Interaction between interpersonal and postural coordination during frequency scaled rhythmic sway

Sofianidis, George; Elliott, Mark T.; Wing, Alan M.; Hatzitaki, Vassilia

DOI:
10.1016/j.gaitpost.2014.10.007

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

Author: George Sofianidis Mark T. Elliott Alan M. Wing Vassilia Hatzitaki

PII: S0966-6362(14)00733-4
DOI: http://dx.doi.org/doi:10.1016/j.gaitpost.2014.10.007
Reference: GAIPOS 4328

To appear in: *Gait & Posture*

Received date: 6-5-2014
Revised date: 21-8-2014
Accepted date: 7-10-2014

Please cite this article as: Sofianidis G, Elliott MT, Wing AM, Hatzitaki V, Interaction between interpersonal and postural coordination during frequency scaled rhythmic sway: The role of dance expertise, *Gait and Posture* (2014), http://dx.doi.org/10.1016/j.gaitpost.2014.10.007

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

George Sofianidis[a], Mark T. Elliott[b], Alan M. Wing[b], Vassilia Hatzitaki[a]

[a]Laboratory of Motor Control and Learning, School of Physical Education and Sport Sciences, Aristotle University of Thessaloniki, Thessaloniki, Greece

[b]Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham, Birmingham, United Kingdom

Correspondence to:

Vassilia Hatzitaki,
Laboratory of Motor Control and Learning,
School of Physical Education and Sport Sciences,
Aristotle University of Thessaloniki, 541 24, Greece.
Tel: ++30 2310 992193
Fax: ++ 30 2310 992193
Email: vaso1@phed.auth.gr

Acknowledgements

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) -Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

The authors wish to thank Dr. Vasillios Kostadakos for providing technical support to the study.

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

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.

.

Key words: interpersonal synchrony, ankle-hip coordination, light touch, dance, metronome

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^o phase angle) and the anti-phase (160^o-180^o) 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.

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, 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 counterbalanced order. A 3-minute 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, MathworksInc, 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^o to 180^o) 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) x 2 (Touch) x 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 ($F(9,198)=25.506$, $p=.001$, Fig3a) and increased during down scaling ($F(9,198)=15.258$, $p=.001$, Fig3b). 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 ($F(9,198)=31.525$, $p=.001$, Fig3c) and decreased during down-scaling ($F(9,198)=18.188$, $p=.001$, Fig3d). This effect however was significant only in the NDG whereas the DG maintained the ankle-hip Relative Phase in the in-phase ($0\text{-}20^{o}$) 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-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-d) significantly decreased with touch toward an in-phase pattern ($< 20^{o}$) (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: $F(9,90)=5.269$, $p=.001$) and the group (down scaling: $F(9,90)=2.574$, $p=.011$). Post hoc analysis revealed that whereas for DG partners the ankle-ankle Relative Phase significantly decreased ($p<.05$) with touch at most frequency levels (Fig4c and d), for NDG partners, the touch effect was significant ($p<.05$) only at the lower range of frequencies (0.25 to 0.40 Hz).

The hip-hip coherence (Fig 5a-b) changed with frequency (up-scaling: $F(9,90)=3.315$, $p=.002$, down-scaling: $F(9,90)=2.446$, $p=.015$) but was not altered by touch or group expertise. On the other hand, the hip-hip Relative Phase (Fig5c-d) significantly decreased with touch towards an in phase pattern (up scaling: $F(1,10)=7.715$, $p=.020$, down scaling: $F(1,10)=8.190$, $p=.017$). Touch effect was dependent on the frequency level (up scaling: ($F(9,90)=2.691$, $p=.008$), down scaling: ($F(9,90)=3.135$, $p=.002$) and the group (down-scaling: $F(9,90)=2.094$, $p=.038$). Post hoc analysis confirmed that DG partners significantly decreased their hip-hip Relative Phase with touch at most frequency levels. By contrast, for NDG partners, the effect of touch was significant only at the lower frequency range (0.25 to 0.4 Hz) during up scaling and at no frequency level during the down scaling trial.

