Power Spectral Analysis of Surface EMG in stroke: a preliminary study

Sudarsan Srivatsan, Xiaogang Hu, Brian Jeon, Aneesha K. Suresh, William Zev Rymer and Nina L. Suresh

Abstract— The objective of this preliminary study was to examine the utility of power spectral analysis of recorded surface EMG signals in identifying altered MUAP characteristics in hand muscles of stroke survivors. We derived parameters from EMG power spectral analysis, such as frequency range and median frequency and made comparisons between data obtained from the affected and contralateral sides of stroke subjects. The goal was to identify whether power spectral analysis of the surface EMG could be used to infer changes in action potential characteristics that can occur in post-stroke muscle. We utilized both a standard single differential electrode (Delsys, Inc.) and in a separate set of experiments, a sensor array electrode (Delsys, Inc.) that consists of 5 slender cylindrical probes. Recordings were made during isometric force contractions at varying levels. Utilizing a novel decomposition system (Delsys, Inc.) and the sensor array electrode, we were able to derive MUAP parameters, such as p-p amplitude and p-p duration. Preliminary results suggest that there were significant differences in the median frequency values between the stroke and contralateral side of three tested stroke subjects; however, this did not follow the differences in MUAP p-p duration values. There were also significant differences in the median frequency recorded from the sensor array electrode as compared to the single differential electrode on both the stroke and contralateral sides of our tested stroke subjects, as expected. We discuss the possible explanations for our results, specifically pertaining to the clinical scores for each subject.

I. INTRODUCTION

Cerebral stroke is a leading cause of disability in the United States [1]. Despite some degree of functional recovery, many stroke survivors exhibit persistent motor impairments. Muscle weakness is one such impairment limiting motor function in stroke survivors [2-4]. Possible mechanisms of weakness include muscle atrophy, uncoordinated muscle activation (e.g., co-contraction), and disorganization of MU pool activation. Muscle atrophy, motor neuron loss and disorganization of MU pool activation can occur in the stroke subjects to varying degrees and thus, muscle weakness or paresis may have multiple contributing mechanisms.

Thus, the ability to differentiate the different neural and muscular factors that contribute to paresis in stroke survivors would provide a needed tool for targeted and efficient drug and rehabilitation therapies. The motor unit action potential recorded from individual motor units can provide relevant information regarding changes in muscle properties. For example, muscle atrophy would lead to MUAPs with smaller average peak to peak amplitudes, whereas reinnervation of motor units following motoneuron loss could result in larger, multiphasic action potentials. Likewise if the duration of a MUAP is longer, this could suggest slower fiber conduction velocities, which could occur as a function of peripheral nerve damage, or a redistribution of motor unit types.

Surface EMG recording is a non-invasive and relatively easy tool to use for diagnosis and for the assessment of changes in overall muscle function, including neural control. The surface EMG is normally recorded from electrodes that provide a composite signal of many superimposed MUAPs.

Power spectral analysis of surface EMG signals has been used to identify possible alterations in the firing frequency as well as action potential shapes. Most EMG amplifiers use a high pass filter (often set at 20-450 Hz) such that the firing frequency range is typically lower than the bandwidth of the filter and thereby limits the ability to identify firing frequencies. Studies have shown that the median frequency of the power spectrum is highly correlated to action potential shape, namely the action potential duration [7, 9].

Intramuscular electrodes can be used to record individual action potentials. However this is an invasive procedure with low yield of individual motor unit action potentials. Recently a novel decomposition system was developed by Delsys, Inc., which includes a surface electrode designed to record MUAP shapes. The decomposition system outputs the shape of individual MUs as well as the firing times associated with each discriminated MU.

Clinical assessment of stroke severity can be determined through the use of different clinical measures including the Fugl Meyer Assessment and Chedoke Score. The Fugl-Meyer test is used to evaluate motor ability in post stroke hemiplegics and is one of the most commonly utilized quantitative assessments of motor impairment [11]. The Chedoke-McMaster Stroke Assessment is used in the determination of physical impairment and disability in patients with stroke and other neurological impairments. Correlations between experimentally derived assessments and clinical assessments could be used to improve targeted therapy and treatment.

