Visuomotor transformations impairment during manual tracking task in a simulated microgravity condition (280)

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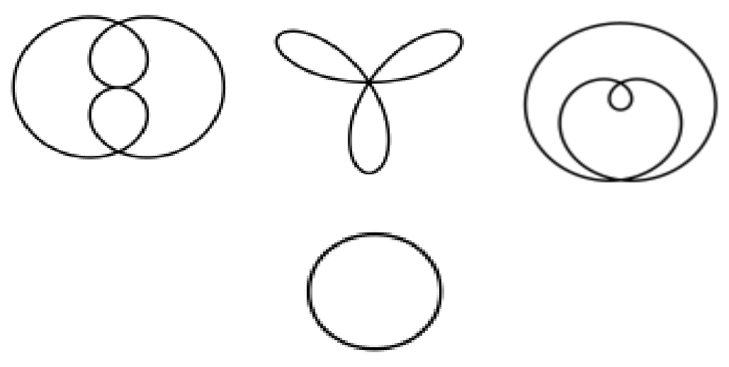
Introduction

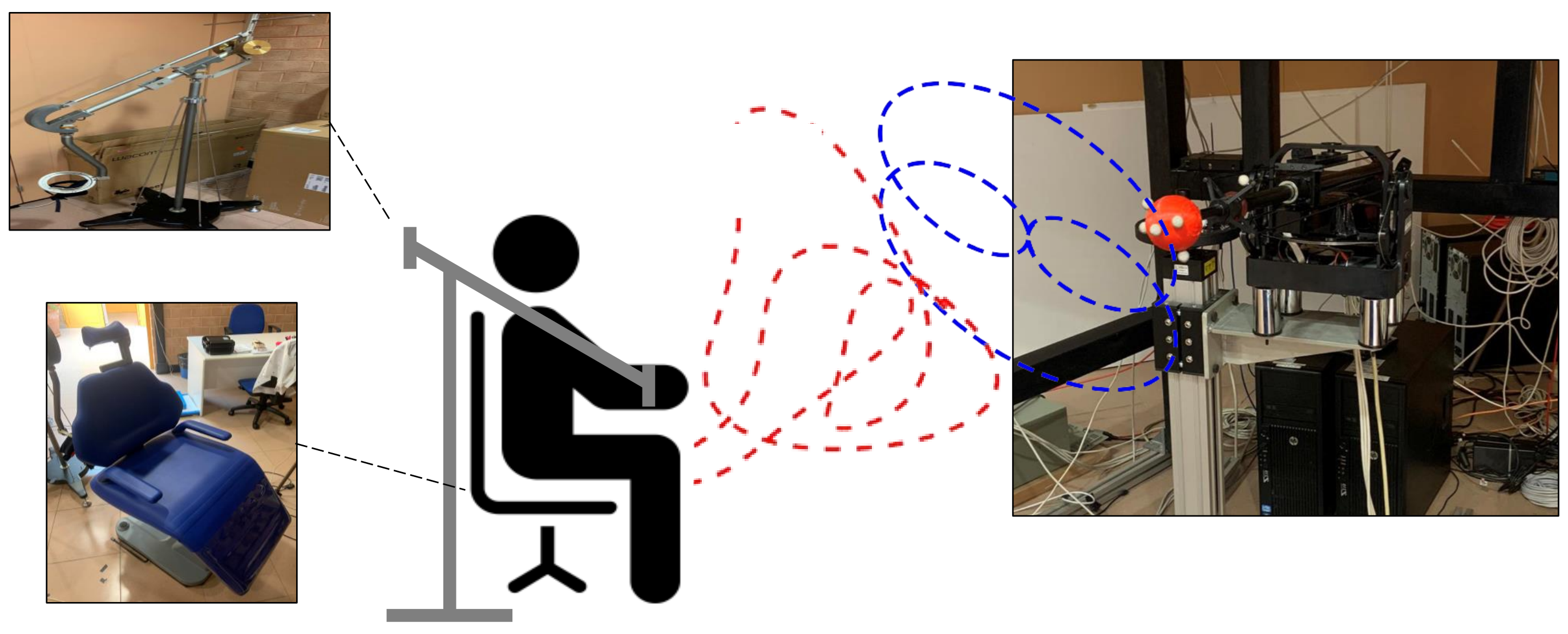
In contrast to performance in cognitive tasks, tracking performance tends to deteriorate fairly consistently during spaceflight. Whereas it is clear that microgravity has several mechanical, visual, and proprioceptive effects which may impair the motor control, it is in no way settled whether the impairment of tracking performance is indeed specifically microgravity-related, due to the variety of stressors which characterize manned spaceflight and may be involved [1]. A better understanding of the tracking task in microgravity is fundamental to develop superior control strategies for robot-human interaction in microgravity and improve human adaptation protocols to such environment. In this experiment the subject is asked to follow a moving target with the upper limb physically attached to a device which is capable to support its total weight during movement. Different kinematics laws and geometries are used for the moving object. The goal of this experiment is to characterize the microgravity impairment on motor control and verify whether or not it is caused by a mis-calibration of the motor system resulting from the underestimation of masses due to weightlessness [2]. The effect of this underestimation should be a certain 'sluggishness' of the pursuit in following the moving target, however, corrective processes may hide this under-specification of forces. A multi-directional oscillator model has been used to measure the tracking performance of the subject and investigate the presence of possible cross-effect compensation between directions.

