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EFFECT OF WEIGHTLESSNESS ON POSTURE AND MOVEMENT CONTROL DURING A WHOLE BODY REACHING TASK

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Abstract

Here are reported preliminary results of the "Synergy" experiment performed aboard the Russian orbital station "MIR" in July 1993 (Altaïr Mission). The experiment was carried out before, during, and after the space flight of two astronauts (S1 and S2) . The duration of the flight was 21 days for S1 and 6 month for S2. The subjects were tested during preflight, inflight and postflight. The astronaut subjects were fixed on the ground by the feet. They were asked to pick up a box in front of them on the ground. Two velocities of movement and two distances of the target to be reached were tested. The movement of several small markers placed on the body was recorded on video tape.

Results show that the shape of head and hand trajectories in the sagittal plane remains roughly the same during the flight in spite of the modification of mechanical constraints. Trajectory invariance does not result in joint angular displacement invariance. These data indicate that the planning of the movement takes place in terms of head and hand trajectories rather than joint rotations as it was previously suggested for simple arm reaching movement.

Introduction

The loss of the vertical gravitational reference in spaceflight conditions induces disturbances of spatial orientation which constitutes an aspect of "Space Adaptation Syndrome" manifested in a great number of astronauts (1,2,3). Modification of a coherent vertical frame of reference in spaceflight condition provides a unique possibility to study the spatial orientation system in astronauts and to find out the contribution of intrinsic and extrinsic factors. Usually used procedures for investigation spatial orientation are based on subjective judgments (using psychophysical method) (4,5) or graphical tasks (6). We propose to study this question by analyzing motor strategies involved during whole body reaching movements.

Methods

The experiment reported here is part of the "Synergy" experiment performed aboard the Russian orbital station "MIR" in July 1993 (Altaïr Mission). It was carried out before, during, and after the space flight of two astronauts, here called S1 and S2. The duration of the flight was 21 days for S1 and 6 month for S2. The subjects were tested two times before the flight (on days D-60, D-30). The post flight tests took place five hours for S1 and three days for S2 after the landing, and five days (R+ 5) (S2) and six days (R+6)(S1) later. Testing during the flight (noted FD) took place on FD5, FD10, FD13 and FD20 for S1, and FD6, FD9, FD19 for S2.

The astronaut subjects were fixed on the ground by the feet. They were asked to reach and catch a box (40 x15x25 cm in wide, heigh and deep, and 500 gr) in front of them on the ground, to lift and maintain it with the arm parallel to the foot support, to place it on the ground, and finally to return to the initial body position (**see fig 1**). Two velocities of movement (normal and rapid) and two distances of the target to be reached (5 cm or 50 cm from the feet) were tested.

The subject performed 5 trials in each condition. Each trial was triggered by the beep of a sequencer. These beeps arrived at a rate of 1 every 5 seconds. Each set of 5 trials was separated by a pause of 1 minute. The movement of several small markers (1.5 cm in

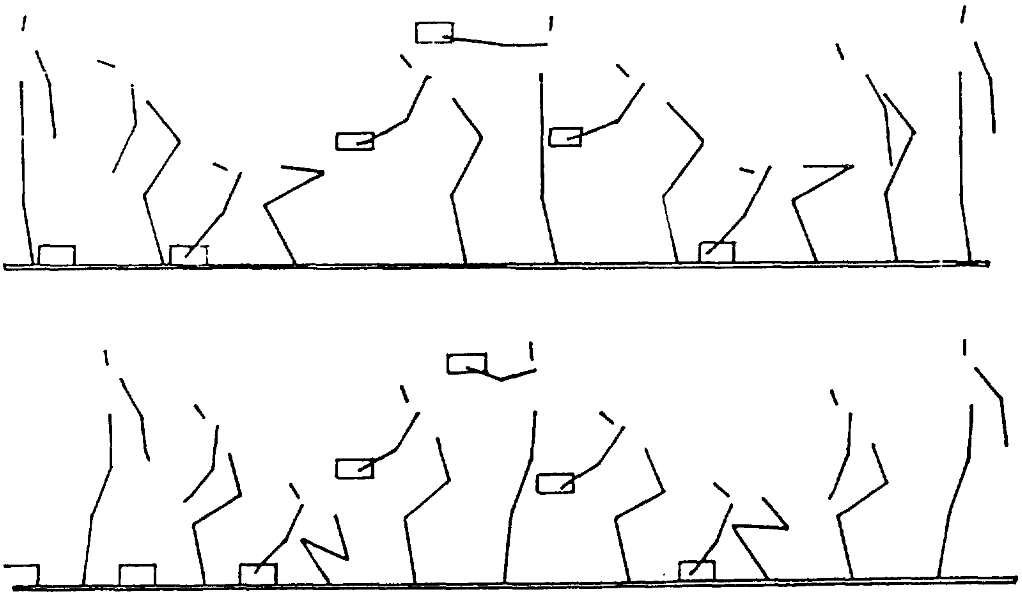

Figure 1. Stick figure of the successive body positios reconstructed by the computer during (from left to right) catching, lifting, placing and returning movement in subject S1 in normal gravity conditions (A) (D-60) and in weightlessness (B) (FD5).

diameter) placed on the the head, trunk, hip, knee, shoulder, elbow and wrist was recorded on video tape. Data were analyzed after digitalization on a computer of the video recording. Kinematic parameters (position, velocity and acceleration in translation and in rotation) were calculated from the successive frames taken at 40 ms intervals.