4. Discussion

This study investigated the interaction between postural coordination and haptically mediated interpersonal entrainment during frequency scaled sway in dancer and non-dancer couples. The main hypothesis was not confirmed because the ankle-hip coordination was not affected by light fingertip touch despite the emerged interpersonal entrainment. This finding is in agreement with the results of previous studies showing that spontaneous visually mediated interpersonal entrainment does not alter the stability of inter-limb coordination during bimanual upper limb rhythmic actions [9] or the ankle-hip coordination during a visual tracking task [11]. It is therefore confirmed that the neuromuscular or mechanical coupling arising between the segments within the body forms a stronger coordinative structure when compared to the sensory (informational) mediated coupling between partners jointly performing a rhythmical task. Moreover, in the present study, the metronome might have imposed a stronger task constraint when compared to touch that did not allow haptic feedback about the other partner's sway to interfere with the ankle-hip dynamic. This possibility is supported by our previous findings showing that non dancers cannot exploit interpersonal touch to further synchronize with their partner when sway is already paced by an auditory metronome [8]. Moreover, when sway was paced by different metronome tempos, dancers completely ignored the interpersonal touch stimulus and stayed tuned to the metronome imposed sway frequency [7].

We further predicted that the effect of touch on interpersonal entrainment would be dependent on the strength of the ankle-hip coupling across increasing/decreasing sway frequencies. A consistent effect of dance expertise on both postural and interpersonal dynamics seems to confirm this prediction. Specifically, dancers showed a strong ankle-hip in-phase coupling across all frequencies and also stayed entrained to their partner with touch. Non dancers on the other hand exhibited a loss of the ankle-hip coupling at higher frequencies that was accompanied by a reduced effect of touch on interpersonal entrainment. These results suggest that the effect of touch on interpersonal entrainment depends on how reliably the haptic signal received at the fingertip depicts the other partner's sway [15]. A reliable feedback signal that enables sensing spatiotemporal information of the other partner's sway assumes an absolute in-phase ankle-hip coupling. When this is lost at higher frequencies, the upper body moves out of phase relative to the lower body and therefore light fingertip touch cannot provide reliable feedback about the other partner's sway. It is therefore likely that non-dancer partners would ignore the less reliable information sensed at the fingertip in this case losing their ability to synchronize with their partner. Dancers on the other hand maintained a consistent in phase ankle hip coupling across the metronome frequencies which enabled the transfer of more reliable sway information with touch also enabling the interpersonal ankle and hip synchronization even at the higher frequencies. Dancers are known to maintain a more stable ankle-hip phase relationship than non dancers across a range of visual driving frequencies [12]. Furthermore, they have an improved multisensory integration capacity due to their prior experience in sensing the other partners' sway through handholding while attending to the instructed music or rhythm. Additionally, based on the present results, expertise in traditional Greek dances seems to modulate the relationship between interpersonal and postural coordination.

In conclusion, this study showed that interpersonal light touch cannot alter postural dynamics during frequency scaled rhythmic sway. Loss of the ankle-hip phase coupling with increasing frequency in non-dancers but not in dancers reduces the effect of touch on interpersonal entrainment suggesting that this depends of the reliability of the haptic information sensed at the fingertip. These results may have implications in clinical practice when using touch to help balance impaired individuals.

