Tuesday, June 10

5/13-53
074007

Session TP3
Room 3
2:30 - 5:30 p.m.

Posture and Movement

MODIFICATION OF GOAL-DIRECTED ARM MOVEMENTS DURING INFLIGHT ADAPTATION TO MICROGRAVITY

M.Berger°, S.Lechner-Steinleitner°, I.Kozlovskaya*, F.Gerstenbrand°
°Institute of Space Neurology, Innsbruck/Austria
*Institute of Biomedical Problems, Moscow/Russia

INTRODUCTION

To investigate sensory motor functions in weightlessness the reproducibility of motor patterns which were learned either actively or passively, was examined pre-,in- and postflight. Results from these experiments are presented, concerning modification of spatial characteristics of pointing arm movements during inflight adaptation to microgravity and postflight readaptation to Earth's gravity.

METHODS

In this study one short-term and 9 long-term cosmonauts participated, age range 31-47 years. The inflight time was 1 week (one cosmonaut), 4 to 8 months (mean value 5.3 months) and 14 months (one cosmonaut) on the Russian MIR-station.

Measurements were performed inflight once a month, postflight tests were on the 2nd and 5th day after landing. In a first test the cosmonaut's outstretched arm was passively moved along a visually given pattern by the second cosmonaut. Still with eyes closed the test person tried to repeat actively the movement sequences (the shape of an isosceles triangle) from memory (passive learned movement). In a second test the cosmonaut traced the figure on the LEDs-matrix for three times with open eyes and repeated it with eyes closed. The position of the arm was measured by two IR scanning cameras. On Earth the subjects were sitting upright on a chair, the arm pointer placed on the right hand, the LEDs-matrix in front of them. In the space lab MIR the cosmonauts were fixed in supine position on the floor by belts.

RESULTS

The spatial position of the corners of each triangle, its area, circumference, lengths of the sides, slopes, angles and its central point were evaluated. In some cosmonauts the reproductions of actively learned movements differed significantly in length parameters of the memorized triangle from those passively learned. But the influence of the different gravity levels resulted in significant offsets and torsions of the reproduced figures in all cosmonauts.

CONCLUSION

In comparing the inflight with the preflight condition, intact proprioceptive afferentation seems to play an important role for reproducing movements from motor short-time memory.

QUANTITATIVE ANALYSIS OF MOTION CONTROL IN LONG TERM µGRAVITY

G. Baroni[1,2], G. Ferrigno[1,2], A. Anolli[2], G. Andreoni[1,2] and A. Pedotti[1,2]
[1]Dipartimento di Bioingegneria, Politecnico di Milano, Milano, Italy
[2]Centro di Bioingegneria, Fnd. Don Gnocchi, Politecnico di Milano, Milano, Italy

INTRODUCTION

During the 179-days EUROMIR '95 mission, two in-flight experiments (T4 and 38-D) required quantitative human movement analysis in µ-gravity. T4 was designed in order to assess effects of the long term adaptation to µgravity. Among the experiments, three were voluntary postural perturbations: axial movements (AM), abduction of one leg (LR) and rhythmic oscillations of the body in the frontal plane (HT). Similar experiments were already performed during parabolic flights or in the course of a two weeks mission [1,2,3]. This work focuses on LR and HT. LR task is to elevate one leg up to 45° laterally keeping for few seconds the position and then to return back. During space sessions the supporting leg was fixed to the floor by a velcro shoe. Two conditions (open and closed eyes) were considered and for each condition the subject raised four times the right leg and four times the left one. On ground leg raising is split in two phases: *preparation* where the weight is displaced toward the supporting leg and *flight* where the leg is raised and the centre of gravity is "adjusted" inside the supporting area. We will show that this is no longer true in space, although the centre of gravity is still roughly maintained near the supporting foot [1]. Goal of HT was to verify experimental evidences concerning the dynamic vestibular contribution to head stabilisation[2]. Results will show the capability to stabilise the head in space without gravitary inputs also without vision input.