Methods

Four subjects partecipated in the pilot experiment of this study. The target they were asked to track moved in a frontal plane according to 10 conditions:

- 3 Rose Geometry with 3 Kinematic Laws (Two-Third Power Law, One-Third Power Law, Constant Velocity);
- 1 Circle Geometry with Constant Velocity.





Protocol summary:

- 5 trials for the 10 conditions of the target movement;
- 2 gravity conditions (Earth gravity and microgravity).

→ 100 total trials for each subject in 2 blocked sessions (Earth gravity and microgravity) in randomized order.

We collected and analyzed the kinematics of the shoulder, the elbow, the wrist and the hand with respect to the target kinematics.

At any time istant, the target position 2D vector P_T and the tracking hand position 2D vector P_P differ in their values and in the values of their time derivatives. In principle, the visuomotor control system may use these differences as input error signals so that the force signal that drives the subject movement is a linear combination of them. By supposing that the processing of the error takes a constant time Δt, the equation of the pursuit movement may be written as:

$$\ddot{P}_P(t) = \begin{pmatrix}\delta_x\\ \delta_y\end{pmatrix} + \begin{pmatrix}k_{xx} k_{xy}\\ k_{yx} k_{yy}\end{pmatrix}\left(P_T(t-\Delta t) - P_P(t-\Delta t)\right) + \ldots$$

$$+ \begin{pmatrix}c_{xx} c_{xy}\\ c_{yx} c_{yy}\end{pmatrix}\left(\dot{P}_T(t-\Delta t) - \dot{P}_P(t-\Delta t)\right)$$

Where the position and velocity coefficients k_{ii} and c_{ii} can be conceptualized as virtual stiffnesses and virtual viscosities. It is also supposed that the errors in one direction may influence the control in the other direction.

A second model has also been considered to include the following acceleration error term:

$$\begin{pmatrix}m_{xx} m_{xy}\\ m_{yx} m_{yy}\end{pmatrix}\left(\ddot{P}_T(t-\Delta t) - \ddot{P}_P(t-\Delta t)\right)$$

