NASA Technical Memorandum 100 466

Eye and Head Motion During Head Turns in Spaceflight

(NASA-TM-100466) EYE AND HEAD MOTION DURING HEAD TURNS IN SPACEFLIGHT (NASA) 26 p CSCL 06P

N89-14676

Unclas
G3/52 0185226

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July 1988

NASA
National Aeronautics and
Space Administration

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ABSTRACT

Eye-head motion was studied pre-, in- and postflight during single voluntary head turns. A transient increase in vestibuloocular reflex (VOR) gain occurred early in flight, but later trended toward normal. This increased gain was produced by a relative increase in eye counterrotation velocity. Asymmetries in gain with right and left turns also occurred, caused by asymmetries in eye counterrotation velocities. These findings were remarkably similar to those from Russian primate studies using gaze fixation targets, except the human study trended more rapidly toward normal. These findings differ substantially from those measuring VOR gain by head oscillation, in which no significant changes were found inflight. No visual disturbances were noted in either test condition or in normal activities. These head turn studies are the only ones to date documenting any functional change in VOR in weightlessness.

INTRODUCTION

The following are results from a portion of the study of neurological adaptation, performed as a joint investigation by Johnson Space Center Flight Operations Division and Medical Sciences Division on STS-4 (1982) through STS-8 (1983)(1). This portion of the investigation had two goals, study of abnormal nystagmus and examination of interaction of eye-head motion. Results of the latter are reported here.

There are both theoretical and practical reasons to study eye-head motion in spaceflight. At one time it seemed possible or even probable that a disturbance in the interaction of these motions might contribute to or even cause Space Motion Sickness (SMS)(2). In addition, weightlessness is a unique environment for investigation of the role of gravitational inputs to ocular control through otolith organs or somatosensory mechanisms.

The most common way of studying visual-vestibular interaction is oscillation of the body(3) or head(4,5), and recording and analyzing the resulting eye motions as affected by the head's motion. Another is shifting of gaze and recording the resulting eye-head motion. The first method has been used several times in US space flight(1, 6, 7, 8, 9, 10), while the Russians have used the second in humans pre- and postflight(11), during immersion studies(12, 13), and with one(14) and two(15) monkeys in spaceflight. Target lights were presented to produce change in gaze fixation and the resulting eye and head motion recorded.

The study described here employed voluntary gaze shifts without targets with a total of four subjects on STS-5, 7 and 8. Although fixation targets werre not used in this study, changes in gaze with or without targets involve the same responses and pathways and the resulting head and eye motions are similar(16).

BACKGROUND

Eye motions during single head turns follow regular, well described patterns(17). When a target is presented to cause a gaze fixation change or the head is turned voluntarily, the eyes first rotate (initial saccade) in the desired direction (Figure 1). This is followed by a rotation of the head in the same direction, which would move the eyes off the target if an opposing corrective eye motion did not occur. The eyes therefore counterrotate at a rate which will maintain foveal fixation on the target until head motion ceases. These motions are controlled by a number of inputs including visual target displacement(18) and distance(19), and cortical commands(16), vestibular inputs both canal(20) and otolith(20, 21), and cervical inputs(22). Horizontal head turns, with eye and head motion recorded, have been used to study all of the above phenomena.

A second purpose of this investigation was an attempt to elicit inappropriate nystagmus or other abnormalities of extraocular motion and for this reason fixation targets were not used. Results of this aspect of the study have been reported(7).

The results obtained were in general agreement with the Russian primate flight studies, with a significant increase in Vestibulo-Ocular Reflex gain (K_{VOR}) early in flight which trended toward normal as the flight progressed. This change resulted primarily from a decrease in head velocity.

MATERIALS AND METHODS

The four volunteer subjects for this study were all male astronauts and experienced jet pilots with no detectable visual or vestibular defects, ranging in age from 39 to 55 years old.

Details of the apparatus have been described elsewhere(10). Eye position was recorded by conventional EOG methodology using 1 cm Ag-AgCl electrodes at the lateral canthi with nasion ground. Amplification had a minimum high frequency response of 30 Hz and low frequency response was either DC, or AC with 0.05 Hz 3 dB point. Calibration was performed by having the subject look at horizontal LED targets located at 0° and 10° and 20° right and left of center and presented in a pseudo-random fashion. Head position was recorded with better than 2% accuracy by a potentiometer coupled to the head with a cap and chin strap.

Protocol. After performing calibration, the subjects were instructed to stare straight ahead without visual fixation and turn the head approximately 20° right, without visual fixation hold the position for a minimum of 5 seconds and repeat the process back to center, to the left, and back to center again. Horizontal EOG and head position were recorded.

Data were graphically recorded, 100 mm width per channel and 10 mm/sec speed on a Brush MF 120 recorder, and manually reduced for the quantities shown in Figure 1. Typical records are shown in Figure 2.

RESULTS

Records obtained are summarized in Table 1. All values obtained are given in the Appendix. Technical problems with potentiometer invalidated head position, head velocity and K_{VOR} data inflight on STS-5 and after Mission Day (MD) 1 on STS-7. Head velocities (V_h), head amplitudes (A_h), eye counterrotation velocities (V_e) and K_{VOR} for the STS-8 subject are plotted as a function of flight phase in Figure 3. Eye saccade amplitudes, velocities and their percent changes from preflight values are plotted in Figures 4 and 5, and eye counterrotation velocities and percent changes are plotted in Figure 6. Percent asymmetry in eye counterrotation velocity between leftward and rightward head turns for all subjects are plotted in Figure 7. Asymmetry in head velocity, eye counterrotation velocity and K_{VOR} in the STS-8 subject are plotted in Figures 8, 9 and 10.

K_{VOR} in the STS-8 subject was significantly increased on MD 2 primarily through a relative increase in eye counter-rotation velocity with regard to head velocity, while amplitude of the head turn was unchanged. A somewhat smaller increase in K_{VOR} was also noted in the STS-7 subject on MD 1. There was a general relative decrease in saccade amplitude and velocity during the first portion of flight. This was followed by a return to normal or slightly elevated amplitudes but still reduced velocities for the latter part of the flight. An asymmetry in K_{VOR} between rightward and leftward head turns was recorded inflight on STS-8, which was not present preflight or postflight. This appears to have been caused by an asymmetry in eye counterrotation velocity, since no asymmetry in head velocity was observed.

DISCUSSION

VOR gain* is the quantity of primary concern here, for with a visual target and an initial saccade adequate to place the new target on the fovea, any significant deviation of K_{VOR} from unity during head turning implies blurring, loss of target fixation and finally the need for corrective saccades. In the Russian primate studies, there were large increases in K_{VOR} inflight; to $\sim$1.5 in the first primate on the second mission day, and to 2.0 by day five in the other two primates, with a later trend toward normal in both cases. In our study, the largest gain was on MD 2 (with a value of 1.8) and was caused primarily by a relative increase in eye counterrotation velocity with regard to head velocity, which agrees with the Russian primate findings. In this case head rotation velocity was reduced early in flight but then increased. Under the circumstances of increased K_{VOR} there was the expected increase in corrective saccades with the Russian studies. In the absence of a target, as in this study, one might not expect corrections, and in fact they were rarely seen.

The equivalence of studies with and without visual targets must be considered. Barnes(16) has studied this extensively,

*It is assumed that the cervico-ocular reflex remains low inflight. A measurement of this in the subject reported here showed this to be the case (gain = 0.2).

including building model analogs which closely mimic the physiological mechanisms. His assumption and the one used here was that cortical input for voluntary eye movement was equivalent to a fixation target displacement. A simplified diagram of his model is shown in Figure 11. Note that the retinal and cortical inputs are treated identically. A minor experimental difference, the absence of corrective saccades, was noted above.

The cause of the increase in VOR gain is not obvious. Sirota(15) reported on microelectrode recordings from vestibular nuclei performed during the second primate flight. They found an increase in rate of firing from vestibular nuclei associated with the semicircular canals that were comparable to the gain changes. This would indicate that increased angular sensitivity occurs at an early stage of vestibular input, possibly at the level of the hair cells, for they are known to have efferent fibers.