METHOD

The ELITE system [4,5] has been used for data collection on the MIR station. It has been modified reducing the size to one half, increasing reliability and suiting space requirements, leading to the ELITE-s. Four cameras at 50 Hz were put in the core module. The field of view was 1810 x 2430 mm (h x v). LR has been performed by applying to the subject 14 markers (15 mm diameter) on the following body landmarks :

1 - 2	left and right infra-orbital margins;	7 - 8	left and right great trochanters;
3 - 4	left and right acromions;	9 - 10	left and right lateral femoral epicondyles;
5 - 6	left and right superior anterior iliac spines;	11 - 12	left and right external malleoli;
		13 - 14	left and right fifth metatarsal heads.

The subject presented alternatively his right and left side to the cameras one and two raising the leg facing these two cameras. Data were acquired on board and processed, including system calibration, on ground. Three-dimensional co-ordinates of the markers have been computed. Shoulders and pelvis displacements during the two phases of the LR (preparation and flight phases) were analysed, as well as the qualitative behaviour of the movement. Angle between the supporting leg and the horizontal (α) was computed.

For HT 12 markers (15 mm diameter) have been applied on the following body landmarks :

1 - 2	left and right infra-orbital margins;	7 - 8	left and right great trochanters;
3 - 4	left and right acromions;	9 - 10	left and right tibial plates;
5 - 6	left and right superior anterior iliac spines;	11 - 12	left and right medial malleoli;

Roll dispersion and anchoring indexes have been calculated, in order to evaluate subjects performances and strategy in head and other body segment stabilisation [3]. Roll dispersions and anchoring indexes have been analysed statistically (t-test, ANOVA for inter-condition significance). Cross-correlation function calculations for head and shoulder rotations have allowed to quantify the delays between their movements.

RESULTS

The results obtained on LR show a significant influence of the gravity on the whole motor strategy. In normogravity, body weight transfer on the supporting leg consists of two phases, as previously indicated. The preparation phase in which the body weight is displaced toward the supporting limb, no longer exists in µg. This statement is supported by the results obtained with cinematic analysis of both the displacement of the pelvis toward the supporting leg and α angle. On Earth, centre of mass displacement toward the supporting side results from a rotation of the supporting leg around the antero-posterior ankle joint axis towards the supporting side, i.e. an α angle modification. In all the flight sessions, α is approximately nil, attesting that the supporting leg is fixed. Displacements results confirm this thesis. A consequence of this new motor strategy is that the second phase of the movement begins on the whole earlier in µg than in normogravity.
The second phase is different from normogravity to µg (Fig. 1) for several reasons. α variation during this

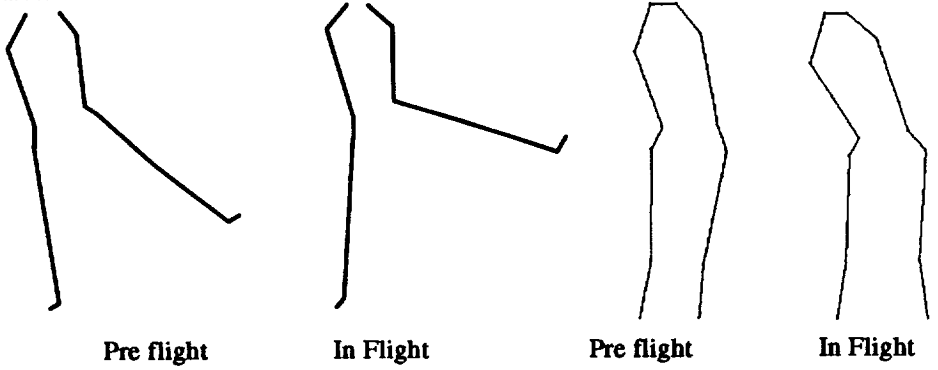

Figure 1 - Stick diagram for LR (left) and HT (right): differences between motor strategies at 0g and 1g.

