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The Influence of Microgravity on Memorized Arm Movements

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Abstract

To investigate sensory and motor functions in microgravity, goal-directed arm movements were performed by 9 cosmonauts in weightlessness. The ability to reproduce predefined motor patterns was examined pre-, in-, and post-flight under two different paradigms: In a first test, the cosmonaut had to reproduce passively learned movements with eyes closed, while in the second test, the cosmonaut learned the pattern with eyes open. The different learning paradigms effected the metric parameters of the memorized stimulus pattern while the influence of the different gravity levels resulted in significant offsets and torsions of the reproduced figures. In comparing the inflight condition with preflight, intact proprioceptive afference seemed to play an important role for reproducing movements from motor short-time memory correctly.

Introduction

The execution of a pointing arm movement requires the brain to predict the relative positions of arm and target during the whole movement. An internal representation of the target and a body reference for directional coding of the movements is necessary. Visual, vestibular and somatosenory signals have to generate an internal representation of "egocentric" coordinates, a body scheme, which provides a reference for actions within personal space and actions directed at objects within extrapersonal space. This internal visual and proprioceptive map has to be updated permanently [1].

Weightlessness, however, causes modifications in this central interpretation of afferent signals from the otolith organ, from proprioception and from exteroception. Without the gravitational force, a stable spatial reference system is missing. Even visual information seems to be affected due to altered eye motion in course of the changed vestibular and proprioceptive afferent inputs.

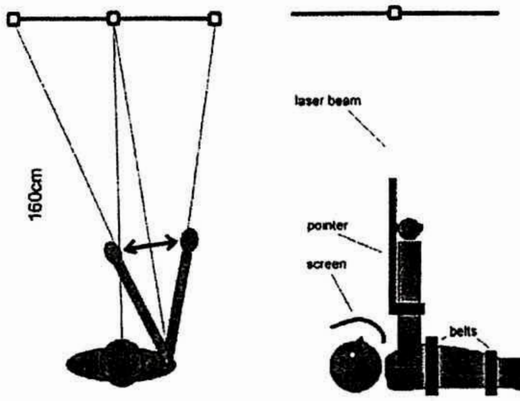

Fig. 1) Position of the cosmonaut during the experiments in the Mir-station

For that reason studies of motor performance in weightlessness have revealed pronounced disturbances of coordination of voluntary movements during the periods of adaptation and readaptation [2-5]. Deficits in the ability to judge elbow angles and to point at memorized targets were found [6;7]. These findings were interpreted to result from changes in proprioceptive function, a loss of sensory information about position of limbs, angles and motions. In experiments investigating sensorimotor functions with 10 cosmonauts on the MIR space station, spatial disorientation of pointing arm movements in different head-to-body positions were found, in short-term as well as long-term flights [8].

In normal gravity environments single joint arm movements made in the horizontal plane are characterized by time-symmetric velocity profiles which were found to remain consistent in spite of changes in load, velocity and movement amplitude [9]. The trajectories of these pre-programmed arm movements in the sagittal plane are highly reproducible [10;11].

The aim of our study was to examine the ability to reproduce a defined motor pattern pre-, in- and postflight under different (passive and active) learning conditions.

Methods

1. Persons

Ten sets of measurements were taken in 9 cosmonauts (8 male, 1 female) with mean age of 41 years (range 31- 47 years). One cosmonaut stayed in orbit for two times. They all gave informed consent to participate in these experiments. Investigations were performed 4 or 5 times preflight, on the 2nd and on the 5th day after landing (postflight), twice during one short-term flight (inflight time one week), approximately once a month during eight long-term flights (inflight time 4 to 8 months, mean value 5.3 months) and one super long-term flight (inflight 14 months).

2. Procedure

In experiments during space missions as well as in terrestrial control experiments an equipment for 3-

dimensional monitoring of head and arm position allowed to consecutively study the processing between visual, vestibular and proprioceptive input [12;13]. The pointing accuracy during learning could be controlled by a laser beam. Two infrared cameras recorded the movements of the stretched right arm, on which infrared LEDs and a laser diode was attached. In the terrestrial experiments all subjects were sitting upright in a chair, fixed with a thoracic belt. In the inflight tests, the cosmonauts were fixed in supine position on the floor by thoracic and pelvic belts with the head free to move (Fig.1).

The visual stimulus pattern was presented on a matrix of LEDs in front of the cosmonaut. The pattern consisted of an isosceles triangle with 3 movement sequences (up, down, close). In a first test the cosmonaut's outstretched arm was passively moved three times along the visually presented pattern by the fellow cosmonaut. Still with eyes closed, the test person attempted to reproduce actively the movement sequences, the shape of the triangle, from memory. In a second test the test person traced the figure on the matrix of LED for three times with open eyes and repeated it with eyes closed. Thus each test was divided into two parts, the learning phase and the memory phase. This task was learned pre-flight to a standard performance until no more improvement was seen.

