Integrated feedback displays to facilitate bimanual coordination in simulated gravity

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INTRODUCTION

The ability to coordinate actions between the limbs is important for many activities associated with spaceflight. For example, tasks such as controlling a rover or piloting a spacecraft often involve some type of coordination between the limbs. Numerous ground studies have demonstrated that bimanual tasks that require phase relationships other than 1:1 in-phase (0°) or anti-phase (180°) are difficult or near impossible without extensive training (Lee et al., 1995;Fontaine et al., 1997;Swinnen et al., 1997). The difficulty associated with producing complex relative phase patterns, such as 90°, have been traditionally attributed to inherent constraints associated with the structure of the neuromuscular system (Schoner and Kelso, 1988). It is important to note, however, that auditory and/or visual metronomes were typically used to pace bimanual performance in these experiments (Zanone and Kelso, 1992).

More recent research, however, has indicated that complex coordination patterns (e.g., 90° relative phase) could be performed quite well within a few minutes of training when provided integrated feedback information and other attentional distractions were minimized (e.g., metronomes, vison of the limbs) (Kovacs et al., 2010;Kennedy et al., 2015). One type of integrated feedback that has proved successful in facilitating complex modes of coordination is Lissajous displays (Figure 1). Lissajous displays provide a goal template along with on-line integrated information regarding the position of two individual points (e.g., limbs) as a single point (e.g., cursor). The general results of experiments using Lissajous displays have indicated that this type of feedback information allowed participants to quickly and effectively produce a wide range of complex bimanual tasks. (Kovacs et al., 2009a;Kovacs et al., 2009b;Kennedy et al., 2016;Kovacs et al., 2020).

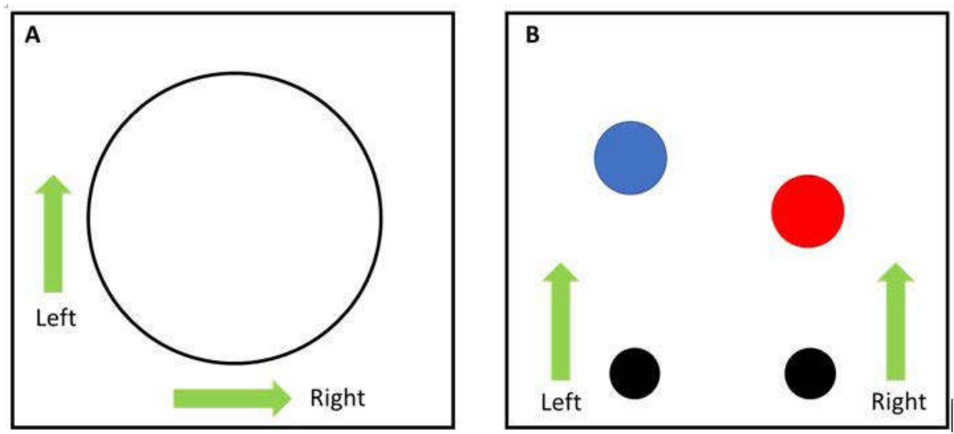

FIGURE 1: Illustration depicting Lissajous plot of 90 degrees relative phase (**A**), and visual metronome (**B**) feedback conditions.

In a recent experiment directly comparing bimanual performance with Lissajous displays to visual metronomes, Kovacs et al. 2020 demonstrated that participants could produce a wide variety of relative phase patterns after only 6 minutes of practice whereas participants were not able to produce the same relative phase patterns with visual metronome. The ability to coordinate complex bimanual tasks with the limbs when provided integrated feedback information suggest that the detrimental effects associated with complex bimanual coordination tasks may be due to attentional, perceptual, and or cognitive constraints associated with the task or environment (Shea et al., 2016). It is believed that Lissajous displays provide the CNS system an opportunity to override the perceptual and/or neurophysiological constraints acting on the system However, producing complex bimanual coordination in altered-gravity environments may be even more challenging for the CNS due to the increased attentional, perceptual, and cognitive demands associated with spaceflight and altered gravity environments (Friedl-Werner et al., 2021). As such, it is not clear whether individuals can use Lissajous displays to coordinate complex bimanual coordination patterns in altered-gravity environments similar to ground studies. Therefore, the purpose of the current study is to determine if individuals can coordinate a complex pattern of force (90°) in simulated microgravity similar to performance on Earth and to compare performance between the two types of feedback information (Lissajous plots vs. visual metronome).

