PILOT TEST OF THE PROTOTYPE WEARABLE EMG ANALYSIS FOR REHABILITATION (WEAR) SYSTEM

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INTRODUCTION

Surface electromyography (sEMG) can provide information on the timing and force of muscle contractions, co-contractions, and indicators of spasticity and muscle fatigue [1]. Despite strong evidence for clinical utility, sEMG in a clinical setting is limited and still in its infancy [2][3]. Barriers to wide-spread sEMG use in the clinic are time, equipment, and expertise for sEMG data acquisition [4][5][6]. The Wearable Electromyography Analysis for Rehabilitation (WEAR) project aims to provide a sEMG acquisition system that overcomes these barriers [6].

Conventional sEMG acquisition is performed by placing an electrode pair above the muscle of interest using anatomical landmarks (e.g., Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project guidelines [7]). Instead of a single electrode pair, the WEAR system employs an electrode array that can be quickly positioned above the muscle of interest; an optimal electrode pair can be selected from the array automatically.

In a previous paper, we proposed a WEAR prototype design [6]. This system used an integrated analog front-end (ADS1298, Texas Instruments, Dallas, TX, USA). The ADS1298 is a low-power, 8-channel biopotential amplifier, with 24-bit analog-to-digital converters, that is targeted for applications in electrocardiography or electroencephalography; however, its technical specifications suggests suitability for sEMG. Such integrated electronics enables a practical implementation of a wearable, multichannel sEMG system. This paper presents an initial performance evaluation of the WEAR system with respect to sEMG signal quality and validation of the ADS1298 for sEMG applications. Results are compared to a conventional sEMG acquisition system used in gait analysis.

METHODS

WEAR System

The WEAR prototype consists of the ADS1298ECG-FE demonstration board (Texas Instruments, Dallas TX, USA) and the Explorer 16 development board (Microchip, Chandler AZ, USA) to integrate the ADS1298 and a PIC24 microcontroller, respectively. The ADS1298 was configured with the programmable gain amplifiers set to a gain of 6 and a sampling rate of 1000 Hz per channel.

The PIC24 interfaces with the ADS1298 via a serial port interface (SPI). A separate SPI is used to interface the PIC24 to a Secure Digital (SD) flash memory card, where digitized sEMG signals are stored.

Significant low frequency artifacts were noted in the recorded data (e.g., motion artifact). Therefore, data were digitally high-pass filtered using a 3rd order Butterworth filter, with a frequency cutoff of 30 Hz. Filtering was performed in the forward and reverse direction for zero-phase filtering.

Conventional sEMG Acquisition System

The conventional sEMG acquisition system was located in The Ottawa Hospital Rehabilitation Centre's Rehabilitation Technology Laboratory. The custom built amplifier system included an AD524 instrumentation amplifier (Analog Devices, Norwood MA, USA), with a gain of 100, in series with a OP27 precision operational amplifier (Analog Devices, Norwood, MA, USA)

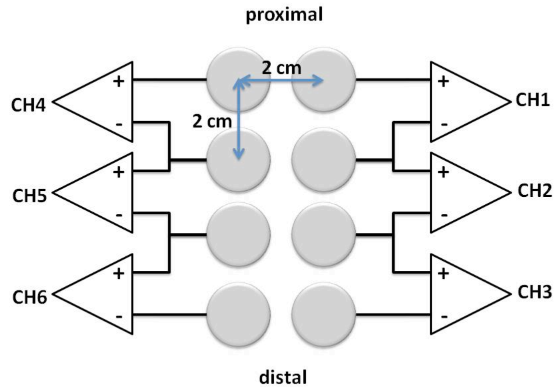

Figure 1: Electrode array configuration.

that had an adjustable gain set to 20 (total gain of 2000). Data were sampled at 2000 Hz using a Vicon MX Ultranet HD console with a 16-bit analog-to-digital converter. Data were resampled in Matlab to 1000 Hz for consistency with the WEAR system's sampling rate.

Electrode Arrays

An array of 8 electrodes was used, comprised of 2 columns of 4 electrodes aligned in parallel with the muscle fibers. Electrodes were paired to form 6 data channels, with channels 1 and 4 proximal to the body (Fig. 1). Dry and wet electrodes were used in this work: LTI medium dome 14.3 mm diameter metal electrodes (EL02, Liberating Technologies Inc., Holliston MA, USA) and 5 mm diameter pre-gelled Ag/AgCl electrodes (Meditrace 130, Kendall, Mansfield MA, USA). LTI electrodes were integrated into a wearable sleeve. The electrodes were incorporated into a piece of non-stretchable fabric, with a polyurethane backing (Cordura 1000). Two pieces of stretchable prosthetic liner (Össur Iceross), along with two Velcro straps were used to ensure a custom, secure fit around the subject's lower leg. Ag/AgCl electrodes were self adhesive and did not require the sleeve.