Results

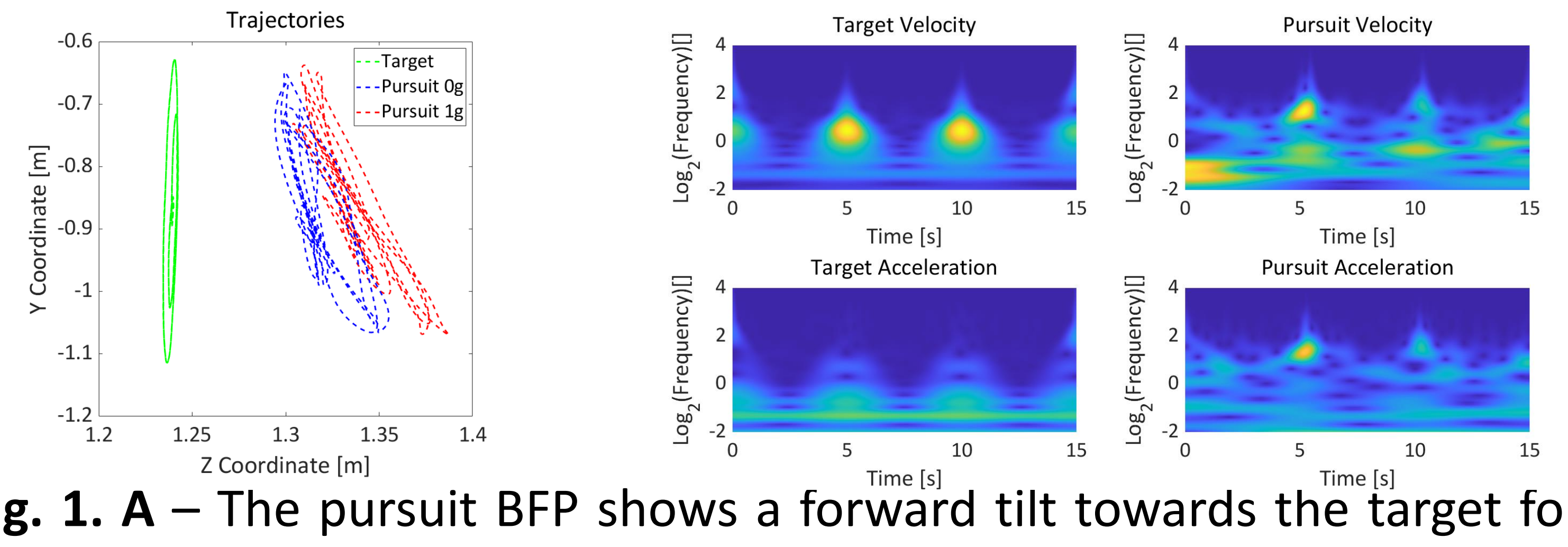


Fig. 1. A – The pursuit BFP shows a forward tilt towards the target for both the gravity conditions. **B** –Morlet Wavelet analysis to evaluate the frequency coupling between the velocities and the accelerations of the target and the pursuit.