METHOD

A head-up tilt (HUT)/head-down tilt (HDT) paradigm was used to compare microgravity and Earth. Earth (90° HUT) and microgravity (-6° head-down HDT) environments were simulated with a tilt table (Figure 2). Right limb dominant participants (N= 8) attempted to produce a continuous 1:1 bimanual force pattern with a 90° relative phase offset paced with a visual metronome or Lissajous displays. The metronome consisted of two separate targets, one for each limb, with a 90° phase offset moving at 1 Hz from bottom-to-top (Figure 1B). Participants produced force with each limb to match the pattern paced by the metronome. The Lissajous display consisted of a goal template and a cursor indicating the forces produced by the two arms (Figure 1A). For the Lissajous condition, participants' movement were self-paced to meet a goal frequency of 1 Hz. Participants were asked to speed up or slow down when their movements frequency was slower or faster than 1 Hz. The cursor moved from left-to-right as force was produced with the right arm and from bottom-to-top as force was produced by the left arm. The template illustrated the specific pattern of force needed to produce the 90° goal coordination pattern. Participants performed 14 trials for each feedback (metronome, Lissajous) and gravity (Earth, microgravity) condition, counterbalanced across conditions. Each trial was 30 s. Absolute error (AE) of the continuous relative phase was used a measure of the degree to which the required goal relative phase was achieved. Variability of error (VE) and constant error (CE) were used as measures of stability and bias of the 90° coordination pattern.

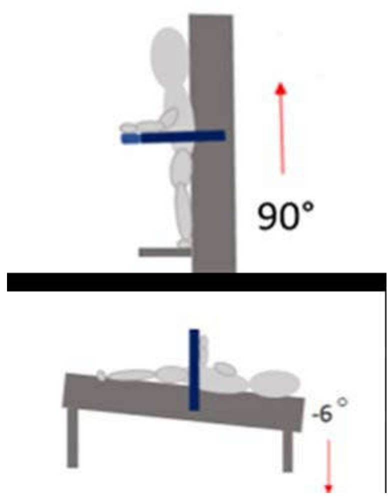

FIGURE 2: Illustration depicting the experimental arrangement for the gravity conditions (**a**), Earth (90° HUT) (**b**), Microgravity (-6° HDT).

All force signals were processed by using MATLAB, and the two-way repeated measure of variances analysis (Feedback × Gravity) for the variables AE, VE and CE was performed by SPSS 27.0.

RESULTS

Results indicated significantly lower AE with Lissajous displays compared to visual metronomes (P= .03) (Figure 3). However, participants were not able to tune-in the goal coordination pattern (high AE and VE) within the 6 minutes of practice with the metronomes and performance was biased (CE) toward the anti-phase coordination pattern (180°).

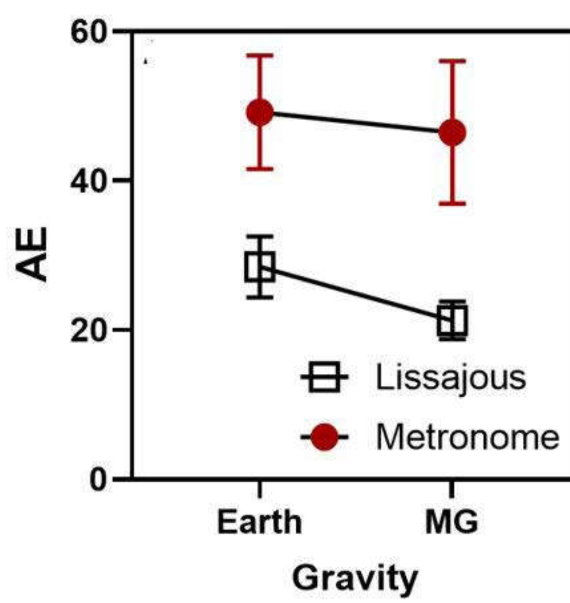

FIGURE 3: Mean absolute error (AE) by feedback condition. The results indicate that participants were more accurate with Lissajous displays than metronomes for both Earth and microgravity conditions.

DISCUSSION

The results of the current investigation indicate that participants were able to effectively (low AE) produce the 90° relative phase bimanual force pattern within the 6 minutes of training when provided Lissajous displays. This result is similar with a number of ground studies demonstrating that complex bimanual coordination patterns could be performed following relatively little training when provided integrated feedback information (Shea et al. 2016; Kovacs et al. 2020; Wang et al. 2021). Extending this line of research to microgravity environments provides further evidence for the robust utility of Lissajous displays in facilitating complex bimanual coordination tasks (Shea et al. 2016).

The Lissajous displays provided a goal template of the 90° relative phase pattern along with on-line feedback information regarding the position of the position of the two limbs as a single point. Participants were able to use this information, regardless of the gravity condition, to produce the goal pattern within a few minutes of practice. Given that participants were able to perform the goal in microgravity is particularly impressive considering the increased attentional, cognitive, and perceptual demands associated with spaceflight and altered-gravity environments (Friedl-Werner et al. 2021).

