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EYE-HEAD-ARM COORDINATION AND SPINAL REFLEXES IN WEIGHTLESSNESS

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ABSTRACT

The MONIMIR experiment was part of the investigation program for the Austrian-Soviet spaceflight in October 1991. This experiment investigated the adaptation and readaptation of eye, head and arm movements. These are highly coordinated under the control of visual, vestibular and proprioceptive systems. Disturbances in the vestibular and proprioceptive systems caused by weightlessness during spaceflight are responsible for initial movement disorders in space. Visual information is primarily responsible for adaptation of the sensory motor system. Special hardware was developed for the presentation of standardized visual signals (LED matrix) and for registration of eye, head and arm movements (EOG, infrared (IR) diodes on helmet and armlamp with focused light beam, 2 IR-scanner cameras). Preprogrammed movements, tracking movements, memorization of movements and the influence of neck reflexes on arm movements were investigated. Analysis of accuracy, velocity, reproducibility of eye, head and arm movements and their changes during and after spaceflight gives further information on the adaptive process of the sensory motor system.

Keywords: sensory motor system, preprogrammed movements, T-reflex, motor coordination, adaptation in weightlessness, microgravity

1. INTRODUCTION

The human motor control system has evolved in the earth's gravitational field that affects many mechanisms controlling the reliability, accuracy and stability of motor activities. A decreased G-load can thus dramatically affect the functioning of several mechanisms of the human motor regulation system. Studies in weightlessness and under simulated weightless conditions have shown that a weightlessness-dependent motor syndrome is characterized by changes in all parts of the motor system. On short-term exposures it manifests itself as decreased muscle tone and decreased strength of muscle contractions, muscular hyperreflexia, disturbances in motor coordination with decreased accuracy of execution of muscular efforts and increased motor reaction time (Ref.3). In addition to weight unloading, microgravity causes alterations in the functioning of sensory inputs, such as otolithic, proprioceptive and others, which are mainly involved in motor regulation. Part of the center of motor coordination is localized in cerebellar and brainstem structures. Changes in afferent inputs naturally have an influence on the closed-loop control of the motor system. Adaptive reorganization of motor coordination involves recalibration of effort scaling, accentuation of intermittent control mechanisms and deprivation of all kinds of phasic-static linkage (Ref.3). All this should lead to an adaptive reorganization of motor coordination and accentuation of control mechanisms.

The Monimir experiment was performed by the Austrian Cosmonaut F. Viehböck during the first Austrian-Soviet spaceflight in Oct. 1991 on the second and fith days of spaceflight as well as before and after the flight. In this experiment we investigated the coordination of eye, head and arm movements in weightlessness and the adaptation and readaptation of the human sensory motor system during and postflight.

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2. SCIENTIFIC QUESTIONS

Kinematic characteristics of preprogrammed movements (closed-loop condition) and of pursuit movements (open-loop condition) of eye, head and arm movements on acoustic, visual and proprioceptive stimuli
Influence of visual feedback mechanism on different movements by investigation of accuracy characteristics
Quantitative analysis of spinal reflex mechanisms before, in- and postflight
Influence of proprioception of the neck on precise horizontal arm movements

3. MATERIAL AND METHODS

A special program was developed to study the cosmonaut motor system in order to assess the state of the motor control system and of the main proprioceptive, visual and acoustic inputs. Adaptive mechanisms of the sensory motor system were investigated by standardized acoustic, visual and proprioceptive stimuli. Changes in motor pattern and motor performance of eye, head and arm movements before, during and postflight were registered. The cosmonaut's trunk was "fixed" to the "floor" of the MIR spacestation by two velcro belts; head movements were possible in all three dimensions. The visual targets were presented on LED matrix (14 LEDs in horizontal and vertical direction) 1.5 meters in front of the cosmonaut. The acoustic targets were received through special headphones (Fig.1)

Every signal was presented five times at random on visual stimuli 4 degree and 16 degree horizontal and vertical for 0,5 sec for eye movement tasks and for 1 sec for head and arm movement tasks. Acoustic stimuli were presented in 100-ms bursts in two sec. steps. We used AC-EOG to register eye movements (horizontal and vertical). To record head and arm movements we used infrared diodes, ten IR-diodes on a special helmet with focused light beam (helmlamp) and six IR-diodes on an armlamp ("gun"), both of which are switched on with the gun's trigger. Information from the diodes on the helmet and the armlamp during motor performance was recorded by 2 IR-scanner cameras. The T-reflex was investigated by a specially developed T-reflex stimulator with standardized reflex trigger and registration of leg movement and EMG of M.quadriceps femoris.