The goal of our study was to characterize changes in median frequencies in the power spectrum of surface EMG signals.
between the paretic and contralateral side of individual stroke subjects and to evaluate whether these differences were related to changes observed in MUAP duration. We recorded surface EMG using the sensor array electrode during different force contraction levels in the first dorsal interosseous muscle of stroke survivors. We computed the power spectrum of the surface EMG signal, and we derived MUAP shapes utilizing the decomposition system. We repeated the same set of experiments in our subjects, utilizing a standard single differential surface electrode, for comparative purposes. The objective of our preliminary study was to compare the median frequency recorded from our different electrodes within a subject, to make systematic comparisons of the median frequency recorded from both electrodes between the paretic and contralateral sides of each stroke subject and finally, to assess whether the differences in median frequency from the sensor array EMG signal were correlated with the MUAP shapes derived from the surface EMG signal and as well, correlated with clinical measures.

II. METHODS

A. Subjects

Two control subjects and three chronic hemiparetic stroke subjects (see Table 1 for demographics) were tested. All participants gave informed consent via protocols approved by the Institutional Review Board at Northwestern University.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Chedoke Score</th>
<th>Modified Ashworth</th>
<th>Fugl Meyer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>Biceps 1+, triceps 1+</td>
<td>63</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>Biceps 1, triceps 0</td>
<td>66</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Biceps 3, triceps 2</td>
<td>17</td>
</tr>
</tbody>
</table>


B. Experimental Setup

The participants were seated upright in a Biodex chair with their upper arm comfortably resting on a plastic support. To standardize hand position and to minimize activity of unrecorded muscles, the forearm was placed in a brace frame of a ring-mount interface that was mounted to the table. The index finger was fixed in line with the long axis of the forearm (Fig. 1A). The proximal phalanx of the index finger was fixed to a ring-mount interface attached to a six degrees-of-freedom load cell (ATI, Inc.). The recorded forces from the x (abduction/adduction) direction was low passed (cutoff =200 Hz) and digitized at a sampling frequency of 1 kHz.

At the first session, sEMG were recorded from the first dorsal interosseous (FDI) muscle using a surface sensor array (Delsys, Inc.) as shown in Fig. 1B that consists of 5 slender cylindrical probes. The probes are located at the corners and at the center of a 5 × 5 mm square (Fig. 1C). Pairwise differentiation of the 5 electrodes yields 4 channels of sEMG signals (Fig. 1D). The sEMG sensor and a reference electrode were connected to 4 channels of a Delsys Bagnoli sEMG system. The signals were amplified and filtered with a bandwidth of 20 Hz to 2000 Hz.

At a second session sEMG was again recorded from the FDI muscle, using a single differential electrode (Delsys, Inc.) as shown in Fig. 1F consisting of two parallel bars. The bars are each 1 cm in width and 1 mm in height with a spacing of 1 cm between each bar. The sEMG sensor and corresponding reference electrode were connected to 2 channels of the same Delsys Bagnoli system and were again amplified and filter with a bandwidth of 20 Hz to 2000 Hz.

C. Procedures

For the chronic hemiparetic stroke subjects, the first trial consisted of the assessment of the subject’s maximal voluntary contractions (MVCs) for both arms. For fair comparison between the two sides, the MVC of the paretic side was used to determine the force level for the contralateral side.

Subsequent to MVC testing, the rest of the session consisted of a series of isometric force contractions during which the subject was asked to follow trapezoid force trajectories displayed on a computer screen, each at a different varying percentage of the MVC. The force output in one exemplar trial is shown in Fig. 1E. To ensure that the subjects could trace the trapezoid trajectory closely, they practiced 3 trials of 30% MVC constant force trapezoid before the main experiment. The subjects then performed 5 blocks of trials that with 3 repetitions of each block. Five constant force levels (20%, 30%, 40%, 50%, and 60% MVC) were tested and assigned to each block. The order of the force levels was randomized for each subject. A 1 min rest period between trials was provided to minimize fatigue. Upon request, additional resting time was provided.

For control subjects the same procedure was repeated with subject’s dominant arm.

The second experimental session was a repeat of the above protocol with the only difference being the use of the single differential sensor as opposed to the sensor array.

D. Data Analysis

To ensure smooth force traces and good quality in the EMG signal, the sEMG and force trials were selected for further analysis based on the following criteria: (1) There was no sudden change (i.e., larger than 20% MVC/s) in the up-ramp force; (2) The force variability during the steady state force was low (within ± 2 standard deviation (SD) of background force level); and (3) The sEMG signals had a P-P baseline noise < 20 µV and signal to noise ratio > 5.

For each subject, three trials at each force level were selected based on the preceding criteria for further analysis. The data collected include force generated in abduction (Fx)
and surface EMG signal. Each of the trials was then converted to MATLAB data and was processed.

