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Wavelet transform coherence based investigation of existence of relationship between the cardiovascular and postural control systems during orthostatic challenge

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Abstract— **Previous studies have established the effects of orthostatic challenge on the cardiovascular and postural control systems, but the interdependent behavior of the systems under such condition is unclear. In the present study we examined the simultaneous changes in posture muscle electromyography (EMG) and systolic blood pressure (SBP) during quiet standing in healthy young individuals. Photoplethysmography based SBP, surface EMG, electrocardiogram (Lead II ECG) and posturography data were acquired during the experiment. Wavelet transform coherence (WTC) analysis was applied to identify the zones of interdependent behavior of the systems. The WTC thresholds were identified for the specific data under investigation. The coherence was analyzed in three frequency bands namely, LF (0.05 – 0.1 Hz), VLF (0.01-0.05 Hz) and ULF (0.005 – 0.01 Hz). WTC estimates for the EMG – SBP comparison showed greater than threshold values in all three frequency bands (LF: 0.31 ± 0.02; VLF: 0.41 ± 0.01; ULF: 0.45 ± 0.01).**

In conclusion this study showed the existence of relationship between the posture muscle EMG and blood pressure during natural orthostatic stress, by validation based on wavelet transform coherence. Further validation is required to objectively characterize this relationship between the two systems during orthostatic stress.

I. INTRODUCTION

Activation of skeletal muscle in the lower limbs, such as through postural shifts, walking or running, increases venous return by pumping blood collected in the veins back to the heart (skeletal muscle pump) [1]. The maintenance of upright posture not only requires coordinated neuromuscular control of postural muscles [2], but also cardiovascular reflexes to maintain blood pressure.

The use of Fourier spectral analysis to characterize these systems would assume stationarity of the signals and provide an inadequate treatment of existing complex interactions. A more appropriate analysis requires methods accounting for non stationary nature of the signals. To this end we proposed the use of Wavelet methodology. Wavelet methods have already been used to analyze non-stationary electromyography (EMG) signals [3, 4] and blood pressure (BP) signals [5]. The wavelet transform coherence (WTC) method has been applied in geophysics [6], neuroscience methods [7] and cardiovascular research [8] and provides time-frequency analysis of dependence between two signals without assuming signal stationarity.

We applied WTC analysis to the relationship between the EMG to center of pressure (COPx, COPy), systolic blood pressure (SBP) and cardiac output (CO); all of these have been shown to vary with changes in orthostatic condition [1, 2]. We hypothesized that these interaction represent real physiological interactions and are not random. The study involved data collection from 13 young healthy individuals who underwent 5 minute sit to stand test. The data collected was analyzed using the WTC method for coherence to be above the threshold of coherence.

II. METHODS

A. Data collection

The protocol was approved as minimal risk by Simon Fraser University's research ethics board. Written informed consent was obtained from each participant prior to the experiment.

Prior to the start of the experiment, each participant changed into loose clothing and their anthropometric data were collected. A sit to stand test was then performed. For the test, they were required to be seated for 5 minutes, after which they were asked to stand (assistance was provided during the transfer from sit to stand) for 5 minutes with eyes open (eo). They were instructed to make a passive transition from the seated to upright stance phase without altering their foot position. During the test duration, they were required to maintain eye-level gaze focused to an eye level red dot 1.5 m in front of them. The same 10-minute procedure was repeated with eyes closed (ec) with the participant requested to maintain their blinded gaze at the same position as before. The feet were placed in a parallel foot configuration with a distance of 5 cm between the first toe and heel of each foot. The experiment was conducted in a sensory input reduced environment within an enclosed space of black drapes to remove all random visual stimuli. Apart from equipment sounds, there was no noise in the room.

All participants were screened for any cardiovascular disease or postural complications through verbal confirmation. All participants were required to refrain from exercise and caffeine for 24 hours prior to the experiment.

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Table 1: Anthropometric details of participants.