phase indicates that the supporting leg is displaced toward the rising leg rather than in the opposite direction (movement which stabilises the body in standard g). Pelvis displacements confirm this result. The motor strategy observed in μg might be linked to the conservation of the angular momentum or to the co-contraction of hip abductors. Other differences coupled with the μgravity condition are the amplitude of the target movement (hip φ angle), which increases with time (φ_{mean} = 45° for pre-flight and FD16 session, φ_{mean} = 62° for FD19, φ_{mean} = 73° for FD69) and the duration of the second phase, which diminishes with time. Despite this behaviour which seems to forget the gravity rules, the trunk is however rotated toward the supporting side and seemed to be not influenced by the gravity conditions. In particular, the more is the moving limb elevated, the more is the trunk toward the supporting side inclined. This behaviour could be dictated from the maintenance of the centre of mass within a limited area (even not sufficient for keeping the equilibrium under standard g) or to a better performance (increased hip angle). Head is better stabilised in space than on the ground during the LR movement.

About HT, subjects are still able to stabilise actively the head, even after a prolonged exposure to μ-gravity (Fig. 1). Roll dispersion shows no significant differences among sessions in-flight and on-ground before and after the flight. Head anchoring index significantly suggests that the absolute vertical direction is exploited as reference for head alignment, both in 1g and 0g. Due to low significant changes with eyes open and closed, vision does not seem to play a fundamental role. Concerning latencies between head and shoulder movements, variable segment activation strategies could be observed in both subjects.

CONCLUSIONS

Obtained results seem to confirm previous findings during short term μ-gravity exposures[3]. Rather than depending on static vestibular contribution and proprioceptive information (absent o greatly reduced in 0g), voluntary head stabilisation appears to be regulated by dynamic inputs, which are not modified by weightlessness [6]. No evidence of adaptation processes could be pointed out by means of the performed analysis. In terms of roll dispersion and head anchoring index, subject A does not change significantly his behaviour from the first to the last in-flight session (Flight Day 19-Flight Day 113).

AKNOWLEDGEMENT
The Authors wish to thank the Italian Space Agency (ASI) for giving them the opportunity of flying ELITE.

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DOES THE CENTRE OF GRAVITY REMAIN THE STABILISED REFERENCE DURING COMPLEX HUMAN POSTURAL EQUILIBRIUM TASKS IN WEIGHTLESSNESS?

P.Stapley[1], T.Pozzo[1], & A.Grichine[2].

[1] Groupe d'Analyse du Mouvement, U.F.R. S.T.A.P.S., Campus Universitaire, B.P.138, Université de Bourgogne, 21004, Dijon, FRANCE. Email : *tpozzo@satie.u-bourgogne.fr*

[2] Institute for Problems of Information Transmission, 19 Ermolova Street, Moscow, RUSSIA.

INTRODUCTION

A number of studies have suggested that preceding voluntary movements in normal gravity conditions (1g), anticipatory postural adjustments (APA's) minimise forthcoming disequilibrium of the centre of gravity (CG) (Massion,1992). Clément et al.(1984) have confirmed such a goal of APA's to remain in conditions of weightlessness (0g). Locomotion studies in 1g have however, shown these APA's to be responsible for initiation in movements where the goal is to displace the CG (Brenière et al.,1987). Stapley et al.,(1997). have also recently suggested that APA's are responsible for movement initiation during dynamic equilibrium tasks conducted with a fixed base of support, creating necessary conditions for CG displacement Hence, there seems to be some confusion in terms of the role of APA's between static and dynamic equilibrium tasks in terms of the control of the CG.

Mouchnino et al.,(1996) have recently shown that during leg raising in 0g, the CG remains the stabilised reference. Their findings agreed with the suggestion that CG regulation is independent of gravity conditions (Lestienne & Gurfinkel, 1988). Nevertheless, during movements of whole body reaching in 0g, Pozzo et al.,(1994) have recorded anticipatory backward leaning postures that aimed to stretch ankle flexor muscles in order to obtain adequate joint torques for movement production. It was suggested that the purpose of APA's was not to minimise disequilibrium, but to prepare movement execution. In addition, CG amplitudes contradicted the idea of an invariance of the CG within the base of support.

