The influence of perceptual constraints on bimanual coordination in simulated microgravity

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INTRODUCTION

Understanding how individuals control and coordinate movement within their environment has been the focus of a large body of research for over 50+ years (Shea et al., 2016). The general results of this line of research have indicated only two inherently stable coordination patterns: in-phase (Φ = 0°) and anti-phase (Φ = 180°); while other phase relationships (e.g., Φ = 90°) have proved difficult or near impossible without extensive training (e.g., (Fontaine et al., 1997; Lee et al., 1995; Swinnen et al., 1997). Based on non-linear dynamics, the Haken-Kelso-Bunz (HKB) model provides a formal account of the stability properties associated with coordination dynamics in Earth gravity (Haken et al. 1985). In-phase and anti-phase coordination patterns are modeled as stable fixed-point attractors while other relative phase patterns represent repellers in the attractor landscape.

The difficulty of producing complex bimanual coordination patters, such as Φ = 90°, has been typically attributed to inherent constraints (e.g, structure and/or function of neuromuscular, visual, vestibular systems). For example, strong phase attraction to inherently stable coordination modes (i.e., in-phase and anti-phase) can be associated with the activation and associated proprioceptive signals of non-homologous muscles via crossed and uncrossed cortical pathways (Swinnen, 2002). However, evidence also suggest that the difficulty may be due, in large part, to incidental constraints (perceptual, attentional, and/or cognitive factors associated with the task or the environment) (Shea et al., 2016).

Research has indicated that much of the difficulty associated with complex bimanual coordination patterns can be circumvented with relatively simple visual feedback manipulations (e.g., Lissajous feedback) that reduce the perceptual and/or attentional constraints associated with the task or task environment (Panzer et al., 2018; Shea et al., 2016). Lissajous displays integrate the position of two limbs into a single point (cursor) in one plane with one limb moving the cursor in the horizontal direction while the other limb moves the cursor in the vertical direction, much like a videogame control system. That is, one avatar is often controlled with two effectors (i.e., thumbs). Lissajous displays have been used to successfully produce a variety of bimanual coordination patterns (e.g., Kovacs et al. 2020; Wang et al., 2021) in normal gravity. It is believed that Lissajous displays provide the central nervous system (CNS) an opportunity to override the perceptual and/or neurophysiological constraints acting on the system (Shea et al., 2016).

Advances in science and technology have altered the way billions of people interact with the environment. For example, the use of virtual and augmented reality is becoming more common in domains such as education, entertainment, healthcare, military, sport, and telecommunications (e.g., Oman et al., 2021). In addition, the use of virtual reality has become a popular tool for space exploration and astronaut training (e.g., Chen et al., 2017). Yet, it is unclear if altered environmental information changes the coordination landscape. To begin the process of understanding how constraints associated with altered environments (e.g., feedback, gravity) influence coordination dynamics, an experiment was designed to assess bimanual coordination performance in simulated microgravity when visual feedback was presented via headset goggles compared to traditional feedback displays.

MATERIAL AND METHODS

Right limb dominate subjects (N=8, mean age = 21.4 SD=2.3) participated in the experiment. A tilt table was used to simulate altered gravity using a head-up tilt (HUT)/head-down tile (HDT) paradigm to compare bimanual performance between Earth (90° HUT) and simulated microgravity (6° head-down HDT) conditions (Figure 1). Participants were required to produce a continuous 1:1 bimanual force pattern with a 90° relative phase offset. Lissajous feedback information was displayed via goggles or on a screen directly in front of the participant to guide performance (see Figure 2). Participants performed 14 trials in each feedback (goggles, no goggles) and gravity (Earth, microgravity) condition, counterbalanced across conditions. Each trial was 30 s.