4. INVESTIGATION PROGRAM

- preprogrammed movements (eye, head, arm) on visual and acoustic targets
- pursuit movements (eye, head, arm) on visual targets
- memory movements (head, arm)
- neck reflexes (head, arm)
- T-reflex (patellar reflex)
- biomechanics of the cervical spine

FIG. 1) : COSMONAUT F. VIEHBÖCK DURING EXAMINATION OF EYE, HEAD AND ARM COORDINATION IN THE SPACESTATION MIR

5. RESULTS

Analysis of our data demonstrated the difference in the programming of movements before, during and after short term spaceflight. We found disturbances in the motor pattern as well as changes in kinematics and amplitude of movements in the early beginning of exposure to weightlessness.

Fig.3) shows very standardized, regular head movements to visual targets before flight. The cosmonaut was well trained for this task. In weightlessness, the variance of movement-characteristics increased (characteristics of time and amplitude). Error was found by moving the head away from as well as back to the center of the LED matrix. The mean value of error increased during spaceflight. Of 22 head movements, the number of precise movements without correction decreased from 35% to 5% on the second and to 15% on the fith day of flight (Fig.2). The number of correcting movements under visual control increased during flight (from 65 % to 85 % of total movements), whereas most of the correcting movements were not successful. Accuracy of movements decreased. Furthermore mean and maximal velocity of head movements decreased and the duration of head movements in gaze fixation reaction increased. The inflight increase in VOR was statistically significant.

Eye-head coordination to acoustic targets rehearsed prior to flight (= counter-rotation of closed eye while head moves to acoustic target) changed to an eye-head coordination previously seen in the initial training program (physiological pattern: eye and head movements in the same direction). Surprisingly the trained motor coordination pattern returned during the fith day of flight and remained unchanged even under terrestrial conditions (adaptation) (Fig.4)

Slow pursuit movements of the head and arm by visual feedback were not significantly disturbed, which shows the important role of the visual system in tracking movements at zero gravity.

For investigation of motor short-time memory, arm and head movements (task = triangle) were learned by visual control or proprioceptive information (passive arm movement by another cosmonaut) and repeated from memory without visual control. During flight the pattern of movements changed, the form of the triangle was disturbed and enlarged by every repetition of movement and the center of mass of the triangle shifted. These changes were more prominent on the fith day of flight (no adaptation). Inflight passively learned movements were more disturbed, which indicates the lack of proprioception in weightlessness.

FIG. 2) : PREPROGRAMMED HEAD MOVEMENTS ON VISUAL TARGETS. ACCURACY BEFORE AND AFTER VISUAL CONTROL (HEADLAMP)

