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SPACE MOTION SICKNESS: PHENOMENOLOGY, COUNTERMEASURES, MECHANISMS

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1. Introduction

Among various changes seen in the Soviet cosmonauts and American astronauts vestibular disorders termed space motion sickness (SMS) are of particular importance in view of the fact that they have been detected in many space crewmembers (4, 7). The etiology of the disorders still remains obscure; therefore approaches to their prevention and therapy are mostly empirical.

The Salyut-6 - Soyuz manned flights yielded new data concerning SMS phenomenology, vestibular changes and sensory interactions during and after flight.

The Salyut-6 - Soyuz orbital complex flew 27 cosmonauts, who made 11 short-term (4, 7, 14 days) and 5 long-term (7[illegible], 96, 140, 175 and 185 days) missions (except for 2 cosmonauts who made a 2-day flight onboard Soyuz-34).

2. Methods

The investigations of the vestibular function and space motion sickness were carried out in several stages: preflight examinations, inflight examinations, and postflight examinations at the recovery site and, if indicated, at the cosmodrome and in the sanatorium (Table 1). Most examinations were conducted 30-45 days preflight, and at R + 0, 1-2, 3-5 and 8-9 days (following long-term flights at R + 30 days as well).

3. Results

Symptoms of Space Motion Sickness and Spatial Illusionary Sensations

An analysis of the questionnaires (Table 2) shows that illusionary sensations occurred in 24 (88%) crewmembers and SMS symptoms of varying degree in 12 (44%) crewmembers.

Illusionary sensations of the inversion type included the feelings of forward or backward tumbling, upside-down or head-down position, and occasionally were accompanied by the feelings of displacement of the surrounding objects (displacement of the panel downwards, to the feet area, etc.) or of body spinning (Table 3).

Most cosmonauts reported illusionary sensations immediately upon insertion into orbit. However, some cosmonauts noted illusionary sensations at a later period (several hours after insertion into orbit).

The most typical symptoms of space motion sickness are as follows: indisposition, pallor, perspiration (cold sweat), stomach awareness, nausea and vomiting. After vomiting events the health condition of the cosmonauts improved noticeably.

There was a correlation between the development of SMS and motor activity: an increase in the number of head and body movements (especially forward tilts) rapidly deteriorated the health state and resulted in the Malaise III endpoint of motion sickness.

Some cosmonauts showed distinct symptoms of SMS. This can be exemplified by the Soyuz-T-4 Flight Engineer who made a 75-day space flight. During the first mission days he displayed pronounced symptoms of SMS which rapidly reached the Malaise III endpoint of SMS after an insignificant increase in the intensity of motor activity. The cosmonaut showed SMS symptoms till mission day 14.

As a rule, during their second flight the cosmonauts adapted to zero-g better; however, they still experienced motions sickness manifestations.

The cosmonauts voiced different ideas about the contribution of blood run to the head to the development of SMS. Some of them held that this event promoted the development of adverse reactions during adaptation to zero-g, motion sickness including. Other cosmonauts doubted the importance of this event and attributed the development of SMS to an increased motor activity. Still others described optokinetic stimulation as a factor aggravating their health state during SMS.

Results of Postflight Vestibulometric Examinations

Immediately upon recovery essentially all cosmonauts showed statokinetic disorders, i.e. they staggered and fell, during Romberg's tests.

Postflight, vestibulo-autonomic disorders of varying degree were seen in 9 (33%) cosmonauts and illusionary sensations in 8 (29%) cosmonauts. They were characterized by weakness, pallor, dry mouth or, on the contrary, hypersalivation, distinct perspiration (sometimes profuse sweat), vertigo, nausea, and sometimes vomiting (in some cosmonauts occurring several times).

The cosmonauts who showed vestibulo-autonomic disorders displayed more pronounced changes in the postural equilibrium function than other crewmembers immediately postflight (Fig.1)

The major stress-agent that led to the endpoint of vestibulo-autonomic disorders postflight was increased motor activity, as was the case inflight.

The Soyuz-T-4 Flight-Engineer who exhibited distinct symptoms of SMS inflight also showed vestibulo-autonomic disorders postflight, that were 40 min after touchdown accompanied by spontaneous horisontal and vertical nystagmus (Fig. 2B) Spontaneous nystagmus persisted during the first 3 days postflight.