References

[1] Bardy BG, Marin L, Stoffregen TA, Bootsma RJ. Postural coordination modes considered as emergent phenomena. J Exp Psychol Human. 1999;25:1284-301.
[2] Oullier O, Bardy BG, Stoffregen TA, Bootsma RJ. Postural coordination in looking and tracking tasks. Hum Movement Sci. 2002;21:147-67.
[3] Stoffregen TA, Villard S, Kim C, Ito K, Bardy BG. Coupling of Head and Body Movement With Motion of the Audible Environment. J Exp Psychol Human. 2009;35:1221-31.
[4] Marin L, Bardy BG, Baumberger B, Fluckiger M, Stoffregen TA. Interaction between task demands and surface properties in the control of goal-oriented stance. Hum Movement Sci. 1999;18:31-47.
[5] Bardy BG, Oullier O, Bootsma RJ, Stoffregen TA. Dynamics of human postural transitions. J Exp Psychol Human. 2002;28:499-514.
[6] Harrison SJ, Richardson MJ. Horsing around: spontaneous four-legged coordination. J Mot Behav. 2009;41:519-24.
[7] Sofianidis G, Elliott MT, Wing AM, Hatzitaki V. Can dancers suppress the haptically mediated interpersonal entrainment during rhythmic sway? Acta Psychol (Amst). 2014;150:106-13.
[8] Sofianidis G, Hatzitaki V, Grouios G, Johannsen L, Wing A. Somatosensory driven interpersonal synchrony during rhythmic sway. Hum Mov Sci. 2012;31:553-66.
[9] Schmidt RC, Bienvenu M, Fitzpatrick PA, Amazeen PG. A comparison of intra- and interpersonal interlimb coordination: Coordination breakdowns and coupling strength. J Exp Psychol Human. 1998;24:884-900.
[10] Coey C, Varlet M, Schmidt RC, Richardson MJ. Effects of movement stability and congruency on the emergence of spontaneous interpersonal coordination. Exp Brain Res. 2011;211:483-93.
[11] Varlet M, Marin L, Lagarde J, Bardy BG. Social Postural Coordination. J Exp Psychol Human. 2011;37:473-83.
[12] Kiefer AW, Riley MA, Shockley K, Sitton CA, Hewett TE, Cummins-Sebree S, et al. Multi-segmental postural coordination in professional ballet dancers. Gait Posture. 2011;34:76-80.
[13] Johannsen L, Guzman-Garcia A, Wing AM. Interpersonal Light Touch Assists Balance in the Elderly. J Motor Behav. 2009;41:397-9.
[14] Winter AD. Biomechanics and motor control of human movement. In: Winter AD, editor. 2 ed. Toronto,Ontario: Wiley; 1990. p. 45-7.
[15] Johannsen L, Wing AM, Hatzitaki V. Contrasting effects of finger and shoulder interpersonal light touch on standing balance. J Neurophysiol. 2012;107:216-25.

Figure Legends

Fig 1

An illustration of the experimental task during the four experimental trials.

Fig 2

Representative ankle (dashed black line) and hip (solid gray line) rotations of a dancer and a non-dancer during sway at three frequency levels (0.25Hz, 0.5Hz, 0.7Hz) of one no-touch trial

