Posture muscle relationship with cardiovascular changes under orthostatic challenge

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Abstract— **Lower leg muscles are known to be activated during standing. On the other hand, standing is known to induce orthostatic stress. Our recent work presented that the posture control and cardiovascular systems are related to each other. However, the relationship of the individual muscle activation with blood pressure changes is not fully understood. The present preliminary study conducted experiments to collect data for muscle activation (EMG) and blood pressure (BP) changes during quiet standing. High coherence (>threshold) values observed between the EMG and BP signals suggest a strong relationship between the two. Additionally, the results of the study suggest a compensatory relationship of different lower leg muscles with blood pressure changes during quiet standing.**

I. INTRODUCTION

Activation of skeletal muscles in the lower limbs (skeletal muscle pump), such as through postural shifts, walking or running, increases venous return by pumping blood collecting in the veins back to the heart [1]. The maintenance of upright posture not only requires coordinated neuromuscular control of postural muscles [2], but also cardiovascular reflexes to maintain blood pressure (BP). It has been shown that different muscles in the lower leg (below knee) are activated during quiet standing [3]. Among these the medial and lateral gastrocnemius group has been shown to be associated with the skeletal muscle pump [1] while, the gastrocnemius group along with the soleus and tibialis anterior are related to posture control [2], [3]. It is possible that different muscles in the same leg relate differently with the BP changes.

Spectral analysis of the characteristic signals for these systems gets inadequate treatment by use of methods assuming stationarity of the signals. The use of methods accounting for non-stationary nature of signals is necessary. Wavelet methods have already been used to analyze non-stationary EMG signals [4], [5] and BP signals [6] and the two together [7], [8]. The wavelet transform coherence (WTC) method has been applied in geophysics [9], neuroscience methods [10] and cardio-postural investigations [7], [8] and provides time-frequency analysis of dependence between two signals without assuming signal stationarity.

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Our previous work [7], [8] has already shown the existence of a bidirectional relationship between the BP changes and aggregate muscle activity during quiet standing. In this paper we investigate the relationship of individual muscles in the lower leg with the changes in BP during quiet upright stance. We hypothesize that 1) the muscles have compensatory activation within the same leg, and 2) the same muscle in the two legs have an alternating relationship with BP. The evidence from this study is expected to provide deeper insight into selective muscle excitation with cardiovascular alterations. This can potentially aid the decision making process to prevent falls in elderly and cure cardio-postural deficits.

II. METHODS

The protocol was approved as minimal risk by Simon Fraser University's research ethics board. Written informed consent was obtained from each subject prior to the experiment. The subject changed into loose clothing and anthropometric data were collected. Then they proceeded for the sit to stand test after the instructions were provided. 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. They were instructed to make a passive transition from the seated to upright stance phase without altering their foot position. The 5-minute resting phase was necessary for the participants to stabilize to their baseline physiological response. Additionally the absence of active orthostatic challenge would further reduce the effects of fatigue. During the test duration, they were required to maintain eye-level gaze focused to a red dot in front. The same 10-minute procedure was repeated with eyes closed. 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.

A. Participant Pool

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. Subject demographic and anthropometric measurements are provided in detail in the table I below.

TABLE I

DEMOGRAPHIC DETAILS OF THE PARTICIPANTS.

Participant No.	Gender	Age (Years)	Height (cms)	Weight (Kg.)
10	5M/5F	25.4±2.17	173.15±9.88	67.6±16.6

B. Signals Acquired

Bilateral lower leg electromyography (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 [11]. 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. Electrocardiography (ECG) signals were acquired (LifePak 8, Medtronic Inc, Minnesota, USA) using the Lead II configuration of ECG electrode placement. Blood pressure signals were acquired by photoplethysmography using a finger cuff electrode (Finapres, Ohmeda 2300 Ohmeda, Ohio, 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.

The beat-by-beat systolic blood pressure time series was obtained via the R-wave detection applied to ECG. This waveform was used in the subsequent analysis in relationship to EMG. The signals were resampled at 10Hz frequency prior to the subsequent WTC analysis. For this study the analysis was applied to the EMG-BP signal pair and other signals were not analyzed to retain the focus on the hypotheses.