Optokinetic stimulation at a rate of 40 and 60 stripes/min of both Soyuz-T-4 crewmembers caused pronounced eye reactions. At a stimulation rate of 80 stripes/min and over their eyes failed to track the stimulus. The eye reactions were asymmetric when the stimuli moved to the right and to the left (Fig.3). The check experiment carried out 56 days postflight demonstrated the lack of spontaneous and positional nystagmus in both cosmonauts (Fig.4). Their eye reaction was distinct at every rate of optokinetic stimulation (from 40 to 120 stripes/min).

The examination of the otolith function (4) revealed otolith hyperreflexia (uni- or bilateral) in 15 cosmonauts, and otolith hyporeflexia in 6 cosmonauts. In many cosmonauts the otolith reflex was characterized by asymmetry which was more distinct in the crewmembers after long-term space flight (4).

The study of the function of semicircular canals demonstrates a slight increase of thresholds with respect to the nystagmus and illusions ( ).

The precision of perception of spatial coordinates was term flights and in all crewmembers who made long-term flights.

Assessment of the Efficiency of Motion Sickness Countermeasures

In some flights the efficiency of pharmacological and biophysical methods for preventing and treating SMS was assessed (Table 5). Forinstance, the effect of Dedalone (Drammamine), an antihistamine drug with pronounced anticholinesterase properties, was evaluated. The cosmonauts reported that the drug diminished slightly vestibulo-autonomic disorders but failed to eliminate them completely.

At an early period of adaptation to weightlessness the Soyuz-38 crewmembers used specially devised pneumatic cuffs at ached to the hip area(at -40 to -60 mm Hg for 20-30 min); this procedure improved their health state when they showed SMS symptoms. These cosmonauts also reported an improvement in their health state as a result of LBNP exposures (-25 mm Hg) applied by the Chibis device.

The crewmembers of the Soyuz-T-3, Soyuz-39 and Soyuz-40 flights used as a countermeasure against SMS a specially designed device termed "A Neck Pneumatic Shock-Absorber" (NPSA). The device supplies a controlled load of a known force to the cervical vertebrae and neck antigravitational muscles and restricts head movements during adaptation to weightlessness. The NPSA is a structure consisting of a soft cap that has loopholes for rubber cords (Fig.7). When a person has the cap on, he has to strain neck muscles in order to unbend his head and keep it in a natural, erect position. To do this, he has to apply the force equal to the tensile strength of two rubber cords.

shoulders which restrict head tilts and turns, depending on the strap stretch.

The cosmonauts who used the Neck Pneumatic Shock-Absorber reported that it helped inhibit vestibulo-autonomic and sensory disorders during adaptation to weightlessness.

There was another deviceused as a countermeasure, i.e. a device that provided a pressure of up to 60 mm Hg to the sole of the feet. The use of the device reduced the level of spatial illusions and motor disturbances in one of the Soyuz-38 crewmembers (2).

4. Discussion

A distinct correlation between space motion sickness and head movements, a characteristic syndrome of autonomic and sensory disorders, a contribution of optokinetic stimulation and concomitant sensory stimulation - all this makes it possible to regard space motion sickness as a peculiar state that manifests as a complex of autonomic symptoms associated with perceptual, oculomotor and postural disorders.

The data obtained suggests that a strong sensory rearrangement (mismatch) of the afferent information from the otolith organs, semicircular canals, eye, as well as of proprioceptive and musculo-skeletal afferentation is a major etiological factor leading to SMS.

The spontaneous nystagmus recorded in the Soyuz-T-4 Flight-Engineer is indicative of a central vestibular dysfunction at the level of stem mechanisms, and a changes in the function of vestibular nuclei and their central pathways. The concept of stem etiology of the spontaneous nystagmus is vertical nystagmus with the slow phase being in predominance.

The positional nystagmus recorded in this cosmonaut and in the Soyuz-35 Commander who also displayed vestibulo-autonomic disorders may indicate, on the one hand, changes in the otolith modulation on the semicircular canals (5), and, on the other, the development of central vestibular dysfunction and, probably, of vestibulo-cerebellar connections (6).

In this context, mention should be made of the fact that the cosmonauts who had symptoms of vestibulo-autonomic disorders showed more distinct unilateral arm deviations when tested by the finger-pointing test, and a predominant unilateral body deviations when tested for the postural equilibrium function. These observations may also confirm vestibulo-cerebellar disintegration (6).

