Effect of centrifuge generated altered-gravity on bimanual coordination

Renee Woodruff[1]*, Madison M. Davis[2], Yiyu Wang[2], Traver Wright[2], Bonnie J. Dunbar[1], Deanna Kennedy[2], Ana Diaz-Artiles[1,2]

[1]Department of Aerospace Engineering, Texas A&M University, College Station, US
[2]Department of Health and Kinesiology, Texas A&M University, College Station, US
**renee.woodruff@tamu.edu*

INTRODUCTION

Space exploration missions subject astronauts to extreme environments that can adversely affect physiological function. Consequently, this can jeopardize performance and mission operations (Buckey, 2006). Although we make continuous progress understanding how human physiology is affected by various stimuli, we still do not know the range of gravity levels that maintain nominal physiological function. By investigating and determining the relationship between gravity level (i.e., gravity dose) and physiological response, we can then predict physiological responses at Martian and Lunar gravity and define what range of gravity levels elicits an "Earth-like response" (Galvan-Garza, 2018). Sensorimotor function in altered gravity has been somewhat explored, and findings have shown performance decrements in manual control tasks accompanied by adaptation in hyper-gravity environments (Rosenburg et al, 2018; Clark et al, 2015). However, these investigations primarily focused on unimanual control tasks, and there are many space mission relevant tasks (e.g., rover teleoperation or landing a spacecraft) that require the use and coordination of two limbs while in an altered gravity environment or during periods of rapid gravity level transitions. Thus, to address this gap, this research will specifically investigate the effect of altered gravity on bimanual coordination.

AIMS AND OBJECTIVES

The four main objectives of this research are to 1) generate gravity dose-response relationships between bimanual coordination operational variables as a function of gravity level in a centrifuge setting, 2) determine the G-thresholds that result in decrements in bimanual coordination performance, 3) investigate if bimanual coordination adaptation occurs after repeated exposure to altered gravity environments in a centrifuge setting, and 4) compare findings to results generated from other altered gravity analogs.

MATERIAL AND METHODS

Performance during two different bimanual control tasks will be compared across six simulated gravity levels. Altered gravity levels of 0, 0.25, 0.50, 0.75, 1, and 1.8 G will be delivered via a short-arm centrifuge located on the Texas A&M University campus (see Figure 1). Subjects will lay supine, feet facing radially outward, and rotated at an angular velocity that results in the desired gravity level at the subject's center of gravity in the head-to-toe direction. During

FIGURE 1: Short Radius Centrifuge, located on the Texas A&M University Campus at the Human Clinical Research Facility. Subjects will perform a bimanual movement or force coordination task at 0, 0.25, 0.5, 0.75, 1, and 1.8 G.

the experiment, subjects will perform either a bimanual force coordination task or bimanual movement coordination task (see Figure 2).

For the force task, participants must coordinate forces produced with their triceps muscles for in-phase (1:1) and multi-frequency (1:2) bimanual force patterns. Subjects, with their upper arms parallel to the ground and elbows at 90° angles, will rest their forearms on force transducers. A Lissajous plot template and a black cursor, controlled by the triceps forces produced, will be displayed on a screen for the subject. The subject must trace the template with the cursor by producing and coordinating forces between their right and left arms (i.e., the cursor moves bottom to top as force is produced with the left arm whereas the cursor moves left to right as force is produced with the right arm). The movement coordination task will require subjects to

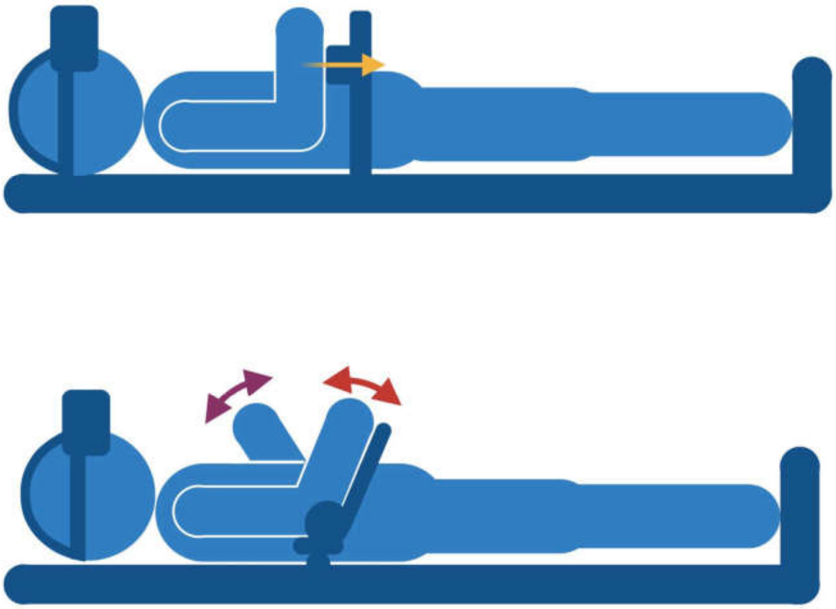

FIGURE 2: Bimanual coordination tasks setup on the short radius centrifuge. For both tasks, subjects will lay supine with their feet pointing out radially. Top: Force task configuration with the subject's forearms resting on force transducers. Subjects must produce an isometric force with their triceps and coordinate these forces to follow the Lissajous template provided on the headset display. Bottom: Movement task configuration with the subject's forearms positioned on rotating levers. The subject must coordinate their arm movements to follow the guide template provided on the headset display.