Participants were not able to tune-in the goal coordination pattern (high AE and VE) within the 6 minutes of practice when provided metronomes to pace performance. In addition, performance was biased (CE) toward the anti-phase coordination pattern (180°). This result is consistent with the Haken, Kelso, and Bunz (HKB) model. A feature of the HKB model is that both in-phase and anti-phase coordination patterns are modeled as stable fixed-point attractors. Other phases (e.g., 90°) act as repellers in the coordination landscape which may result in a phase transition to a fixed-point attractor (i.e., 0°, 180°). It is believed that Lissajous displays provide the system an opportunity to override the perceptual and/or neurophysiological constraints acting on the system. It appears this type of feedback is also effective in overcoming constraints imposed by microgravity. Research should further explore Lissajous displays as a countermeasure to the detrimental performance effects often associated with altered-gravity (e.g., Clark et al. 2015).

CONCLUSIONS

Results indicated that participants were able to effectively produce (low AE) a complex 90° relative phase when provided Lissajous displays in microgravity similar to Earth. This result provides additional evidence regarding the robust nature of Lissajous displays in facilitating complex bimanual performance.

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Keywords: bimanual coordination, altered-gravity, visual feedback

REFERENCES

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.

Fontaine, R.J., Lee, T.D., and Swinnen, S.P. (1997). Learning a new bimanual coordination pattern: reciprocal influences of intrinsic and to-be-learned patterns. Can. J. Exp. Psychol. 51, 1-9.doi: 10.1037/1196-1961.51.1.1

Friedl-Werner, A., Machado, M.L., Balestra, C., Liegard, Y., Philoxene, B., Brauns, K., Stahn, A.C., Hitier, M., and Besnard, S. (2021). Impaired Attentional Processing During Parabolic Flight. Front. Physiol. 12, 675426.10.3389/fphys.2021.675426

Gentili, R., Cahouet, V., and Papaxanthis, C. (2007). Motor planning of arm movements is direction-dependent in the gravity field. Neuroscience 145, 20-32.doi: 10.1016/j.neuroscience.2006.11.035

Kennedy, D.M., Boyle, J.B., Rhee, J., and Shea, C.H. (2015). Rhythmical bimanual force production: homologous and non-homologous muscles. Exp. Brain Res. 233, 181-195.doi: 10.1007/s00221-014-4102-y

Kennedy, D.M., Wang, C., Panzer, S., and Shea, C.H. (2016). Continuous scanning trials:Transitioning through the attractor landscape. Neurosci. Lett. 610, 66-72.doi: 10.1016/j.neulet.2015.10.073

Kovacs, A.J., Buchanan, J.J., and Shea, C.H. (2009a). Using scanning trials to assess intrinsic coordination dynamics. Neurosci. Lett. 455, 162-167.doi: 10.1016/j.neulet.2009.02.046

Kovacs, A.J., Buchanan, J.J., and Shea, C.H. (2010). Impossible is nothing: 5:3 and 4:3 multi-frequency bimanual coordination. Exp. Brain Res. 201, 249-259.doi: 10.1007/s00221-009-2031-y

Kovacs, A.J., Han, D.W., and Shea, C.H. (2009b). Representation of movement sequences is related to task characteristics. Acta Psychol. (Amst.) 132, 54-61.doi: 10.1016/j.actpsy.2009.06.007

Kovacs, A.J., Wang, Y., and Kennedy, D.M. (2020). Accessing interpersonal and intrapersonal coordination dynamics. Exp. Brain Res. 238, 17-27.doi: 10.1007/s00221-019-05676-y

Lee, T.D., Swinnen, S.P., and Verschueren, S. (1995). Relative Phase Alterations During Bimanual Skill Acquisition. J Mot Behav 27, 263-274.doi: 10.1080/00222895.1995.9941716

Schoner, G., and Kelso, J.A. (1988). Dynamic pattern generation in behavioral and neural systems. Science 239, 1513-1520.doi: 10.1126/science.3281253

Shea, C.H., Buchanan, J.J., and Kennedy, D.M. (2016). Perception and action influences on discrete and reciprocal bimanual coordination. Psychon Bull Rev 23, 361-386.doi: 10.3758/s13423-015-0915-3

Swinnen, S.P., Van Langendonk, L., Verschueren, S., Peeters, G., Dom, R., and De Weerdt, W. (1997). Interlimb coordination deficits in patients with Parkinson's disease during the production of two-joint oscillations in the sagittal plane. Mov. Disord. 12, 958-968.doi: 10.1002/mds.870120619

Zanone, P.G., and Kelso, J.A. (1992). Evolution of behavioral attractors with learning: non-equilibrium phase transitions. J. Exp. Psychol. Hum. Percept. Perform. 18, 403-421.doi: 10.1037//0096-1523.18.2.403