The detection of asymmetry of the otolith reflex in many cosmonauts, especially in those with vestibulo-autonomic disorders postflight, may point to an important role of the latent functional asymmetry of the otolith apparatus in the etiology of the vestibular dysfunction during adaptation to weightlessness and subsequent readaptation to 1 g (1).

The hypothesis that the mechanisms of postural equilibrium changes are associated with the central nervous rearrangement of the processes controlling the treatment of the sensory afferent information from the otolith, kinesthetic and tactile systems (3, 7) has been confirmed in the present investigation. They include changes in the vestibular function (particularly otolith afferentation), variations of deep proprioreception and joint sensitivity, muscle mass losses, decrease of the tone and strength of antigravitational muscles, etc.

The disturbances on the optokinetic nystagmus detected in some cosmonauts are, in all likelihood, manifestations of complex changes in the oculomotor, vestibular and cerebellar functions. In this context, mention should be made of the investigations carried out by Ito (8) who demonstrated an important role of the cerebellum (especially the flocculus) in the generation of eye tracking movements and nystagmus.

When assessing the efficiency of the countermeasures employed in this program, it should be noted that the Neck Pneumatic Shock-Absorber was sufficiently effective in the control of the sensory and autonomic components of vestibular reactions during SMS. This effect should be primarily considered in direct association with the vestibulo-cervical reflex which is known to involve the labyrinth (semicircular canals and otolith organs) as a receptor and neck muscles as effectors (9). Wilson has demonstrated a significant influence of the vestibulo-neck reflex on the labyrinthine input (9).

The beneficial effect of the device providing a load on the foot suggests an important role of the support unloading and concomitant changes in the morpho-functional structure of the foot in the development of vestibulo-motor disorders in weightlessness (2).

The fact that some cosmonauts reported an improvement of their health state when using pneumatic cuffs and LBNP at an early stage of adaptation to weightlessness makes it necessary to clarify the contribution of fluid shifts into the etiology of SMS, Until now the ground-based simulation studies have yielded controversial results.(3).

It appears important to accumulate during the forthcoming space missions new data concerning vestibulo-optic, vestibulo-spinal, vestibulo-cortical, vestibulo-cerebellar functions at an early period of adaptation to weightlessness.

Table 1

PROTOCOL

of vestibular examinations of the Salyut-6 - Soyuz crewmembers

Preflight examinations: detection of spontaneous and positional nystagmus by the method of electronystagmography (ENG); index-finger target test according to the method of Malan-Harshak modified by Sklyut and Hauptman (1973); evaluation of otolith reflexes with respect to the eyeball counter-rolling (consecutive visual imaging) when changing from the upright to the recumbent position (on the right and left side), i.e. a modified method of indirect otolithometry according to Fischer and Fluur; determination of the function of semicircular canals with respect to the threshold sensitivity to adequate stimulation (in relation to the nystagmus and sensory reaction); investigation of the interaction between the otolith organ and semicircular canals, i.e. a modified otolith test according to the method of Vojacek*; study of optomotor reactions to optokinetic stimulation*; evaluation of the perception of spatial coordinates using a portable Vertical device (in the sitting position, on the right and the left side); cupulometric study during an exposure to stop-stimuli of 30, 60 and 90°/sec*; investigation of postural equilibrium and gait by means of tests to reveal ataxia according to the method of Fregly and Graybiel (1972).

Inflight examinations: investigation of symptoms of space motion sickness with the aid of special questionnaires; evaluation of the efficiency of certain drugs and biophysical methods used to prevent space motion sickness.

Postflight examinations: interview of the crewmembers; recording of the spontaneous and positional nystagmus; index-finger target test; investigation of postural equilibrium and gait; examination of optokinetic nystagmus at the recovery site. Later the protocol of postflight examinations was similar to that of preflight ones.

Note: *No systematic examinations were carried out.

Table 2

Occurence of motion sickness and illusionary sensations in 27 Salyut-6 - Soyuz crewmembers during and after flight

Salyut-6 - Soyuz flights	Number of crew-members	Illusionary reactions		Motion sickness	
		Inflight	Post-flight	Inflight	Post-flight
11 short-term flights (4, 7 and 14 days) and 5 long-term flights (75, 96, 140, 175 and 185 days)	27*	24(88%)	8(29%)	12(44%)	9(33%)

Notes: *Excluding 2 cosmonauts who made a 2-day flight onboard Soyuz-34

Six cosmonauts made two flights in this project

Table 3

Symptoms of space motion sickness and spatial illusionary sensations in Salyut-6 - Soyuz crewmembers

