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INFLUENCE OF SHORT- AND LONG-TERM EXPOSURE TO REAL MICROGRAVITY ON KINEMATICS OF POINTING ARM MOVEMENTS

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INTRODUCTION

Movement control in microgravity is complicated by several factors: changed physical properties of the body and extremities, functional proprioceptive deprivation due to reduction of the input from proprioceptors of postural muscles, and increased excitability of the motor control structures. These factors cause complex disturbances of co-ordination of aimed voluntary movements, which are known as hypogravitational ataxia (Kozlovskaya, 1988) and manifest by reduced accuracy and altered movement kinematics.

If movements should be performed in microgravity under high accuracy constraints (as most real tasks), a pronounced increase of movement duration is observed. Reason for that was supposed to be a re-orientation of the motor control system to a more reliable source of information - the visual system. According to this point of view the motor control changes to the visual tracking mode. Movements performed in the visual tracking mode tend to have more than one deceleration, which results in prolongation of the deceleration phase.

Numerous studies of movement organization (for review Jeannerod, 1988), reported that changes of motor control strategy lead to the deformation of normal bell-shaped velocity profile, which becomes asymmetric with prolonged deceleration phase. This is true also for visually controlled movements. Therefore, the symmetry of the velocity profile seems to be an important parameter, providing information about the role of the visual system in movement organization.

The gravitational force is integrated in the organization of every movement performed on the earth surface (Lackner, 1993). As shown recently, movements performed under normal gravity conditions in different directions, with and against gravity, have very

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similar kinematics. However, the correspondent EMG patterns tend to change in order to compensate the influence of the gravity force (Virji-Babul et al., 1993).

Under earth conditions the body is fixated on the surface by the gravity force and can compensate the impact of the moving limb by additional postural adjustment. In microgravity any rapid muscular contraction evokes a counter-movement of the body if no additional fixation is provided. In this situation the central nervous system should elaborate new control patterns to preserve its ability to organize and conduct temporally and spatially accurate aimed movements, and to reduce the destabilization of the body.

Observations have shown that movement accuracy, defined as final position of the limb at the end of the movement, tends to be preserved in microgravity. Furthermore, cosmonauts are able to perform almost the full repertoire of movements from the beginning of exposure to microgravity. However, movements become slower and their kinematics are altered. Visual input, supposedly, becomes more important for movement organization in the microgravity environment.

Since for single-joint movements the kinematics are proportional (neglecting viscosity) to force production, the kinematic analysis can elucidate the mechanisms underlying the reorganization in motor control during the adaptation to microgravity.

We studied simple single-joint arm movements in order to analyze the alterations of movement kinematics, and to elucidate the role of the visual system in the movement organization in microgravity.

METHOD

Subjects

Two cosmonauts, which were crew members of two different space missions on board the Russian MIR space station performed several pre-flight, in-flight, and post-flight sessions. Cosmonaut A participated in 10-days space flight and performed three pre-flight, two in-flight (on the 2d and 5th day), and two post-flight sessions. Cosmonaut B participated in 132-days space flight and performed two pre-flight, four in-flight (on the 27th, 60th, 70th, and 102d day) and two post-flight sessions.

Hardware

The MONIMIR equipment was used for data collection (Berger et al., 1992). The equipment was developed for investigation of eye-head-arm coordination in microgravity and consists of a matrix of LED's for signal presentation and of an opto-electronic system for three-dimensional recording of the position of infrared light emitting diodes (IR-LED's). Arm movements were recorded by using an arm clamp fixed on the forearm and shoulder to prevent possible elbow flexion. The lamp was equipped with two pairs of IR-LED's allowing reliable definition of the arm position. The opto-electronic system included two IR video cameras that allowed registration of the position with a 25 Hz sampling rate.

Experiment

On earth the subjects were tested in a sitting position. In flight they were fixed to the floor of the station by two belts. They were instructed to perform pointing arm movements towards flashing LED's as accurate and as fast as possible, and to begin the movement as soon as the next flashing LED appears. Importance of accuracy was emphasized. The sequences of flashing LED's were randomized in time and direction. Targets appeared at 4 and 16 angular degrees from the center of the visual field. They required movements in the horizontal and vertical planes. In this paper only horizontal movements at 16 angular degrees are analyzed.

Data Processing

Three-dimensional Cartesian position data were converted into values of arm angular displacement and interpolated using the "two-bells" model of simple single joint arm movements (Mescheriakov et al., 1994). The model was proposed in order to separately estimate the angular acceleration produced by agonist and antagonist muscles (or muscle groups) during simple pre-programmed arm movements (that is one acceleration and one deceleration phase). The basic assumption of the model was that time profiles of the angular acceleration produced separately by agonist and antagonist muscles could be approximately described using Gaussian distribution functions. Two best fitting Gaussian functions were selected using simplex algorithm. Linear combination of these two functions yielded the acceleration-time profile which, when integrated, produced velocity- and position-time profiles. This interpolation procedure showed high fitting ability. The original software MONIGRAF was used for extraction of the kinematic parameters.