coordinate their right and left limb movements in a pattern that continuously changes from 0 ° to 180 °. Subjects will lay in the supine position with their forearms on custom levers and elbows limited to flexion-extension in the vertical plane. In a similar method as the force task, participants will be asked to trace a template on a screen by controlling a cursor's horizontal movement with one arm and vertical movement with the other arm. Potentiometers at the pivot point of the levers will monitor the movement of the subject's arms. For both the force and movement coordination tasks, wireless EMG sensors will be placed on the subject's triceps muscles to monitor muscle activation patterns. Subjects will complete the force coordination task in the 1:1 and 1:2 patterns and the movement coordination task for all 6 gravity levels. Dependent variables investigated include interpeak interval ratio, standard deviation of interpeak interval, harmonicity, peak force, peak force bias, mean force, phase angle slope ratio, EMG-EMG coherence, phase angle velocity, absolute error, constant error, and error variability.

DISCUSSION AND CONCLUSION

Determining a gravity dose-response relationship and the G-thresholds at which bimanual coordination is adversely affected will allow us to predict how physiological function is affected in relevant altered gravity conditions such as at lunar or Martian gravity levels. Moreover, while previous studies have indicated that sensorimotor function performance can adapt to new gravity levels within a few minutes (Clark et al, 2015), this was only investigated in hyper-gravity and not in hypo-gravity environments. Determining the presence or absence of adaptation to partial gravity levels will further expand our understanding of physiology and coordination dynamics for the context of human spaceflight. With this knowledge, we can make more informed decisions when developing astronaut training to better prepare them for future missions.

This research is part of a larger effort to investigate bimanual coordination in altered gravity environments. Current testing is using a tilt-table analog to simulate gravity levels ranging from 0 to 1 G (Kennedy, 2021; Davis, 2021; Wang, 2021). These research efforts will culminate in a set of experiments conducted during parabolic flight simulating 0, 0.25, 0.50, and 0.75 G (Diaz-Artiles, 2021). Gravity-dose response curves will be generated for each of the three analogs (tilt-table, centrifuge, parabolic flight) and then compared to each other to inform recommendations on the relationship between dose-response curves and the chosen altered gravity analogs. These results will provide further insight into the relationship between each analog and its associated dose-response curve. Additionally, this research as a whole will further develop our understanding of human neurophysiology in altered gravity environments.

ACKNOWLEDGMENTS

Work Supported by NASA 80NSSC20K1499

Keywords: bimanual coordination, altered-gravity, centrifuge, coordination dynamics

REFERENCES

Buckey, J.C. (2006). Space Physiology. Oxford University Press.

Galvan-Garza, R.C., Clark T.K., Sherwood D., Diaz-Artiles A., Rosenberg M.J., Natapoff A., Karmali F., Oman C.M., Young L.R. (2018). Human Perception of Whole-Body Roll Tilt Orientation in a Hypo-Gravity Analog: Underestimation and Adaptation. J. Neurophysiol. 120:6, 3110-3121. doi: 10.1152/jn.00140.2018.

Rosenberg, M.J., Galvan-Garza, R.C., Clark, T.K., Sherwood, D.P., Young, L.R., Karmali, F. (2018). Human manual control precision depends on vestibular sensory precision and gravitational magnitude J. Neurophysiol. 120:6. doi: 10.1152/jn.00565.2018

Clark, T.K., Newman, M.C., Merfeld, D.M., Oman, C.M., Young, L.R. (2015). Human manual control performance in hyper-gravity. Exp. Brain Res. 233, 1409-1420.

Kennedy D.M., Davis M.M., Woodruff R., Wang Y., Wright, T., Dunbar B.J., Diaz-Artiles A. (2021). The influence of Altered-Gravity on Bimanual Force Coordination (extended abstract). ISGP.

Davis M.M., Wang Y., Woodruff R., Wright, T., Dunbar B.J., Diaz-Artiles A., Kennedy D.M. (2021). The influence of perceptual constraints on bimanual force coordination in microgravity (extended abstract). ISGP.

Wang Y., Davis M.M., Woodruff R., Wright, T., Dunbar B.J., Diaz-Artiles A., Kennedy D.M. (2021). Integrated Feedback Displays to Facilitate Bimanual Coordination in Simulated Gravity (extended abstract). ISGP.

Diaz-Artiles A., Woodruff R., Davis M.M., Wang Y., Dunbar B.J., Kennedy D.M. (2021). Bimanual Coordination in Altered Gravity during Parabolic Flight (abstract and short presentation). NASA Human Research Program Investigators' Workshop.