Experimental Procedures

This research was reviewed and approved by the Ottawa Hospital Research Ethics Board and the Carleton University’s Research Ethics Board. Data were collected from the *tibialis anterior* muscle of the left leg of one male subject (age 35), with no known neuromuscular disorders. The subject was seated on a bed with their legs extended.

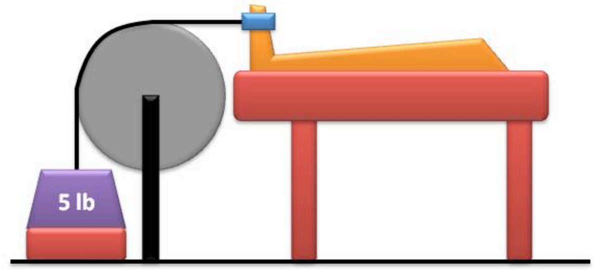

Figure 2: Experimental setup for flexion of the *tibialis anterior* muscle.

Three trials were performed in succession. In the first trial, the WEAR system was used with the LTI electrodes. The surface of the skin above the *tibialis anterior* muscle was cleaned with an alcohol wipe before the sleeve was donned. The electrode array was visually positioned so that the center of the array was close to the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM; www.seniam.org) recommended location. Positioning was rapid (< 20 s), since no measurements were made to guide the electrode placement. In the second trial the WEAR system was used with Ag/AgCl electrodes. Skin blanching from the LTI electrodes was used to position the Ag/AgCl electrodes in the same locations. The skin surface was cleaned with an alcohol wipe before the electrodes were placed. In the third trial, the conventional sEMG acquisition system was used, with the same Ag/AgCl electrode array from the second trial.

In each trial, 10 s of data were acquired while the subject’s leg was relaxed and supported (i.e., no sEMG). These data should be representative of the noise associated with the acquisition system. A 5 lb (22 N) weight was then tethered, via a pulley, to the top of the left foot (Fig. 2). The weight rested on a support block while the subject’s muscle was relaxed. Ankle dorsiflexion (*tibialis anterior* contraction) raised the weight, which provided a counter force of approximately 22 N. The subject performed 10 trials of: ankle dorsiflexion, holding an isometric contraction for 3 seconds, plantarflexion to the start

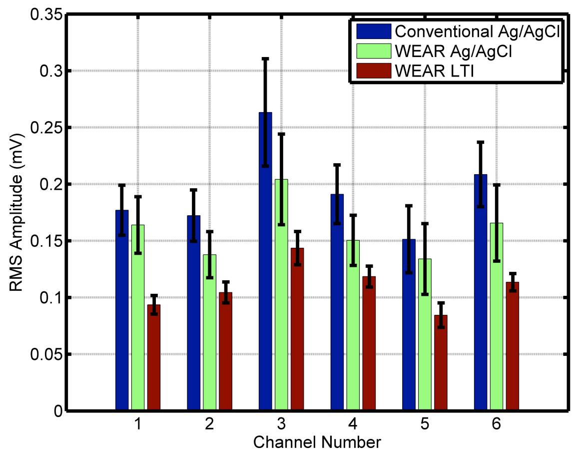

Figure 4: Mean RMS amplitude, averaged across 10 contractions (1 standard deviation error bars), for all 6 channels of sEMG.

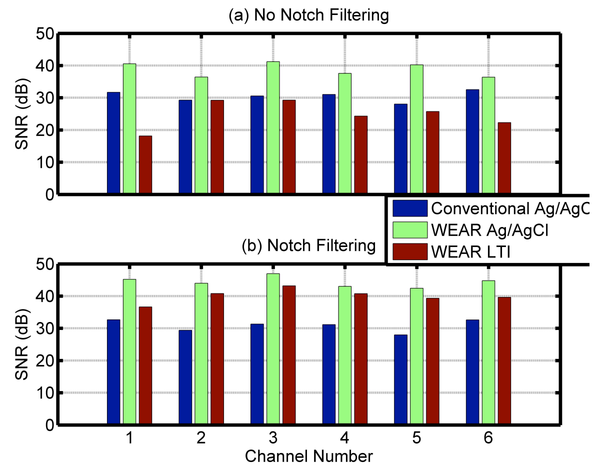

Figure 3: Mean SNR, averaged across 10 contractions for all 6 channels of sEMG (a) without notch filtering and (b) with notch filtering.

position, and 3 s with the muscle relaxed before the next trial.

