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Effect of Microgravitation on the Human Equilibrium

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Abstract: The 38-year period of human space exploration has gained for us a lot of experience in the problem of space motion sickness. The authors collected some causes of space sickness from the literature and from their research results. We collaborated with the Soviet-Russian space researchers and elaborated those vestibular research methods that were carried out by human space missions in the Soviet-Russian space station, on Earth, and after flight: spontaneous eye movement, foveal and peripheral optokinetic nystagmus, and vestibular stimulation. Using an earthly model of the effect of microgravitation on the human body, we tried to provide explanations of the origin of space motion sickness.

Key Words: antimotion drugs; microgravity; long mission; space motion sickness; space oculomotor disturbances

Cicero said that he "would rather be killed than again suffer the tortures of *nausea maris*" [1]. Sea sickness is the oldest problem in the history of human traveling. A recent problem is microgravity, which is a new notion: The centripetal force of the orbital spacecraft and the attraction of Earth equalize each other, but as the result is not exactly zero, it is called *microgravity* in the literature. Microgravity causes a new type of motion sickness—*space motion sickness* (SMS)—which is a motion maladaptation syndrome.

SMS is a well-recognized problem of space flight and affects 39–73% of all astronauts [2] during the first few days of their initial flight [3]. The symptoms of SMS are discomfort in the stomach, nausea, paleness, sweating, increased salivation, feeling of warmth, depression and apathy, and vomiting. After 2–3 days in microgravity, those so afflicted tend to adapt, but returning to Earth can trigger an exacerbation, though it is shorter because readaptation is quicker [4].

The exact cause of SMS is not established fully. The most important causes of SMS originate from unusual information from the vestibular end-organs, from the somatosensory system, and from the presumed asymmetry of bilateral otoliths in weight. All are the consequences of microgravity.

The cranial shifting of the body fluids (blood, cerebrospinal fluid, lymph) that happens in microgravity deteriorates the central processing of the aforementioned factors. The cranial shifting of the body fluids can be detected by otoacoustic emission in antiorthostatic position on Earth [5]. All of these actions also disturb oculomotor activity [6]. The labyrinths have a central role in SMS (no motion sickness occurs in labyrinthine-defective individuals on Earth) [7]. The basic concept is that the result of gravitation, linear acceleration, and angular acceleration affects the labyrinths on Earth. In microgravity, only the linear acceleration and the angular acceleration prevail, because the gravitation—as a vector—is missing [8, 9]. Hence, it produces an unusual processing condition to the central nervous system (CNS) for this reason (e.g., the amplitude of eye movement becomes higher) [10]. The provocative stimuli, such as body or head movements that produce changes in orientation, are necessary to induce SMS [11, 12].

The *sensory conflict theory* of SMS assumes that human orientation in three-dimensional space, under normal gravitational conditions, is based on at least four sensory inputs to the CNS: otolith organs (linear acceleration); semicircular canals (angular acceleration); visual system (visual scene, surround); and touch,

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pressure, and kinesthetic system (limb and body position). When the environment is altered in such a way that information from the sensory system is not compatible and does not match previously stored neural patterns, motion sickness may result [13].

Hungary is not one of the great powers of space; it can only cooperate with them. The Hungarian Vestibular and Psychological Research Group worked for 25 years with Soviet-Russian colleagues via INTERCOSMOS until 1990. Since 1991, this cooperation has been realized by coordination of the Hungarian Space Office. The Hungarian and Soviet-Russian space sickness researchers collaborated in the successful selection of a Hungarian astronaut, investigation of the vestibulooculomotor disturbances in microgravity, and the search for a satisfactory medicament against SMS.

The search for vestibular fitness for space flight in Hungary was carried out at the Military Aeromedical Research Institute in Kecskemét [14]. It was performed in accordance with Soviet specifications. The astronaut must be fit for the unfavorable factors of space flight: accelerations, state of weightlessness, artificial essential conditions, nervous and emotional strain, and characteristics of labor and regimen. The psychological and psychophysiological examinations were undertaken by loading functional diagnostic tests. Among them, the test of Coriolis acceleration's cumulative effect by continuous stimulation and the test of Coriolis acceleration's cumulative effect by periodic stimulation were the most difficult for the candidates for space flight [15]. Finding the limit between the normal and pathological vestibular function is not easy because of the complexity of the vestibular system. The result of calorimetry (e.g., in a healthy person) is not always equal in both sides, so, on this basis, unfitness can be declared only reservedly. From the standpoint of serviceability, not the solitary signs of alteration but functional ability and the psychophysiological dynamics of the entire organism must be considered. Taking into consideration the aforementioned factors, the selection of the Hungarian candidates for space flight was successful, and Hungarian astronaut Bertalan Farkas excellently endured the stress of microgravity.

