The influence of altered-gravity on bimanual force coordination

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

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

INTRODUCTION

Many of the activities associated with spaceflight require individuals to coordinate actions between the limbs (e.g., controlling a rover, landing a spacecraft). However, much of the research investigating the effects of gravity on manual control have examined unimanual rather than bimanual performance (e.g., Rosenberg et al. 2018). Bimanual tasks are characterized by precise spatio-temporal relationships between the limbs and are described using variables that reflect the spatial and/or timing relationship between the limbs (e.g., relative phase, frequency relationship). A large body of research has focused on how bimanual coordination patterns emerge, stabilize, and transition in normal gravity environments (e.g., Kelso 1994). The results have identified only two inherently stable bimanual coordination patterns, in-phase (0°) and anti-phase (180°) with in-phase more stable than anti-phase. Other phase (e.g., 90°) and frequency (e.g., 1:2) relationships have proved difficult or near impossible to perform without significant training (e.g., Summers et al. 1993).

The difficulties associated with producing bimanual tasks such as 90° relative phase and 1:2 multi-frequency relationships have been attributed to both inherent and incidental constraints. Inherent constraints are associated with the structure of the neuromuscular system (e.g., Swinnen 2002), whereas incidental constraints are associated with specific perceptual, cognitive, and/or attentional features of the task or task environment (Shea et al. 2016). The objective of our project is to understand the neurophysiological and psychological constraints that influence coordination dynamics in altered-gravity environments. To achieve this goal, a series of experiments in altered-gravity using a tilt paradigm, a short radius centrifuge, and a parabolic flight have been designed. The purpose of the current experiment was to determine an individuals' ability to adapt to altered-gravity environments when performing simple (1:1) and complex (1:2) bimanual force tasks in an altered-gravity environment using a tilt paradigm.

MATERIAL AND METHODS

A tilt table was used to simulate gravity on Earth (90° Head Up Tilt or HUT), Mars (22.3° HUT), the Moon (9.5° HUT), and in microgravity (-6° Head Down Tilt or HDT) (see Figure 1). Right arm dominant participants (N=12) were required to produce rhythmical 1:1 and 1:2 bimanual coordination patterns by producing a pattern of isometric forces with their left arm that was coordinated to a pattern of isometric forces produced with their right arm (see Figure 2). The 1:1 task required participants to produce simultaneous patterns of force with their two arms while the 1:2 task required participants

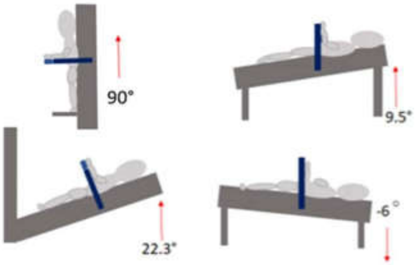

FIGURE 1: Illustration depicting the experimental arrangement for the gravity conditions (**a**), Earth (90° HUT) (**b**), Mars (22.3° HUT) (**c**), Moon (9.5° HUT) (**d**), Microgravity (-6° HDT).

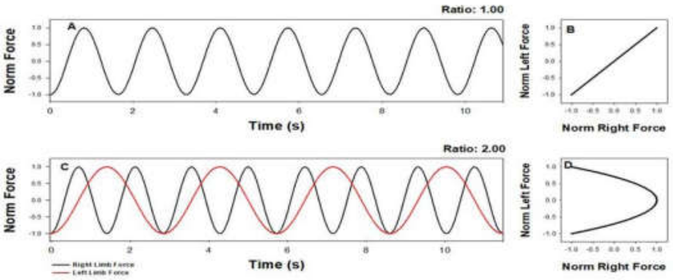

FIGURE 2: Simulated goal coordination pattern and corresponding Lissajous template for the 1:1 (a,b) and 1:2 (c,d) tasks.

to produced two patterns of force with the right arm for each pattern of force produced by the left arm. Lissajous feedback information was provided to guide performance. The Lissajous displays consisted of a goal template and a cursor indicating the forces produced by the two arms. The cursor moved from left-to-right as force was produced with the left arm and from bottom-to-top as force was produced by the right arm. The template illustrated the specific pattern of force requirements needed to produce the goal coordination patterns. Participants performed 14 practice trials for each coordination pattern at 90° HUT (Earth). Following a 30-minute rest period, participants performed 2 retention trials (Earth) followed by two transfer trials for the two coordination patterns at each simulated gravity environment (Mars, Moon, microgravity) in a counterbalanced order. All trials were 30 s.

