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Coupling of postural and manual tasks in expert performers

A.C. Amado *, C.J. Palmer, J. Hamill, R.E.A. van Emmerik

Department of Kinesiology, University of Massachusetts, Amherst, MA 01003, USA

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ABSTRACT

The purpose of this study was to investigate the integration of bimanual rhythmic movements and posture in expert marching percussionists. Participants ($N = 11$) performed three rhythmic manual tasks [1:1, 2:3, and 2:3-F (2:3 rhythm played faster at a self-selected tempo)] in one of three postures: sitting, standing on one foot, and standing on two feet. Discrete relative phase, postural time-to-contact, and coherence analysis were used to analyze the performance of the manual task, postural control, and the integration between postural and manual performance. Across all three rhythms, discrete relative phase mean and variability results showed no effects of posture on rhythmic performance. The complexity of the manual task (1:1 vs. 2:3) had no effect on postural time-to-contact. However, increasing the tempo of the manual task (2:3 vs. 2:3-F) did result in a decreased postural time-to-contact in the two-footed posture. Coherence analysis revealed that the coupling between the postural and manual task significantly decreased as a function of postural difficulty (going from a two-footed to a one-footed posture) and rhythmic complexity (1:1 vs. 2:3). Taken together, these results demonstrate that expert marching percussionists systematically decouple postural and manual fluctuations in order to preserve the performance of the rhythmic movement task.

1. Introduction

Skilled actions emerge from organizing and exploring the available degrees of freedom in accordance with the demands of the task (Bernstein, 1967). A growing body of literature is investigating the adjustments in degrees of freedom across the entire system as a function of task constraints, demonstrating that the control of each task is context dependent (Bardy, Marin, Stoffregen, & Bootsma, 1999; Haddad, Gagnon, Hasson, Van Emmerik, & Hamill, 2006; Huys, Daffertshofer, & Beek, 2003). A substantial body of literature on bimanual coordination has served as a backdrop for our understanding of the dynamics of rhythmic movement; however most of this research has been conducted in a seated posture with a focus on the manual task (Kugler & Turvey, 1987; Schmidt, Shaw, & Turvey, 1993; Sternad, Collins, & Turvey, 1995). As a result, how coordinative dynamics in the upper extremities are impacted by different postural constraints, or how manual task performance impacts postural stability is still largely unknown.

Static posture is generally considered stable if the position of the center of pressure (CoP) changes slowly over time with respect to the boundary of support defined by the geometry of the feet, resulting in a long time-to-contact (TtC) the support boundary (Galgon, Shewokis, & Tucker, 2010; Haddad et al., 2006; Riccio, 1993). High precision manual tasks have been shown to affect these postural dynamics. For example, when performing a block fitting task, participants increased their time-to-contact as the block approached the opening; decreasing the size of the aperture caused further increases in

* Corresponding author at: 30 Eastman Lane, Amherst, MA 01003, USA.
E-mail address: aamado@kin.umass.edu (A.C. Amado).

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time-to-contact (Haddad, Claxton, Melzer, Hamill, & van Emmerik, 2013). Similarly, in a 2010 study, Galgon and colleagues had participants perform a serial pointing task 300 times while recording their postural dynamics. Over the course of practice, the authors reported a longer time-to-contact the boundary of support. The increased time-to-contact in these studies demonstrates that posture is modulated with respect to the task (Galgon et al., 2010; Haddad, Ryu, Seaman, & Ponto, 2010; Haddad et al., 2013). This observed modulation of posture with respect to the constraints of the manual task may be a function of the degree of systemic coupling. For example, Huys et al. (2003) demonstrated in the case of learning to juggle that, as individuals become more proficient, the degree of coupling between the control of posture and the manual task decreases. Decreasing the degree of coupling, may allow the individual to vary their resistance to perturbations while still being able to perform the task successfully (Huys, Daffertshofer, & Beek, 2004a, 2004b).