Participant No.	Gender	Age (years)	Height (cm.)	Weight (kg.)
13	7M 6F	24.8(1.9)	173.1(9.7)	66.7(15.2)

B. *Signal Acquisition*

Bilateral lower leg EMG was performed for four leg muscles: tibialis anterior, medial gastrocnemius, lateral gastrocnemius, and medial soleus. The sites for electrode placement were chosen in accordance with the recommendations for placement of electrodes from the SENIAM project [9]. Transdermal differential recording of signals was performed using an 8-channel EMG system, (*Myosystem 1200,* Noraxon Inc., Arizona, USA) and Ag/AgCl dual and single electrodes were used for signal transduction. Electrocardography (ECG) signals were acquired (LifePak 8, Medtronic Inc, Minnesota, USA) using the Lead II configuration of ECG electrode placement. BP signals were acquired by photoplethysmography using a finger cuff electrode (Finapres, *Ohmeda 2300* Ohmeda, Ohio, USA). The postural sway data, in terms of the coordinates of the COPx and COPy of the body, were calculated from the force and moment data collected with a force platform (Accusway, Advanced medical technologies Inc, MA, USA).

The data were acquired using a custom data acquisition platform comprised of a 32-analog input channel DAQ card, personal computer and Labview 8.2 software (National Instruments Inc., TX, USA). A custom virtual instrument (VI) was designed using the in-built libraries and the system was configured to acquire data at 1000 Hz sampling rate and 16-bit analog-to-digital conversion.

Data analysis was conducted in MATLAB software (Mathworks, Natick, MA, USA). The data were resampled at a frequency of 10 Hz to study the effects in the frequency ranges of interest (< 0.1 Hz).

III. DATA ANALYSIS METHODS

A. *Wavelet transform coherence.*

Wavelet transform is a well know method for time frequency analysis of signal spectral characteristics. The WTC method has been studies in detail and explained by Torrence and compo [10] and will not be detailed here. In order to find a threshold of coherence value (value above which it is considered as significant coherence) for the WTC estimator, signals for SBP and EMG were synthesized as filtered white Gaussian noise. Using the SISO system model for physiological systems [11], the output signals were obtained with added white noise, but the variance was kept at a level that gave a SNR<<1, which provided a theoretical band coherence value close to zero [12]. The input/output pairs were then created and checked for the threshold of WTC. The band coherence was calculated in three frequency ranges, namely LF (0.05–0.1 Hz), VLF (0.01-0.05 Hz) and ULF (0.005–0.01 Hz) by averaging the output over scales in the corresponding frequency ranges. The band coherence was estimated between each input/output pair and averaged over 1000 iterations to give a coherence time series; and the empirical sampling distribution (frequency histogram) was computed for each frequency band. The threshold for zero coherence, T(f), was set at the 100(1-α) percentile of the coherence sampling distribution, where α is the significance level of the statistical test kept at 95% confidence or 0.05 [13].

The WTC estimates for the signals were calculated for the relationship of EMG to the center of pressure (COP), CO and SBP and the same value of the wavelet coefficient ($\omega_0 = 6$) was used throughout the analysis. The Average value of the signals and the percentage time of coherence along with average coherence value were computed for all the comparisons.

To test whether the outcome variable values were associated with eyes condition (2 levels) and frequency bands (3 levels), a repeated measure ANOVA analysis was conducted. The significance level for the tests was kept at $\alpha = 0.05$ and all analyses were conducted with the JMP 7 statistical package (SAS Inc, USA).

IV. RESULTS

A. *Wavelet transform coherence*

Threshold values of 0.1894 (LF), 0.3162 (VLF), and 0.3141 (ULF) were obtained from the simulations. Fig 1, details the outputs of the WTC analysis as time-frequency plot, and corresponding band- coherence plots.