The basic methods to evaluate vestibulooculomotor disturbances were carried out by two Russian researchers (IB Kozlovskaya and LN Kornilova) and one Hungarian researcher (G Bodó). We cooperated with them in elaborating the following methods in ground-based testing, in-flight testing, and after-flight testing:

1. SMS questionnaire
2. Spontaneous eye movements in differing stimulations
3. Optokinetic foveal and peripheral stimulation on videotape in horizontal, vertical, and diagonal directions
4. Vestibular stimulation by roll (*z*-axis) and yaw (*y*-axis) head movements
5. Oculographic registration (video recorder)
6. Evaluation of results by short (7- to 14-day) and long (166- to 241-day missions

The main results in microgravity included spontaneous floating and saccadic eye movements at the beginning of the flight (1–5 days). In the case of some astronauts, different types of nystagmus, such as horizontal, vertical, and oblique, appeared. The optokinetic stimulus produced individual horizontal variability and diminished eye movements, mainly in the vertical direction. The vestibular stimulation, caused by head roll and yaw movements, produced strong nystagmus in the adaptation period but, in the long-term flight (164 days), nystagmus was undetectable. Finally, the optovestibular stimulation revealed a predominant vestibular reaction at the beginning of the adaptation period but, after 5 days, the visual reaction was stronger [6,16].

To resolve many problems of SMS, numerous possibilities exist for examining the separate effects of weightlessness in ground-based (i.e., Earth-based) models. Our scientific group examined the effect of hypoxia on diagonal optokinetic nystagmus (DOKN). We stated that the dimension of the vertical component of DOKN decreases considerably more in hypoxia than does the horizontal [17]. We reasoned that the tectal and pretectal gaze centers–organizing the vertical eye movement—are more sensitive to hypoxia than is the horizontal eye movement directing pontine gaze center. In our other study, we also examined the horizontal and vertical components of DOKN but in antiorthostatic posture (with −30-degree head-down tilt position loading for 3 hours), modeling the microgravitational cranial shifting of body fluids on Earth. We ascertained that the frequency of the vertical component of DOKN decreases in the course of antiorthostatic posture as compared to the frequency, measured in sitting posture. The result suggested that the tectal and pretectal gaze centers are much more sensitive to the antiorthostatic posture than is the pontine gaze center. This result is similar to those observed in hypoxia. We may suppose, by the detailed results of examination, that different fields organize the amplitude and the frequency of nystagmus in the brainstem or in the archicerebellum [18].

Prevention and treatment of SMS are very complex and difficult tasks of SMS researchers. Reducing the unpleasant symptoms of SMS with maintenance of the psychological and physiological working capability at the same time is the most important aim of any countermeasure. Many kinds of pharmaceuticals were administered to protect astronauts from the symptoms of SMS. Among them, the most frequently used were scopolamine [19], cinnarizine (Stugeron) [20], dimenhydrinate (Daedalon) [21], promethazine [22], and amphetamine [23]. Two kinds of Hungarian medications were found to be satisfactory drugs for managing motion sickness. One is vimpocetinum (Cavinton; G. Richter, Budapest), which is an apovincaminic acid–ethyl ester. This medication improves the cerebral blood circulation, sensorineural hearing loss, and resistance to artificial rotary motion sickness. Cavinton did not deteriorate the mental activity but improved the vegetative resistance in sensitization caused by the head-down tilting position [24]. The other Hungarian antimotion drug is deprenyl or selegiline (Jumex; Chinoin, Budapest) which is a selective inhibitor of monoaminooxidase B. It facilitates the nigrostrial dopaminergic neurons, increases the stability of equilibrium, and decreases the disturbances of vegetative reactions. After the poststimulation malaise, dimenhydrinate caused sleepiness and headache subsequent to 2–3 hours' sleep, whereas with Jumex, the complaints quickly and completely returned [25]. These two medications are on board in the spacecraft.