The present study aimed to clarify these suggestions and answer two main issues : Firstly, are APA's modified in order to achieve task requirements in the absence of gravity? and secondly, in 0g conditions, does the CG remain the stabilised reference during multijoint forward oriented movements, involving dynamic postural equilibrium, but using a fixed base of support?

METHODS

The experimental task used during a series of parabolic flights was the same as that used aboard the Russian orbital station "Mir" as part of the experiment "synergy", during the spatial mission ALTAIR of 1994. 4 subjects (20-25yrs), previously unexposed to conditions of 0g participated in the study. Subjects were asked to begin in a standing upright position with both hands crossed at the level of the navel. The task consisted of 4 phases : reaching towards an object placed at 5 (D1) and 45cm (D2) distances in front of subjects' feet, (P1), lifting it to shoulder height (P2), pausing for two seconds and replacing it at its' starting position (P3), subjects finishing with a return to their original upright starting position (P4). Apart from constraints of distance, subjects executed movements at normal (N) and fast (F)speeds. In order to study the initiation of this whole body reaching (WBR) movement, here only P1 was considered. Movements have been measured using the optoelectronic device ELITE. Markers were placed at 11 anatomical sites, including the head (vestibular apparatus -the Frankfort plane), the trunk, arm, leg, and foot. Feet were strapped to the supporting surface, in order that subjects could generate forces necessary to reach the object. A total of 30 trials in 0g, and 30 in a 2min recovery period of 1g were conducted for each subject.

From kinematic measures of different segments, CG displacements were calculated using a rigid 7-link model and the technique of inverse dynamics. Joint torques at the ankle, knee, and hip were obtained from the same model by applying equations of motion to observed motions of a one-joint limb and thus treating the model as an open loop kinematic chain. All joint forces and torques were derived step-by-step considering one segment at a time. Each segments' mass, moment of gyration and position of its' CG were obtained using anthropometric data given by Winter,(1979). The total body CG was thus determined by considering each segments' mass and CG along AP and vertical axes and the subjects' overall mass.

RESULTS

- *Anticipatory postural adjustments* : In 1g, total torque produced at the ankle was taken as representing the sum of inertial activity (produced by postural muscles) and gravity force acting on the body. Anticipatory ankle torque (between -500ms and *t0*-1st segment displacement), causing ankle flexion was the precursor to forward and downward displacements of the CG. In 0g, significantly larger anticipatory total ankle torques were recorded in all subjects compared to 1g trials, in particular with constraints of speed.

- *CG Control* : In 1g conditions CG amplitudes in the AP axis ranged between values of 53.7mm (D1/N), and 89.5mm (D2/F). In the vertical axis, the CG displacements ranged between 392.8 (D1/N) and 537.3mm (D2/F). In 0g, along the AP axis, values ranged between 194.3 (D1/F) and 304mm (D2/F) but vertically between 384.3 (D1/N) and 428.6mm (D2/F). Therefore in 0g, reduced amplitude in the vertical axis was compensated for by increased AP displacement of the CG.

CONCLUSION

Under 1g conditions, during WBR target attainment is achieved through a rupture of static equilibrium caused by an initial backward displacement of the CP and a forward displacement of the CG (Stapley et al.,1997). This effect is stimulated by postural muscular activity, in particular of the soleus and tibialis anterior (TA) muscles. Thus, total muscular ankle torque possesses inertial and gravitational elements, which induce AP and vertical displacements, and a combined rotational effect of body segments towards the target. In 0g conditions, gravitational torques are lacking. Therefore, the sole source of ankle torque becomes muscular, with subjects being obliged to more greatly sollicit TA activity. The increase in total torque recorded in all subjects in conditions of 0g may be interpreted therefore as a compensation for the lack of a gravity component producing rotational displacement of body segments. Results concerning CG amplitudes have shown that far from being stabilised in 0g, the CG displaces to a greater extent in the AP axis than in 1g. Results from the present study would suggest that in the absence of gravity increased ankle torque is produced in order to move the CG over a larger distance in the AP axis, to compensate for the subjects' inability to use gravity. Further analysis of muscular activity preceding WBR in 0g may clarify such an hypothesis. In addition, analysis of head stabilisation or the conservation of segment verticality in prolonged 0g conditions may help in the identification of the stabilised reference in this particular postural task.