Parameters

Three different time profiles were analyzed. (i) Position-time profile: movement amplitude (maximal angular displacement), movement duration, and mean velocity. (ii) Velocity-time profile: peak velocity, acceleration phase (time from the movement onset to the peak velocity), and deceleration phase (time from the peak velocity to the end of movement). (iii) Acceleration-time profile: peak acceleration, peak deceleration, acceleration time (the time from the movement onset to the peak acceleration), "switch" time (the time from the peak acceleration to the peak deceleration), and deceleration time (the time from peak deceleration to the end of movement). Mean values and standard deviations of each parameter were calculated and analyzed.

RESULTS

Constantly high accuracy of angular displacement for movements of 16 angular degrees is observed in all test sessions including in-flight for cosmonauts. Mean deviation from the target in all in-flight sessions did not exceed 5% of the movement amplitude. Movement duration increased in-flight in both short- and long-term flights and was up to 300 ms longer in short-term and up to 200 ms longer in long-term flight. Significant decrease of peak and mean velocities is observed in all in-flight sessions for both cosmonauts.

Velocity-time profile was asymmetric in all sessions due to prolonged deceleration phase. No changes of the symmetry of the velocity-time profile could be detected in in-flight sessions, because both phases increased in-flight by the same factor.

Analysis of the acceleration-time profile shows that for cosmonaut A the acceleration and deceleration times were almost equal in all sessions. The lower curve on the Fig. 2 results from overlapping values of the acceleration and deceleration times. For cosmonaut B the deceleration time was up to 100 ms longer than the acceleration time. The switch time for both cosmonauts constituted about 50 % of the movement duration.