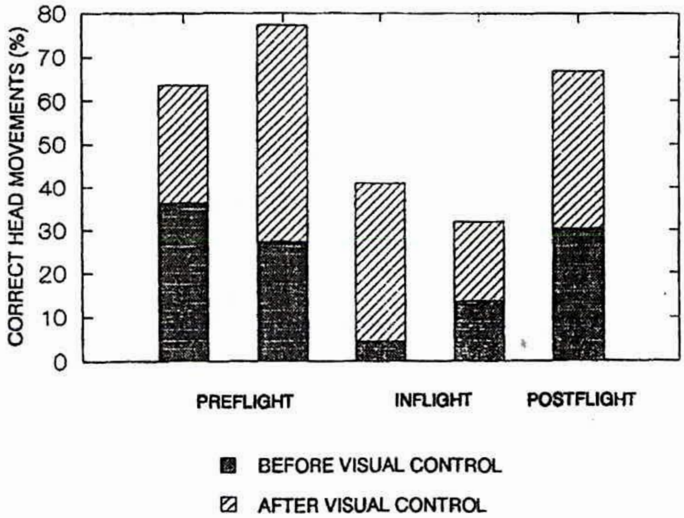
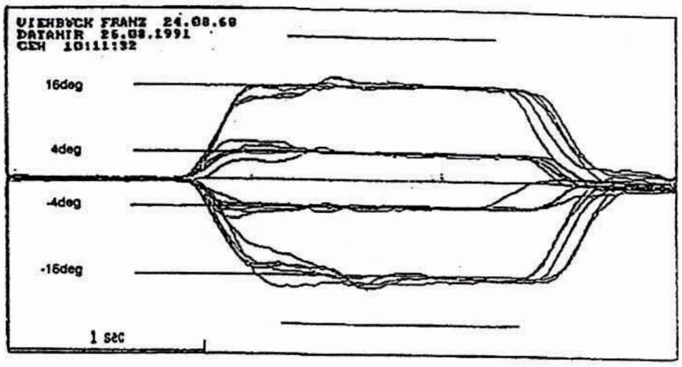


FIG. 3) : PREPROGRAMMED HEAD MOVEMENTS ON VISUAL TARGETS (SUPRAPOSITION OF 22 HORIZONTAL HEAD MOVEMENTS)

PREFLIGHT (DAY 36)

ACCURACY AND RELIABILITY OF PREPROGRAMMED HEAD MOVEMENTS AND PRESERVATION OF POSITION

PREFLIGHT (DAY 36)



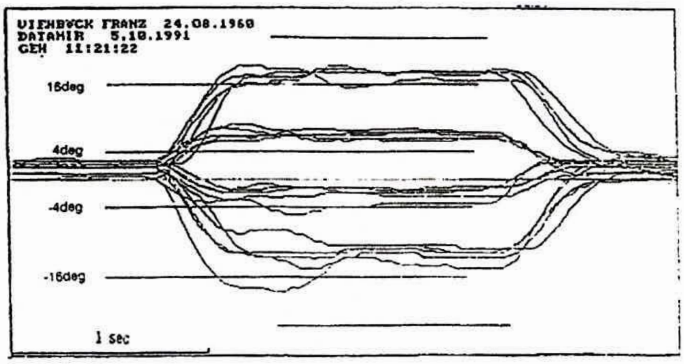
INFLIGHT (DAY 2)

VARYING NEUTRAL POSITION

PREPROGRAMMED COMPONENT:
CHANGES: VELOCITY
ACCURACY

MAINTENANCE OF POSITION:
OSCILLATION OF HEAD MOVEMENTS

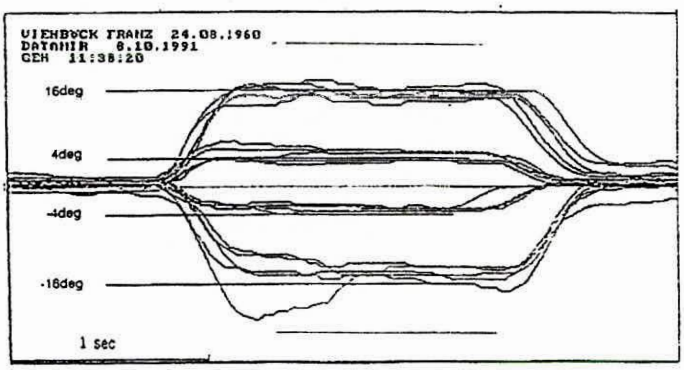
INFLIGHT (DAY 2)



INFLIGHT (DAY 5)

INCREASED ACCURACY OF PREPROGRAMMED HEAD MOVEMENTS AND PRESERVATION OF POSITION (SIGNS OF ADAPTATION TO WEIGHTLESSNESS)

INFLIGHT (DAY 5)



POSTFLIGHT (DAY 1)

INCREASED DEVIATION FROM NEUTRAL POSITION

PREPROGRAMMED COMPONENT:
CHANGES: VELOCITY
ACCURACY

PRESERVATION OF POSITION:
OSCILLATION OF HEAD MOVEMENTS

POSTFLIGHT (DAY 1)

