Gait & Posture 41 (2015) 209–216

Contents lists available at ScienceDirect

Gait & Posture

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

Interaction between interpersonal and postural coordination during frequency scaled rhythmic sway: The role of dance expertise

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ARTICLE INFO

Article history:
Received 6 May 2014
Received in revised form 21 August 2014
Accepted 7 October 2014

Keywords:
Interpersonal synchrony
Ankle–hip coordination
Light touch
Dance
Metronome

ABSTRACT

Light fingertip touch between partners swaying rhythmically side by side evokes interpersonal synchrony. In non-dancers and dancers swaying to a metronome, we examined the effects of frequency scaling and touch between the partners on both postural (ankle–hip) and inter-personal coordination. In both groups, touch did not interfere with the ankle–hip coordination. In non-dancers but not dancers, increasing frequency resulted in a loss of the ankle–hip coupling that was accompanied by a reduction of the touch mediated interpersonal synchrony. It is suggested that the effect of touch on interpersonal synchrony depends on the reliability of the haptic information sensed at the fingertip and assumes an in phase ankle–hip coupling. These findings have implications in clinical practice when using touch to help balance impaired individuals.

1. Introduction

In human standing, the body's degrees of freedom are organized in two spontaneously emerging and intuitively stable coordination modes depicted in the phase relationship between the ankle and hip angular motions, namely the in-phase (0–20° phase angle) and the anti-phase (160–180°) mode [1]. Transitions between modes are determined by interactions between task and environmental constraints such as visual and auditory driving stimuli [2,3] and support surface dynamics [4]. When the frequency of the driving stimulus reaches a critical level (i.e. 0.5 Hz for a visual target oscillation) a transition from the in-phase to the anti-phase ankle–hip coordination occurs in order to maintain coupling to the external driving stimulus [5].

Somatosensory information coupling between partners enrolled in a rhythmic activity results in spontaneous interpersonal entrainment. This has been observed in people walking [6] or swaying rhythmically [7,8] side by side while maintaining mechanical or haptic contact. Yet, interpersonal entrainment is a weaker form of coordination when compared to the coupling arising between the limbs/segments within the human body [9]. This is due to a difference in the strength of the attractor dynamics underlying these two forms of coordination, i.e. sensory feedback versus neuromuscular linkage.

Whether spontaneous interpersonal entrainment emerging by sensory information coupling can modulate within person postural dynamics or vice versa is still an open question with conflicting evidence. The emergence of visually mediated interpersonal synchrony does not alter the stability of inter-limb bimanual coordination [10], which suggests that upper limb bimanual synergies represent hard wired motor synergies within the body and therefore are resistant to spontaneous interpersonal interactions. On the other hand, the interpersonal synchrony mediated by peripheral visual coupling between partners enrolled in a postural visual tracking task modified the critical stimulus frequency at which a transition from the in-phase to an anti-phase ankle–hip coordination occurred [11]. Yet, other measures of ankle–hip coupling were not affected by visual entrainment between partners. This could be due to the weak nature of the visual linkage between partners (i.e. peripheral vision) not being sufficient to modulate the postural dynamics. Moreover, partners had to attend to the visual target stimulus to maintain sway–target coupling while at the same time stay visually linked to their partner. This shared visual attention task may not allow the emergent interpersonal synchrony to impact the ankle–hip coordination due to the competition between the coupling to target and coupling to partner requirement.

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http://dx.doi.org/10.1016/j.gaitpost.2014.10.007
0966-6362/

The aim of the present study was to examine how spontaneous haptically mediated interpersonal entrainment interacts with ankle–hip coordination during frequency scaled (from 0.25 to 0.70 Hz) rhythmic sway. The selected frequency range was sufficient to modulate postural coordination [5] while being within the range of spontaneous rhythmic sway [7,8]. Two hypotheses were tested; first, that the spontaneous haptically mediated interpersonal entrainment affects the ankle–hip coordination across increasing/decreasing sway frequency and second, that changes in ankle–hip coordination with frequency scaling affect the strength of the haptically mediated interpersonal entrainment. An additional motivation for this study was to investigate the effects of prior expertise in traditional Greek dance on the relationship between postural and interpersonal coordination. Based on previous findings showing that dance expertise influences the strength of both postural and interpersonal coordination [7,12], we expected that dancers would demonstrate a more stable postural coordination and better entrain to their partner with touch across the range of sway frequencies.

2. Method

2.1. Participants

Twenty-four (24) young adults, classified into two groups based on their prior experience in traditional Greek dance, volunteered to participate in the study. These comprised the Dancer Group (DG, 22.57 ± 4.17 years, 6 males and 6 females) consisting of experienced dancers having at least 10 (13.08 ± 1.62 years) years of systematic (3 hourly sessions per week) practice in traditional Greek dance and the Non-Dancer Group (NDG, 25.05 ± 4.69 years, 6 males and 6 females) consisting of individuals with no prior systematic experience in any type of dance. Partners in each couple were matched for gender, age, and height and did not know each other prior to the experiment. All participants were free of musculoskeletal and/or neurological impairments. Participants were informed of the purpose of the study and gave their consent. An elaborate cover story was used to distract participants from the experiment's true purpose, and thus to maintain the single-blind nature of this study (for a description of the cover story see [8]).