The increased VOR gain found in this study did not occur in the same subject at the same time when head oscillation at approximately 0.3 Hz was used as the stimulus(10). There are a number of possibilities to explain this, including vestibular stimulation at different peak velocity and frequency regimes. Both quantities were lower in this study than in the head oscillation studies.

Asymmetry between leftward and rightward head turns was another finding in both human and primate studies. One primate on the second flight had a difference of 15% to 20% between left and right K_{VOR} which developed and persisted inflight. In this study, there was only one recording (MD 2) in which the gains were significantly different, amounting to 25%, Figure 10. This asymmetry was caused by differences in eye counterrotation velocities, with head velocities remaining symmetric. The primate microelectrode studies also showed varying asymmetry in the activity of vestibular nuclei in response to leftward and rightward head turns(15).

The primates reduced both head amplitudes and velocities throughout the flight, even with target lights; i.e., eye movement was subsitituted for head motion. In the human subject with valid head position data, the changes were transient. Head amplitude was unchanged, while head velocity decreased by 30% on MD 2 but was within normal limits for the rest of the flight.

In summary, there was a transient increase in VOR gain in weightlessness during single, voluntary head turns. Transient asymmetry in eye counterrotation velocity and K_{VOR} was present early inflight, but these became essentially normal by the end of the flight. This finding differs from those of VOR studies using head oscillation as the stimulus where gain is unchanged. However, since no complaints of visual abnormalities were present in this period, it seems unlikely that this change was a significant contributor to SMS.

Further investigation using this technique should be made, for this study plus the Russian primate experiments are the first to document a significant change in visual-vestibular function in weightlessness.

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, and especially the crewmembers who participated in this study.

Table 1.— Schedule of Records Obtained

Flight/Subject	Preflight Launch minus	Inflight (MD) 1	2	3	4	5	6	Postflight Recovery plus
STS-5								
1	28D, 14D		X		X			—
2	35D, 28D, 14D		X					6D
STS-7								
3	14D, 0D	X	X	X	X		X	5D
STS-8								
4	57D, 42D, 40D 33D, 32D, 14D		X		X	X		9D

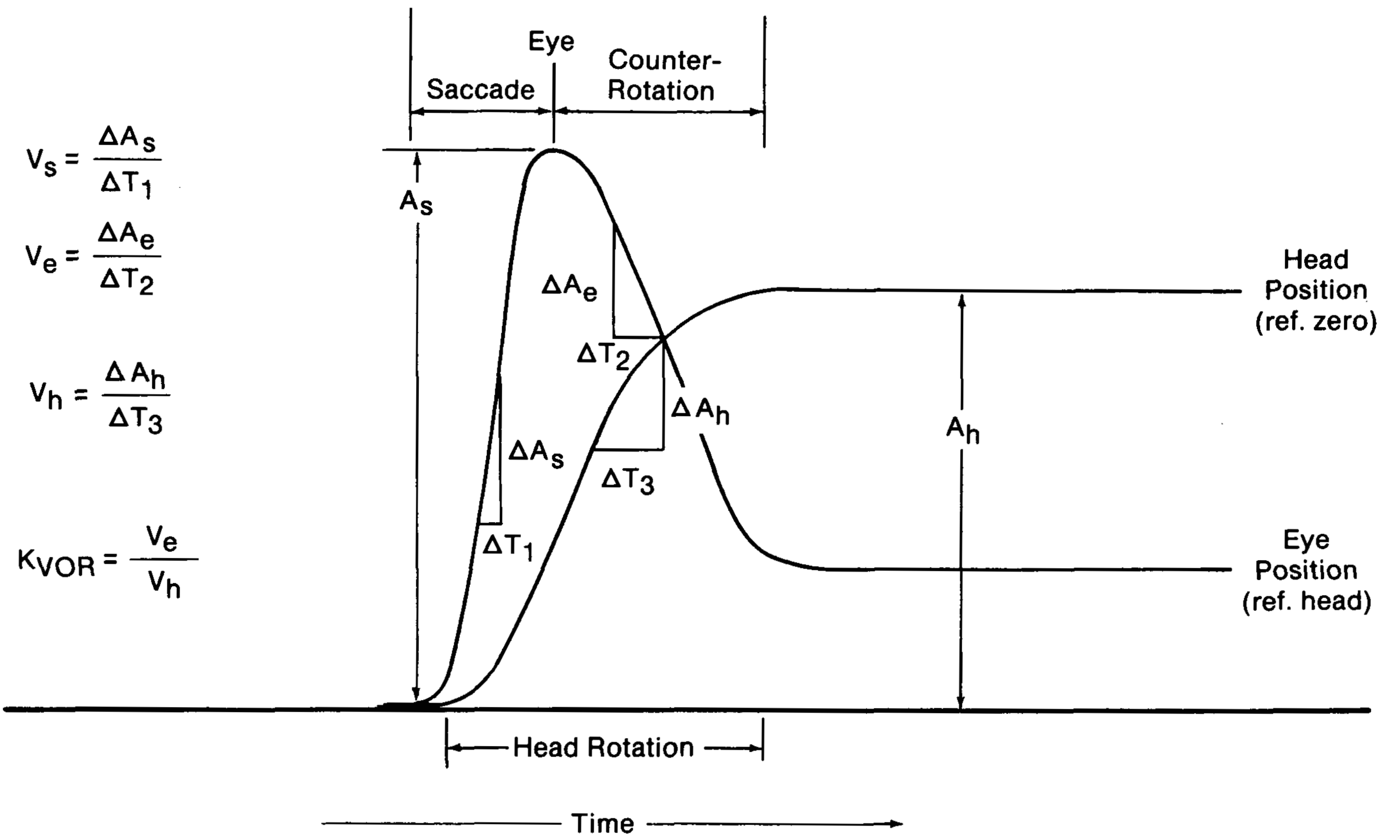

Fig. 1.— Major components of head and eye motions during change in gaze, with derived quantities shown. A_s, eye saccade amplitude; V_s, eye saccade velocity; A_e, eye counterrotation amplitude; V_e, eye counterrotation velocity; A_h, head amplitude; V_h, head velocity; K_{VOR}, gain of vestibulo-ocular reflex. These acronyms are used in subsequent figures.

