Neuroscience Letters 580 (2014) 41–46

Contents lists available at ScienceDirect

Neuroscience Letters

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

The pattern of coupling dynamics between postural motion, isotonic hand movements and physiological tremor

S. Morrison[a,*], N. Cortes[b], K.M. Newell[d], G. Kerr[c]

[a] School of Physical Therapy and Athletic Training, Old Dominion University, United States
[b] School of Recreation, Health, and Tourism, George Mason University, United States
[c] School of Exercise and Nutrition Sciences, Queensland University of Technology, Australia
[d] Department of Kinesiology, Pennsylvania State University, United States

HIGHLIGHTS

- Performing rapid, alternating wrist movements affects postural motion.
- Tighter coupling of center of pressure motion (AP-ML) develops from rapid wrist movements.
- Physiological tremor in the upper limb is unrelated to that observed in the contralateral limb or to postural sway.
- Under postural tremor conditions, the body is able to effectively decouple oscillations within the upper limb from postural motion.

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form 15 July 2014
Accepted 16 July 2014
Available online 24 July 2014

Keywords:
Physiological tremor
Bilateral coupling
Postural sway
Acceleration

ABSTRACT

This study was designed to examine differences in the coupling dynamics between upper limb motion, physiological tremor and whole body postural sway in young healthy adults. Acceleration of the hand and fingers, forearm EMG activity and postural sway data were recorded. Estimation of the degree of bilateral and limb motion–postural sway coupling was determined by cross correlation, coherence and Cross-ApEn analyses. The results revealed that, under postural tremor conditions, there was no significant coupling between limbs, muscles or sway across all metrics of coupling. In contrast, performing a rapid alternating flexion/extension movement about the wrist joint (with one or both limbs) resulted in stronger coupling between limb motion and postural sway. These results support the view that, for physiological tremor responses, the control of postural sway is maintained independent to tremor in the upper limb. However, increasing the level of movement about a distal segment of one arm (or both) leads to increased coupling throughout the body. The basis for this increased coupling would appear to be related to the enhanced neural drive to task-specific muscles within the upper limb.

1. Introduction

In a simple mechanical system, oscillations initiated at one level can be passively transmitted through adjacent linkages, emerging at a distal element in an amplified form unless some damping process is utilized. For biological systems, this process of damping is critical for optimal control since there are numerous oscillatory outputs that have the potential to be transmitted throughout the body [1–3]. For example, even when a person is standing in a relaxed position, the body needs to minimize the impact of (and interaction between) periodic outputs related to heart rate, respiration rate, physiological tremor and postural motion in order to maintain stability [4].

The neuromuscular system has the capacity to effectively dissociate potential interactions between many different intrinsic oscillatory forms [1,2], although the question of the mechanisms involved in this process still needs to be answered. Previous research has shown that when healthy individuals hold their arm against gravity, the physiological tremor recorded from one arm is unrelated to that in the contralateral arm [5,6]. This independence between the arms is preserved under conditions where individuals are fatigued [7]. This same phenomena has been reported for healthy older adults [8] and for patients with increased tremor due to neurological disorders including Parkinson's disease (PD) [1,9] and multiple sclerosis [10]. A similar pattern of independence has also been reported between whole body postural motion (sway) and physiological tremor, whereby upper-limb tremor

* Corresponding author at: School of Physical Therapy and Athletic Training, ODU, VA 23529, United States. Tel.: +1 757 683 6757; fax: +1 757 683 4410.
E-mail address: smorriso@odu.edu (S. Morrison).

http://dx.doi.org/10.1016/j.neulet.2014.07.030
0304-3940/

responses were effectively uncoupled to trunk acceleration and/or COP motion for both healthy young and older adults [6,9]. However, this same finding has not been shown for neurological populations where strong coupling between finger/hand tremor and postural sway has been described for persons with PD [3,9]. Interestingly, for these same patients, the strong tremor–sway coupling is present despite the lack of any notable bilateral tremor coupling.

The consequences of any significant changes in the typical pattern of coupling can be problematic for many everyday activities, especially those involving control of balance. For example, the emergence of stronger sway–tremor relations in individuals with PD [9] has been viewed as a factor that could compromise balance, possibly contributing to the increased fall risk. With specific regard to physiological tremor, there is still no definitive understanding of what would drive increased tremor coupling between limbs or increased tremor–postural sway relations. One assumption is that output from parallel oscillators within the CNS is largely responsible for the weak coupling of tremor between limbs in both healthy and neurological conditions such as PD [1,11]. In a similar vein, it has been proposed that the emergent pattern of inter-limb coupling observed during voluntary, rapid alternating actions is driven by parallel non-linear oscillators, although here the oscillators are strongly coupled [12,13]. An obvious conclusion from these studies is that increasing neural output to relevant upper limb muscles may drive stronger coupling between limbs [14,15]. However, there is evidence to show that the emergence of increased inter-limb coupling in healthy adults is not singularly driven by greater muscle activity [16]. Despite the growing understanding of the neural basis for inter-limb coupling, the issue of coupling between limb motion and body sway still remains to be clearly elucidated.