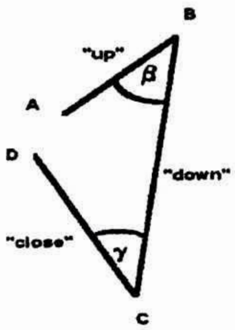

Fig.2: Quantification of metric and spatial parameters of reproduced triangles

3. *Data analyses*

In order to quantify the metric and spatial characteristics of the movement trajectories, the position of the corners of each triangle, its area, circumference, lengths of the sides, slopes, angles and its central point were evaluated (Fig.2). With each of these dependent variables an analysis of variance was performed for each cosmonaut, the independent variables were the two learning conditions (active versus passive learning) and the different gravity levels (pre-, in-, and postflight).

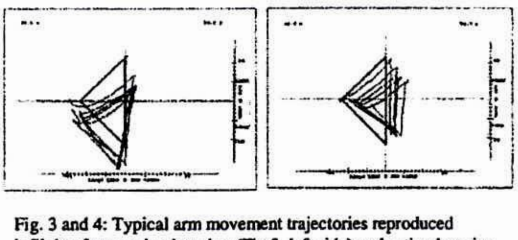

Fig. 3 and 4: Typical arm movement trajectories reproduced inflight after passive learning (Fig 3, left side) and active learning (Fig 4, right side)

Results

Fig. 3 and 4 shows typical results of an inflight test: reproduced triangles, 5 at a time, learned passively (Fig. 3) or actively (Fig 4)

1. Passive versus active learning

Regarding the learning paradigm, the analysis of variance showed significant differences in metric parameters as area ($p< 0.05$), circumference ($p< 0.01$), length AB (up, $p< 0.05$) and length BC (down, $p<0.01$). After active learning pre-, in- and postflight the 5 memorized triangles were larger on the average, caused by the larger sides AB and BC. They were more accurate reproductions of the stimulus pattern. The size of the reproduced triangles changed in the course of performance time: after active learning the reproduction performance get worse after 1 or 2 accurate reproductions while after passive learning the reproduced triangles were less accurate from the beginning but size did not changed in time.

Significant interactions between learning minor changes and gravity levels in the dependent variable horizontal shift ($p< 0.01$) and slope BC ($p< 0.05$) were found. In active learning inflight and postflight there was no vertical shifting of the reproduced triangles. The amount of length AD (error in closing the triangle) was larger in the passive learning experiment pre- and inflight.

2. *The effect of different gravity levels (pre-, in-, and postflight condition)*

Spatial parameters significantly changed inflight compared to preflight experiments, particulary for passively memorized triangles. Highly significant effects ($p< 0.01$) were observed on the co-ordinates of the central points of the reproduced triangles, on the slopes of the „down"-and „close"-movements and the angles gamma at the corner C (fig. 2). This means that inflight the memorized triangles were tilted, due to a clockwise shift of the "vertical" side of the triangle (top-base line). Tested postflight, hardly any rebound-effect was found after short-term flight. The performance was similar to pre-flight. But after long-term space flight, particularly 2days after landing, most movements were quite inaccurate, except a remarkable vertical orientation of the reproduced triangles.

Discussion

To reproduce a learned arm movement task with eyes closed, motor memory is necessary. After passive learning, only proprioceptive feedback was available for memorizing the movement`s features. In active learning, the cosmonaut traced the visually presented pattern. This implicated the interaction of information from central commands. Visual calibration as well as proprioceptive feedback was possible.

After passive learning without a visual reference frame the deterioration of body awareness in microgravity led to larger errors in reproducing metric and spatial parameters of pointing arm movements. The shapes (the angles) of the reproduced figures was preserved in the experiments, maximal after active learning pre-flight, minimal after passive learning inflight. The coding and retention of the triangular shape is more successful due to its high redundancy and is more resistant to reduction of information in the passive learning situation and/or in microgravity. Therefore in microgravity, it seems to be easier to reproduce the particular shape than the size, for shape recognition is a cognitive function, size, however, is a question of calibration [14]

Our findings confirm former results indicating motor slowness and mainly, hypometry of voluntary movements in space flight [15]. The decrease of velocity of movements in microgravity seems to be the consequence of the impaired afferent feedback.

It was necessary to perform the tests always in the order passive-active. A possible transfer effect will be small because during passive learning and reproducing there was not any visual feedback available about the accuracy of performance by which the cosmonaut would increase the accuracy.

We may conclude from our investigation that as long as visual calibration is possible new motor control patterns can be trained and adapted to plan and perform temporally and spatially accurate aimed movements in microgravity. The ability to reproduce movement patterns which are learned from visual, afferent and efferent information (active learning) improved during spaceflight. Proprioceptive feedback alone without a visual reference frame (passive learning) was not sufficient to optimize arm pointings during prolonged space flight

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