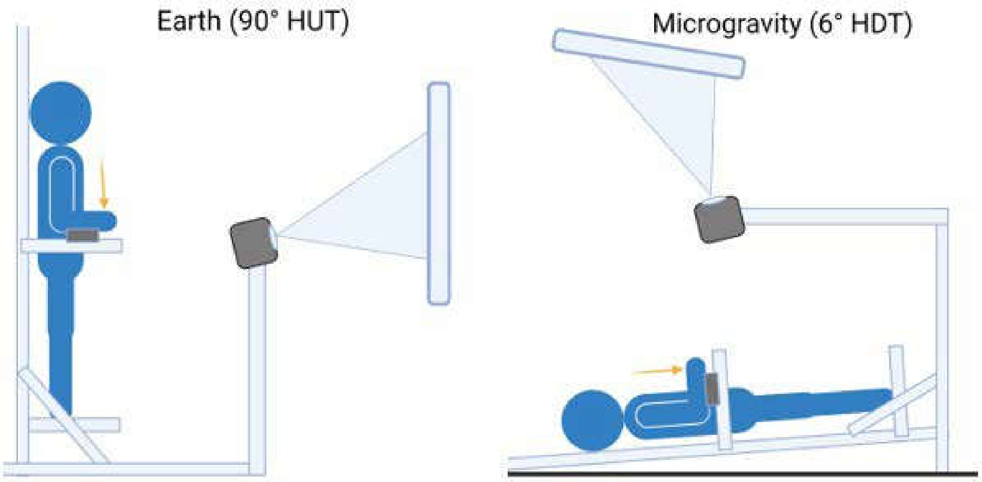

FIGURE 1: These illustrations display the position of subjects during the Earth (90° HUT) and simulated microgravity (6° HDT) condition.

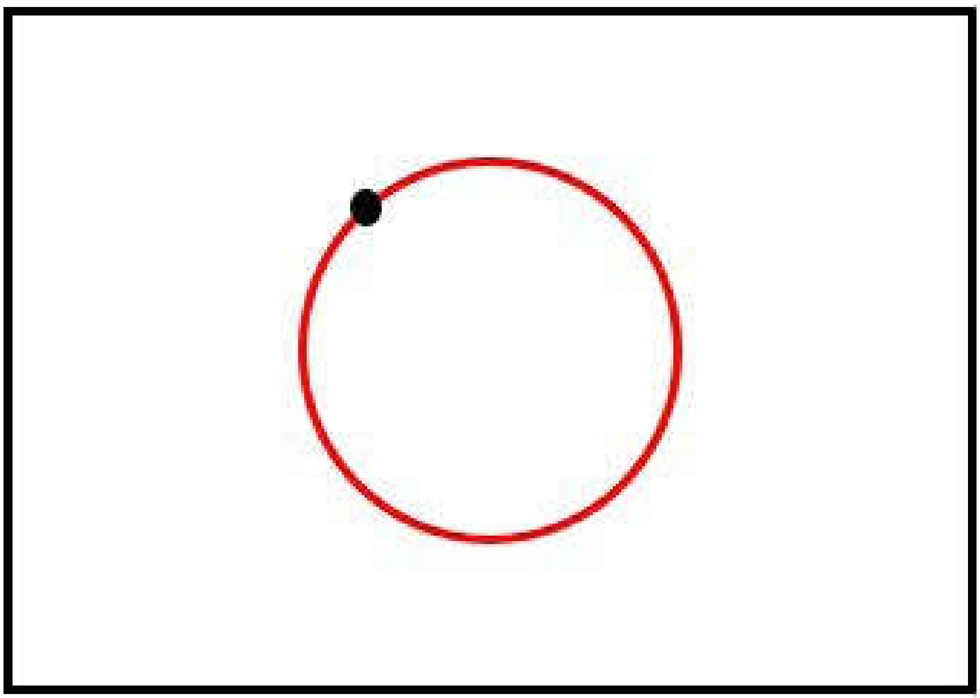

FIGURE 2: This figure represents the Lissajous plot displayed to subjects. The black cursor represents integrated feedback of the left and right limbs force output. The red circle represents the 90° relative phase coordination.