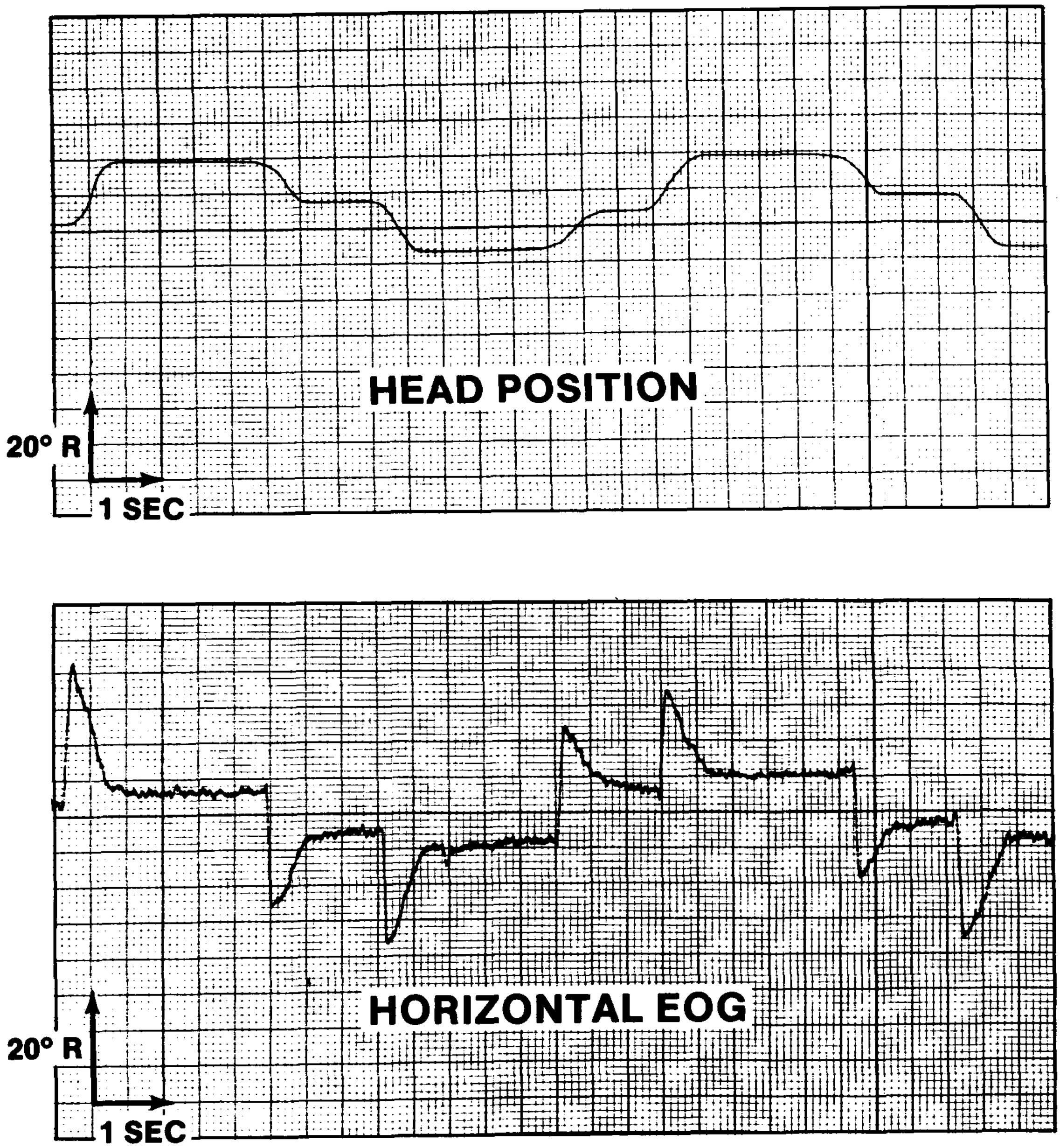

Fig. 2.— (A) Record of preflight eye-head motions from STS-8 subject.

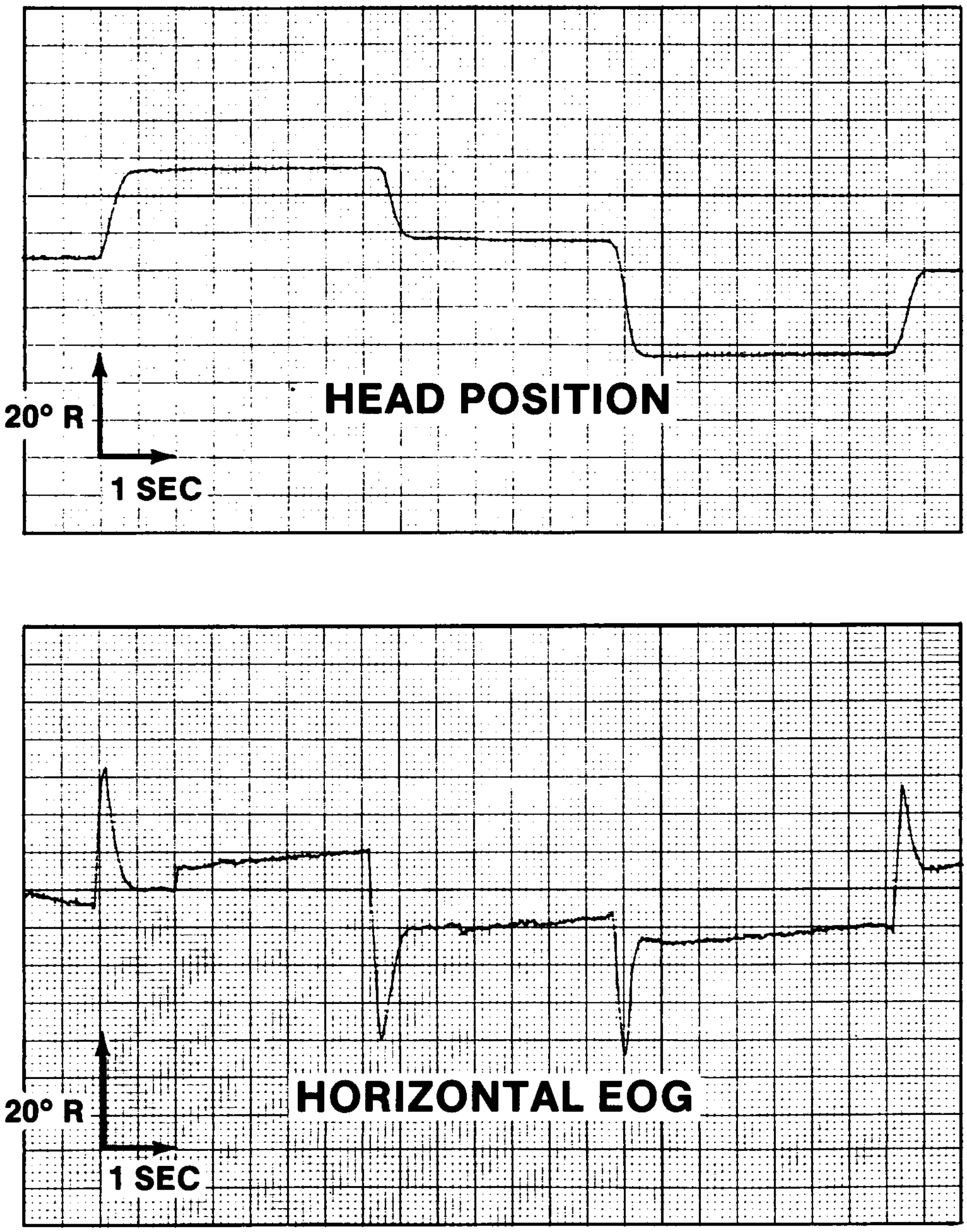

Fig. 2.— (B) Record of inflight eye-head motions from STS-7 subject.

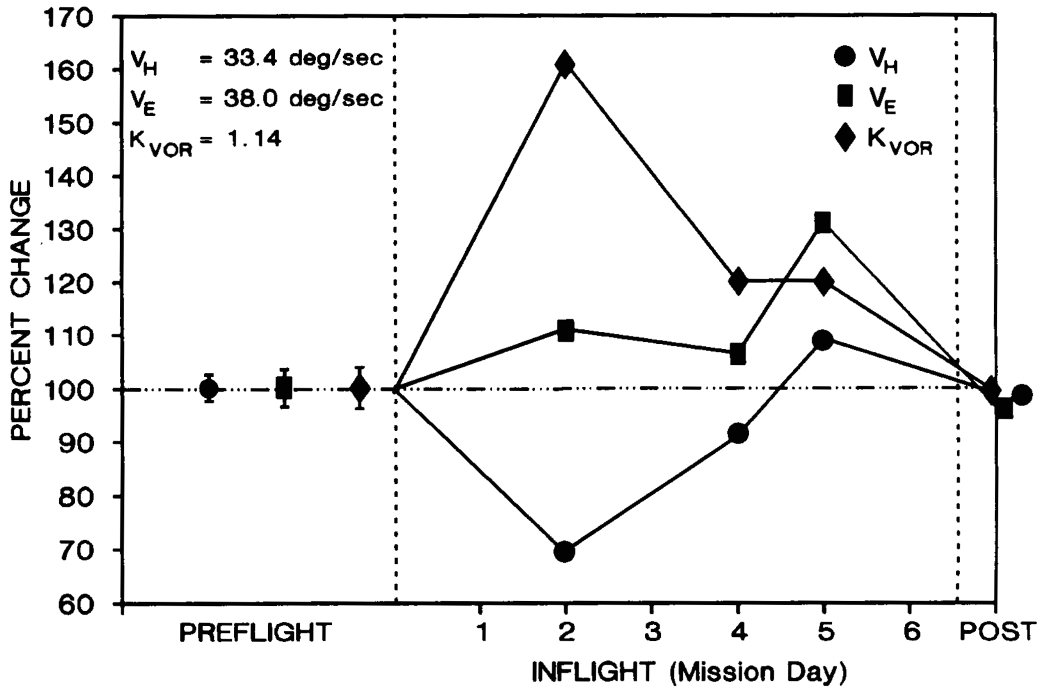

Fig. 3.— Percentage change from preflight means in head and eye counterrotation velocities and K_{VOR} of STS-8 subject.