Results

Initial standing posture

In weightlessness, initial, intermediate and final standing posture preceding and ending the movement was drastically tilted backward compared to normal vertical terrestrial standing posture. This postural change appears two or three seconds just before the begenning of the movement as a preparation of the reaching tasks. We have not calculated the precise position of the center of mass (CM), but the stick diagram reconstructed by the computer clearly shows that the CM is projected outside and on the back of the foot area during the standing posture periods, especially for S1.

Motor strategies in OG

On earth, before the flight, the two subjects adopted quite differents motor strategies. While S1 reaches the box by using the knee flexion, S2 performed the 4 phases of the movement with the knees extended. In contrast, in 0-G condition, both S1 and S2 performed the task by mobilizing knee joint during the whole movement.

Limb trajectories in the sagittal plane

Trajectories analysis in the sagittal plane of the markers placed on the body during pre, in and post-flight tests indicates that the most striking difference between 1-G and 0-G conditions concerns hip and knee trajectories. In weightless, when the subject bends the upper trunk forward (during catching and placing phase) or backward (during lifting and returning), opposite movement along the antero-posterior axix of the hip and the knee occur. This synergy, previously described by Babinski (7) and measured by Crenna et al (8), is devoted to prevent over-large displacement of the projection onto the ground of the center of gravity. In weightlessness, hip trajectory is mainely oriented along a vertical axis, indicating large vertical displacement. In addition, the amplitude of the almost horizontal trajectory of the knee which never exceeded 15 cm in 1-G, increases in 0-G (25 cm in amplitude on FD5) due to a larger flexion of the knee joint compared to 1-G condition (15 cm in amplitude on FD-30).

In contrast with the proximal joint, end-effector trajectories (markers placed at the level of the hand) are not significantly modified under weightlessness condition.

Joint angular displacements.

Figure 2 depicts the pattern of change in amplitude of ankle (upper part) and hip (lower part) angular displacements in sagittal plane before, during and after the flight for the two subjects. Two important observations are made from such records which hold for the two subjects.

The first one concernes the larger dorsi-flexion of the ankle in wheightlessness compared to 1-G. This change is about twofold greater at the beginning of the flight (FD5) (about 40 deg) and gradually decrease, returning to close to its preflight value by FD20 (about 15 deg).

The second one indicates a smaller angular displacement of the trunk with respect to