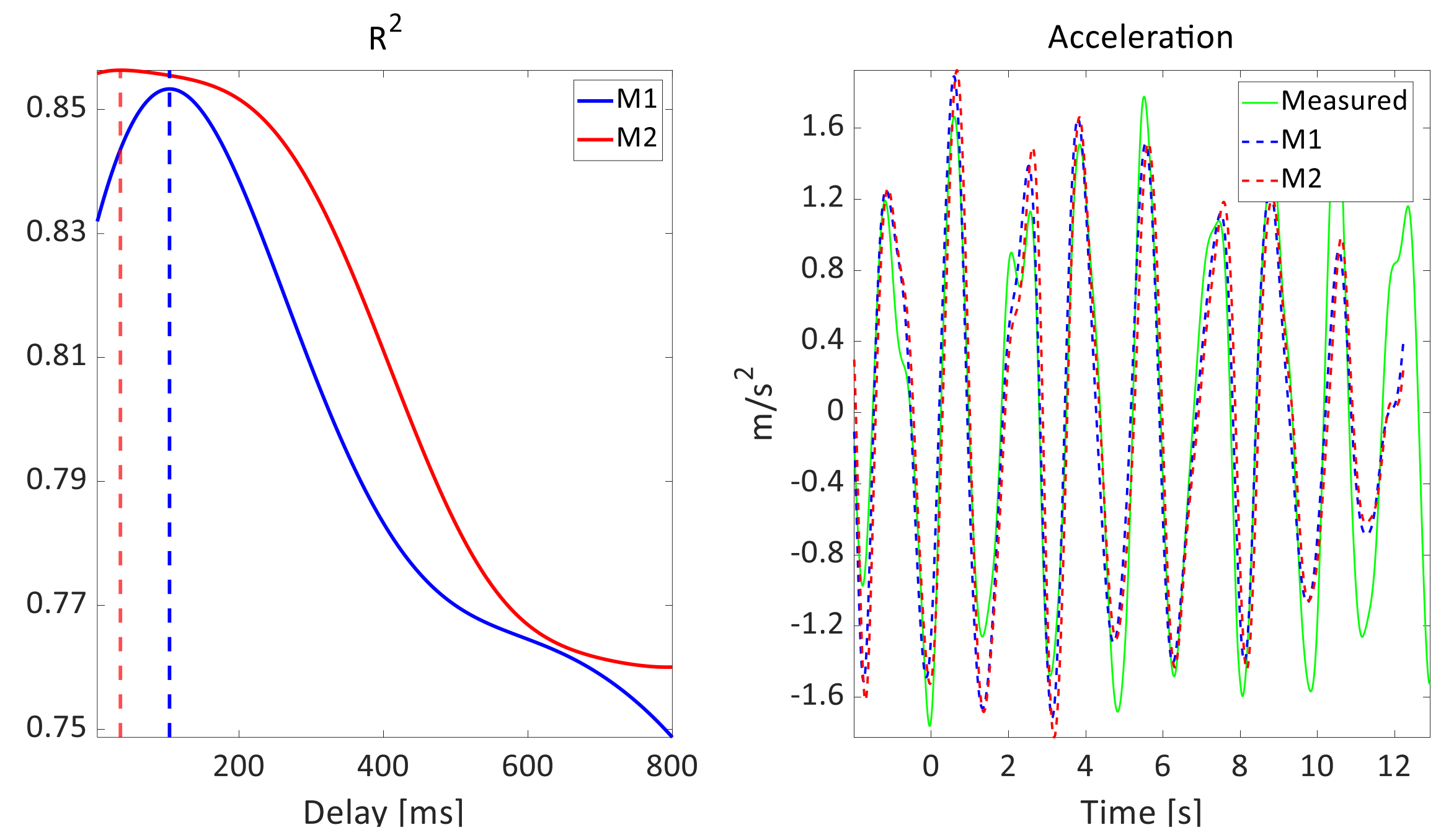


Fig. 2. A – For each trial, multiple regression analysis have been performed for values of Δt between 0 and 800 ms to select the maximum R^2 to represent the pursuit tracking performance of that trial. **B** – Model (1) provides a mean R^2 equal to 0.61 with a standard deviation of 0.17; Model (2) provides a mean R^2 equal to 0.66 with a standard deviation of 0.15.