C. Data Analysis

Wavelet transform is a well know method for time frequency analysis of signal spectral characteristics. The method of Wavelet Transform Coherence has been studies in detail and explained by Torrence and Compo [12] and will not be detailed here. Our prior work investigating cardio-postural interactions [7], [8] has established the threshold of significant coherence for the WTC analysis of BP-EMG signal pairs. Similar to the previous analysis we investigated the wavelet transform coherence in the low frequency (LF: 0.05-0.1 Hz; Thresh: 0.32) and very low frequency (VLF: 0.001-0.05 Hz; Thresh: 0.33) bands. The WTC analysis pipeline provides a time frequency estimate of coherence. We obtained three aggregate measures from the time frequency distribution of the BP-EMG coherence for each muscle. Firstly, time points with >threshold coherence were averaged to get an average significant coherence measure for each frequency band. Second, an average of coherence over the band was obtained presenting the behavior over time. Lastly, the percentage time of significant coherence was obtained as the ratio of the number of time points with significant coherence with the total number of data points in a frequency band. A standard two tailed students t-test was applied to identify the presence of statistical significance in the two groups for the three parameters. The null hypothesis was rejected at a significance level of $p < 0.05$.

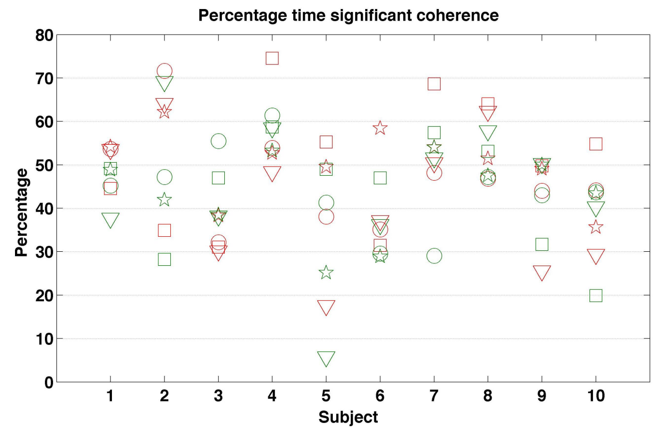

Fig. 1. Percentage time of significant (>threshold) coherence in the low frequency band. The markers differentiate the muscles for the right (red) and left (green) legs.

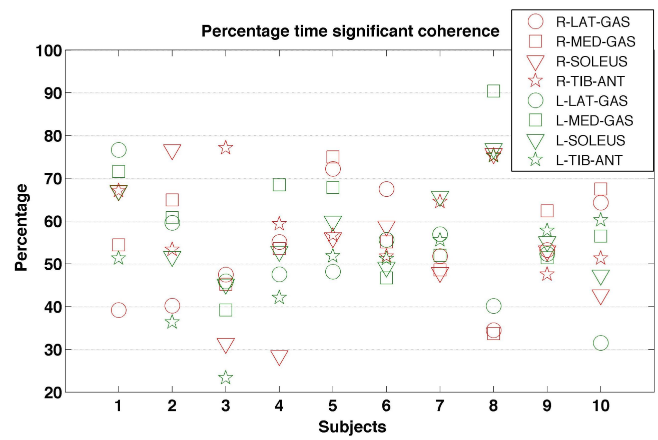

Fig. 2. Percentage time of significant (>threshold) coherence in the very low frequency band. The markers differentiate the muscles for the right (red) and left (green) legs.

III. RESULTS

The coherence threshold was maintained at 0.32 (LF band) and 0.33 (VLF band). The average value of significant coherence and percentage time of significant coherence in aggregate over the 10 subjects are presented in table II. These data are shown for the subjects individually in the bar plot in figure 3 and the marker plot in figures 1 and 2 respectively. The average band coherence for a representative male subject is presented in the figure 4.