Absolute error (AE) of the continuous relative phase was used as a measure of the degree to which the required goal relative phase was achieved. Variable error (VE) was used as a measure of stability, and constant error (CE) was used as a measure of coordination bias.

RESULTS

The analysis of the relative phase AE (Figure 3) indicated a significant difference in simulated gravity environments for the no goggle condition (p=0.017). Thus, participants were more accurate (lower AE) in simulated microgravity than the Earth condition. However, differences in performance between the two gravity conditions were reduced when visual feedback was presented through goggles.

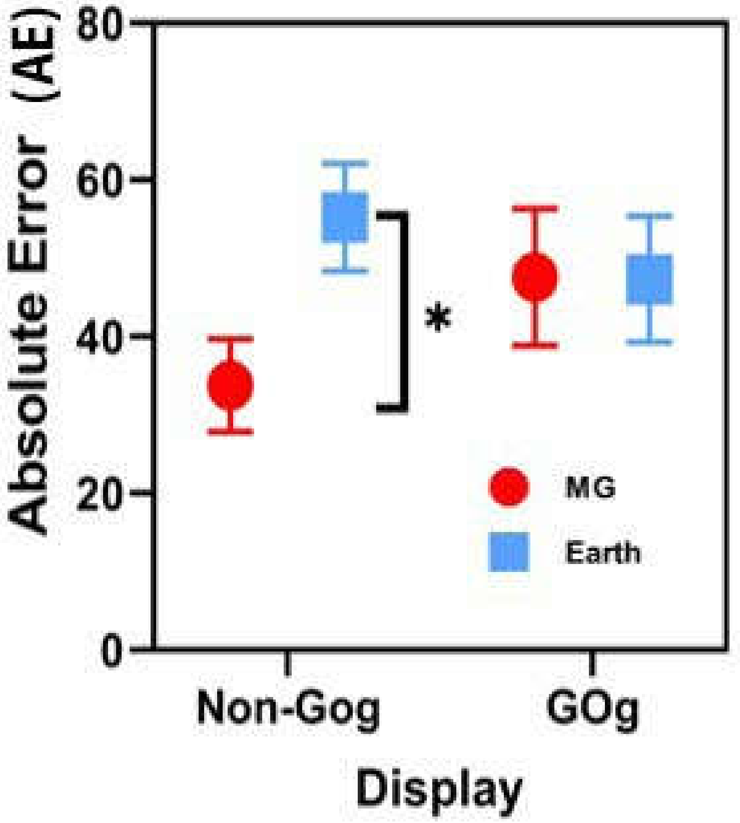

FIGURE 3: Absolute relative phase error (AE) for the Earth (90° HUT) and simulated microgravity (6° HDT) with headset goggles (GOg) and without headset goggles (Non-Gog).

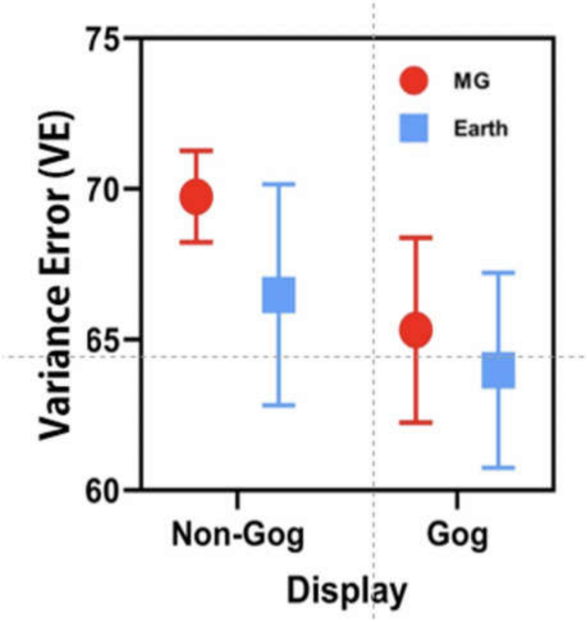

FIGURE 4: Variance error of relative phase (90°) for the Earth (90° HUT) and simulated microgravity (6° HDT) with headset goggles (Gog) and without headset goggles (Non-Gog).