RESULTS

The mean of each sEMG recording was subtracted to remove offsets. To enable direct comparisons between the WEAR and conventional systems, recorded amplitudes were converted to voltages and were divided by the total gain of their respective acquisition systems.

The start of each dorsiflexion was identified manually in the recorded sEMG signal through visual inspection. For each contraction, 2048 ms data segments were extracted, 512 ms after the start of the contraction. This segmentation avoided the transient portions of each contraction; that is, each data segment corresponded just to the isometric part of the contractions.

The root mean square (RMS) value of each sEMG segment was computed. Fig. 3 is a bar plot of the RMS value, averaged over the 10 contractions, for each channel and trial. The conventional sEMG acquisition system, using the Ag/AgCl electrodes, has the highest RMS values, while the WEAR system using the LTI electrodes has the lowest RMS values. The relative RMS values among the 6 channels of sEMG are consistent between trials, with channel 3 providing the highest RMS value and channel 5 the lowest.

An estimate of the noise was established by using the 10 s of data that were acquired while the subject was relaxed. A signal-to-noise ratio (SNR) was derived by taking the ratio of the mean RMS value, averaged across the 10 contractions, and the RMS value of the noise. Significant power line interference noise was noted when using the WEAR system with LTI electrodes; this interference can be easily removed using a 60 Hz notch filter. Fig. 4 is a plot of the SNR for each channel and all trials, with and without notch filtering. Notch filtering was performed on all the data using a second-order digital filter, with a center frequency of 60 Hz and a Q-factor of 35. Filtering was performed in the forward and reverse direction for zero-phase filtering. Without notch filtering, the WEAR system with Ag/AgCl electrodes had the highest SNR, while the WEAR system with LTI electrodes had the lowest SNR; however, with notch filtering, the conventional sEMG acquisition system had the lowest SNR.

DISCUSSION

Since electrode positioning was identical for all trials, the relative RMS amplitudes among the various array channels should be the same. Indeed, this is what is observed in Fig. 3, indicating that the WEAR system, using conventional Ag/AgCl wet electrodes, or using LTI dry electrodes, provides similar information regarding muscle activity. With Ag/AgCl electrodes, RMS amplitudes from the conventional sEMG acquisition system are larger than the WEAR system. Since the same electrode array was used, differences are attributed to the electronics. Inaccurate gain settings in one or both system is a likely explanation for the differences (i.e., the amplifier gain is not exactly what it was programmed or designed to be).

The RMS amplitude for the WEAR system using LTI electrodes is much lower than data from the other two conditions, which includes the WEAR system with Ag/AgCl electrodes (Fig. 3); therefore, system differences are attributed to the electrode type. Dry (polarizable) electrodes, such as the LTI electrodes, tend to have much larger electrode-skin impedances than wet (nonpolarizable) electrodes, such as Ag/AgCl electrodes [8]. The higher skin-electrode impedance can account for the decrease in RMS amplitude, since a greater loss in signal strength associated with higher impedance.

Despite having a larger RMS amplitude (Fig. 3), the conventional sEMG acquisition system has a lower SNR than the WEAR system when using Ag/AgCl electrodes (Fig. 4). The WEAR system must be exhibiting less noise, resulting in the higher SNR. The SNR of the WEAR system SNR with LTI electrodes was much lower than the other two conditions, when there was no notch filtering applied (Fig. 4a). This is explained by the presence of 60 Hz noise in the data acquired by the WEAR system with LTI electrodes. Dry electrodes tend to be more susceptible to power line interference because they have larger electrode-skin impedances and therefore likely to have larger mismatches in electrode-skin impedances between electrodes [8]. The presence of power line interference is confirmed by the marked improvement in SNR when notch filtering was applied (Fig. 4b).

The mean SNR improvement, averaged across all contractions and channels is 0.32 dB for the conventional sEMG acquisition system using Ag/AgCl electrodes, 5.67 dB for the WEAR system using Ag/AgCl electrodes, and 15.21 dB for the WEAR system using LTI electrodes. This suggests power line interference was minimal in data from the conventional sEMG acquisition system but there was an appreciable amount of power line interference present in the WEAR system, especially when the LTI electrodes were used. The WEAR system may be more susceptible to power line interference because the prototype implementation used development boards, which offers modest shielding.

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