B. *Statistics*

The average value of significant coherence (> threshold) for the signal combinations was statistically different in all three frequency bands for the EMG – SBP (LF: 0.33 ± 0.01; VLF: 0.41 ± 0.01: ULF: 0.45 ± 0.01) and EMG – CO (LF: 0.33 ± 0.01; VLF: 0.40 ± 0.01; ULF: 0.44 ± 0.01) combination. The average coherence for the EMG - COPx comparison was significantly high in ULF (0.56 ± 0.03) versus LF (0.47 ± 0.03) and VLF (0.49 ± 0.03) bands. Similarly, for EMG – COPy, the average coherence was significantly low in LF (0.39 ± 0.01) versus VLF (0.43 ± 0.01) and ULF (0.46 ± 0.01) bands, and low in eyes open (0.41 ± 0.01) versus eyes closed (0.45 ± 0.01) condition.

For the EMG – SBP and EMG – CO combinations, the smallest median value for the percentage of time of significant coherence over total 4 minute duration occurs in the VLF and highest in LF frequency bands; for EMG – COPx and EMG – COPy combinations, the smallest median value occurs in ULF and highest in LF frequency bands (Table2).

The Average value of the variables in the time periods of significant coherence (> Threshold) is shown in table 3. No significant difference was detected in the values of the variables across frequency bands. In COPy there was a difference with the eyes condition in all frequency bands (ec: 0.09 ± 0.0; eo: 0.09 ± 0.1).

