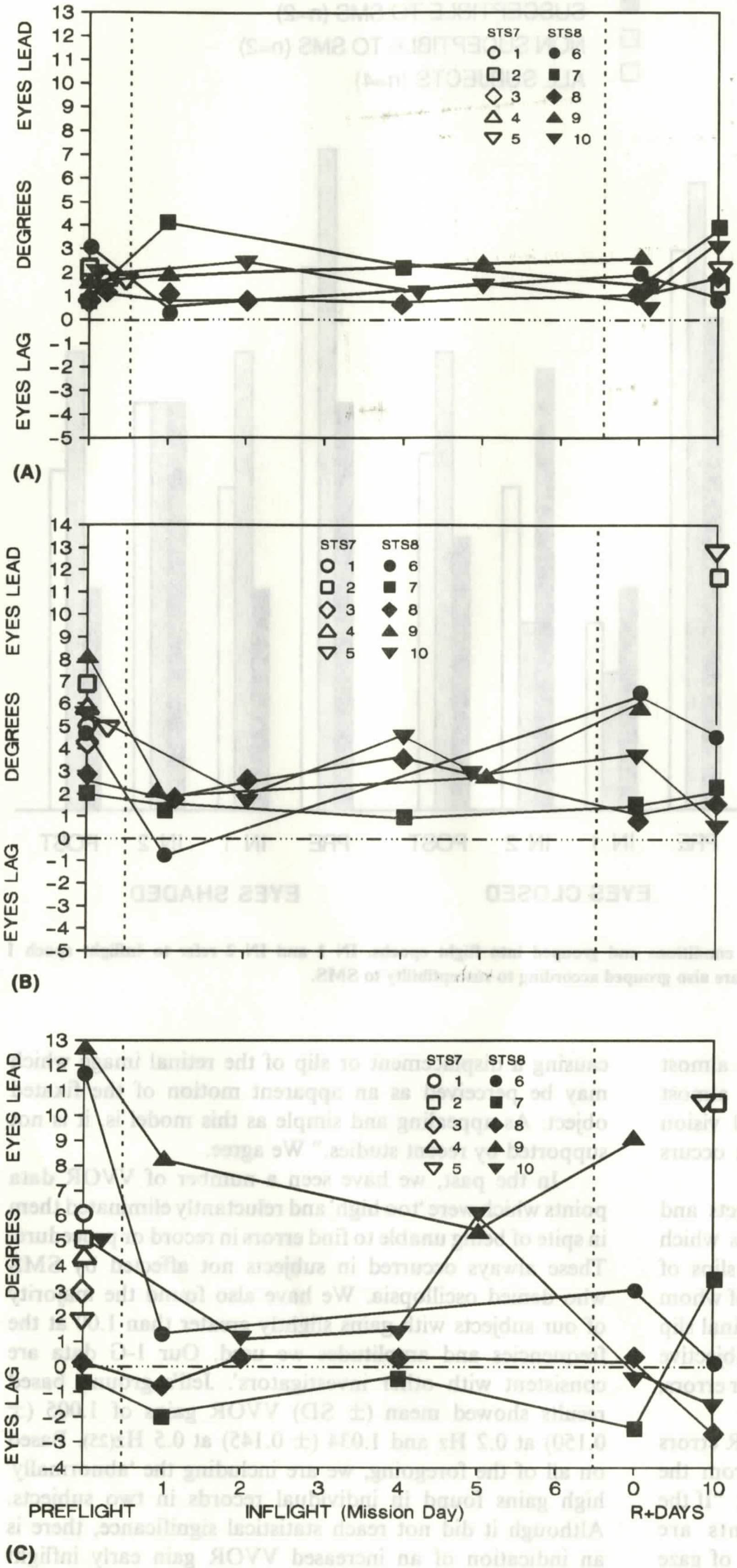

Figure 10.— Eye/head phase relations of individual subjects as a function of flight phase. (A) VVOR eyes open; (B) VOR eyes closed; and (C) VOR eyes shaded.