The current study was designed to assess the coupling relations between the dynamics of limb acceleration (voluntary limb motion and physiological tremor), muscle activity and postural sway. In particular, it was of interest to examine what impact rapid voluntary alternating conditions (unilateral and bilateral) had on inter-limb and postural sway dynamics in contrast to the relations observed during the measurement of physiological tremor.

2. Methods

2.1. Subjects

Twelve young male subjects (mean 23.5 ± 1.5 years) participated in this study. All participants were right-hand dominant, physically active, had normal or corrected-to-normal vision, and reported no known neurological/cognitive disorders, or history of neuromuscular injury that could influence performance. All experimental procedures complied with the University IRB guidelines, and all participants provided written informed consent prior to testing.

2.2. Experimental design

Individuals participated in a four different movement conditions where limb acceleration (tremor), surface electromyographic (EMG) activity for forearm muscles and postural motion (sway) were collected. All testing was performed with the person standing. The specific conditions were (1) bilateral postural tremor (both arms held up against gravity), (2) bilateral rapid, alternating isotonic movement (i.e., movement performed with the arms held in the postural tremor positions), (3–4) unilateral condition where a single arm (left, right) performed the rapid alternating movement (in the postural position) while the contralateral arm was held by the persons side in a relaxed position.

For the postural tremor condition, participants performed a pointing task with their arms held parallel to the ground as per our previous work [6]. For the rapid alternating movements, individuals performed rapid, flexion-extension movements about the wrist joint. These movements were performed with the arm(s) outstretched (as for the postural tremor task) with the movement frequency set at 5 Hz. The selection of this frequency was based upon previous studies where movements at this frequency are used to mimic the dynamics of pathological tremor [15]. Subjects were given 4 trials of practice to generate the required movement frequency prior to data collection. A metronome (set at 5 Hz) provided auditory feedback during this practise period. Six 30 s trials were collected for each condition. Rests were provided between trials/conditions to reduce the effects of fatigue.

2.3. Equipment

During all conditions, individuals stood on a Bertec balance plate (model BP5050, Bertec Corp, OH) which was used to compute the co-ordinate location of each person's center of pressure (COP). Hand and finger tremor were measured using four uniaxial accelerometers and amplified through a transducer coupler (V75-25A, Coulbourn Instruments, PA). Accelerometers were attached to the hand (middle of third metacarpal) and index finger (dorsal distal aspect) of each arm. Bilateral surface EMG activity were collected using pairs of Ag/AgCl surface electrodes from the wrist flexors (flexor digitorum superficialis, FDS) and extensors (extensor digitorum communis, EDC) using Coulbourn isolated bioamplifiers (V75-02). All data were sampled at 1000 Hz.

2.4. Data analysis

Prior to analysis, the COP and accelerometer data were filtered by a second-order Butterworth low-pass digital filter with a cut-off frequency of 40 Hz. EMG data were full-wave rectified and band-pass filtered at 10–500 Hz. All data analysis was performed using custom software developed in Matlab version 7.0 (Mathworks R14).

2.5. Coupling analysis

Estimation of the degree of coupling between selected paired signals (e.g. COP–tremor, tremor–tremor and EMG–EMG) was determined by cross correlation (Pearson product moment), coherence and Cross-ApEn analyses. For the cross-correlation analysis, the peak coefficient between two signals was calculated over a range of time-lags (± 5 s) with the maximal value being used as a measure of the coupling strength. For coherence analysis, the maximum (peak) coherence value used to assess coupling in the frequency domain. This analysis was performed within the range 0–20 Hz for the accelerometer/COP signals and between 10–25, 25–50 and 50–100 Hz bandwidths for the EMG data. Coupling relations were also calculated by applying Cross-ApEn to paired signal outputs. This analysis determines the degree of synchrony of two time-series. Higher Cross-ApEn values are representative of lower synchrony (greater independence) between the two time-series, while lower values represent greater synchrony/similarity [17].

2.6. Frequency analysis

This was performed on the filtered COP and tremor data and the rectified EMG signals using Welch's averaged, modified periodogram method (window size of 512 data points). The dependent measures calculated were: maximum amplitude of each signal (peak power) and the frequency at which the peak power was seen (peak power frequency, PPF). For the tremor and COP data, peak power and PPF were determined between 0 and 20 Hz. For the EMG signals; peak power and PPF were calculated between 10–25, 25–50 and 50–100 Hz bandwidths.