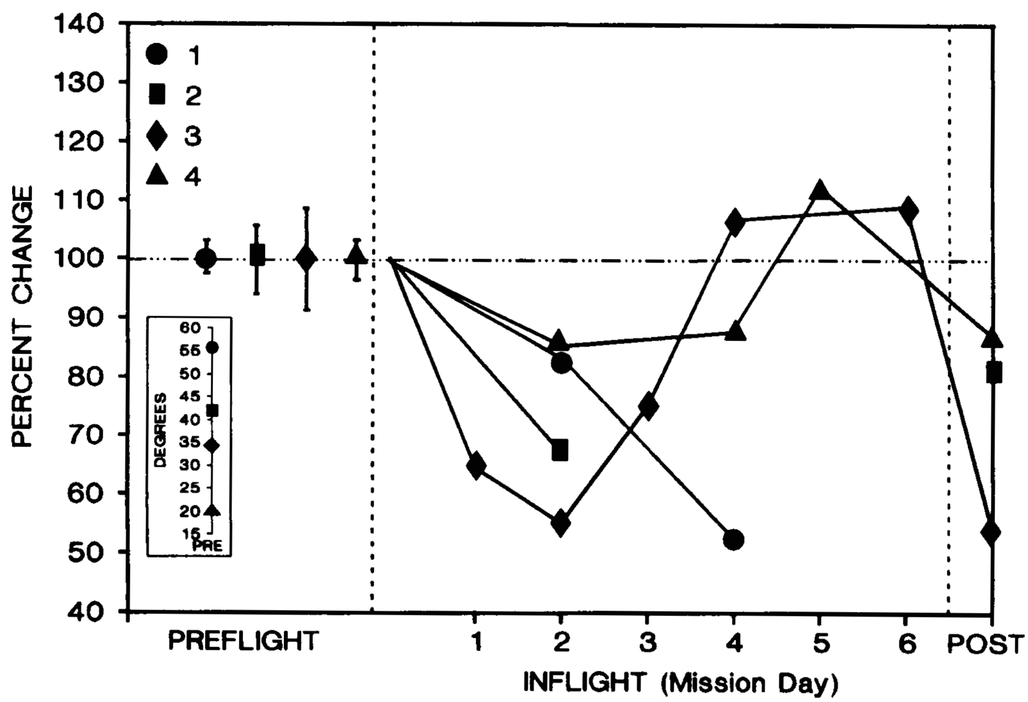

Fig. 4.— Eye saccade amplitudes expressed as percent of preflight levels, with actual preflight mean values indicated in the inset. Numbers 1-4 refer to the four subjects who participated in this study: Subjects 1 and 2 (STS-5), subject 3 (STS-7) and subject 4 (STS-8). This convention is used in subsequent figures.

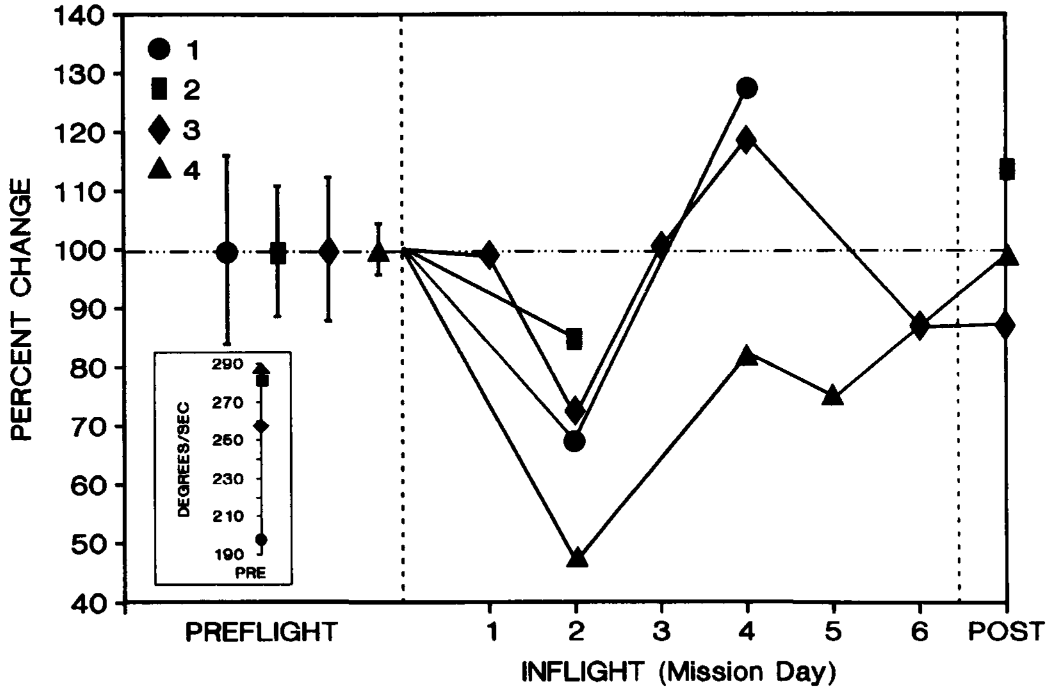

Fig. 5.— Eye saccade velocities expressed as percent of preflight levels, with actual preflight mean values indicated in the inset.

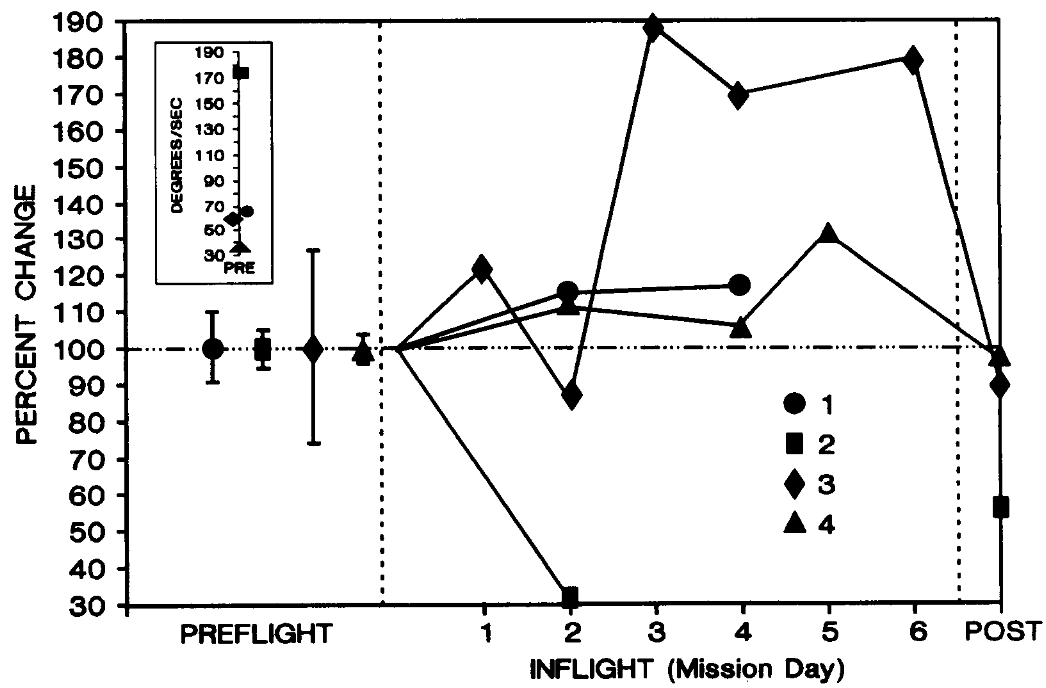

Fig. 6.— Eye counterrotation velocities expressed as percent of preflight levels, with actual preflight mean values shown in the inset.