Along with skill level, coupling strength is also impacted by frequency of oscillation, tempo, as well as the composition of the units in coordination (Huys et al., 2003, 2004a, 2004b; Park & Turvey, 2008). Increasing the tempo away from the participant's preferred movement frequency has a destabilizing effect on coordinative patterns, shown by increased deviation from intended relative phase and increased relative phase variability (Haken, Kelso, & Bunz, 1985; Kelso, 1984; Kelso, Tuller, & Harris, 1983; Schmidt, Beek, Treffner, & Turvey, 1991; Schmidt et al., 1993). When segments in coordination move relative to one another in a pattern other than 1:1 (i.e., multi-frequency rhythms), the interactions become more complex. deGuzman and Kelso (1991) showed lower order multi-frequency rhythms (n:m rhythms with numerators and denominators closer to one) are more stable than higher order couplings (e.g., 2:3 is more stable than 3:5). As multi-frequency rhythms become unstable, and the strength of coupling decreases, the slower moving segment begins to display frequency characteristics of the faster segment in its power spectrum before transitioning to a more stable, lower order polyrhythm. As described by the elementary law of coordination of the Haken–Kelso–Bunz model (Park & Turvey, 2008), or through models like the sine-circle map in the form of Arnol'd tongues (Peper, Beek, & van Wieringen, 1995a), stable coordinative patterns are sustainable over a variety of coupling strengths. Transitions from one coordinative state to another occur when the system can no longer sustain the pattern under the constraints imposed (deGuzman & Kelso, 1991; Peper et al., 1995a; Schmidt et al., 1991, 1993; Sternad et al., 1995; Sternad, Turvey, & Schmidt, 1992; Treffner & Turvey, 1993).

Constraints related to postural orientation and the manual task can decrease the available degrees of freedom to carry out an activity. When overly constrained, the task performance may become increasingly unstable and less resilient to perturbations due to limited available degrees of freedom, and one can predict that the coupling between two concurrent tasks (e.g., postural and manual) increases as a result (Lipsitz & Goldberger, 1992). Given that bi-manual rhythmic coordination has served as the backdrop for most of the current understanding of coordination dynamics, a logical next step is to understand how performance of a manual task is affected by postural constraints. Marching percussion is an activity where postural control is crucial for precise visual and musical performance. Scoring of the visual performance is generally based on the uniformity of the spacing of the performers relative to one another as well as uniformity of the marching technique. Musically, all of the notes being played must be synchronous. When learning a routine, music is always learned first in a static posture making drumming in an upright stance the first stages of integration of postural and manual control. Due the nature of their activity, expert marching percussionists are ideal candidates for studying such interactions. In any musical activity, tempo and rhythmic complexity constrain the performer's degrees of freedom, but for marching percussionists posture serves as an additional constraint.

Therefore, the purpose of this study was to examine the integration between postural control and bimanual rhythmic movements in expert marching percussionists. Aim one assessed the effects of posture on bimanual coordination. We hypothesized that rhythmic task stability would decrease with increasing postural difficulty, as indicated by greater deviation from intended relative phase and increased relative phase variability. Aim two focused on the effects of manual task difficulty (rhythmic complexity and tempo) on postural stability. Here we posed two hypotheses: that increasing rhythmic complexity decreases postural stability, and that increasing tempo decreases postural stability, both shown by a reduction in CoP time-to-contact with the boundary of support. Aim three examined the coupling between posture and manual movements. We hypothesized that with greater postural and rhythmic task demands that the coupling between the postural and manual task would increase, indicated by increased coherence between the postural and manual task.

2. Methods

2.1. Participants

Eleven University of Massachusetts Drumline members (height (m): 1.83 ± .13, weight (kg): 77.19 ± 16.3, age: 20 ± 2, years of experience: 9 ± 3) participated in the study, and signed a university approved consent form. Participants were excluded if they had a history of tendonitis of the wrist, neurological disorders, or lower leg injury that prevented them from standing on one leg for an extended period of time.

2.2. Experimental design

The study was set up as a factorial design with three seated and standing postural conditions in which the participants played from: a seated posture (Se), standing on two feet (S2), and standing on one foot (S1). There were three drumming