Performance was assessed using both unimanual and bimanual measures. Unimanual measures included: inter-peak interval (provides information regarding the rate of performance), standard deviation (STD) of the inter-peak interval (provides information regarding the variability in the rate of performance), phase angle velocity (provides information regarding the rate of performance), harmonicity (quantifies the harmonic nature of the action - an h-index of 0 indicates that the movement time series is inharmonic and that one or more adjustments or perturbations have impacted the action produced by the limb, whereas an h-index of 1 indicates an harmonic time series in which subtle adjustments or perturbations are not evident), peak force, and mean force. The bimanual measures included: inter-peak interval ratio (provides information regarding the accuracy in timing the goal bimanual coordination pattern), inter-peak ratio error (provides information regarding the accuracy of the goal pattern), and phase angle slope ratio (provides information regarding accuracy in timing).

RESULTS

Figure 3 provides the results for inter-peak interval ratio. Note, that the goal inter-peak interval ratio for the 1:1 task is 1.0 while the goal ratio for the 1:2 task is 2.0. The results indicated that participants could perform the required bimanual patterns (1:1, 1:2) in all four environments (Earth, Mars, Moon, microgravity). Similar results were observed for the phase angle slope ratio indicating that participants were able to effectively time the goal bimanual tasks. Furthermore, the performance curve, illustrating the error of the IPI

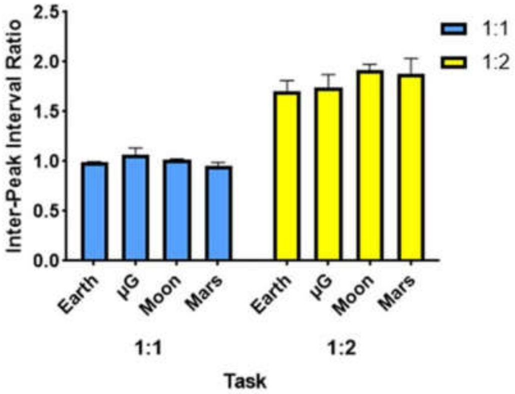

FIGURE 3: Mean inter-peak interval ratio by gravity condition. Error bars represents standard errors. The results indicate the participants performed the required bimanual patterns in all gravity environments.

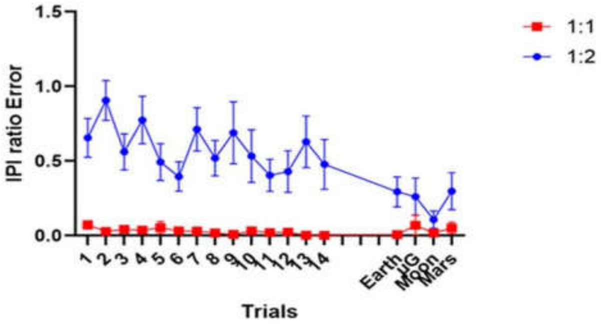

FIGURE 4: Performance Curve for the 1:1 and 1:2 Inter-Peak Interval Error. Participants performed 14 training trials. After 30 minute delay period participants performed retention (Earth) and transfer (microgravity, Moon, Mars) tests.

ratio between left and right limb (see Figure 4), indicated that performance for the 1:2 task improved with training and participants were able to maintain performance after the delay period and transfer training to the altered-gravity environments.

Although no differences between conditions were observed for measures associated with the timing of the task (inter-peak interval ratio, phase angle slope ratio), differences in measures associated with force production (harmonicity, mean force, STD of force) were observed. Results also indicated differences between Earth and the altered-gravity environments for the left limb mean force and STD of force during the 1:1 task (see Figure 5).

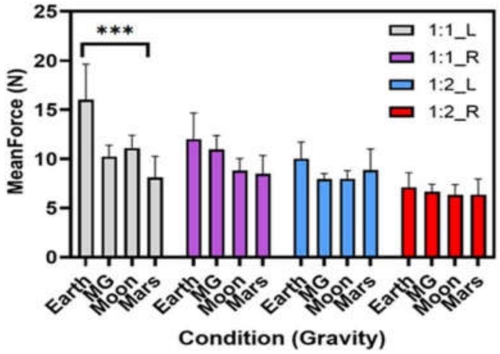

FIGURE 5: Mean Force by gravity condition. Error bars represents standard errors, ** indicates a significance level less than 0.01.