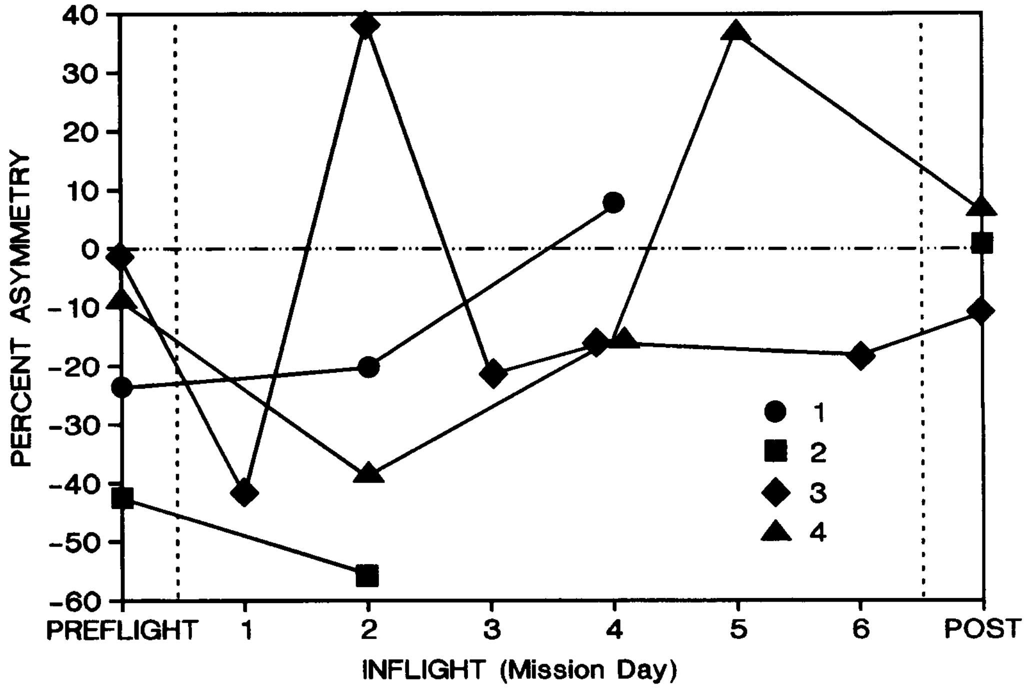

Fig. 7.— Percent asymmetry of eye counterrotation velocity. Positive and negative values refer to rightward and leftward asymmetry, respectively.

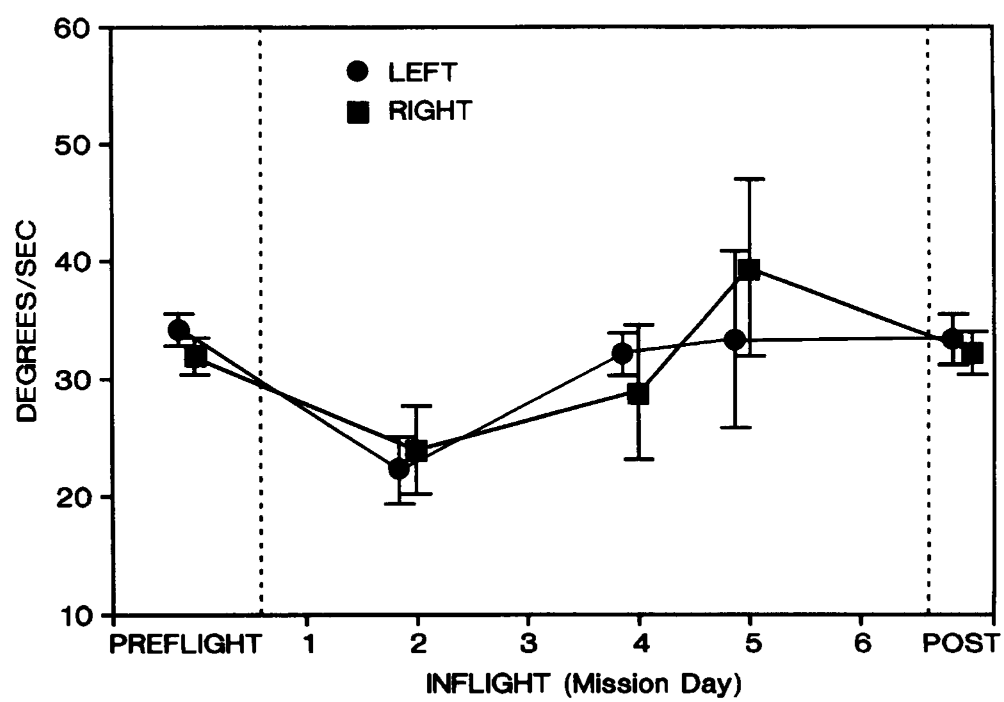

Fig. 8.— Head velocity asymmetry from STS-8 subject.

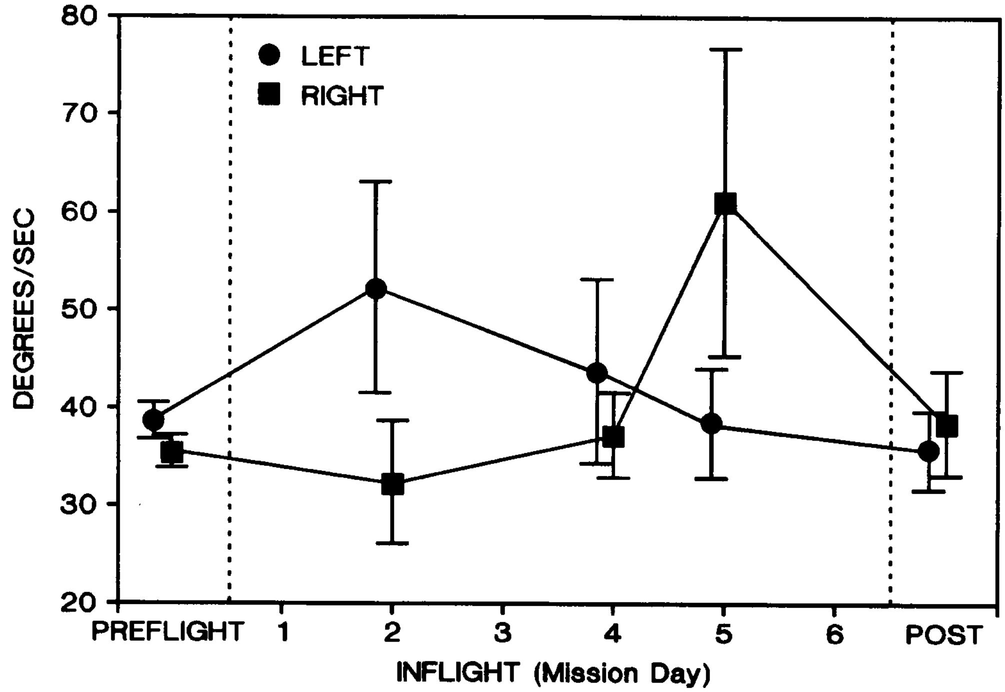

Fig. 9.— Eye counterrotation velocity asymmetry from STS-8 subject.