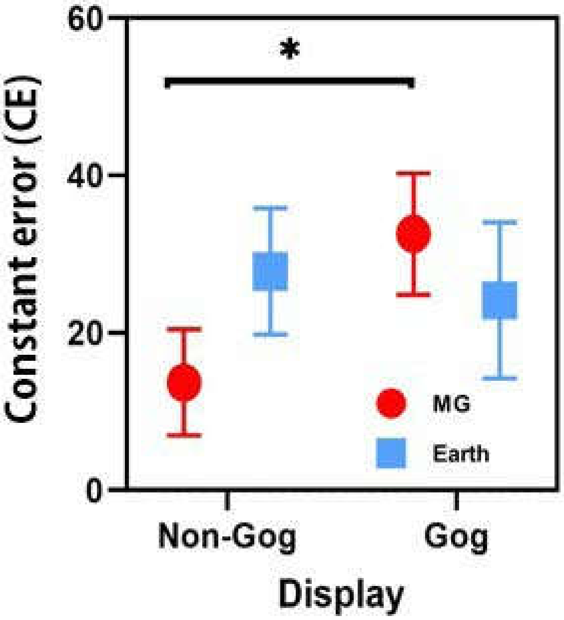

FIGURE 5: Constant relative phase error (CE) for the Earth (90° HUT) and simulated micro gravity (6° HDT) with headset goggles (Gog) and without headset goggles (Non-Gog).

The analysis of the relative phase VE (Figure 4) found no significant differences in stability between the goggle and non-goggle feedback conditions. However, the analysis of the relative phase CE (Figure 5) detected a significant difference between the two feedback conditions (goggle and non-goggle) for the simulated microgravity environment. Higher CE values, or less bias, was found for the goggle condition compared to the non-goggle condition in the microgravity environment. All other interactions were insignificant.

DISCUSSION

When participants were required to produce the goal coordination pattern using a traditional display (no-goggles) performance was more accurate in the microgravity condition than in the Earth condition. In terms of coordination dynamics, this result may suggest that neurophysiological constraints, such as neural crosstalk, are acting on the central nervous system (CNS). Neural crosstalk occurs during bimanual tasks when a mirror image of the motor command sent to one muscle group is also dispatched to the homologous muscles of the contralateral limb via crossed and uncrossed corticospinal pathways (Swinnen, 2002). Research has indicated that the effects of neural crosstalk is partially dependent on the force requirements of the task, with higher forces resulting in stronger crosstalk and lower forces in weaker crosstalk effects (Heuer et al., 2001; Kennedy et al., 2017). As such, it is possible that gravitational force acting on the body may influence an individuals' ability to effectively produce bimanual tasks. From this perspective, bimanual interference would be reduced in microgravity environments. This result may also have important implications regarding body position (supine vs. upright) during task performance.

Interestingly, there were no difference in performance accuracy when information was presented via the headset goggles during both gravity conditions. This result is consistent with previous research that has demonstrated the beneficial effects of removing vision of limbs when producing bimanual tasks (Kovacs et al., 2010). It is possible that the goggles reduce attentional demands of the task by removing non-salient environmental information during task performance while in a simulated microgravity environment. The results suggest that changes in environmental information can influence coordination dynamics. As such, researchers should recognize such limitations when using altered environments to make inferences regarding motor performance.

CONCLUSIONS

Results indicated that participants were more accurate in the microgravity condition than in the Earth condition when visual feedback was displayed on a screen directly in front of the participant. However, differences in performance accuracy between the two gravity conditions were reduced when visual feedback was presented through goggles. These results suggest that altered environmental information (gravity, display) can influence coordination dynamics. Future research should continue to explore constraints that influence coordination dynamics in altered environments.

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Keywords: Bimanual coordination, Simulated gravity, Augmented reality, Visual feedback

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