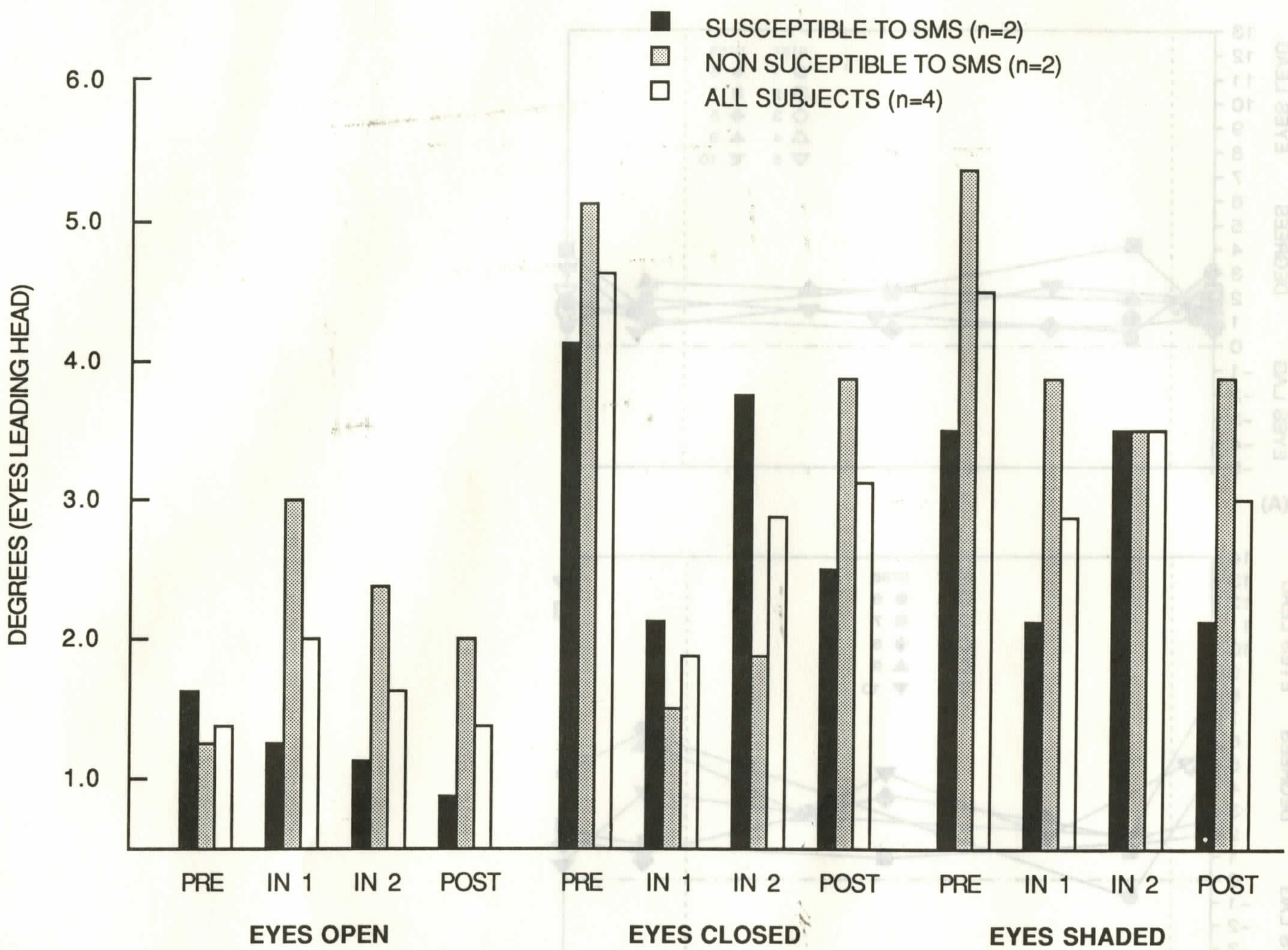

Figure 11.— Means of phase relations during the three test conditions and grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjects are also grouped according to susceptibility to SMS.

Reflex gains and phase relations. While it is almost universally assumed that VVOR gain must be almost exactly 1.00 and phase shift negligible for foveal vision to be maintained without oscillopsia, this seldom occurs under laboratory conditions in normal subjects.