Fig 3

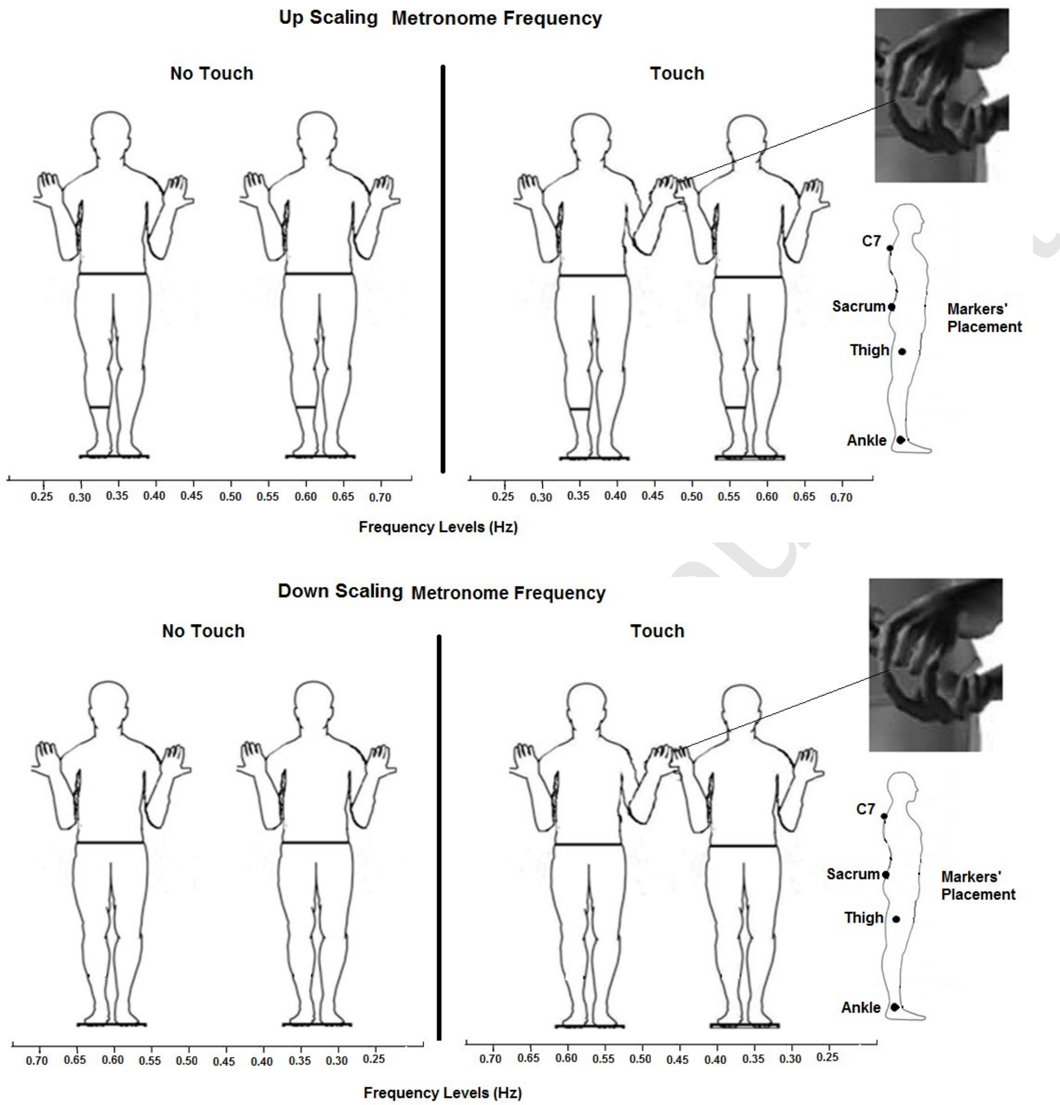
Ankle – hip Coherence (a, b) and Relative Phase (c, d) across frequency levels in the No Touch (in blue) and Touch (in red) condition for Dancers and non-Dancers. Group mean ± st. error is shown.