Spatial illusionary sensations	Motion sickness sympto
Onset and duration: in most crewmembers beginning after the first minutes, in some after several hours in weightlessness; duration varying from several minutes to several hours with occasional events throughout the flight.	Onset and duration: beginning after one to several hours (or 1 to 1.5 days) in weightlessness. Duration from several hours to 3-7 days
Type of illusions: inversion, tumbling forward or backward; inverted body position; head-down position; displacement of surrounding objects (shift of the control panel toward the legs,etc.); spinning of the body.	Motion sickness symptoms: indisposition, lack of appetite, pallor, perspiration (cold sweat), salivation, vertigo, discomfort (stomach awareness), nausea, vomiting.
Factors enhancing illusionary reactions: increased motor activity (especially head movements), optokinetic stimulation (observation through the porthole, etc.).	Factors provoking and enhancing motion sickness: increased motor activity (especially head movements),forward tilts, sensations of blood run to the head (in some cosmonauts), optokinetic stimulation (in some cosmonauts).
Factors inhibiting illusionary reactions: "critical" evaluation of body position in space and object coordinates, visual fixation of surrounding objects, straining of neck muscles, application of pressure to cervical vertebrae, relaxing exercises (auto-training).	Factors alleviating motion sickness: diminished motor activity, overnight sleep, performance of important operations, repeated flights, use of drugs and biophysical methods to prevent and treat motion sickness.
Effect of illusions on performance: With eyes open, spatial illusions did not disturb orientation. Movement coordination when working with "floating" objects and onboard equipment at an early period of adaptation to weightlessness was satisfactory.	Effect of motion sickness on performance: Performance decrease of varying degree.

Notes:* In 2 cosmonauts who performed a 7-day flight some motion sickness symptoms persisted throughout the flight. In the Soyuz-T-4 Flight-Engineer who made a 75-day flight motion sickness symptoms persisted until mission day 14.

Table 4

Results of postflight vestibulometric examinations of Salyut-6 - Soyuz crewmembers

Function examined	Results of postflight examinations: Type of changes	Number of cosmonauts
Spontaneous and positional nystagmus.	Soyuz-T-4 Flight-Engineer showed vestibulo-autonomic disorders and vertical and horizontal nystagmus which parsisted during 3 days postflight. This cosmonaut and Soyuz-35 Commander exhibited positional nystagmus.	2(7.4%)
Optokinetic nystagmus*	Disorders of the nystagmus at high rates of optokinetic stimulation. Nystagmus asymmetry (in some cosmonauts).	-
Function of postural equilibrium	Disorders of postural equilibrium of varying degree during Romberg's test (shaking, falling), difficult step immediately after touch-down.	26(96%)
Otolith function (indirect otolithometry). Norm: 12±7°, asymmetry - 3°	Hyperreflexia (uni- or bilateral up to 21-38°) Hyporeflexia (uni- or bilateral up to 5-6°) "Negative" otolith reflex (eye movement in the direction of the tilt) during 1-2 days postflight Asymmetry of 8 to 14°.	15(55%) 6(22%) 5(18%) 14(51%)
Function of semicircular canals	Threshold increase with respect to nystagmus and illusions up to 10-15°/sec^2 Threshold decrease Sensitivity asymmetry up to 8°/sec^2 Trend for recovery at R + 4-5 after short-term and at R + 8-9 after long-term flights (in two cosmonauts at R + 32)	17(62%) 1(3%) 10(27%)
Function of perception of spatial coordinates (perception error in the norm: in the upright position 0.67+0.3°, in the lateral position 18+5°, asymmetry 5°)	Increase of perception error up to 3-4° in the upright position, up to 38° in the lateral position with the asymmetry of values up to 14°. Trend for recovery at R + 2-4 after short-term and at R + 8-9 after long-term flights (in two cosmonauts at R + 32)	16(59%)
Index-finger target test*	Signs of vestibulo-cerebellar asynergy in some cosmonauts, especially in those showing vestibulo-autonomic	-