Wist(28) conducted a study of 18 normal subjects and several patients with various oculomotor problems which produced retinal slip. At 1 Hz head oscillation, slips of 3° in 40° amplitude were present in subjects, none of whom complained of oscillopsia. One patient had 10° retinal slip in 46° (+/- 23°) head deviation at 0.66 Hz with no subjective oscillopsia. Steinman and Collewijn(29) found similar errors, all without oscillopsia at 1 Hz and below.

The commonly accepted position is that VVOR errors greater than 1° will displace the target image from the fovea resulting in oscillopsia, but to quote Wist(28): "If the amplitude and/or velocity of eye movements are inappropriate, the result is a shift in the direction of gaze causing a displacement or slip of the retinal image which may be perceived as an apparent motion of the fixated object. As appealing and simple as this model is, it is not supported by recent studies." We agree.

In the past, we have seen a number of VVOR data points which were 'too high' and reluctantly eliminated them in spite of being unable to find errors in record or procedure. These always occurred in subjects not affected by SMS who denied oscillopsia. We have also found the majority of our subjects with gains slightly greater than 1.00 at the frequencies and amplitudes we used. Our 1-G data are consistent with other investigators'. Jell's ground based results showed mean (± SD) VVOR gains of 1.005 (± 0.150) at 0.2 Hz and 1.034 (± 0.145) at 0.5 Hz(25). Based on all of the foregoing, we are including the 'abnormally' high gains found in individual records in two subjects. Although it did not reach statistical significance, there is an indication of an increased VVOR gain early inflight