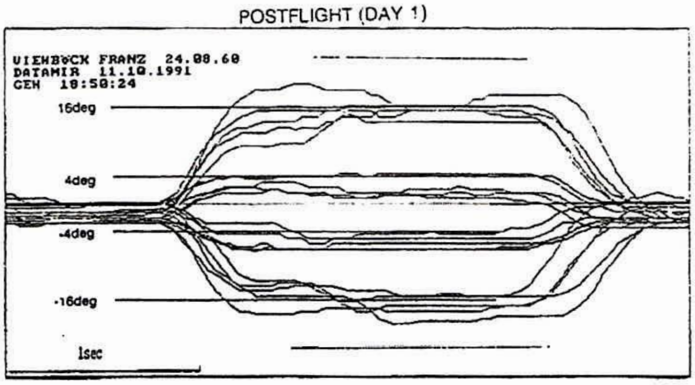
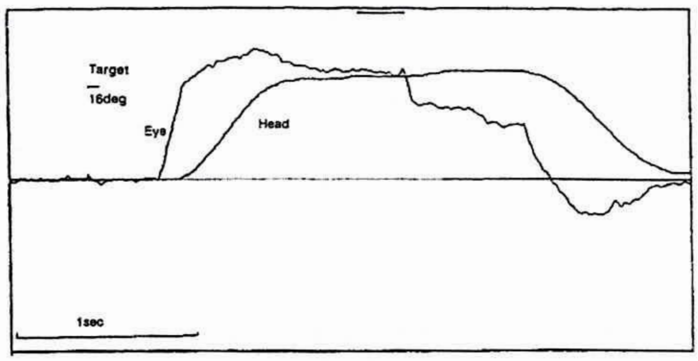


FIG. 4) : PREPROGRAMMED HEAD MOVEMENTS ON ACOUSTIC TARGETS (EYES CLOSED)

PATTERN I

PATTERN I

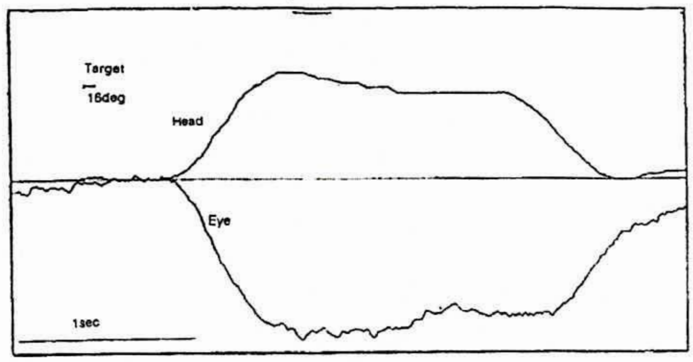
TASK: POINTING HEAD MOVEMENT TOWARDS ACOUSTIC TARGET
PERFORMANCE: HEAD AND EYE MOVEMENT INTO THE SAME DIRECTION (PHYSIOLOGICAL BEHAVIOUR)



PATTERN III

PATTERN III

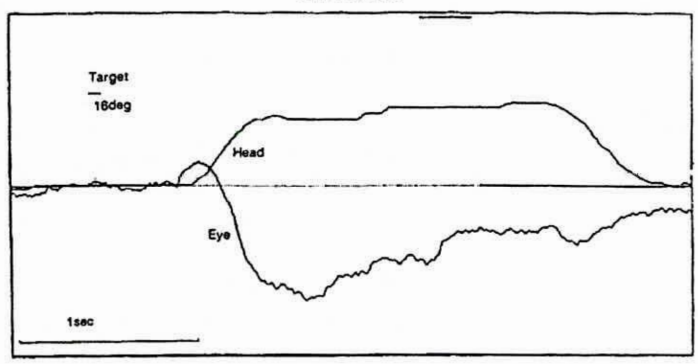
TASK: POINTING HEAD MOVEMENT TOWARDS ACOUSTIC TARGET AND FIXING THE CENTRE OF THE LED-MATRIX WITH CLOSED EYES
PERFORMANCE: EYE AND HEAD MOVEMENT INTO OPPOSED DIRECTION (NEW MOTOR COORDINATION)