Fig 4

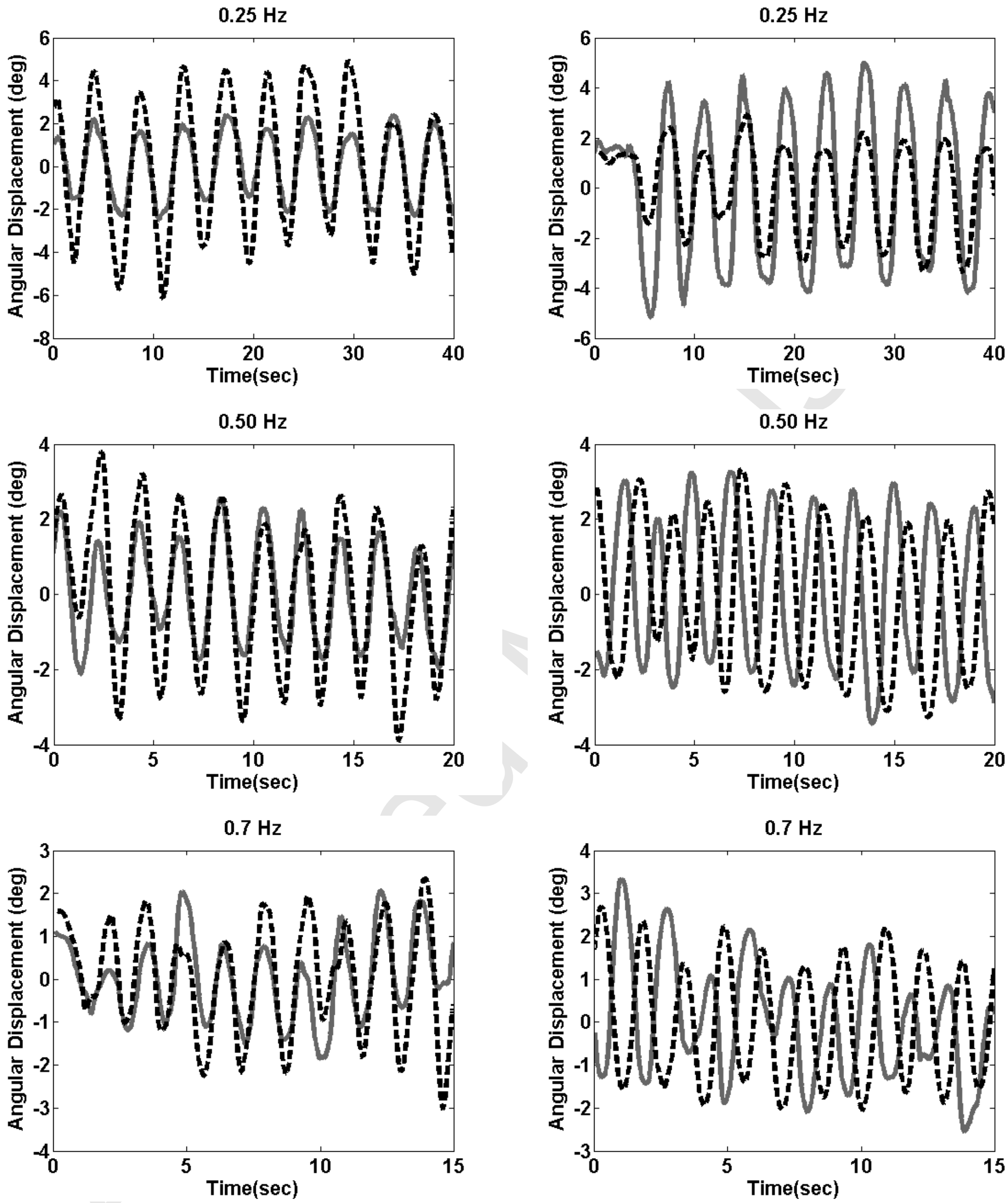
Ankle – Ankle Coherence (a, b) and Relative Phase (c, d) across frequency levels in the No Touch (in blue) and Touch (in red) condition for Dancers and non-Dancers. Group mean ± st. error is shown. Asterisks indicate significant touch effects at $p<.05$