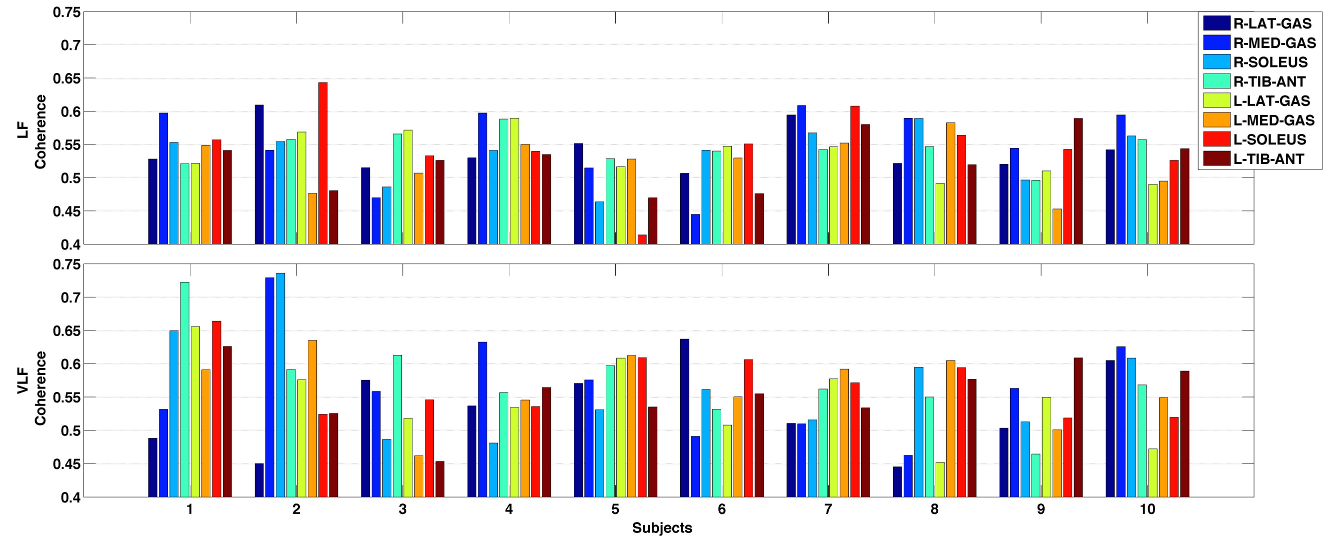

Fig. 3. Average coherence for the time points with significant (>threshold) coherence for the 8 muscle groups and the 10 subjects in the study.

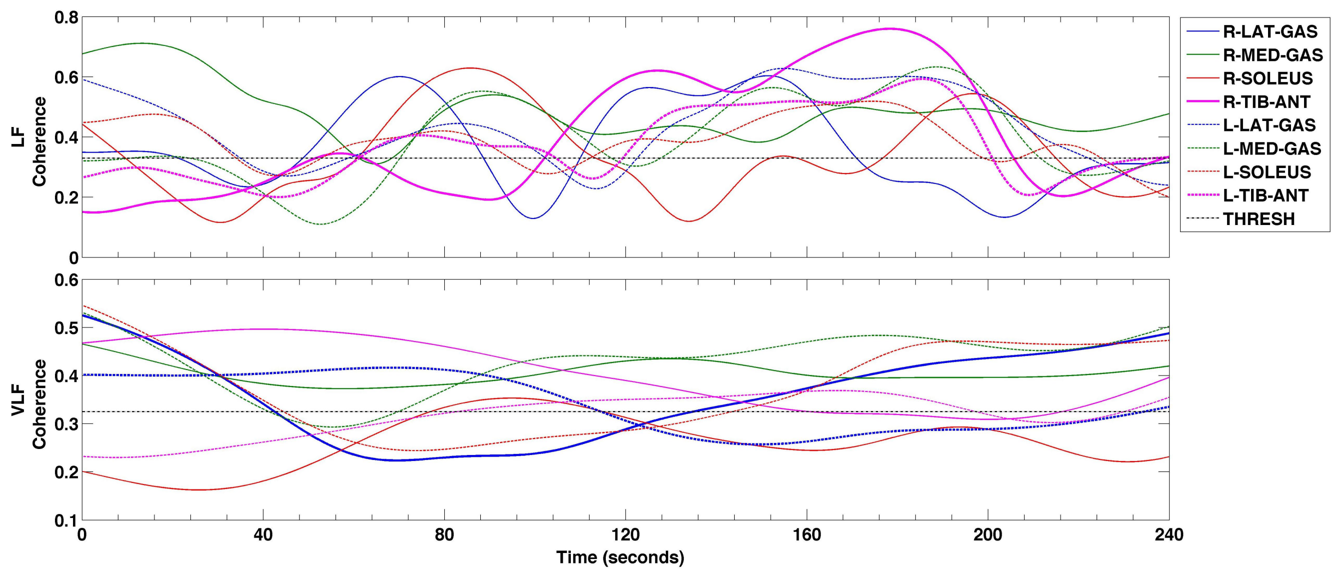

Fig. 4. Averaged coherence in the LF and VLF bands varying over time for one representative male subject. The muscles in right leg (solid lines) and left leg (dashed lines) show alternating behavior.