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This study was supported by the CNES (Centre National d'Etudes Spatiales).

ARM END-POINT TRAJECTORIES UNDER NORMAL AND MICRO-GRAVITY ENVIRONMENTS

C. Papaxanthis[1], T. Pozzo[1], J. McIntyre[2]

[1]Groupe d'Analyse du Mouvement (G.A.M), U.F.R. S.T.A.P.S., Campus Universitaire, Université de Bourgogne, B.P. 138, 21004 Dijon, France, [2] Laboratoire de Physiologie de la Perception et de l'Action CNRS - Collège de France, Paris, France

INTRODUCTION

Neurophysiological (Georgopoulos et al., 1986) and behavioral studies (Soechting and Flanders, 1991) have argued that the brain encodes arm movements in terms of its' kinematics. Other alternative hypotheses that the brain may encode muscle activations and force (dynamics) instead of the direction of hand movements (Mussa Ivaldi, 1988), have been also proposed. Whether kinematic or dynamic representations of movement exist at the neuronal level still remains problematic.

In addition, how the brain encodes gravitational force as well as its' representation during arm movement planning and execution has not attracted a great deal of scientific attention. Gravity can either initiate or brake arm movements and consequently must be represented in the motor command.

In the present study an attempt has been made to study the role of gravity in the control of vertical arm pointing movements. Our working hypothesis was that the CNS takes into account the mechanical effects of gravitational force in order to correctly perform arm movements. Furthermore, we also hypothesized that gravitational force is represented during the planning of the movement and consequently used by the brain in the execution of arm movements in the sagittal plane.

METHODS

Data presented in this study were taken from experiments made in a normal gravitational environment (1G) and in microgravity (0G) collected during the mission EUROMIR (1994) aboard the Russian Space Station MIR.

1G experiment :

Cosmonauts stood erect. Two targets were fixed in front of them, aligned with the midline of the body, one 60 cm above the other, and centered at the level of the shoulders. Subjects performed discrete visually guided, point-to-point reaching movements in upward (UD) and downward (DD) directions, with (0.5 kg) and without an additional load (hand empty). Movements were recorded and analyzed using an optoelectronic system (ELITE). Six markers (plastic spheres of 0.4 cm in diameter) covered with reflective material, were placed on the joints of the arm (shoulder, elbow, wrist and hand). Their positions during the movement were recorded and their centroides underwent 3D reconstruction.

0G experiment

The equipment and experimental protocole used for the reaching task in microgravity was the same as that described for the 1G experiment, except that the feet of the subject were fixed to the floor of the space station by straps. The tests were carried out 45 days before flight (PF 45), 4 times during the flight (FD 6, FD 12, FD 15, FD 18) and 2 times immediately after the subjects return to earth (R 1 and R 7). Both cosmonauts executed 10 movements in each direction per experimental session. The same type of markers as in the 1G experiment were used to calculate the position of the shoulder, elbow, wrist and hand. Movements were recorded using a videocamera (25 Hz). Data were analyzed after digitalization of the video recording, using a computer.

RESULTS

Figure 1 presents mean curvature values of the finger from the two cosmonauts for both movements, directions and loads, before, during and after space flight.

Hand paths without load

Both cosmonauts showed curved paths in pre-flight (PF 45) measurements. Movements in the upward direction presented greater curvature values than movements in downward direction. During exposure to the microgravity, for both cosmonauts, the downward movement curvatures decreased progressively with the length of the flight and showed almost straight paths on the 18th day. In contrast, upward movements, showed irregular patterns with mean curvature values varying during the flight, remaining of the same order as pre-flight values. Post flight measurements (R 1) for DD movements, showed almost straight paths for both cosmonauts. For UD movements, curvatures decreased compared to inflight values. At R 7 measurements, both directions recovered approximately the curvature values obtained during pre-flight testing.