PATTERN II

PATTERN II

TASK: POINTING HEAD MOVEMENT TOWARDS ACOUSTIC TARGET AND FIXING THE CENTRE OF THE LED-MATRIX WITH CLOSED EYES
PERFORMANCE: BEGINNING EYE AND HEAD MOVEMENT INTO THE SAME DIRECTION, FOLLOWED BY COUNTER-MOVEMENT OF EYE



GAZE FIXATION ON ACOUSTIC CUE

USE OF PATTERNS

INFLIGHT (DAY 2): DECREASED USE OF NEW MOTOR COORDINATION (PATTERN III) AND RETURN TO PATTERN I (PHYSIOLOGICAL PATTERN)

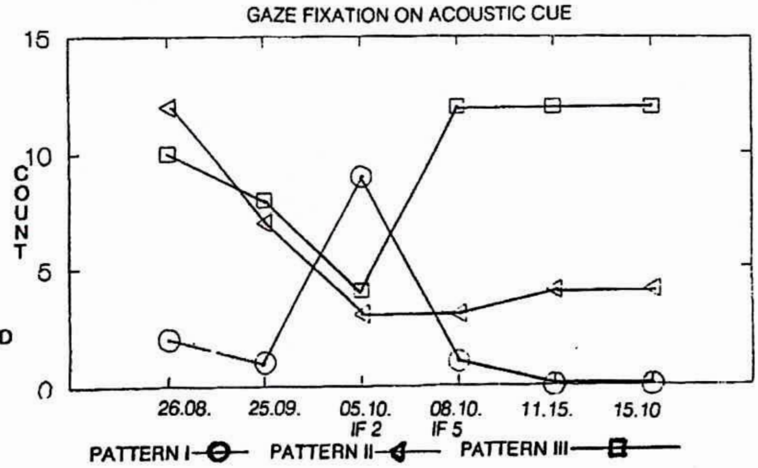
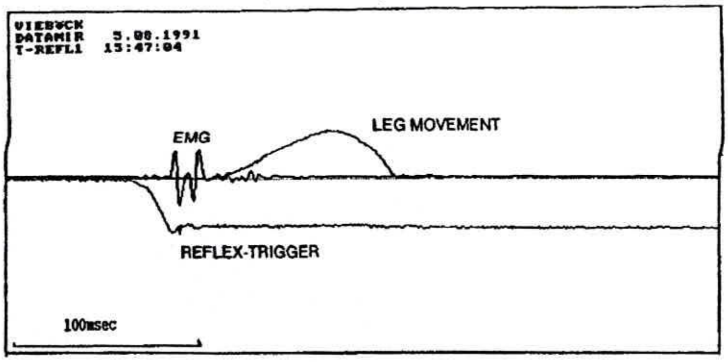


FIG. 5) : INVESTIGATION OF T-REFLEX WITH REFLEXSTIMULATOR PRE, DURING AND POSTFLIGHT

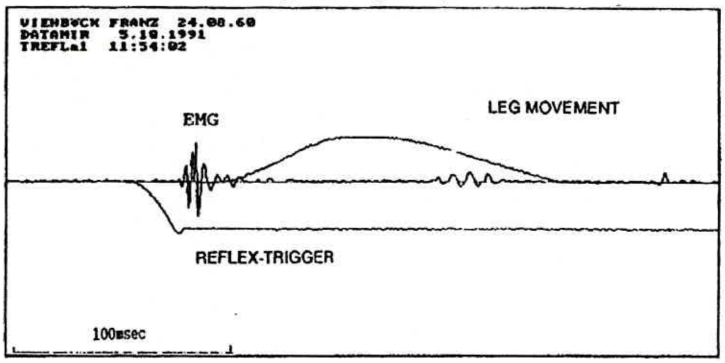
PREFLIGHT (DAY 36)



PREFLIGHT (DAY 36)