The data that were recorded during the constant force phase of each trial were extracted. The channels containing the largest amplitude signals for each trial were then selected and these data sets were used for subsequent analysis. The median frequency of this portion of each trial was then found by calculating the area under the power spectrum curve and finding the frequency corresponding to 50% of the area. The range was calculated in a similar manner with the upper bound represented by the frequency corresponding to 87.5% and the lower bound represented by the frequency corresponding to 12.5%. Data from the single differential electrode were used for power spectral analysis only.

Decomposition of the data recorded using the sensor array electrode was performed using the Delsys decomposition system. Discriminated MUAPs were further filtered using a spike-triggered averaging (STA) method [10]. The STA derived MUAP shapes were used to determine the p-p MUAP durations for each force trial or the trials in which the sensor array electrode were used. The results for each subject were then compared across electrode types in order to determine if there was a significant difference between the single differential electrode and the 5 pin sensor array. Comparisons were also made between the contralateral and affected side of each stroke subject for each electrode. Results

Data from the two types of electrodes were compared using the median frequency and frequency range values calculated.

A total of 72 trials were used in the analysis; there were a total of 24 trials taken from control subjects and 48 trials from stroke subjects (24 for contralateral, 24 for the corresponding paretic). Fig. 3 shows the plot of median frequency vs. force for one of the control subjects and a plot of median frequency vs. force for one of the three stroke subjects. In all three populations (i.e. control, paretic and contralateral) it was found that the median frequencies measured using the sensor array were significantly less than those reported by the single differential electrode at a 95% confidence level.

Despite these statistical differences in median frequency, the range of the frequencies did not differ in a statistically significant standard pattern between the two electrodes. In addition, there was no consistent trend between the median frequency and force level.

Comparisons between the two sides of each stroke subject resulted in an observable difference between the stroke and paretic median frequencies for both types of electrodes. Figure 5 shows the plots of median frequency vs. force using sensor array data. As seen in Figure 5, there were three different relationships detected between median frequencies in the stroke and paretic sides. Subjects 1 and 2 showed little difference between the stroke and contralateral while Subject 3 showed contralateral median frequencies being greater than paretic median frequencies. All of these relationships were confirmed through the use of a Rank Sum test at a 95% significance level.

![Figure 3: Sample Force vs. Median Frequency Plot for Control and Stroke Subjects. (a) Control single differential and sensor array data (b) Stroke single differential and sensor array data](image)

![Figure 5: Force vs. Median Frequency plots stroke subjects featuring sensor array data](image)
MUAP duration data is plotted in Figure 6 for Subject 3; the median paretic duration was found to be greater than the median contralateral duration. For Subject 1 it was found that the median P-P duration for the contralateral side was slightly smaller than that of the paretic side and for Subject 2 the median P-P durations of contralateral and paretic were approximately equal and for Subject 3 the paretic duration was much greater than the contralateral duration.

The magnitude of the differences in the median frequency between the two sides of each subject, as well as the trend of the median frequency as a function of force was not consistent within a subject and also differed between the two recording electrodes.

![Subject 3 P-P Duration Histogram](image)

**Fig. 6:** P-P duration histogram for Subject 3, the red line represents the median paretic duration and the blue line represents the median contralateral duration.

### III. DISCUSSION

The primary objective of this study was to characterize changes in median frequencies in the power spectrum of surface EMG signals between the paretic and contralateral side of individual stroke subjects and to evaluate whether these differences were related to changes observed in MUAP duration. A second objective was to determine whether electrode type would alter stroke comparisons.

Our results matched our expectations based on the configuration of each electrode. The EMG median frequency signal recorded from the sensor array electrode was much greater than the median frequency of EMG recorded by the single differential electrode as the distance between the probes on the sensor array is half of the distance between the bars on the single differential electrode.

Regarding the comparisons between the two sides of our stroke subjects, when the results were compared with the clinical data it was found that the subject with relatively low Chedoke and Fugl Meyer scores had contralateral median frequencies that were significantly greater than the paretic median frequencies. For those subjects who achieved higher scores on their clinical assessments, the paretic median frequencies were approximately equal to the contralateral median frequencies. These results indicate a correlation between the clinical assessments and median frequency differences between the two sides of stroke. It is also worth noting that in two of the three subjects, the median frequency differences also correlated with their respective median P-P durations. The changes in MUAP duration of subject #3 may be indicative of (severe) muscle atrophy that may target type II muscle fibers which shift the MUAP durations lower or severe atrophy leading to a more distant recording site, thereby reducing the recorded MUAP duration.

However, these results show that the correlation between action potential duration and median frequency of the surface EMG power spectrum is complex and further investigation is required to fully understand the utility value of power spectral analysis of the surface EMG for discerning the relative contributions of neural and muscular factors to paresis in stroke.

### References