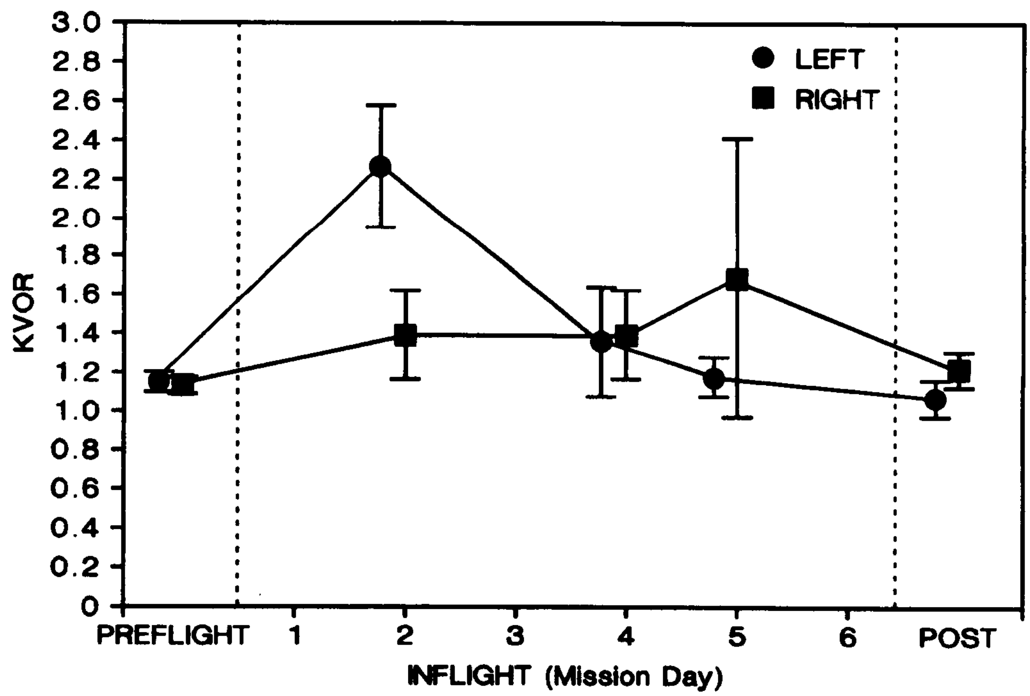

Fig. 10.— K_{VOR} asymmetry from STS-8 subject.

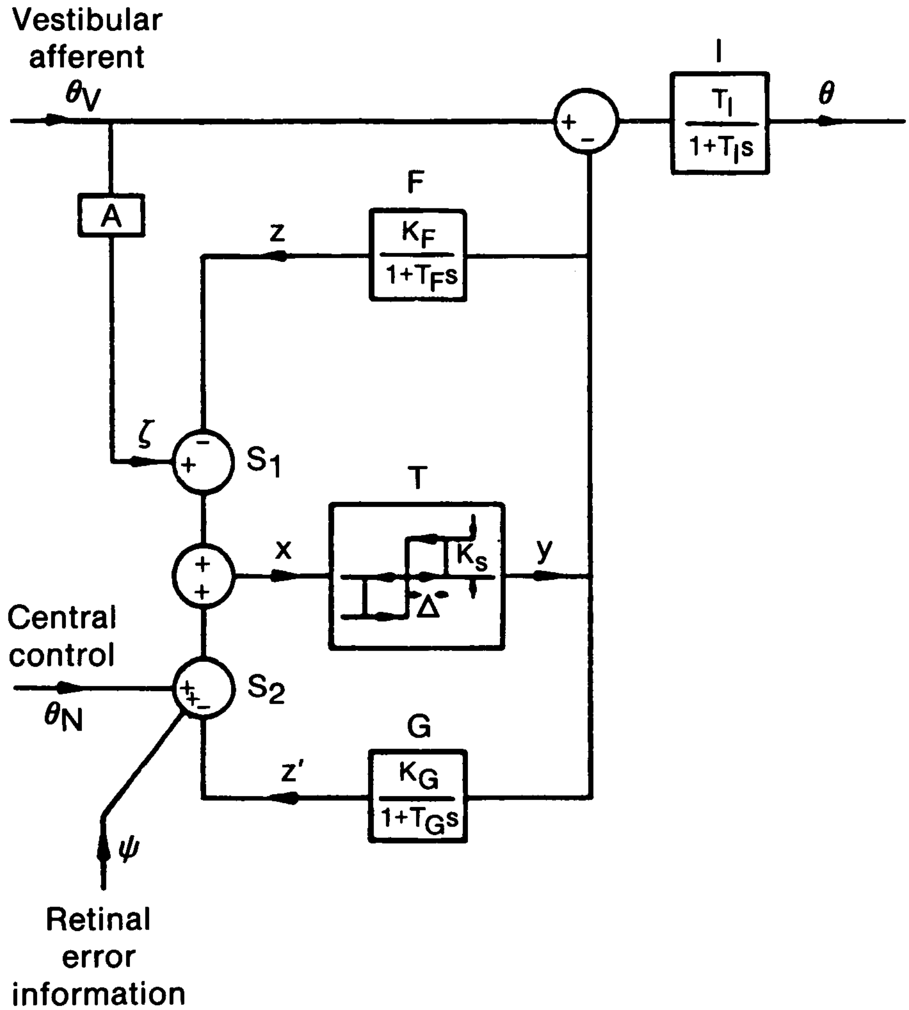

Fig. 11.— Barnes'(16) model of the mechanism by which central, visual and vestibular afferents can effect control of saccadic eye movements. ψ, retinal displacement error (deg); θ_N, centrally generated error signal (deg); θ_V, vestibular afferent signal (deg/sec); θ, eye displacement (deg); T_I~10 sec; K_F~1; T_F~1 sec; K_G~10; T_G~10 sec; =2 to 10 deg/sec; K_S~200 to 300 deg/sec. Δ and K_S (nominally constant) are functions of θ_V and general brain stem neuronal activity (arousal). S_1 and S_2 are specialized inhibitory junctions which transmit only if their excitatory inputs are active. Note that central control of gaze, used in this experiment, is treated identically with retinal error information derived from targets as used in the Russian studies.

APPENDIX — DATA TABLES AND FIGURES

This section is added to present all unprocessed data.

The following acronyms were used throughout the tables:

A_s (deg)	—	Eye saccade amplitude in degrees
A_h (deg)	—	Head amplitude in degrees
V_e (deg/sec)	—	Eye counterrotation velocity in degrees/second
V_h (deg/sec)	—	Head rotation velocity in degrees/second
K_{VOR}	—	Gain of Vestibulo-ocular reflex, defined as (V_e/V_h)
V_s (deg/sec)	—	Eye saccade velocity in degrees/second

Detailed description of data reduction is given in the text.

Table A-1.— STS-5 Preflight Summary

Subject 1		10/14/82	10/28/82	$\bar{X}$ Preflight
A_s (deg)		56.9 ± 3.1	54.6 ± 4.6	55.8 ± 1.2
A_h (deg)*		72.8 ± 5.2	72.4 ± 3.7	72.6 ± 0.2
V_e (deg/sec)		73.4 ± 11.1	61.1 ± 5.4	67.3 ± 6.2
V_h (deg/sec)*		112.9 ± 22.3	107.2 ± 14.6	110.1 ± 2.9
K_{VOR} (V_e/V_h)*		0.65	0.57	0.61 ± 0.04
V_s (deg/sec)		229.8 ± 37.9	167.5 ± 15.5	198.7 ± 31.2
Subject 2	**10/7/82**	**10/14/82**	**10/28/82**	**$\bar{X}$ Preflight**
A_s (deg)	47.0 ± 4.0	38.9 ± 4.2	41.6 ± 3.4	42.5 ± 2.4
A_h (deg)*	30.0 ± 2.5	63.8 ± 9.9	48.2 ± 1.9	47.3 ± 9.8
V_e (deg/sec)	167.9 ± 18.1	191.5 ± 45.9	164.1 ± 24.0	174.5 ± 8.6
V_h (deg/sec)*	84.3 ± 9.1	328.5 ± 91.8	235.7 ± 21.4	216.2 ± 71.2
K_{VOR} (V_e/V_h)*	1.99	0.58	0.70	1.09 ± 0.45
V_s (deg/sec)	337.5 ± 30.6	233.1 ± 43.1	274.7 ± 26.5	281.8 ± 30.3

*These values are considered unreliable due to head pot error.