DISCUSSION

On Earth's gravity, several recent investigations have demonstrated that a variety of complex bimanual coordination patterns, that were once thought difficult or near impossible to perform without extensive training, could be quickly and effectively performed with Lissajous information and movement templates (e.g., Kovacs et al. 2020; Wang et al. 2021). The results of the current experiment extend these findings to include altered-gravity environments. The ability to quickly and effectively coordinate patterns of isometric forces in the altered-gravity environments provide additional evidence for the robust utility of integrated feedback displays in facilitating complex patterns of coordination.

The ability to coordinate complex bimanual tasks when provided Lissajous displays suggest that the detrimental effects associated with poor bimanual control may be due to attentional, cognitive, and/or perceptual constraints associated with the task or task environment (Shea et al. 2016). This may be particularly noteworthy in altered-gravity environments given the increased psychological demands associated with spaceflight (e.g., Friedl-Werner et al. 2021). Our results suggest that feedback information that reduces the attentional demands of the task may prove an effective countermeasure for the manual control performance decrements often associated with altered-gravity (e.g., Paloski et al. 2008). Future research should further explore this possibility.

Despite participants' ability to quickly and effectively time their bimanual actions in altered-gravity environments, differences in measures associated with the control of force were observed between Earth and the altered-gravity conditions (see Figure 5). The results indicated differences between Earth and the altered-gravity environments for the left limb mean force and STD of force during the 1:1 task. Given that 1:1 coordination task is considered to be the brains default coordination mode, differences with gravity suggest that the coordination landscape differs between Earth and altered-gravity environments. We will continue to explore constraints that facilitate or interfere with bimanual coordination in altered-gravitational environments using HUT/HDT paradigms, parabolic flight, and short-radius centrifugation. In addition, we will examine factors such as the impact of motion sickness medication on coordination dynamics and use additional tools such as electromyography.

CONCLUSION

The results of the current investigation indicate that participants can quickly and effectively coordinate complex patterns of force when provided Lissajous information and movement templates in altered-gravity environments. In addition, the results suggest that training on Earth with Lissajous information can be transferred to altered-gravity environments.

ACKNOWLEDGMENTS

Work Supported by NASA 80NSSC20K1499

Keywords: bimanual coordination, manual control, coordination dynamics, altered-gravity

REFERENCES

Friedl-Werner, A., Machado, M. L., Balestra, C., Liegard, Y., Philoxene, B., Brauns, K., Stahn, A. C., Hitier, M., & Besnard, S. (2021). Impaired Attentional Processing During Parabolic Flight. Front. Physiol. 12, 675426.

Kelso, J.A.S (1994). The informational character of self-organized coordination dynamics. Hum. Mov. Sc.i 13, 393-413.

Kovacs, A.J., Wang, Y., Kennedy, D.M. (2020). Accessing interpersonal and intrapersonal coordination dynamics. Exp. Brain Res. 238, 17–27.

Paloski, W.H., Oman, C.M., Bloomberg, J.J., Reschke, M.F., Wood, S.J., ...Stone, L.S. (2008). Risk of sensory-motor performance failures affecting vehicle control during space missions: A review of the evidence. J. Gravit. Physiol. 15, 1-29.

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, 3187–3197.

Shea, C.H., Buchanan, J.J., Kennedy, D.M. (2016). Perception and action influences on discrete and reciprocal bimanual coordination. Psychon. Bull. Rev. 23, 361–386.

Summers, J.J, Todd, J.A, Kim, Y.H. (1993). The influence of perceptual and motor factors on bimanual coordination in a polyrhythmic tapping task. Psychol. Res. 55, 107-115.

Swinnen, S.P. (2002). Intermanual coordination: From behavioural principles to neural-network interactions. Nature Rev. 3, 350-361.

Wang, Y., Neto, O.P., Davis, M.M., Kennedy, D.M. (2021). The effects of inherent and incidental constraints on bimanual and social coordination. Exp. Brain Res., 239, 2089-2105.