Table 5

Motion sickness countermeasures used in Salyut-6 - Soyuz flights

Countermeasure	Prophylactic effect
Administration of the drug Dedalone (Drammamine), an antihistamine drug with a pronounced anticholinesterase effect. Protocol of the administration: 50 mg 3 times a day one day preflight, on mission day 1, before transition to the orbital station, and before donning off the space suit.	In 8 cosmonauts, diminished vestibular discomfort but failed to prevent motion sickness completely.
Application of pneumatic cuffs to the thigh area (at 40-60 mm Hg, for 20-30 min)	Improved the health state of Soyuz-38 crewmembers, who showed motion sickness, on mission day 2.
Application of LBNP using the Chibis device at - 25 mm Hg	Reduced heaviness in the head, restored breathing through the nose, improved the health state of Soyuz-38 crewmembers who showed motion sickness.
Use of a prophylactic device providing a controlled pressure of a known force to the neck vertebrae, neck antigravitational muscles, and restriction of head movements during adaptation to weightlessness.	Inhibited distinctly sensory reactions and vestibular discomfort in Soyuz-T-3, Soyuz-39, Soyuz-40 crewmembers.
Use of a prophylactic device, a personal instep insole, providing a pressure to the foot of up to 60 mm Hg.	Daily application of the device for 6 hours a day during the first 7 days by one of the Zoyuz-38 crewmembers reduced the level of motor disorders and spatial illusions

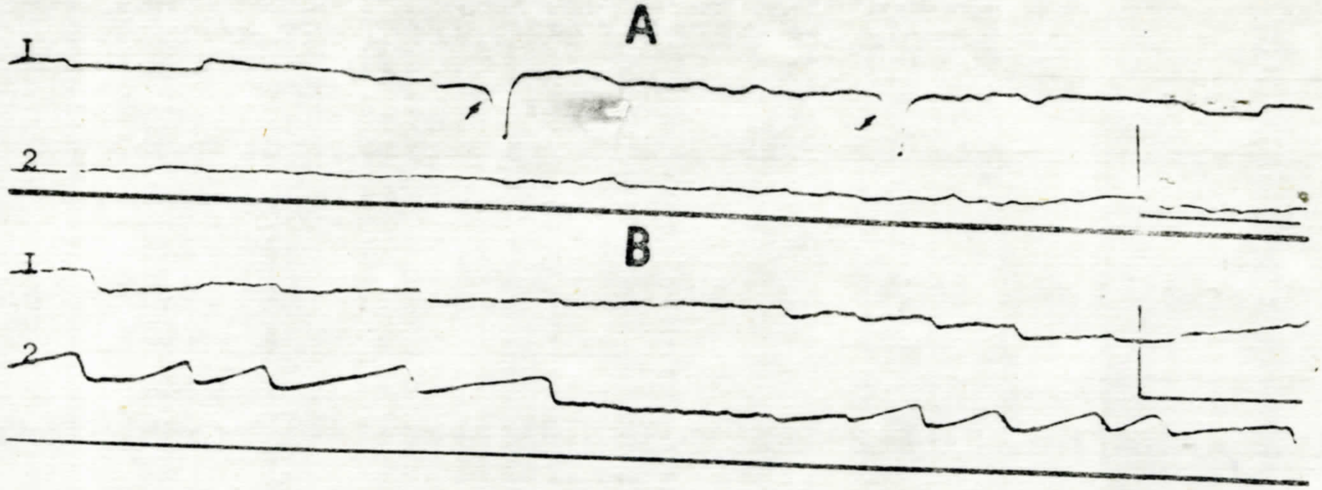

FIG.2. ELECTRONYSTAGMOGRAMS OF THE SPONTANEOUS NYSTAGMUS IN THE "SOYUS-T-4"/75-DAY/ CREWMEMBERS.

A - ENG OF THE COMMANDER,
B - ENG OF THE FLIGHT ENGINEER
1 - VERTICAL NYSTAGMUS,
2 - HORISONTAL NYSTAGMUS

ARROWS SHOW ARTEFACTS (WINKING)
CALIBRATION 20°, 1 SEC.