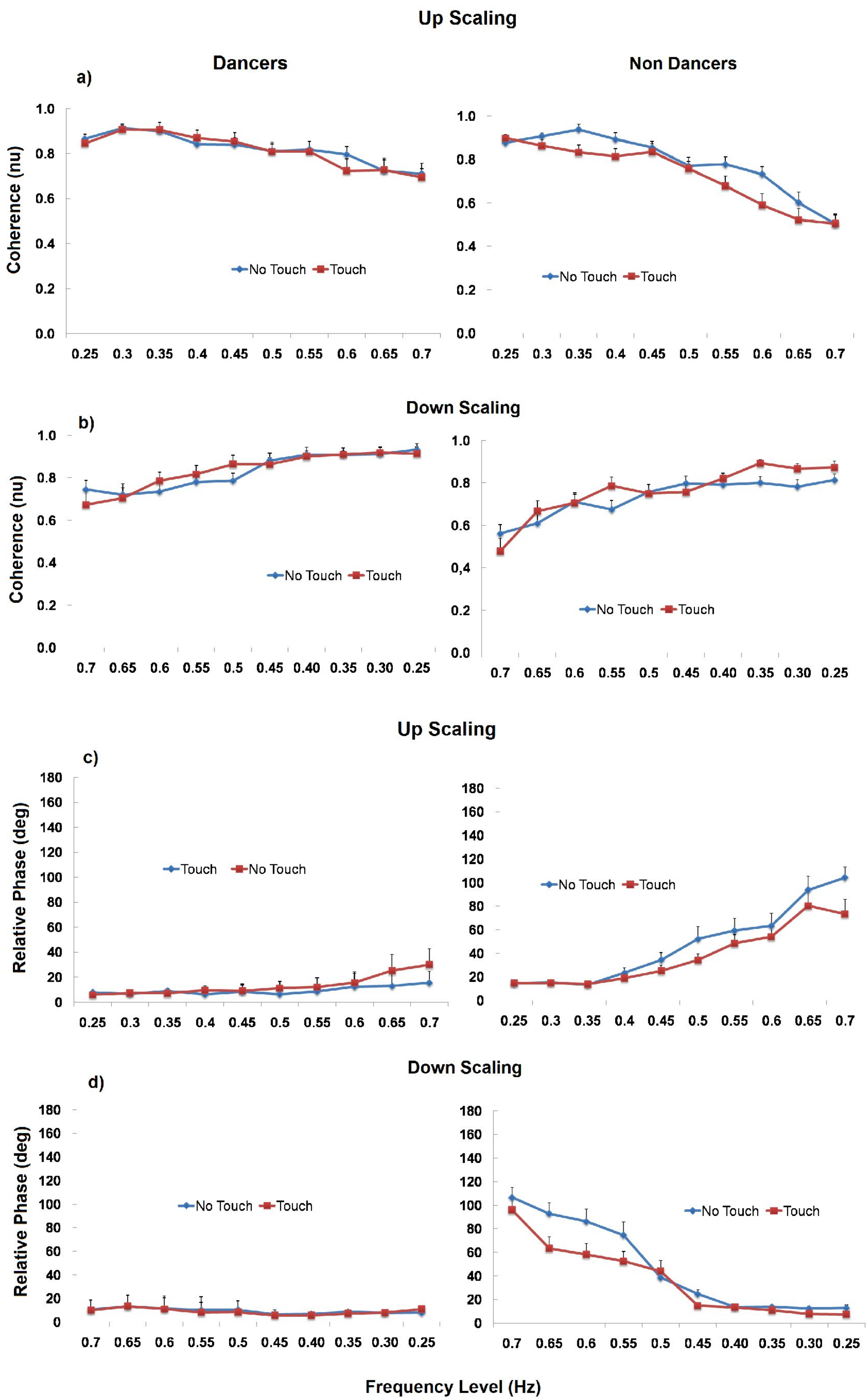
Fig 5

Hip-Hip Coherence (a, b) and Relative Phase (c, d) across frequency levels in the No Touch (in blue) and Touch (in red) condition for Dancers and non-Dancers. Asterisks indicate significant touch effects at $p<.05$.