PHYSIOLOGICAL TENDON-REFLEX

INFLIGHT (DAY 2)

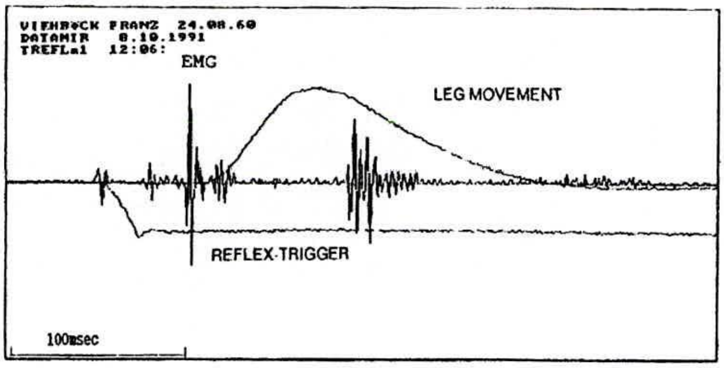


INFLIGHT (DAY 2)

HYPERREFLEXIA:

- INCREASED EMG-AMPLITUDE
- CLONUS
- INCREASED AMPLITUDE OF LEG-MOVEMENT

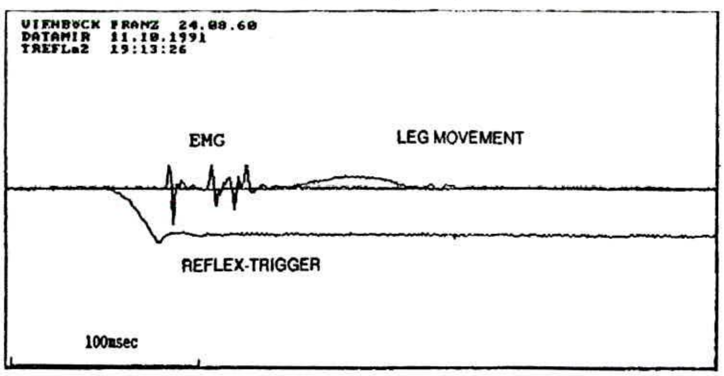
INFLIGHT (DAY 5)



INFLIGHT (DAY 5)

INCREASED DISTURBANCES COMPARED TO MEASUREMENT INFLIGHT (DAY 2)

POSTFLIGHT (DAY 1)



POSTFLIGHT (DAY 1)

RETURNING TO PHYSIOLOGICAL TENDON-REFLEX:

DECREASE OF HYPERREFLEXIA

The influence of neck receptors on horizontal arm movements was investigated in the test of neck reflexes. It is general knowlege that under terrestrial conditions a stimulation of the neck receptors by different head positions (rotation, sidebending) results in a minor drifting of horizontal arm movements in the convers direction of the head, while maintaining the same horizontal distance of arm movement. Inflight we found a turning of the horizontal arm movement in a frontal plane to the left and downwards. This phenomenon increased in the same way on the fith day of flight.

Quantitative investigation of spinal reflexes in weightlessness demonstrated inflight hyperexcitability at spinal level, as evidenced by increased EMG amplitude and the appearance of a clonus. (Fig.5)

6. CONCLUSION

Preprogrammed head movements conducted in weightlessness are highly disturbed, especially during the very first exposure to weightlessness. Adaptation appears from the second to the fith day of flight. These disturbances were also found after flight. Visual afferences play an important role in compensating disturbed preprogrammed movements. Slow pursuit movements were not significantly disturbed, which indicates the dominant role of visual feedback on motor control under weightlessness.

Motor coordination on acoustic targets rehearsed prior to flight changed to a motor pattern seen during previous training. Surprisingly the new coordination pattern returned during the second part of flight and remained unchanged even under terrestrial conditions.

Changes in the study results of the neck reflexes indicate disturbances in body scheme under weightlessness.

There is no adaptation in disturbed motor short-time memory; proprioceptively learned movements are highly disturbed.

In weightlessness, hyperexcitability at the spinal level was demonstrated for the first time by examination of the patellar tendon reflex.

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