IV. DISCUSSION

Ours is the first study to investigate the relationship between the activation of the individual muscles in the lower leg with the blood pressure changes under orthostatic challenge induced during quiet standing. We conducted a 10 minute passive sit to stand test and collected data for muscle activation (EMG) for 8 muscles and blood pressure. The data were analyzed by application of wavelet transform coherence method to check for existence of relationship (coherence). We found strong coherence (>threshold) between the muscle EMG and BP changes in all subjects.

We found that the average measures derived from the time-frequency distribution of coherence did not show a statistically significant difference in the two bands for most muscles. The right tibialis anterior and left medial gastrocnemius had higher percentage time of significant coherence in the VLF band than in the LF with statistical significance ($p<0.05$)(Table II). This suggests that for the cohort under investigation, the two muscles responded on a larger time scale to the perturbation in blood pressure. This observation further opens a research question to characterize the frequency dependent interaction of individual muscles to the changes in BP while standing.

On an individual subject level (Figure 3) we observed a compensatory relation across frequency bands (example: subject 1 & 5). This is observed as a higher value of coherence in the VLF band than the LF band, which is suggestive of an increase in averaged activity in the VLF band with reduced activity in the LF band. Similarly, investigating within the

TABLE II

AVERAGE SIGNIFICANT COHERENCE AND PERCENTAGE TIME OF SIGNIFICANT COHERENCE IN AGGREGATE OVER 10 SUBJECTS. DATA PRESENTED AS MEAN±S.D.

	Avg. Sig. Coherence		Percentage time Sig. Coherence	
	LF	VLF	LF	VLF
R-LAT-GAS	0.54 ± 0.03	0.53 ± 0.06	46.77 ± 11.34	52.55 ± 12.64
R-MED-GAS	0.55 ± 0.06	0.56 ± 0.08	50.89 ± 15.46	56.04 ± 11.98
R-SOLEUS	0.54 ± 0.04	0.56 ± 0.08	41.83 ± 16.11	53.79 ± 16.71
R-TIB-ANT	0.54 ± 0.03	0.57 ± 0.07	50.55 ± 8.18	60.42 ± 10.29*
L-LAT-GAS	0.54 ± 0.03	0.55 ± 0.06	44.31 ± 9.98	51.44 ± 12.17
L-MED-GAS	0.52 ± 0.04	0.56 ± 0.05	44.10 ± 13.04	60.49 ± 14.73*
L-SOLEUS	0.55 ± 0.06	0.56 ± 0.05	44.54 ± 17.43	57.12 ± 10.15
L-TIB-ANT	0.53 ± 0.04	0.56 ± 0.05	43.17 ± 9.83	50.48 ± 14.13

* significant difference with LF ($p<0.05$)

same subject we observed that a single or a pair of muscles show dominant relationship (high coherence) than the other muscles for both left and right legs (example: subject 1 & 2)(Figure 3). This effect was reiterated when data for a representative male subject was plotted as average in the two bands over time (Figure 4) as we see an opposing behavior in the same muscle in the two legs. This observation needs further investigation due to the presence of high inter-subject variability in the response to the orthostatic challenge.

The current study collected data from 10 subjects and was limited in statistical power to draw statistical conclusions. Further data collection with bigger cohorts and detailed analysis is required to enable the statistical inference from the data. Additionally, the current study is limited to the analysis of EMG-BP signal pair. It would be interesting to simultaneously analyze other signals to obtain a fine grain understanding of the underlying processes. The temporal behavior needs to be studied in greater detail and requires newer metrics (e.g. phase difference etc.) in addition to the coherence measurement.

V. CONCLUSIONS

The current paper has investigated the selective excitation and compensatory activation of the muscles primarily associated with posture control under orthostatic challenge in relationship with the cardiovascular system. Strong relationship (>threshold coherence) between activation of individual muscles (lower leg) with BP changes was observed. We found strong evidence of the compensatory activation between muscles in the same leg and the two legs in relationship with blood pressure changes.

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