Effects of Electromyogram Signal filtering on Muscle Activation Time

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INTRODUCTION

Important information gained using dynamic electromyography is to accurately define the muscle action and phase timing within the gait cycle. Human gait relies on selective timing and intensity of appropriate muscle activations for stability, loading and progression over the supporting foot during stance, and further to advance the limb in swing phase. A traditional clinical practice is to low pass filter the integrated electromyogram (EMG) signals and to determine onset and cessation events using a predefined threshold. The accuracy of defining period of significant muscle activations by EMG varies with temporal shift involved in filtering of the signals. Low pass filtering with fixed order and cut-off frequency will introduce delay depending on the frequency of the signal. In order to precisely identify muscle activation and to determine onset and cessation times of the muscles, we explore onset and cessation epochs with denoised EMG signals using wavelets denoising, Empirical mode decomposition (EMD) and Ensemble empirical mode decomposition (EEMD) method, which are considered suitable tools for analyzing nonlinear and non-stationary signals such as EMG. Gastrocnemius muscle onset and cessation were determined in eight participants with two different walking conditions. Low pass filtering of integrated EMG (iEMG) signals resulted in premature onset (about 28% of stance duration) in younger when compared with iEMG signals. We also found significantly different onset time events ($p<0.02$ for normal speed walking, $p<0.01$ for fast speed walking) between those detected by low pass filtering and iEMG signals. Wavelet denoising accurately predicted onsets for normal walking. EEMD denoised signals could further detect preactivation onsets during fast walking condition.

METHODS

Eight young subjects (aged between 18-30 years old) of average height (176.25±6.08 cm) participated in the study. The Virginia Tech Institutional Review Board approved the study and the recruited participants had good health, with no cardiovascular, respiratory, neurological, and musculoskeletal abnormalities.

The subjects performed walking on 15 meter long walkway with two embedded forceplates (BERTEC #K80102, Type 45550-08, Bertec Corporation, OH, 43212, USA). A six-camera ProReflex system (Qualysis) was used to collect three-dimensional infra-red passive marker data of participants as they walked over the test floor surface. Kinematic data were sampled and recorded at 120 Hz. The sampling frequency of sampling frequency was set as 1200 Hz. An eight-channel EMG telemetry Myosystem 900 (Noraxon, USA), was used to record EMG signals of gastrocnemius muscle. Only those walking trials were used for analysis when subjects placed their left foot in the middle of forceplate. Kinematic events such as heel contact (HC) and toe off (TO) of both feet were determined by placing four markers at heel and toe (both right and left foot) and these events were verified by forceplates.

Muscle Onset and cessation points were determined by the following algorithm Raw EMG signals recorded during gait were band-pass filtered using a fourth order filter at 20-500Hz and full-wave rectified [1]. In this study, we have used classical threshold based approach for onset determination[2]. Baseline quiescent portion of EMG record was chosen of length 6msec data, starting from -50% of stance. Threshold was defined as shown below

$$Threshold = Baseline\ Mean + 3X\ Baseline\ STD$$

A threshold of three standard deviations above the baseline was used to identify muscle firing onset and cessation[2]. An algorithm was written with

3msec moving window and muscle onset was assumed to follow two conditions: (1) muscle activity was above the threshold for at least 0.1 sec and (2) If the muscle activity dropped below the threshold for more than 3% of stance duration (or 5% of gait cycle). The onset was updated to the new rise above the threshold and short duration EMG packet was discarded [3]. All muscle activity onset and cessation times are reported as percentage of stance duration. *Statistical Analysis:* Subject means used in statistical analyses were calculated as the mean of the two trials performed by each subject. A four factor analysis of variance (ANOVA) with a Tukey's posthoc was used to assess statistical differences between the four denoising methodologies (JMP , SAS USA). Alpha level was set at 0.05.

RESULTS AND DISCUSSION

Mean medial gastrocnemius muscle onset time events for low pass filtered (LPF) EMG signals of eight participants were found to be significantly different from those of iEMG for both normal ($p<0.02$) and fast walking ($p<0.01$) trials (Table 1). For most of the trials earlier onset were detected, when iEMG signals were filtered by low pass filter for normal speed walking trials (Table 1). We found that the duration of muscle activation was significantly different for both normal speed walking ($p=0.0049$) and fast speed walking ($p=0.0012$) for iEMG and low pass filtered (LPF) signals. Thus, traditional way of low pass filtering (LPF) was found to result in earlier onsets in normal walking whereas it was found to be advantageous in detecting preparatory pre-activations in fast walking.