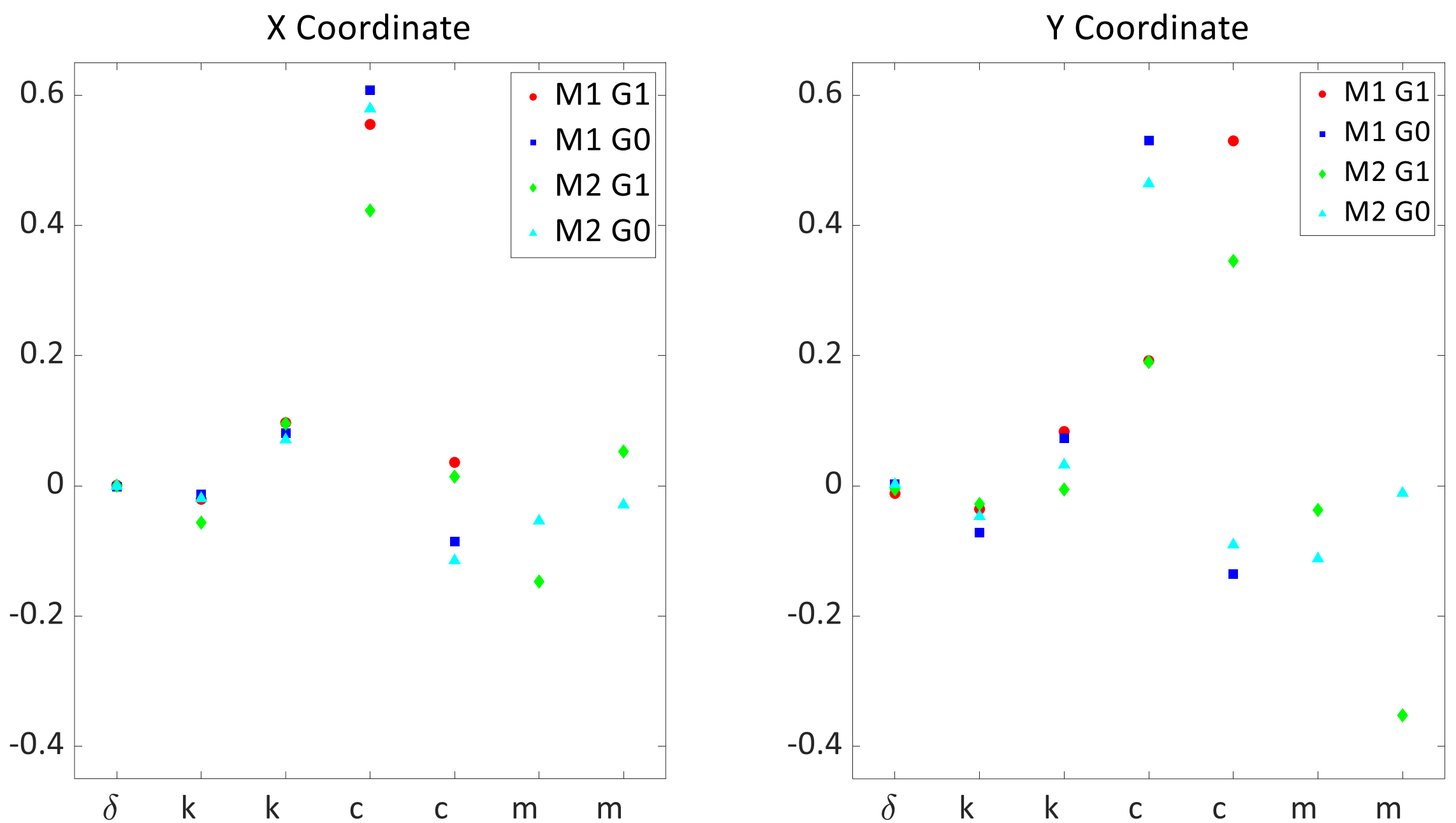


Fig. 3. A – The x-velocity error is the most dominant input signal to control the pursuit along the x coordinate. **B** – The x-velocity error appear to be an input signal which the visuomotor control system uses to control the pursuit along the y coordinate in simulated microgravity.

Conclusions

The analysis of these 4 subjects shows that, suprisingly, the visuomotor control system seems to rely on the velocity error along the X coordinate to control the pursuit movement on the Y coordinate when the simulated microgravity condition is applied, while the acceleration error along the same movement coordinate seems to be less important with respect to the normal gravity condition. A larger sample size is required to confirm this hypothesis.

References

[1] Heuer H., et al. Impairments of manual tracking performance during spaceflight are associated with specific effects of microgravity on visuomotor transformations. Ergonomics 2003, 46:9, 920-934.

[2] Bock O., et al. Performance of a simple aiming task in hypergravity: II. Detailed response characteristics. Aviat Space Environ Med. 1996 Feb;67(2):133-8.

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