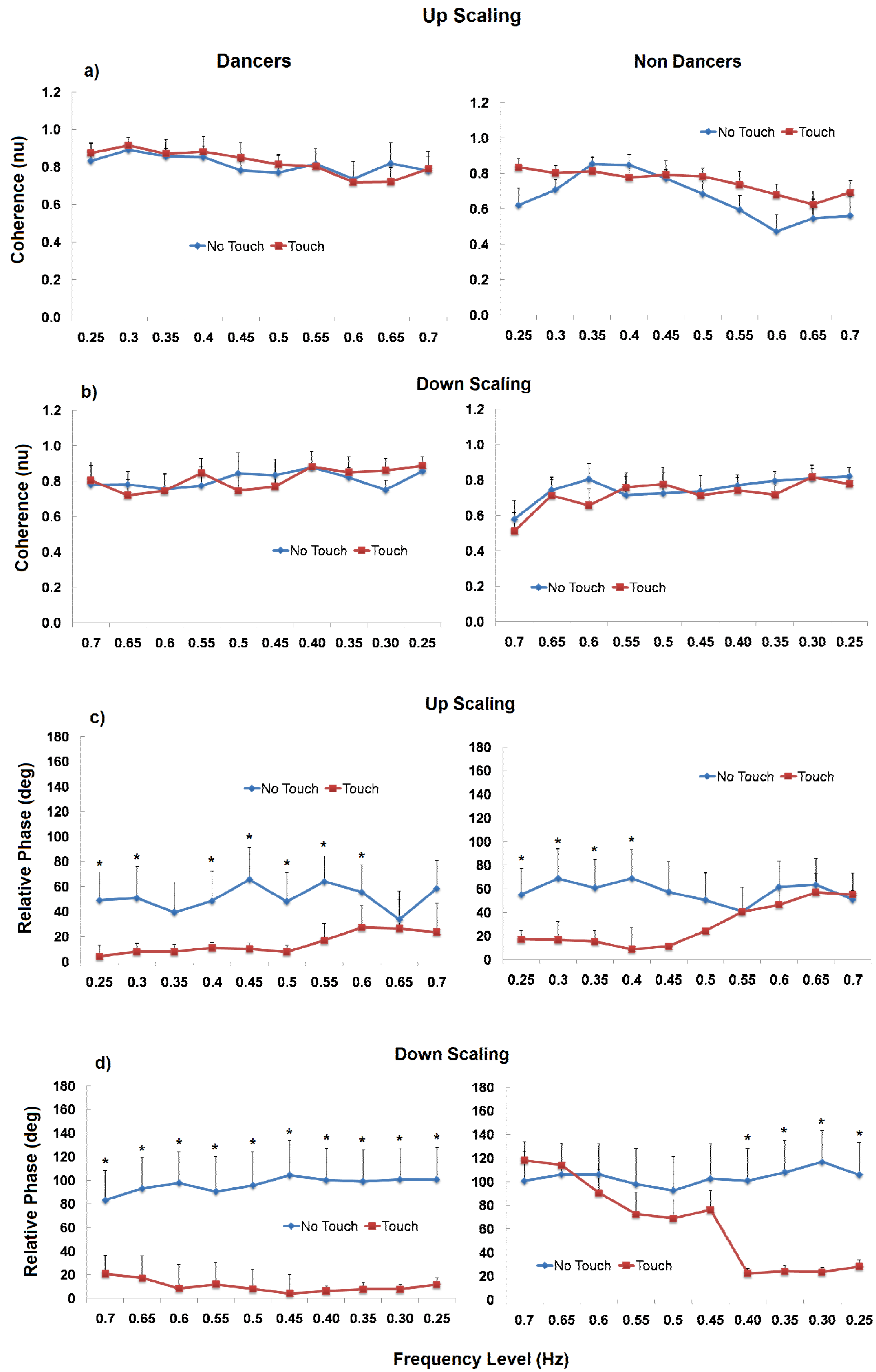

Up Scaling Metronome Frequency
No Touch
Touch
C7
Sacrum
Thigh
Ankle
Markers' Placement
0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
Frequency Levels (Hz)
Down Scaling Metronome Frequency
No Touch
Touch
C7
Sacrum
Thigh
Ankle
Markers' Placement
0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25
0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25
Frequency Levels (Hz)