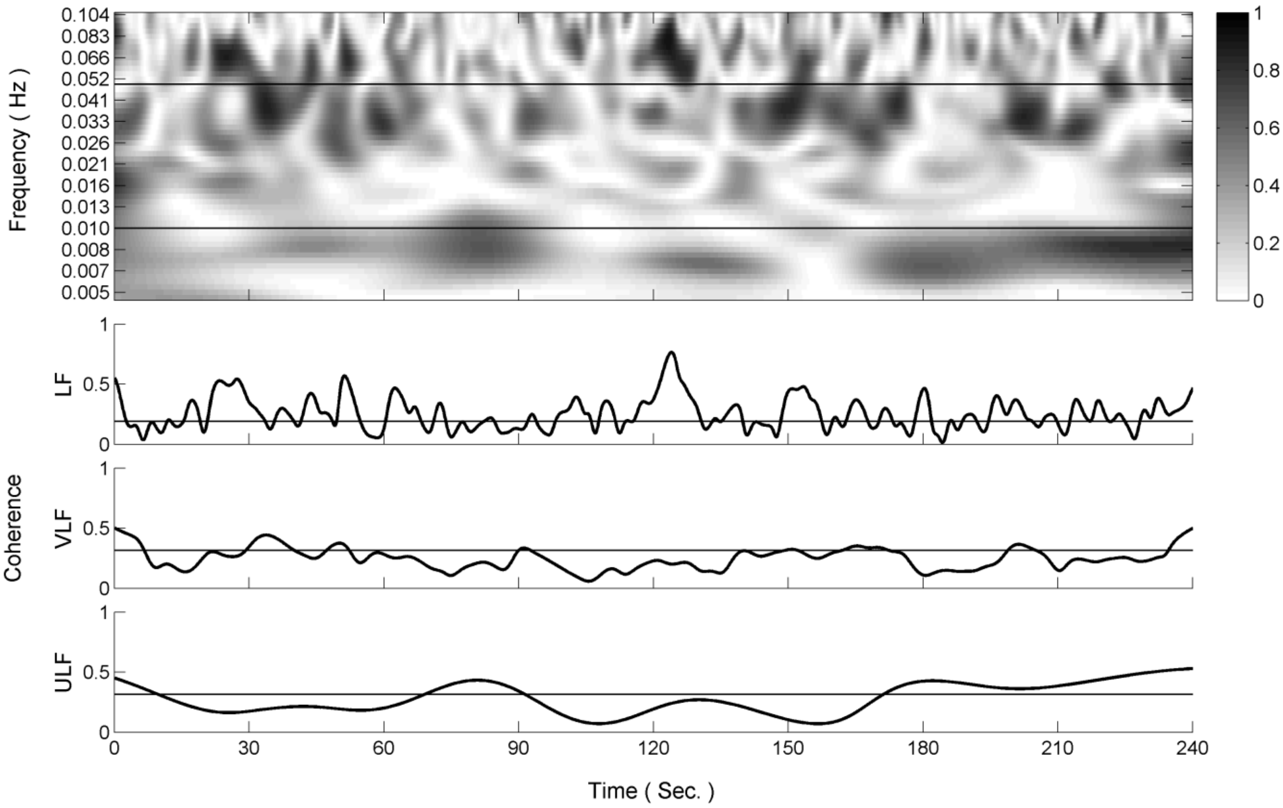

Figure 1: The WTC output for a representative male participant. Time-frequency plot of WTC estimate for EMG-BP comparison (top row). Band coherence estimate obtained from the data in the top row by averaging in the three frequency bands (LF, VLF, ULF) (bottom three rows). Straight line represents the significance threshold.

Table 2 : Percentage values of time of significant coherence between the signals and EMG over the four minute duration in the three frequency bands in all 13 participants.

Signal	Band	Time (%age)		
		Median	Min	Max
SBP	LF	61.8	48.9	74.8
	VLF	39.9	16.5	65.5
	ULF	45.8	13.3	83.2
CO	LF	64.1	49.5	78.1
	VLF	49.2	24.1	59.8
	ULF	53.2	22.1	81.1
COPx	LF	88.3	81.8	99.7
	VLF	73.9	34.8	98.0
	ULF	73.6	37.0	99.7
COPy	LF	83.0	70.3	97.2
	VLF	68.9	36.3	93.5
	ULF	60.0	29.4	95.3

Table 3: value, mean (sd), of the variables in the regions of significant coherence in the three frequency bands with corresponding eyes condition. Data averaged over 13 participants.

Freq. Band	Eyes	EMG (E-03) (mV)	SBP (mm Hg)	CO (L/min)	COPx (E-02) (m)	COPy (E-02) (m)
LF	EO	5.76 (0.8)	116 (4)	4.08 (0.30)	-1.67 (1.17)	8.94 (8.93) #
LF	EC	5.82 (0.8)	113 (4)	4.17 (0.30)	-1.51 (1.17)	9.04 (8.93)
VLF	EO	5.68 (0.8)	116 (4)	4.10 (0.30)	-1.66 (1.17)	8.92 (8.93) #
VLF	EC	5.79 (0.8)	113 (4)	4.17 (0.30)	-1.50 (1.17)	9.05 (8.93)
ULF	EO	5.71 (0.8)	116 (4)	4.20 (0.30)	-1.65 (1.17)	8.96 (8.93) #
ULF	EC	5.87 (0.8)	113 (4)	4.17 (0.30)	-1.49 (1.17)	8.99 (8.93)

V. DISCUSSION

The present study investigated the existence of a relationship between the cardiovascular and postural control systems by analysis of the characteristic signals of the two systems (EMG, BP, CO, COP). Wavelet transform coherence analysis was chosen as it provides time frequency coherence data for the signals pairs and does not assume signal stationarity.

The average values of coherence where it was significant (>significance threshold) for the cardiovascular variables with EMG combination showed a statistically significant ($p<0.05$) association with frequency bands, indicating a frequency dependent interaction between the cardiovascular and postural systems. The average coherence between the COP trajectories in the antero-posterior direction showed a dependence on the eyes condition. There was an increased coherence, and, hence, an increased coupling between EMG and COP with no visual input (eyes closed) which implied a reliance on neuromuscular control rather than central control of posture.

The average value for the variables showed no association with the eyes condition across all frequency bands, suggesting no effect in the young age group of deprivation from visual input.

In summary, the analysis shows the existence of relationship between the cardiovascular and the postural systems. The posture muscles work to regain posture and pump blood back to the heart. Elimination of visual input to the central nervous system elevated the postural control system activity, and increased the activation of the posture muscles. The action of the muscles as a skeletal muscle pump was dominant in the ultra low frequency range for the young participants. This could indicate its possible function in a long-term stabilization approach. The statistical difference in the coherent behaviour in the three frequency bands indicates the presence of a frequency dependent co-activation pattern.

Further analysis is needed to derive conclusive control system models for the proven interaction.

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