The human organism adapts to microgravity after a short (2- to 3-day) adaptation period. The cranial shifting of body fluids comes to an end after 1 week. During this time, the organism increases urination to emit the redundant body fluids, felt by the pressoreceptors, from the upper body part. The crew members wear vacuum trousers with pneumatic occlusion cuffs to create lower-body negative pressure for 1 hour daily to remind the heart not to forget the pulling-back power of gravitation, and they drink plenty of liquids in the first week to avoid desiccation. As soon as the organism adapts to weightlessness in that way, the capacity of the cardiovascular system decreases, and the heart assumes a higher position in the thoracic cavity. The astronauts avoid physical strain in this period of body adaptation, but afterward, according to a strict program, they perform gymnastic exercises daily to prevent muscular atrophy. At the end of the month, the organism is in such a rest condition as adapts to the environment incidental to weightlessness. The plasticity of the human CNS allows individuals to adapt to altered stimulus conditions encountered in a microgravity environment [26].

Astronauts experiencing long periods of space flight suffer from severe loss of bone tissue, particularly in those bones that carry the body weight under normal gravity. Ca^{++} ions are being lost from bones, as in osteoporotic patients on Earth, but it is much more significant in microgravity. An osteoporotic patient loses 2% of the bone mass yearly on Earth; in microgravity, the rate of loss is 1–2% per month in healthy individuals. The Ca^{++} ions are excreted via urine, so that nephrolithiasis is a potential risk of long missions. The lack of mechanical load decreases connective-tissue biosynthesis in bone-forming cells [27]. On the other hand, the loss of muscle mass was proved before and after the STS-47 Shuttle mission by magnetic resonance imaging examination and measurement of muscle strength and limb girth [28]. Even short-duration space flight can result in significant muscle atrophy.

The alteration of electrolytes, volume of urine, levels of hormones, and the like always are investigated before, during, and after flight. The use of alternative methods that are easier to execute during space flight, such as collection of saliva instead of blood and urine, should permit more thorough study of circadian rhythms and rapid hormone changes in weightlessness. More investigations of dietary intake of fluid and electrolytes must be performed to understand the regulatory processes. Alteration in body fluid volume and blood electrolyte concentrations during space flight have important consequences for readaptation to the 1-g environment [29].

Structural alteration of otoliths was investigated by Ross and Cuttler (NASA Ames Research Center, Moffet Field, CA), who established that otoliths degenerate from the changes of Ca^{++}, carbohydrate, and protein metabolism and from fluid distribution and sweeping hormonal changes in microgravity. The animal experiments were made in space and on Earth in rats.

In long space missions—travel to other planets or staying in a space station—important maintenance for psychophysical capability of crew members is necessary. The symptoms of SMS during adaptation to microgravity can be reduced by administration of tested anti–motion sickness drugs. The most important factors are to avoid muscle atrophy and osteoporosis and to preserve the essential blood vessel reflexes for being able to return to normal gravitation. For this purpose, astronauts also need other possibilities to prevent the negative effects of weightlessness:

- Preflight vestibular training by Coriolis acceleration
- Training of plasticity of CNS (developed training devices and procedures to readapt astronauts to the sensory stimulus rearrangements of microgravity)
- Pneumatic occlusion cuff and lower-body negative pressure
- Neck pneumatic shock absorber
- Special gymnastic exercises

Returning to Earth requires readaptation of an organism to the Earth's gravity after a long space mission. Astronauts wear a lower-body positive-pressure device for 1 week to help the readaptation process of the cardiovascular system. The vestibular system recovers within 1 week.

Many satellites are in orbit around Earth. The pertinent question is: Is it necessary to preserve the presence of humans in space flights? To answer this, let us look at an example: Though the vision of crew members deteriorates for a very short time in microgravity, later on it is restored to health. After such restoration of sight, the crew members in our studies found that they were able to distinguish extremely fine shades of color that were not visible again on standard color pictures. So seemingly, human sight presents a special value in the visual observation of, for example, ocean currents, blooming of plankton, hurricanes, and shoals of fish [30]. We conclude that indeed the presence of humans *is* needed in revealing the secrets of space.

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