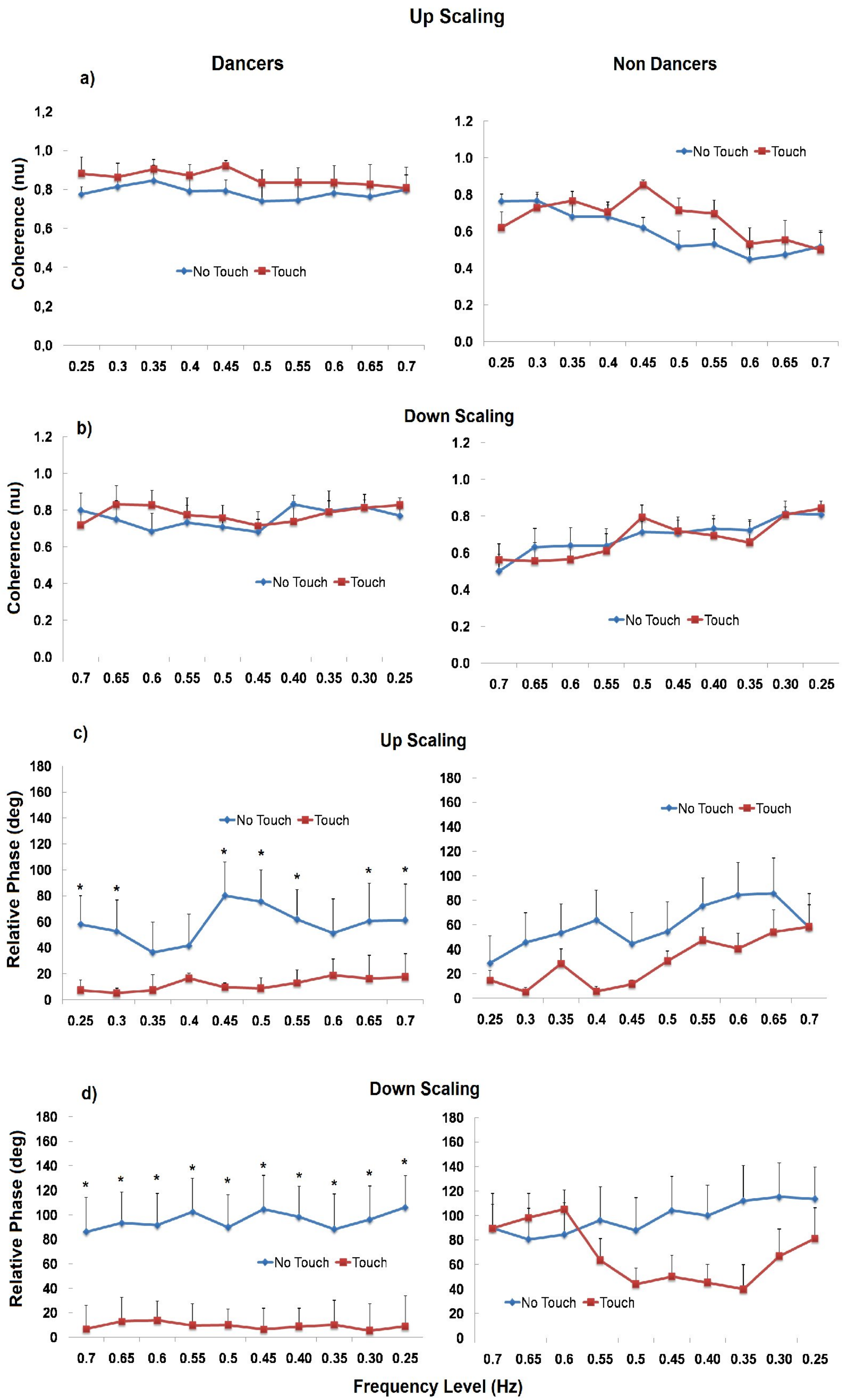
DANCER NON DANCER





Up Scaling
a)
Dancers
Non Dancers
Coherence (nu)
No Touch
Touch
Down Scaling
b)
Up Scaling
c)
Relative Phase (deg)
Down Scaling
d)
Frequency Level (Hz)


Up Scaling
a)
Dancers
Non Dancers
Coherence (nu)
No Touch
Touch
b)
Down Scaling
c)
Up Scaling
Relative Phase (deg)
d)
Down Scaling
Frequency Level (Hz)


Up Scaling
a)
Dancers
Non Dancers
Coherence (nu)
No Touch
Touch
0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7
Down Scaling
b)
Coherence (nu)
No Touch
Touch
0.7 0.65 0.6 0.55 0.5 0.45 0.40 0.35 0.30 0.25
c)
Up Scaling
Relative Phase (deg)
No Touch
Touch
0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7
d)
Down Scaling
Relative Phase (deg)
No Touch
Touch
0.7 0.65 0.6 0.55 0.5 0.45 0.40 0.35 0.30 0.25
Frequency Level (Hz)

Research Highlights

- Light fingertip touch evokes interpersonal synchrony during rhythmic sway
- We asked how interpersonal interact with postural dynamics in frequency paced sway
- Haptically evoked interpersonal synchrony did not alter the ankle-hip coordination
- Ankle-hip coupling was lost at high sway frequencies in non dancers
- Non-dancers did not entrain with touch at high sway frequencies