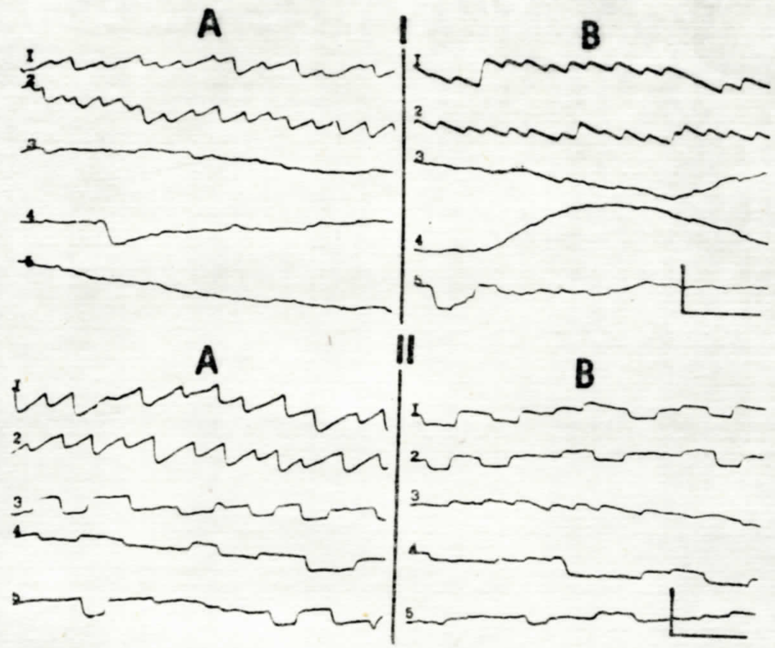

FIG.3. OPTOKINETIC NYSTAGMUS IN THE COMMANDER /I/ AND FLIGHT-ENGINEER /II/ OF THE "SOYUZ-T-4" 75-DAY FLIGHT.

MOVEMENT OF BLACK-WHITE STRIPS TO THE LEFT (A) AND TO THE RIGHT (B) AT A VELOCITY OF 40(1), 60(2), 80(3), 100(4), AND 120(5) STRIPS PER MINUTE.

CALIBRATION 20°, 1 SEC.

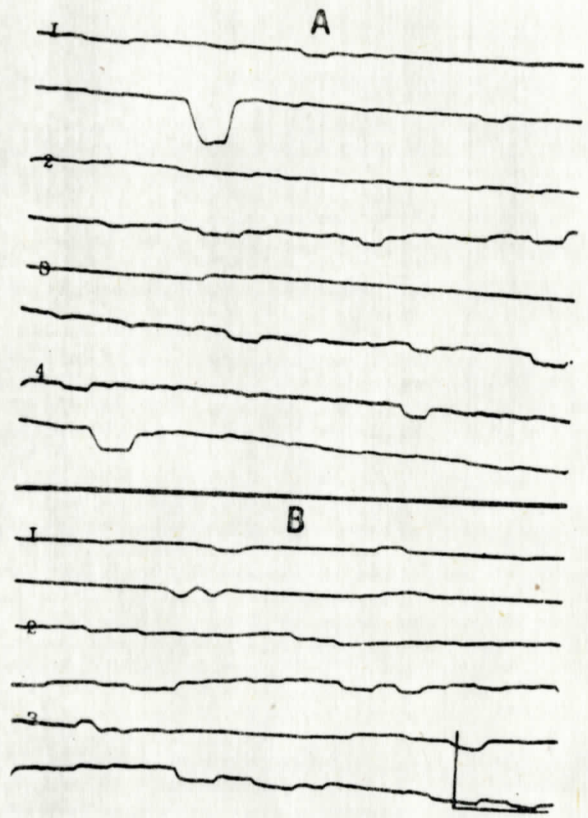

FIG.4. SPONTANEOUS AND POSITIONAL NYSTAGMUS IN THE COMMANDER /A/ AND FLIGHT-INGINEER /B/ OF THE "SOYUZ-T-4" 75-DAY FLIGHT AT R+56

1 - ENG IN THE SUPINE POSITION,
2 - ON THE RIGHT SIDE,
3 - ON THE LEFT SIDE,
4 - IN THE SUPINE POSITION WITH THE HEAD THROWN BACK

CALIBRATION 20°, 1 SEC.