2.2. Task and procedure

Participants were tested in couples of similar gender, age and height. A set of binaural earphones (Stereo Headphones HD3030) provided the auditory pacing tone and blocked any sounds other than this cue. Partners stood next to each other (shoulder to shoulder distance: 10 cm) while facing forward adopting a natural bipedal quiet stance (feet flat and parallel, inter-malleolar distance at 10 cm, Fig. 1).

The experimental task required rhythmically swaying the body in the anterior–posterior (AP) direction at a metronome guided pace. The instruction was to sway back and forth aligning maximum forward and backward leaning with each successive beep of the metronome while keeping the body straight, the feet flat on the platform and the eyes closed all time. During each trial, the metronome frequency was progressively up scaled (from 0.25 Hz to 0.70 Hz) or down scaled (from 0.70 Hz to 0.25 Hz) in 10 steps of 0.05 Hz every 10 cycles. This resulted in 100 sway cycles performed in 240 s. Each trial was performed either with light fingertip touch between partners [13] or without touch. In order to avoid touch with parts of the hand other than the tip of the index finger, partners maintained a curved hand configuration during touch (Fig. 1). Four (two with frequency up scaling and two with frequency down scaling) trials were presented in a counter-balanced order. A 3-min break was given between trials.

2.3. Data analysis

Kinematic data were recorded with a 10-camera motion capture system (Vicon Motion Systems, Oxford, UK, 100 Hz). Four reflective markers were attached to the skin (with double sided adhesive tape) on the following anatomical landmarks (Fig. 1): 7th cervical vertebra (C7), 5th lumbar vertebra (midline between left and right posterior superior iliac crest), right thigh (2/3 of the distance between the knee and the hip joint) and right ankle (lateral malleolus of the fibula).

Marker position coordinates were smoothed using a 4th order low-pass (cut-off: 6 Hz) digital Butterworth filter. To assess postural coordination, the body was modeled as a double inverted pendulum consisting of two segments; the lower limb and the trunk [1]. The absolute pitch segment angles of the lower limb and the trunk were calculated from the anterior–posterior (x) and vertical (z) coordinates of the ankle and thigh markers (for the lower limb) and the pelvis and cervical markers (for the trunk) [14]. In order to be consistent with the relative literature terminology, the lower limb and trunk pitch rotations will be referred as ankle and hip rotations for the rest of this manuscript.

Cross-spectral analysis (Matlab 7.7.0, Mathworks Inc, USA) was performed in order to determine the magnitude of coherence and spectral Relative Phase between (a) the ankle and hip rotations within each partner (postural coordination) and (b) the individual rotations (hip–hip and ankle–ankle) of the two partners (interpersonal coordination) at each target frequency. Coherence is a measure of the degree of correlation between the signals in the frequency domain. Relative Phase is obtained from the phase cross-spectrum and indicates the temporal relationship between signals in degrees (from 0° to 180°) over a range of frequencies. The coherence and Relative Phase value at each target frequency was selected for further analysis. For each dependent measure, the effects of group, light touch and frequency level were evaluated employing a 2 (Group) × 2 (Touch) × 10 (Frequency level) repeated measures ANOVA. Analysis was run separately for up and down frequency scaling trials. Significant interactions between factor levels were further analyzed by performing pairwise (t-tests) comparisons between the respective factor levels after adjusting (Bonferroni test) p values for multiple comparisons.

3. Results

3.1. Postural (ankle–hip) coordination

Fig. 2 shows representative ankle and hip angular joint excursions of one dancer and one non-dancer at selected frequency levels of a no-touch trial. The magnitude of ankle–hip coherence significantly decreased during frequency up-scaling ($F(9,198) = 25.506$, $p = .001$, Fig. 3a) and increased during down scaling ($F(9,198) = 15.258$, $p = .001$, Fig. 3b). The decrease in the ankle–hip coherence with increasing frequency was significant only in the NDG whereas DG partners maintained a high ankle–hip coherence (>0.7) across all frequency levels ($F(9,198) = 3.471$, $p = 001$). Fingertip touch had no effect on the ankle–hip coherence. Similarly, the ankle–hip Relative Phase significantly increased during frequency up-scaling ($F(9,198) = 31.525$, $p = .001$, Fig. 3c) and decreased during down-scaling ($F(9,198) = 18.188$, $p = .001$, Fig. 3d). This effect however was significant only in the NDG whereas the DG maintained the ankle–hip Relative Phase in the in-phase (0–20°) region across all frequency levels (up-scaling: $F(9,198) = 13.016$, $p = .001$ and down-scaling: $F(9,198) = 13.277$, $p = .001$). Touch had no effect on the ankle–hip Relative Phase.

3.2. Interpersonal coordination

The magnitude of the ankle-ankle coherence (Fig. 4a and b) significantly changed with frequency (up-scaling: $F(9,90) = 5.802$, $p = .003$; down-scaling: $F(9,90) = 2.079$, $p = .040$). However, this was not significantly different between groups and was not affected by touch. On the other hand, the Relative Phase between the partners' ankle rotations (Fig. 4c and d) significantly decreased with touch toward an in-phase pattern (<20°) (up-scaling: $F(1,10) = 9.979$, $p = .010$, down-scaling: $F(1,10) = 18.711$, $p = .001$). The effect of touch was dependent on the frequency level (up scaling: $F(9,90) = 2.879$, $p = .005$, down scaling: $F(9,90) = 5.269$,