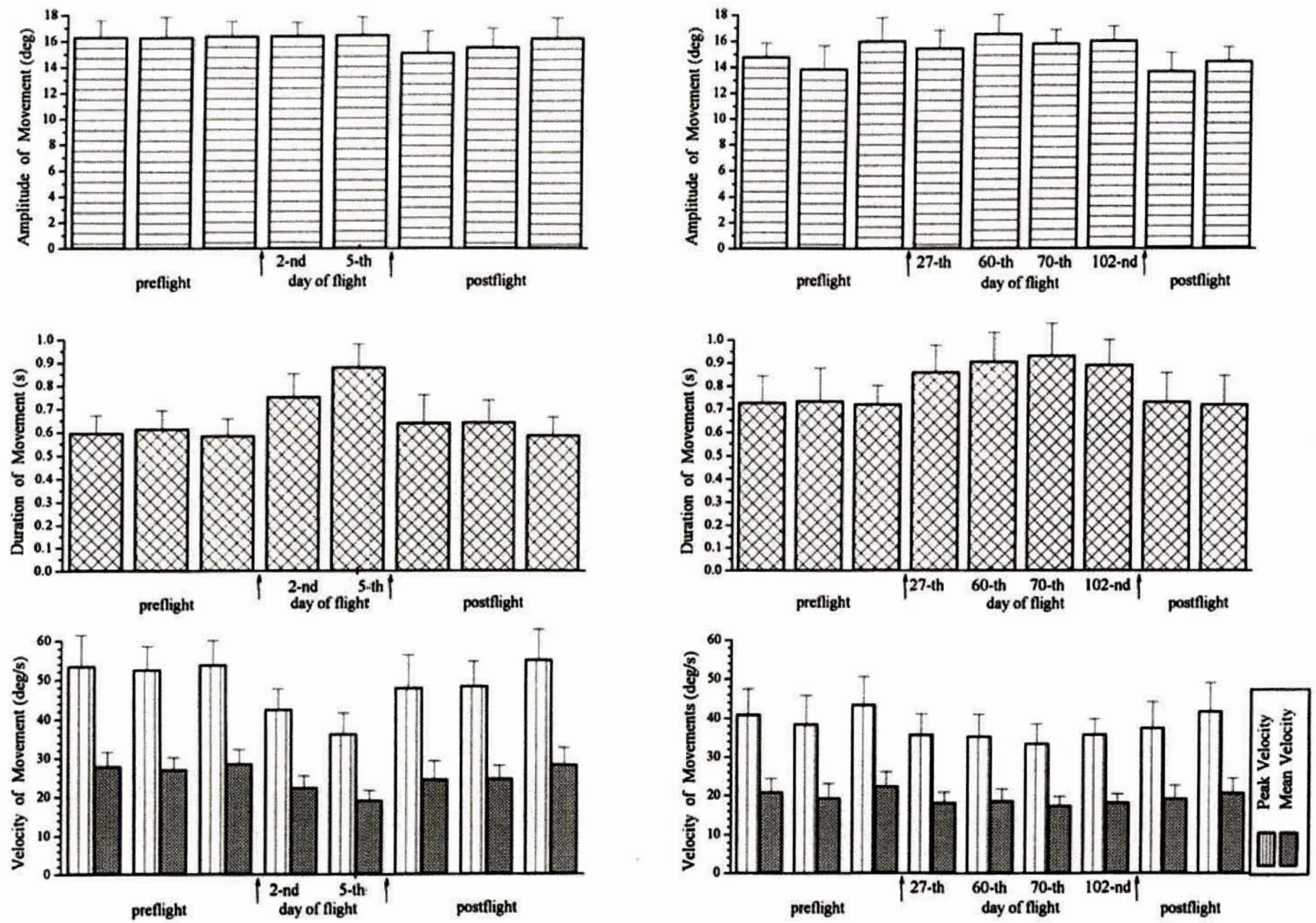

Figure 1. Angular displacement, duration, and peak and mean velocities of pointing arm movements. Left: Cosmonaut A - short-term flight, right: Cosmonaut B - long-term flight. Arrows below the horizontal axis indicate launch and landing. Target angular displacement was 16 degrees. All values are means and S.E.D. per session.

