

HUMAN STABILITY WHILE EXERCISING ON A VIS DEVICE IN ZERO GRAVITY

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BACKGROUND: A Vibration Isolation and Stabilization (VIS) system is being designed for use with the European Enhanced Exploration Exercise Device (E4D) [1]. The exercise bar is attached to cables that extend and retract through openings in the E4D platform, which the subject stands on while exercising. Since the E4D is mounted on a moving VIS device, the whole system moves under the subject's feet. While tension in the cables does help stabilize a crew member in 0g by bracing him or her against the moving platform, flexible cables do not offer full support against falling. This raises the question of whether various exercises that are successfully performed in 1g on a stationary device can be performed without losing balance in 0g on a moving device. Quantifying stability conditions and establishing stability requirements for exercise countermeasure systems is a long-standing challenge and this work helped to inform this specific need for integrated E4D/VIS flight project development.

METHODS AND RESULTS: A simplified stability analysis can be attempted based on platform accelerations generated by the VIS device simulation. In this type of analysis, the subject is conceived as standing on the platform in 0g while being held down to it by the tension in the cables. If the sideways acceleration of the platform is such that the cables cannot generate a sufficient moment relative to, e.g., the heels or the toes of the subject to overcome the tipping moment from the inertial forces on the accelerated subject's body, the subject becomes unstable. This approach, which we refer to as the 'static' approximation, indicated failure of all the exercises that were considered in the comprehensive VIS analysis of the E4D. It was realized, however, that platform accelerations are not externally imposed but are themselves induced by the motion of the subject's body during exercise, and a model calculation confirmed that this drastically altered the tipping moment on the subject, with the potential to even switch the direction in which the body would tip over. This made it imperative to consider in a coupled manner both the motion of the exercising subject's body and the induced VIS platform motion while considering stability. The coupled dynamics requirement was met by the VIS simulation incorporating time-dependent human mass properties atop the platform and driven by the inertial forces from the prescribed subject motion relative to the platform based on motion-capture recorded human trajectories in 1g on a stationary E4D [2].

To analyze simulation results, a stability criterion was also needed. We do not know how to account for the human 'control system' that would take visual and vestibular cues as inputs as the platform moves in 0g. We thus chose to follow an approach we had previously used to analyze the dynamic feasibility of performing a task in lunar gravity along the human body trajectory recorded in 1g [3]. In this approach, one analyzes the center of pressure (COP) between the shoes and the ground (or platform) and checks if the COP remains within the convex hull of the footprints on the ground (or platform), commonly referred to as base of support (BOS). Since pressure is vertical and, in the absence of foot restraints, positive, the COP going outside the BOS indicates that the trajectory recorded in 1g is not dynamically feasible in microgravity and/or on the moving platform of the device.

The outcome of the COP-based analysis was that some of the key exercises, especially the deadlift and the back squat exercises, were found to be dynamically feasible for at least some number of the exercise cycles, this number increasing with the cable tension. While this type of stability analysis does not account for the likely alteration of the exercise trajectory from its 1g form in space, it does show that there exist at least *some* realistic trajectories that pass the dynamic feasibility criterion. This adds confidence that, with further adjustment by the subject of the exercise form in 0g on a moving device, a number of exercises can be performed without losing balance.

REFERENCES:

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