Neuroscience Letters 610 (2016) 66–72

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research paper

Continuous scanning trials:Transitioning through the attractor landscape

Deanna M. Kennedy [a], Chaoyi Wang [a], Stefan Panzer [b], Charles H. Shea [a,*]

[a] Texas A&M University, USA
[b] Saarland University, Germany

HIGHLIGHTS

- Participants were asked to transition from in-phase to anti-phase in 1° increments within a trial.
- Participants were very effective in navigating through the relative phase landscape.
- The results indicate integrated displays greatly increase performers' bimanual capabilities.

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 29 October 2015
Accepted 30 October 2015
Available online 3 November 2015

Keywords:
Perception-action
Coordination dynamics
Relative phase
Phase transition

ABSTRACT

Bimanual 1:1 coordination patterns other than in-phase (0°) and anti-phase (180°) have proven difficult to perform even with extended practice. The difficulty has traditionally been attributed to phase attraction that draws the coordination between the limbs towards the bimanual patterns of in-phase and anti-phase and variability associated with the activation and associated proprioceptive signals of non-homologous muscles via crossed and uncrossed cortical pathways. However, recent experiments have demonstrated that a wide range of relative phase and multi-frequency coordination patterns can be effectively produced with only a few minutes of practice when Lissajous or online relative phase information is provided. The present experiment was designed to determine if participants provided Lissajous feedback comprised of continuously transitioning relative phase goals could be effectively performed as the participant navigates through the attractor landscape. The results clearly indicated that participants can effectively produce a large range of supposedly unstable coordination patterns (between 0° and 180° in 1° increments) after only a few minutes of practice. These findings clearly indicate that the perception-action system is fully capable of effectively producing and transitioning through a wide range of bimanual coordination patterns and that the reason for the failure to produce these patterns in previous experiments resides in the perceptual information and attentional requirements typically found in experimental testing environments.

1. Introduction

Research over the last 40 years has repeatedly found that 1:1 bimanual coordination patterns other than in-phase ($\phi = 0°$) or anti-phase ($\phi = 180°$) are initially unstable [27,28] and difficult to perform even with extended practice [4,16,24,25]. The difficulty in producing other relative phase coordination patterns has typically been attributed to phase attraction that draws the coordination between the limbs towards the bimanual patterns of in-phase and anti-phase resulting from features of the relative phase landscape [7,20,21] and/or the instability associated with the activation of non-homologous muscles via crossed and uncrossed cortical pathways [10,11]. This pattern of bi-stability has been explained using concepts taken from nonlinear dynamics and modeled using nonlinearly coupled limit cycle oscillators [7] perturbed by stochastic forces [20]. Indeed, experiments [27,28] which assessed bimanual coordination across a variety of phase relationships, have consistently demonstrated that 0° and 180° to be substantially more stable than other phase relationships with 0° more stable than 180° [8].

However, it appears that perceptual information can play a large role in bimanual coordination. Research [5] has shown that some spatial arrangements of feedback presentation allow for the integration of independent hand paths and in turn stabilize bimanual in-phase coordination, whereas others lead to increased variability. In other words, what initially is perceived as a dual tasks becomes a single task when the visual display allows the

* Corresponding author at: Department of Health and Kinesiology, Texas A&M University College Station, TX USA. 77843-4243. Fax: +1 979 847 8987.
E-mail address: cshea@tamu.edu (C.H. Shea).

http://dx.doi.org/10.1016/j.neulet.2015.10.073
0304-3940/

integration of the two tasks into a unified representation. Similarly, Mechsner et al. [17] provided compelling evidence that coordinated bimanual movements were organized in terms of perceptual symmetry and not motoric symmetry as previous work suggested. A more direct test of the influence of perceptual information on the 1:1 bimanual coordination landscape was conducted by Kovacs et al. [13]. This experiment directly compared scanning trials (0° to 180° in 30° increments) where performance was tested in a control condition using a protocol similar to that used by Zanone et al. [28] with an experimental condition where enhanced perceptual information was provided. The perceptual information was presented in the form of a Lissajous display and goal templates. The Lissajous display integrates the position of the two limbs into a single point (cursor) in one plane with, for example, the left limb moving the cursor up (extension) and down (flexion) and the right limb moving it left (flexion) and right (extension). The Lissajous goal templates were two dimensional plots that exhibit the desired coordination pattern. This type of Lissajous display has been shown to greatly enhance 1:1 [12] as well as multi-frequency [14,15] bimanual coordination. The results for the control condition were similar to that found in earlier research [27,28] with relative phase errors and variability at 0° smaller than that at 180° with substantially larger errors and variability at all other relative phase relationships. For the experimental condition, where enhanced perceptual information was provided in the form of Lissajous displays, relative phase errors and variability were substantially smaller than that found for the control condition at all goal relative phases except 0°. In the experimental condition no differences were detected between 30° and 180° with relative phase errors and variability ≈10°. For the in-phase pattern errors and variability were exceptionally low (≈5°). Clearly, the perceptual information provided by the Lissajous display allowed participants to effectively "tune-in" the required coordination pattern. We use the term "tune in" because participants appear to gradually move the cursor into alignment with the goal template. It should be noted that participants were only provided 3 min of practice at each goal relative phase before being tested. Given that relatively little practice was provided and the fact that relative phase errors and variability were remarkably small, it was clear that the enhanced feedback provided the perception-action system the information necessary to detect errors in performance and provided an efficient way to evaluate and then implement strategies to correct these errors.