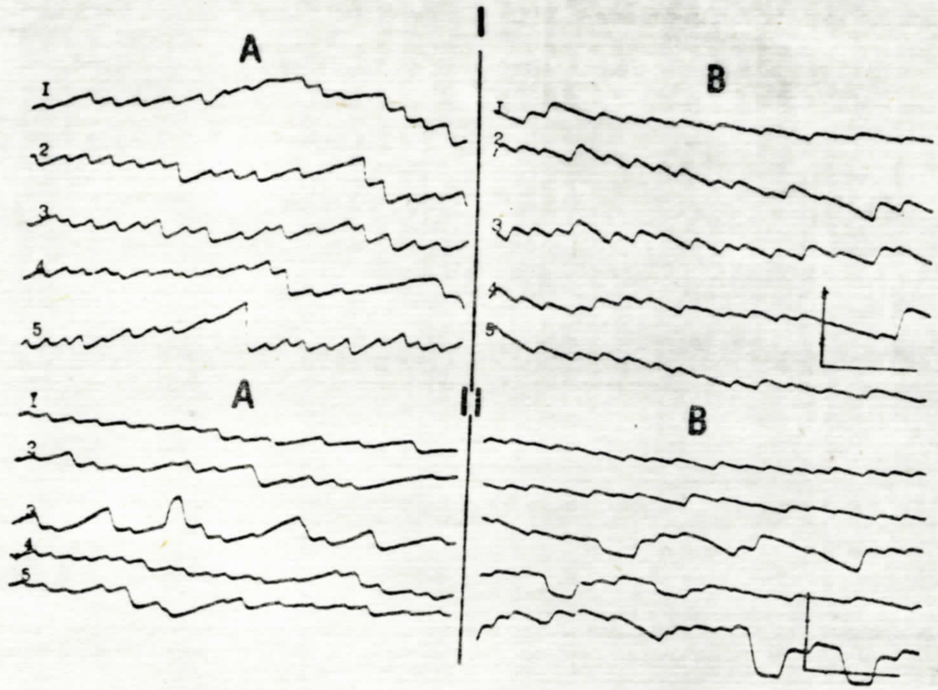

FIG.5. OPTOKINETIC NYSTAGMUS IN THE COMMANDER /I/ AND FLIGHT-ENGINEER /II/ OF THE "SOYUZ-T-4" 75-DAY FLIGHT AT R+56-DAY.

MOVEMENT OF BLACK-WHITE STRIPS TO THE LEFT (A) AND TO THE RIGHT (B) AT A VELOCITY OF 40(1), 60(2), 80(3), 100(4), AND 120(5) STRIPS PER MINUTE.

CALIBRATION 20°, 1 SEC.

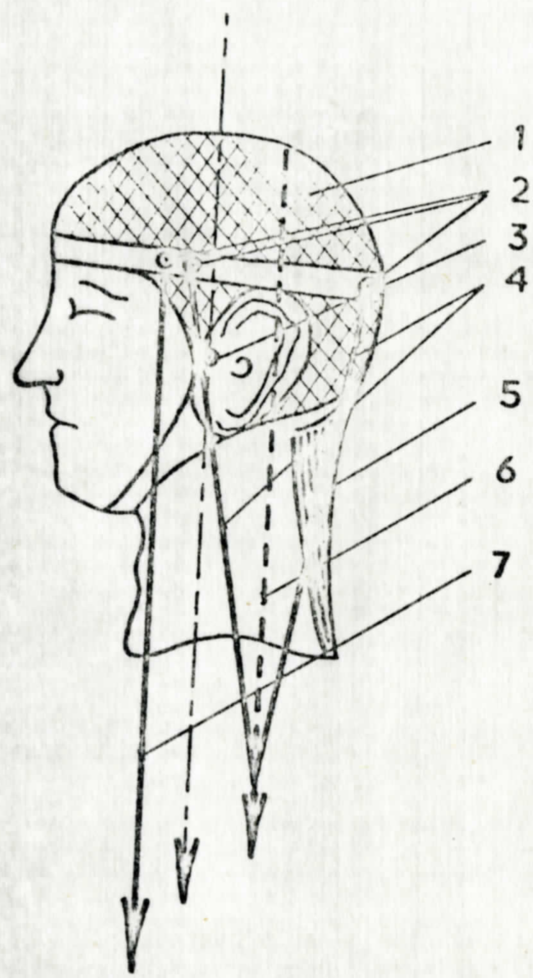

FIG. 7. SCHEMATIC REPRESENTATION OF THE "ANTIMOTION SICKNESS DEVICE".

1 - CAP,
2 - LOOPS OF THE CAP,
3 - MASS CENTER OF THE HEAD,
4 - VECTOR OF FORCES OF SHOULDER STRAPS LIMITING HEAD MOVEMENTS,
5 - CERVICAL-OCCIPITAL ANTIGRAVITATIONAL MUSCLES,
6 - AXIAL LINE OF THE SUPPORT CERVICAL-OCCIPITAL JOINT,
7 - VECTOR OF FORCES OF THE LOAD APPLIED BY A PAIR OF RUBBER RESTRAINTS

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