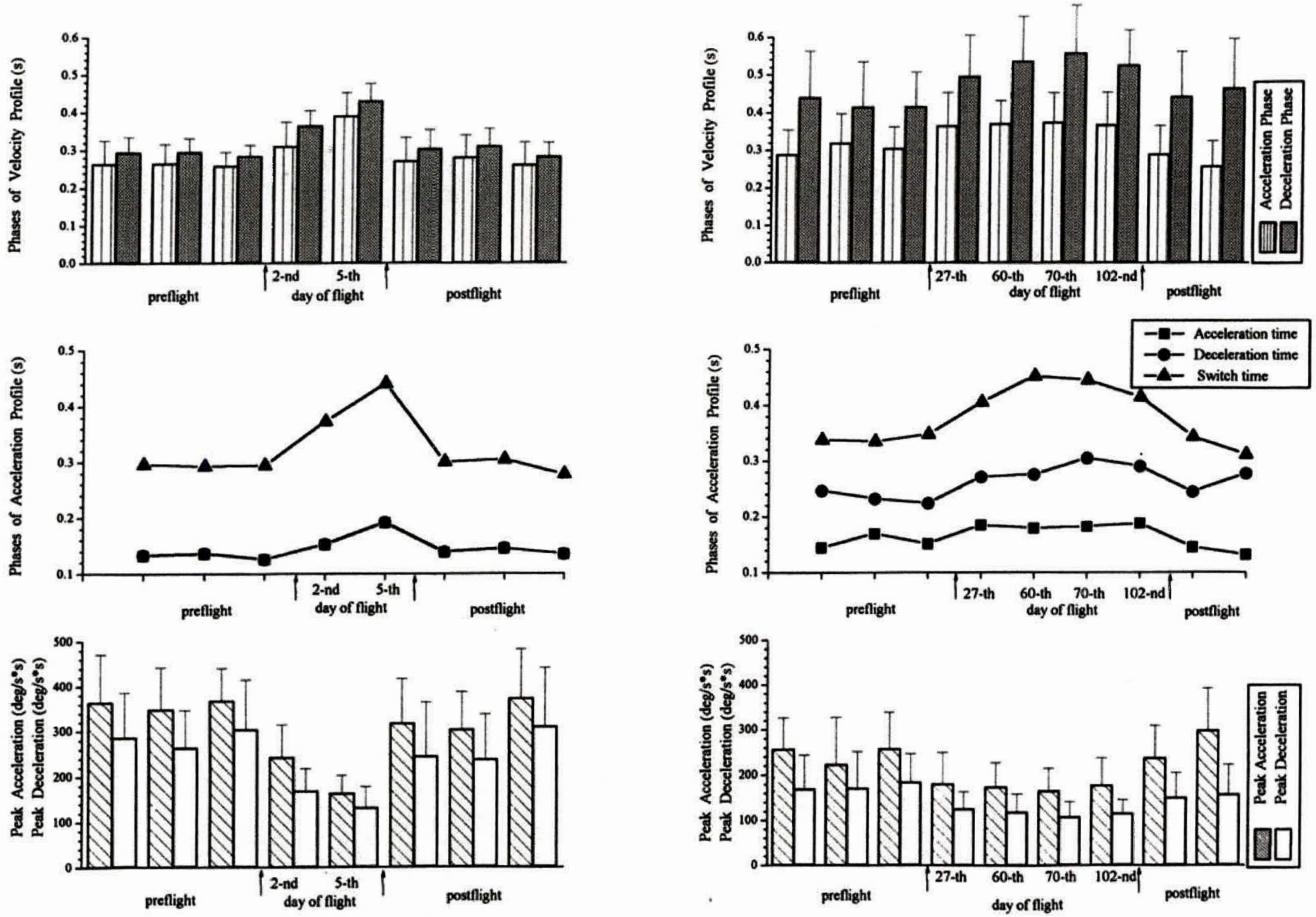

Figure 2. Parameters of the velocity-time and acceleration-time profiles. Left: Cosmonaut A - short-term flight. Right: Cosmonaut B - long-term flight. Arrows below the horizontal axis indicate start and landing. Further explanations in text.

The increase of movement duration in-flight results from lengthening of all three phases of the acceleration-time profile. However, the absolute contribution of the switch time is considerably higher. Mean values of peak acceleration were higher than values of peak deceleration and both considerably decreased in-flight.

DISCUSSION

Our data suggest that the CNS can successfully organize movements and maintain high accuracy in weightlessness and during the re-adaptation to normal gravity. However, it requires additional time for the movement organization under new conditions, which results in prolongation of movement. Since in our task the accuracy constraints were high and cosmonauts were instructed to perform movements as fast as possible, certain decrease of movement duration can be expected when changes in control mechanisms occur.

Pointing to visual targets is obviously controlled by proprioceptive and visual input. Movements seem to be ballistic, that is they are not controlled during the movement. Only terminal visual feedback is possible. The question arises whether movements in microgravity are also executed ballistically or if the visual system intervenes on the late phases of movement. If the latter is true, general undershooting and/or prolonged final phases of movement could be expected. Participation of the visual system in the middle phase of movement, where actual velocity is very large, seems to be impossible because of difficulties in visual perception. The visual system can control movement only in the phases where velocity is small, that is after the deceleration peak.

Since no specific changes in the final part of movement (deceleration phase and deceleration time) were observed, we can not make a conclusion about an increased role of the visual system in control of this type of movements in microgravity during both short and long-term space flights.

The most sensitive part of the acceleration profile, the switch time, seems to be very important for the regulation of movement amplitude in microgravity. Generally, the switch time contributes more to the prolongation of movement than either acceleration or deceleration times. There are strong correlations between the peak velocity and length of the switch time, as well as between peak acceleration and deceleration and switch time.

In general, we observed that lower accelerations and decelerations were characteristic for movements in weightlessness. There are several possible explanations for this effect. The first is that the proprioceptive system, altered in microgravity, needs more time for coordination between the agonist and antagonist activity because of disturbances in proprioceptive control loops. This explains the prominent increase of the time between peak acceleration and peak deceleration (switch time on the Fig. 2). The second explanation could be that lower and prolonged accelerations of extremities reduce the counter-movements of the body in microgravity. The CNS elaborates a strategy of careful and slow movements and therefore avoids the destabilization of the body during the movement. This explains the decrease of peak values of accelerations and decelerations.

Detailed analysis of kinematics of movements in microgravity should be conducted in order to clarify strategies of the motor control system in adaptation to altered force environment.

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Chapter

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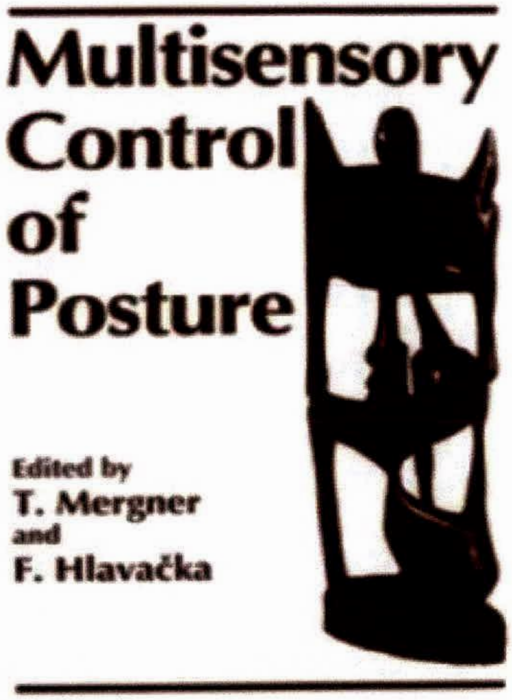

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