Hand paths with a 0.5 kg load

Curved paths for both directions and cosmonauts were also recorded for the load condition, during the pre-flight measurements. UD hand paths presented greater curvature values than hand paths in DD. The FD 6 hand curvature increased for both directions, representing greater values for the UD compared to DD. As in the unloaded condition, while the curvature of DD movements decreased progressively within flight, the curvature of UD movements remained almost of the same order as pre-flight values. With R 1 measurements, hand paths for the DD movements were straighter compared to 18th flight day. In contrast, UD curvature increased on R 1. At R 7 both directions tend to the same as values obtained during pre-flight testing.

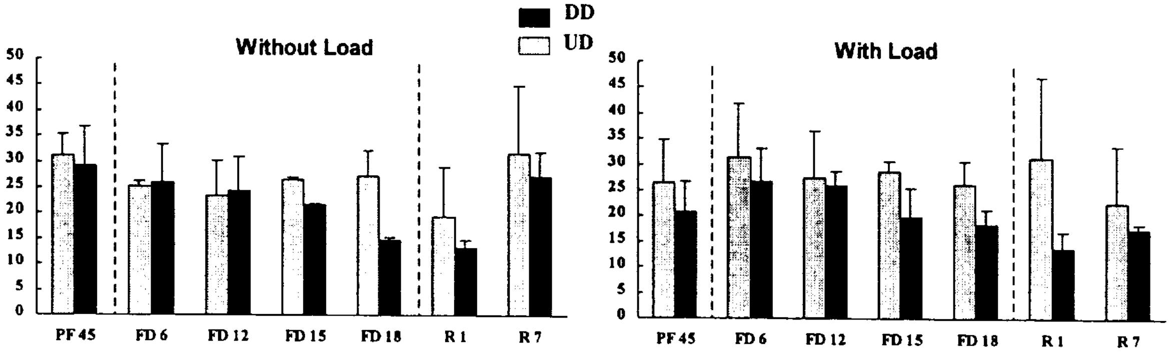

Figure 1. Means and standard errors from both cosmonauts, of the greater perpendicular distance from the path to the straight line. PF 45: pre-flight, FD 6 : 6th flight day, FD 12: 12th flight day, FD 15: 15th flight day, FD 18: 18th flight day, R+1: first-post flight day, R+7: 7th post-flight day. Pre-flight, flight and post-flight periods are separated by dotted lines.

CONCLUSION

The major finding of this study was the kinematic differences between the two directions tested in both normal and microgravity conditions. Hand paths were seen to straighten gradually, at least for downward movements, over the course of an 18 day space flight for both load conditions. The fact that hand paths remain curved early in flight, and that the hand paths remain straight shortly after return to earth supports the idea of an adaptation of the internal movement template, rather than a transient perturbation brought on by the sudden lack or addition of a constant bias force. This argument is further strengthened by the fact that hand path curvature returned to preflight levels after several days adaptation to a normal 1G environment. Attributing changes in movement kinematics according to the gravitational context to a representation of gravity in the planning stages of movement begs the question as to why the motor plan should be modified. Furthermore, what is the impetus behind different kinematic patterns for upward vs. downward movement? We propose that the CNS takes advantage of the gravity force to produce movements, rather than treating gravitational torques as a disturbance that needs to be cancelled. In this case, joint torques produced by gravity will be used by subjects to initiate (DD), and stop (UD) arm movements. Thus, gravity may be treated as a driving force whereas another, less predictable external load might not. A central representation of gravity force, which implies the encoding of vertical direction, is consistent with findings that neuronal populations in the motor cortex (Georgopoulos, 1986; Caminiti et al., 1991) encode the direction of the movement.

This study was supported by the European Space Agency and the Centre National d'Etudes Spatiales.