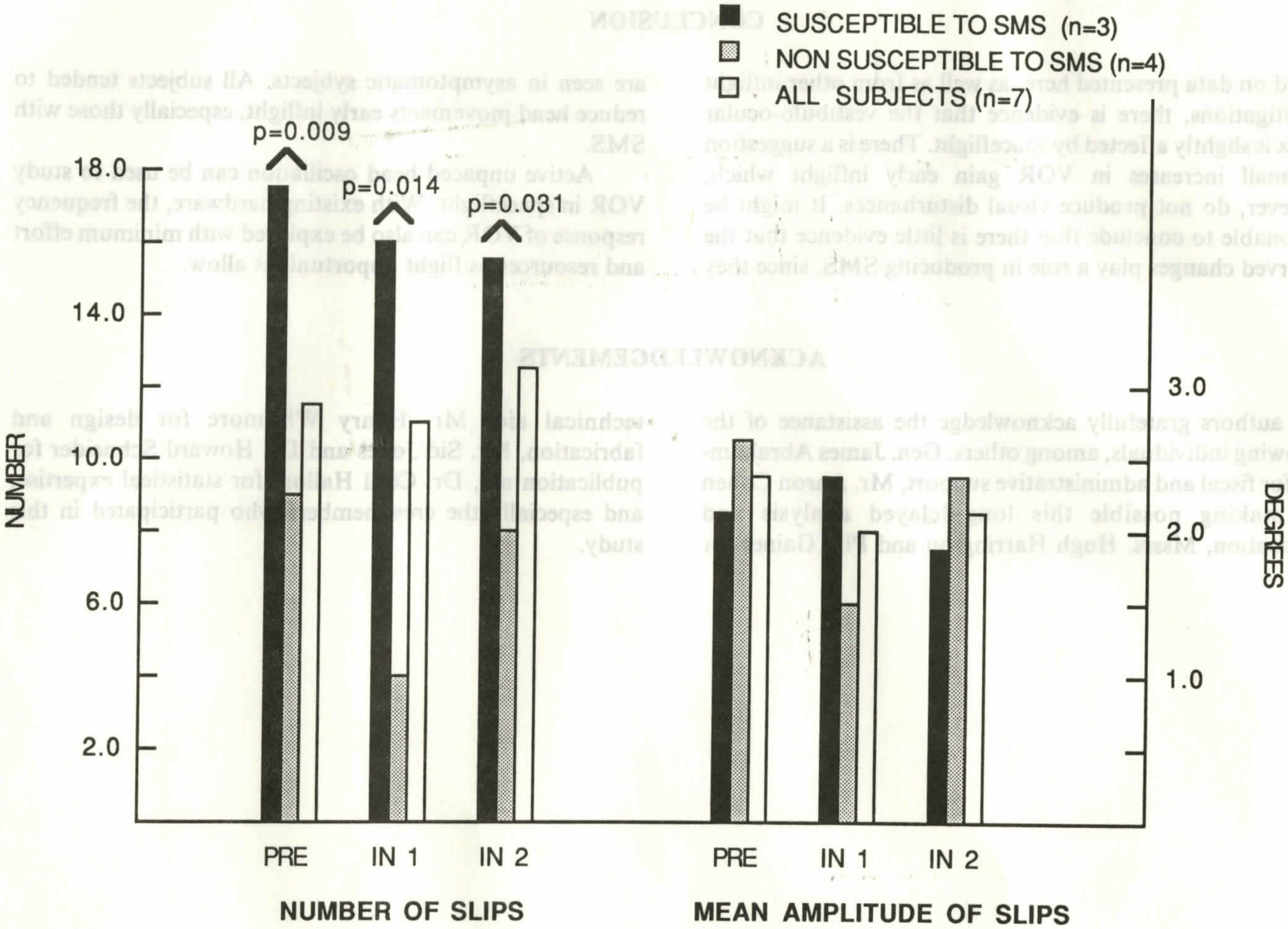

Figure 12.— VOR suppression. Mean number of slips and their mean amplitude in degrees grouped into flight epochs. IN 1 and IN 2 refer to Inflight epoch 1 (MD 1-2) and Inflight epoch 2 (MD 3-6), respectively. Subjects are also grouped according to susceptibility to SMS. Statistically significant differences between the two populations are noted.

in subjects not affected by SMS.

We place little value on eyes closed studies for their results are frequently variable and inconsistent. VOR-EC data are shown here only for comparison with other inflight studies. VOR-ES values were increased during the first flight period and postflight but did not reach significance. Preflight values for VOR-ES found here are consistent with other crews and other investigators.

Based on these results, there is a slight but consistent suggestion that VOR gain may be increased during the first 1 to 2 days of spaceflight. This is supported by the gaze shift studies we did in humans and by the Soviet primate studies. Conversely, we saw no such changes in 4 subjects on STS 6, but we did see a significant increase in VOR-ES values in the second inflight period. The differences between flights may be accounted for by differences in the eye-to-target distances, which were much shorter on STS-6. Although this was accounted for geometrically, the VOR is known to be extremely plastic and sensitive to target distance(30). Sampling error in the small populations is also a possibility.

VOR suppression. Our studies, both pre- and inflight, consistently had sinusoidal components too low to reliably measure (gain < 0.1) and the nystagmus beats too infrequent to allow either sinusoidal reconstruction or reasonable estimates of velocities. Although other investigators report gains at these frequencies, Benson's subjects also had gains and nystagmus too low to measure(15). We feel it is more realistic to consider the infrequent nystagmus as tracking errors and corrections or 'slips' which are better characterized by number and magnitude. The number of slips were significantly greater at all times in the SMS susceptible population, but no changes were seen inflight. The mean amplitude of the slips was unchanged.

CONCLUSION

Based on data presented here, as well as from other inflight investigations, there is evidence that the vestibulo-ocular reflex is slightly affected by spaceflight. There is a suggestion of small increases in VOR gain early inflight which, however, do not produce visual disturbances. It might be reasonable to conclude that there is little evidence that the observed changes play a role in producing SMS, since they are seen in asymptomatic sybjects. All subjects tended to reduce head movements early inflight, especially those with SMS.

Active unpaced head oscillation can be used to study VOR in spaceflight. With existing hardware, the frequency response of VOR can also be explored with minimum effort and resources as flight opportunities allow.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of the following individuals, among others: Gen. James Abrahamson for fiscal and administrative support, Mr. Aaron Cohen for making possible this long-delayed analysis and publication, Mssrs. Hugh Harrington and Phil Gainer for technical aid, Mr. Henry Whitmore for design and fabrication, Mr. Sid Jones and Dr. Howard Schneider for publication aid, Dr. Cecil Hallum for statistical expertise, and especially the crewmembers who participated in this study.