In all fast walking trials, an earlier preparatory pre-activation was found, which was not detected by our threshold based algorithm for iEMG and wavelet denoised signals. This may be one of the reasons for finding significant difference among onsets for iEMG and LPF and that of Wavelet and LPF (Table 1). Thus EMD, EEMD and LPF signals posed advantageous as were able to detect preparatory pre-activations in fast speed walking trials (Figure 1 & 2).

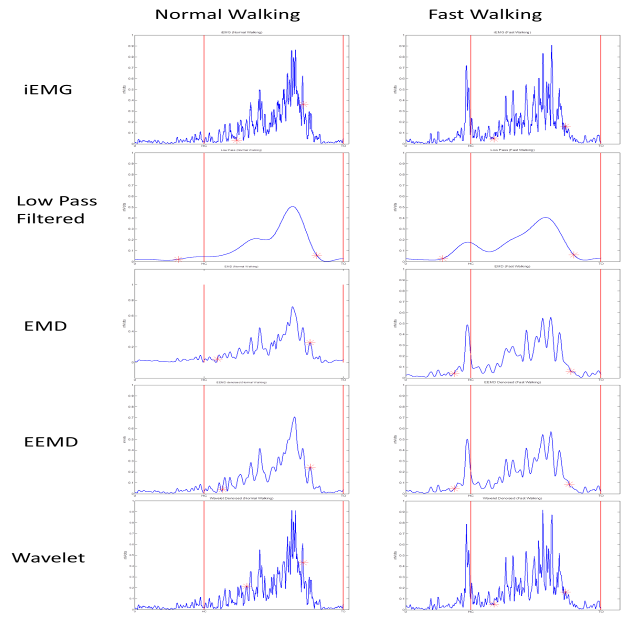

Figure 1: Onset and cessation for normal and fast walking with iEMG (as standard ground truth) and other denoised EMG signals for one participant.

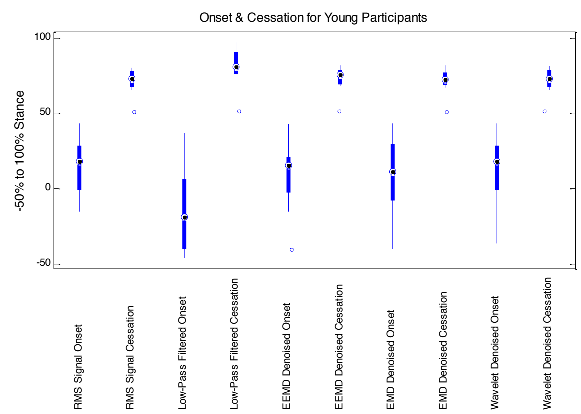

Figure 2: Onset and cessation points of medial gastrocnemius in eight participants

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Table 1: Tukey's HSD comparison of onset point and time of muscle activation

		Onset Points [% of Stance]		**Muscle Activation Time [sec]**		**Onset Points [% of Stance]**		**Muscle Activation Time [sec]**	
		Fast Walking		Fast Walking		Normal Walking		Normal Walking	
		Difference	p-Value	Difference	p-Value	Difference	p-Value	Difference	p-Value
iEMG	LPF	43.55	0.001*	0.30	0.0012*	34.14	0.0118*	0.28	0.004*
Wavelet	LPF	35.88	0.005*	0.25	0.0091*	32.81	0.0171*	0.27	0.007*
iEMG	EEMD	28.91	0.039*	0.19	0.0923	12.84	0.7227	0.11	0.628
iEMG	EMD	22.73	0.162	0.16	0.2088	10.69	0.8358	0.08	0.825
Wavelet	EEMD	21.24	0.216	0.14	0.3298	11.51	0.7956	0.10	0.699
EMD	LPF	20.81	0.234	0.14	0.3040	23.44	0.1627	0.20	0.091
Wavelet	EMD	15.06	0.553	0.11	0.5646	9.36	0.8918	0.07	0.876
EEMD	LPF	14.63	0.581	0.11	0.5327	21.30	0.2432	0.17	0.188
iEMG	Wavelet	7.67	0.936	0.04	0.9640	1.32	0.9999	0.01	1.000
EMD	EEMD	6.17	0.970	0.02	0.9947	2.14	0.9996	0.02	0.997