Table A-2.— STS-5 Summary

Subject 1	Preflight	MD 2	MD 4#1	MD 4#2	
A_s (deg)	55.8 ± 1.2	46.8	27.2	30.9	
A_h (deg)*	72.6 ± 0.2	41.8	16.5	36.4	
V_e (deg/sec)	67.3 ± 6.2	77.3	97.0	60.3	
V_h (deg/sec)*	110.1 ± 2.9	58.3	50.0	16.0	
K_{VOR} (V_e/V_h)*	0.61 ± 0.04	1.33	1.94	3.77	
V_s (deg/sec)	198.7 ± 31.2	134.1	328.3	177.0	
Subject 2	**Preflight**	**MD 2**			**R+6D**
A_s (deg)	42.5 ± 2.4	28.5			34.5
A_h (deg)*	47.3 ± 9.8	29.0			39.3
V_e (deg/sec)	174.5 ± 8.6	55.6			96.8
V_h (deg/sec)*	216.2 ± 71.2	75.7			105.3
K_{VOR} (V_e/V_h)*	1.09 ± 0.45	0.73			0.92
V_s (deg/sec)	281.8 ± 30.3	239.6			320.1

*These values are considered unreliable due to head pot error.

Table A-3.— STS-7 Preflight Summary

Subject 3	6/4/83	6/18/83	$\overline{X}$ Preflight
A_s (deg)	36.5 ± 4.6	30.8 ± 4.4	33.7 ± 2.9
A_h (deg)	26.8 ± 6 5	22.7 ± 1.2	24.8 ± 2.1
V_e (deg/sec)	79.0 ± 9.0	36.3 ± 3.4	57.7 ± 15.1
V_h (deg/sec)	80.8 ± 12.8	33.5 ± 4.2	57.2 ± 16.7
K_{VOR} (V_e/V_h)	0.98	1.07	1.03 ± 0.05
V_s (deg/sec)	224.9 ± 10.2	287.8 ± 68.8	256.4 ± 31.5

Table A-4.— STS-7 Summary

Subject 3	Preflight	MD 1	MD 2	MD 3#1	MD 3#2	MD 4	MD 6	R+5D
A_s (deg)	33.7 ± 29	21.8	18.6	18.8	31.8	35.8	36.6	18.1
A_h (deg)	24.8 ± 2.1	17.9	30.0*	20.2*	22.6*	17.7*	26.7*	15.4
V_e (deg/sec)	57.7 ± 15.1	70.2	49.6	71.6	145.9	97.8	103.9	51.7
V_h (deg/sec)	57.2 ± 16.7	55.3	85.8*	68.2*	89.0*	69.5*	84.1*	59.8
K_{VOR} (V_e/V_h)	1.03 ± 0.05	1.27	0.58*	1.05*	1.64*	1.41*	1.24*	0.86
V_s (deg/sec)	256.4 ± 31.5	253.5	183.6	216.7	298.1	304.4	221.7	223.7

*These values are considered unreliable due to head pot error.

Table A-5.— STS-8 Preflight Summary

Subject 4	A_s (deg)	A_h (deg)	V_e (deg/sec)	V_h (deg/sec)	K_{VOR} (V_e/V_h)	V_s (deg/sec)
7/4/83	24.2 ± 1.7	11.1 ± 1.1	43.2 ± 5.1	40.7 ± 5.5	1.06	255.6 ± 13.5
7/19/83	19.8 ± 1.1	12.2 ± 0.8	31.1 ± 3.1	30.6 ± 2.4	1.02	292.9 ± 22.2
7/21/83#1	21.2 ± 0.8	11.8 ± 0.9	39.6 ± 3.3	33.4 ± 2.6	1.19	321.8 ± 30.3
7/21/83#2	21.0 ± 0.8	9.9 ± 0.6	38.8 ± 4.8	30.8 ± 3.5	1.26	323.3 ± 46.0
7/28/88	18.7 ± 0.4	10.0 ± 0.4	37.3 ± 2.3	32.9 ± 1.7	1.13	260.2 ± 16.5
7/29/83	19.1 ± 0.6	11.0 ± 0.6	39.0 ± 2.3	33.9 ± 2.3	1.15	257.0 ± 11.8
8/16/83	20.5 ± 0.9	13.1 ± 0.9	37.1 ± 3.2	31.5 ± 3.2	1.18	311.5 ± 26.5
Mean Pre	20.6 ± 0.7	11.3 ± 0.4	38.0 ± 1.4	33.4 ± 1.3	1.14 ± 0.03	288.9 ± 11.7

Table A-6.— STS-8 Summary

Subject 4	Preflight	MD 2	MD 4	MD 5	R+9D
A_s (deg)	20.6 ± 0.7	17.6	18.2	23.1	18.0
A_h (deg)	11.3 ± 0.4	10.8	16.0	8.2	12.9
V_e (deg/sec)	38.0 ± 1.4	42.3	40.5	49.9	36.9
V_h (deg/sec)	33.4 ± 1.3	23.1	30.5	36.5	32.7
K_{VOR} (V_e/V_h)	1.14 ± 0.03	1.83	1.37	1.37	1.13
V_s (deg/sec)	288.9 ± 11.7	137.5	238.0	216.8	286.7

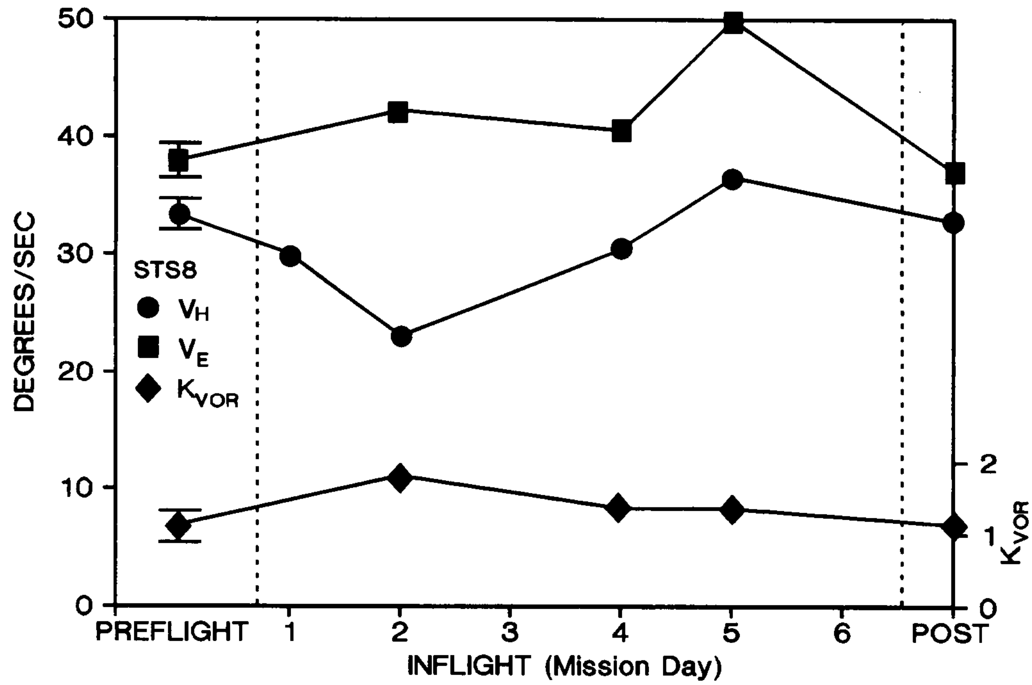

Fig. A-1.— Head and eye counterrotation velocity and K_{VOR} as a function of flight phase in STS-8 subject.