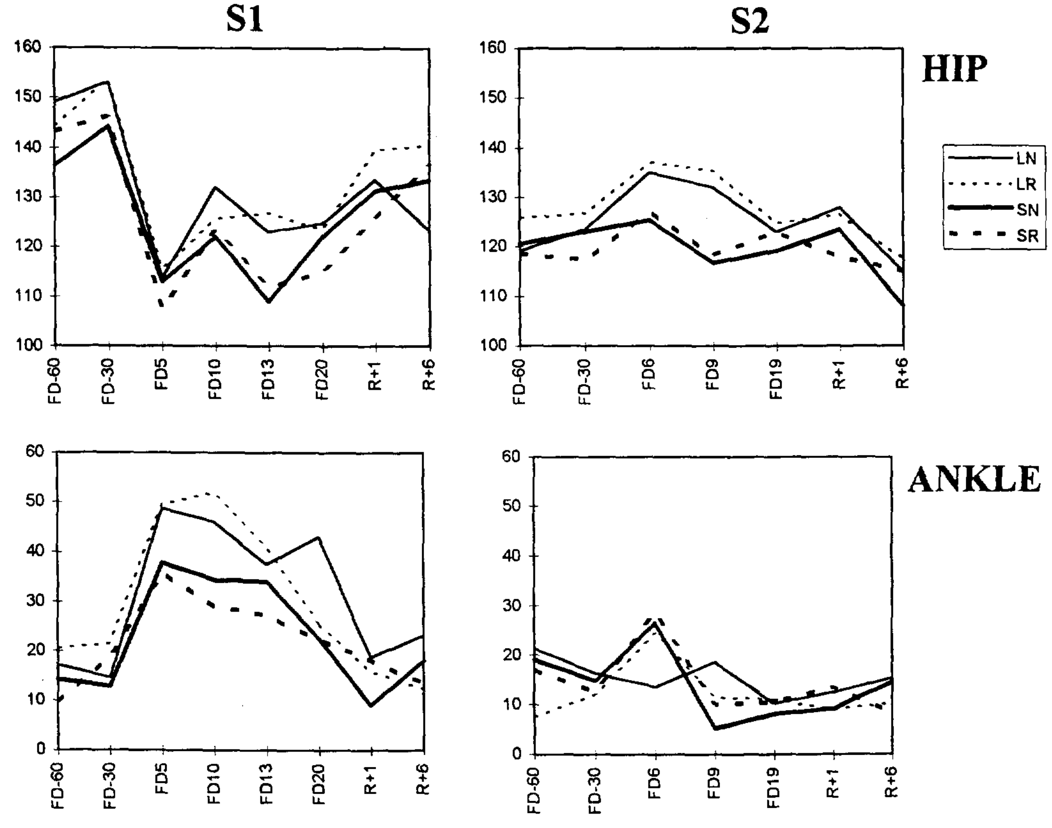

Figure 2. Hip (upper part) and ankle (lower part) angular displacement before, during, and after the space flight for S1 (left part) and S2 (right part) and for the two velocities (N: Normal velocity; R: Rapid velocity) and the two distances (S: Short distance, 5cm; L: Long distance, 45cm) of the target to reach.

the lower limb in weightlessness (about 120 deg for S1 and 130 deg for S2) compared to normal gravity environment (about 145 deg for S1 and 120 deg for S2). In other words, in the early days of the flight, the whole movement is performed by mainly using the knee and ankle joint and by minimizing forward bending of the trunk which remains close to the vertical of the cabin.

Adaptation and readaptation process

The abrupt changes in values in the first days of flight (FD5 for S1 and FD6 for S2) compared to pre-flight values are available for both subjects. In contrast, the time course of the modification is consistently different for the two subjects. For S1, who had never flown in space before, the adaptation to exposure to weightlessness is progressive, that is to say that kinematic parameters recover values on FD20 close to these obtained during pre-flight test. In contrast, for the astronaut S2 who had participated previously in two spaceflights, adaptation to exposure to weightlessness is faster than for S1 (on FD9).

In addition, whereas readaptation to normal gravity environment on R+1 is almost immediate for S1, no such readaptation appear for S2 up to R+5. This result must be linked to the longer duration of the spaceflight for S2 (180 days) compared to S1 (21 days).

Discussion

One of the main results of this study is the initial backward posture inclination preceding the whole body reaching movement. Backward-leaning standing posture never described before, remains during all the duration of space flight test. Conversely, previous study (9) had demonstrated a characteristic forward-leaning posture in subjects during early exposure to weightlessness condition. The authors suggested that more than a perturbation of spatial orientation, this strong initial forward inclination of the whole body which decreased after 7 days of flight, is a manifestation of a functional deafferentation of the otolithic system.

The apparent contradiction between the two studies can be explained if one considers the whole sequence of movement. In 1-G environment, forward bending movement is facilitated by gravity force. In contrast, in weightlessness active and passive elastic forces of the muscles can only generate joint torques. A backward body tilt stretch the flexor muscle of the ankle joint and consequently increases the strengh of the muscle. Consequently, the whole-body backward tilt described here can be considered as an anticipatory postural adjustement. Its purpose is not to minimize equilibrium disturbances caused by the movement (10, 11) but to prepare and optimize the movement execution, especially when rapid velocity were imposed.

Otherwise, this backward-leaning standing posture which results in a displacement of the center of mass out of the foot area seems to contradict recent theories on invariance of the strategy aimed at maintaining the center of mass position in the foot area even under microgravity conditions. The present results demonstrat that the theory hold for some tasks like arm lifting (12) or small upper trunk movements (13) but must be reconsidered for complex goal oriented and postural tasks.

During a whole body reaching task toward an object in extracorporal space, the entire body segments is involved in the movement and consequently multiple joint configurations and trajectory solutions of distal limbs can be used. Our results show that the shape of head and hand trajectories in the sagittal plane remain roughly the same during the flight in spite of the modification of mechanical constraints. In contrast, trajectory invariances do not result in joint angular displacement invariance. Thus, in weightlessness we found a minimization of the trunk angular displacement and a larger flexion of the knee joint compared to 1-G condition. Taken together, these finding lead to several speculations.

Invariance of limbs trajectories suggest that the planning of the movement takes place in terms of head and hand trajectories rather than joint rotations as it was previously suggested for simple arm reaching movement (14). Invariance of head and hand velocity profiles (result not shown here) emphasize this hypothesis.

Finally, in weightlessness, the CNS cannot use the gravity reference to compute the displacement of body segments. The strategy which consist to stabilize the trunk in rotation provides a substitute (egocentric) frame of reference used to calculate the target position in extracorporal space as well as the limb trajectory necessary to reach the target (15).

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