It is possible, however, that testing bimanual coordination performance only at discrete goal relative phases may mask subtle attractions and instabilities that would occur if one would have to continuously transition though a wide range of phase relationships. If the notion of an attractor landscape [7] is true for this type of task then participants will find it difficult to move out of the in-phase pattern (0°) and will be drawn into the anti-phase pattern (180°) when transitioning from 0° to 180°. More specifically the question addressed in the present manuscript was—Can participants continually adapt their performance to continually changing relative phase goals where goal relative phase transitions between 0° and 180° in 1° increments? This demonstration would clearly indicate the attractor landscape for bimanual coordination when provided Lissajous feedback.

2. Methods

2.1. Participants

Right-handed individuals ($N = 12$, 6 females and 6 males, average age 27.4 years) volunteered to participate in the experiment after reading and signing a consent form approved by the local IRB council for the ethical treatment of experimental participants. None of the participants had significant musical training.

2.2. Apparatus

The apparatus consisted of two horizontal levers and a projector (Fig. 1B). The levers were affixed at the proximal ends to near frictionless vertical axles. The axles, which rotated freely in ball-bearing supports, allowed the levers to move in the horizontal plane over the table surface. Near the distal end of each lever, a vertical handle was attached. The positioning of the handle was adjustable. When the participant rested their forearm on the lever with their elbow aligned over the axis of rotation the position of the handle was adjusted so they could comfortably grasp the handle (palm vertical). The horizontal movement of the levers were monitored (200 Hz) by potentiometers that were attached to the lower ends of the axles. A projector was mounted above and behind the participant and was used to provide the display.

2.3. Procedure

Participants were provided on-line Lissajous feedback which consisted of a cursor (small circle) on a screen directly to the front of the participant with the position of the left lever moving the cursor up (extension) and down (flexion). The movement of the right lever resulted in moving the cursor left (flexion) and right (extension). Also projected onto the screen was the Lissajous template that represent a 1:1 pattern of continuous sinusoidal motion with the required relative phase changing each second from 0° to 180° in 1° increments (Fig. 1A). The cursor and Lissajous templates were generated with customized software and displayed concurrently with the movement.

All participants sat at a table with their forearms resting on the levers that limited elbow motion to flexion-extension in the horizontal plane. Participants were seated on a height adjustable chair with the horizontal eye line corresponding with the midway point of the display projected onto the screen in front of them. Their limbs were covered throughout the experiment. All participants were informed that they were to attempt to move their left and right limbs about the elbow (approximately 30°) in order to produce the desired relative phase relationship. It was emphasized that the movements of both limbs should be continuous. The current position of their limbs was indicated by the cursor overlaid on the plot with their goal defined as moving the cursor in a way to match the general shape of the changing Lissajous template projected on the screen in front of them. Participants were instructed to pay attention to the cursor and template and avoid paying attention to the movement of their limbs. All participants completed three practice scanning blocks and one test block. Each practice and test block was 180 s in duration with the goal relative phase template incrementing each second. They were informed that they would receive a 4 min rest interval between each scanning block and 10 min rest prior to the test block. Each scanning block involved practice with each relative phase pattern in an ascending order (0° to 180° in 1° increments). The general pattern of Lissajous plots are illustrated in Fig 1A and examples of the changing Lissajous template and a participant's performance is also provided (Fig. 1C). Note that not all relative phase patterns are depicted and that the current Lissajous template always appeared in the center of the display area.

2.4. Data reduction

All data reduction was performed using MATLAB. The potentiometer signals representing the limbs' displacements were low-pass filtered (Butterworth, cutoff frequency 10 Hz). Velocity and acceleration signals were computed with each signal filtered