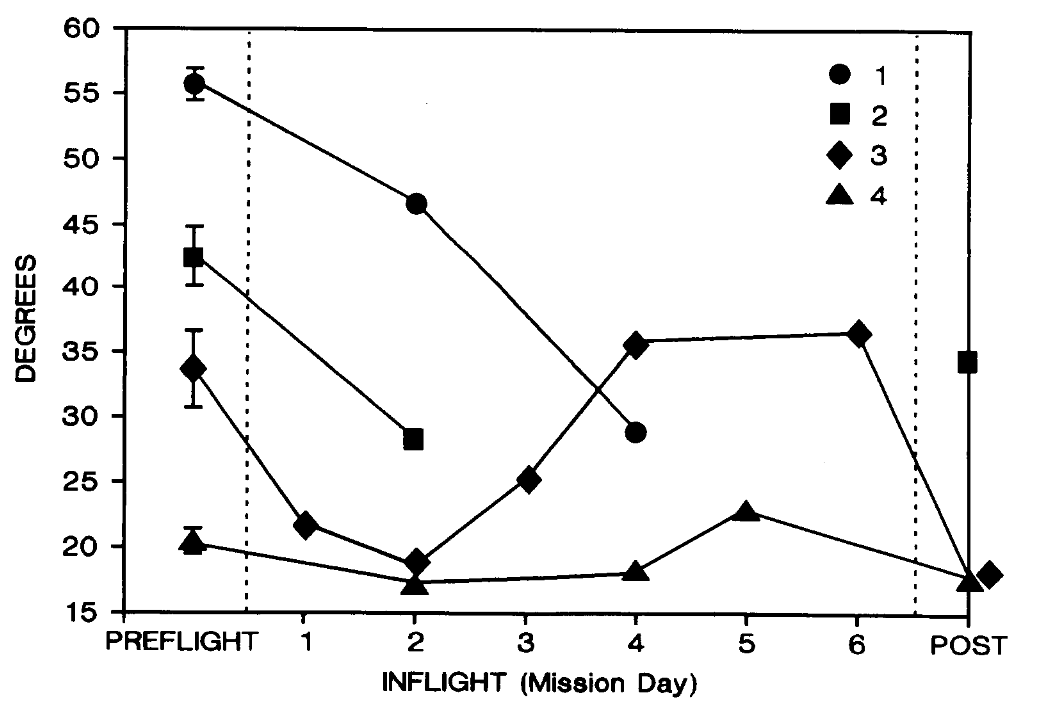

Fig. A-2.— Eye saccade amplitudes of four subjects.

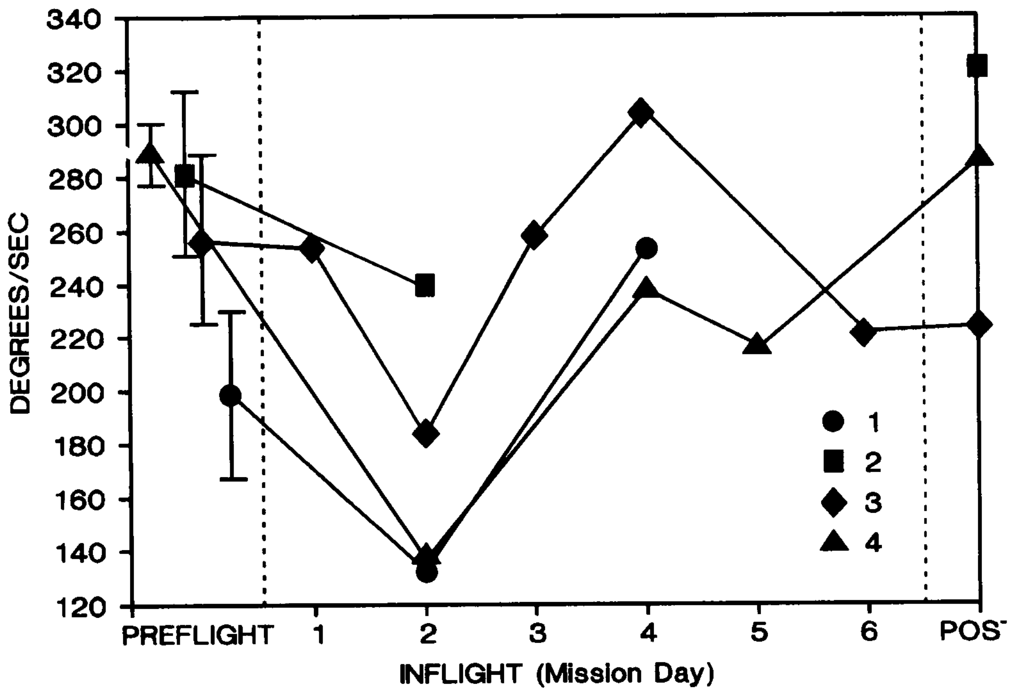

Fig. A-3.— Eye saccade velocities of four subjects.

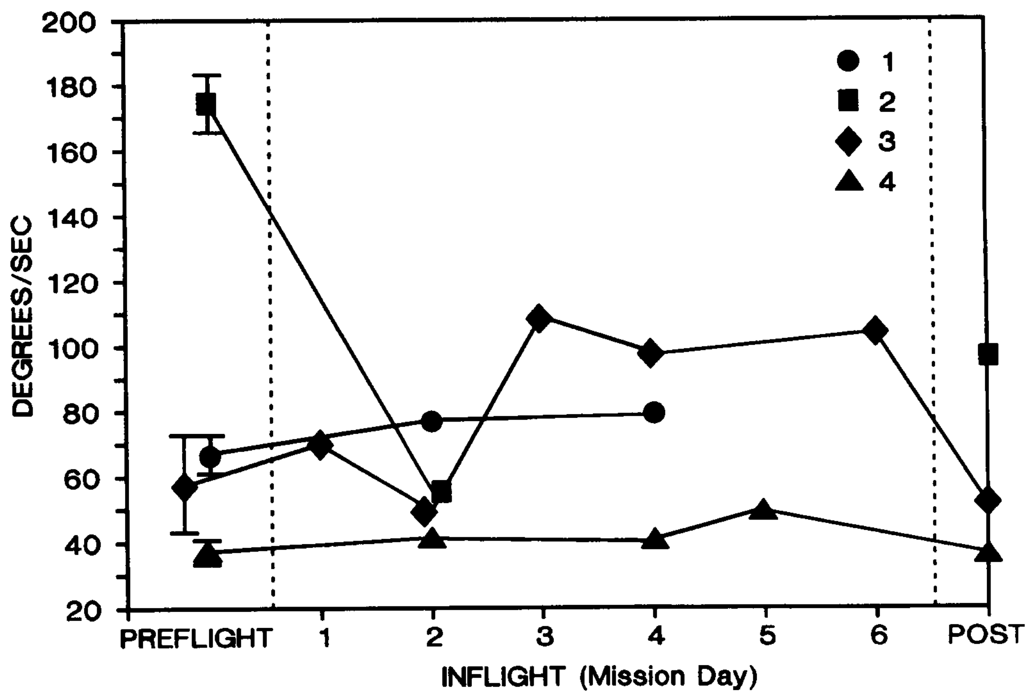

Fig. A-4.— Eye counterrotation velocities of four subjects.

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NOTES

REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM 100 466		

4. Title and Subtitle EYE AND HEAD MOTION DURING HEAD TURNS IN SPACEFLIGHT	5. Report Date July 1988
	6. Performing Organization Code
7. Author(s) William E. Thornton, John J. Uri, Thomas P. Moore, and Sam L. Pool	8. Performing Organization Report No. S-580
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058	10. Work Unit No. 073-36-00-00-72
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered TM July 1988
	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

Eye-head motion was studied pre-, in- and postflight during single voluntary head turns. A transient increase in vestibulo-ocular reflex (VOR) gain occurred early in flight, but later trended toward normal. This increased gain was produced by a relative increase in eye counterrotation velocity. Asymmetries in gain with right and left turns also occurred, caused by asymmetries in eye counterrotation velocities. These findings were remarkably similar to those from Russian primate studies using gaze fixation targets, except the human study trended more rapidly toward normal. These findings differ substantially from those measuring VOR gain by head oscillation, in which no significant changes were found inflight. No visual disturbances were noted in either test condition or in normal activities. These head turn studies are the only ones to date documenting any functional change in VOR in weightlessness.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
electrooculogram, space flight, gain, V.O.R., gaze deviation, head turns	Unclassified - Unlimited Subject Category: 52

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	26	

For sale by the National Technical Information Service, Springfield, VA 22161-2171

*U.S.GOVERNMENT PRINTING OFFICE:1988-561-009/80462