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Vibromyographic Quantification of Voluntary Isometric Contractile Force in the Brachioradialis

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***Abstract*—This study investigated the ability of vibromyography (VMG) to accurately represent voluntary forearm muscle contractile force during attempted-isometric contraction of the brachioradialis. VMG signals were collected from the brachioradialis of healthy adult men (mean age, 26.6 ± 9.8 years, N=24) during attempted-isometric contraction over a force range of 4.45N to maximum sustained load. The VMG signals were decomposed using wavelet packet analysis techniques, and the corresponding wavelet packets were utilized in a multiple regression model for parameter reduction and identification of signal components which best correlated to muscle force. It was observed that just two wavelet components were sufficient to accurately predict muscle force (R^2 = 0.984, $P < 0.0001$). The signal force relationship observed is monotonic, though quadratic in form. More importantly, the wavelet data was able to predict *Absolute* force output of the brachioradialis *without* normalization or prior knowledge of a subject's maximum voluntary force. These data show that VMG recordings are capable of providing a monotonic relationship between VMG signal and muscle force. Moreover, in contrast to EMG technology which can only provide relative force levels, VMG appears to be capable of reporting absolute force levels, an observation which is expected to lead to numerous applications in medicine and rehabilitation**

***Keywords* — Vibromyography, Mechanomyography, Muscle Force Measurement, Wavelet Analysis, Electromyography**

I. Introduction

Electromyography (EMG) is commonly used to assess voluntary contractile muscle force despite its limitations. The most common practice is to integrate a rectified EMG signal to arrive at a measure of muscle activity, which can subsequently be translated to muscle force [1,2]. Unfortunately, this technique can only provide relative relationship between the recorded signal and muscle force, such that comparisons cannot be made from day to day, or from person to person. These limitations of the EMG are, in part, a result of acquiring a differential signal of a traveling wave. Mechanomyography is the measurement of muscle activity based on motion of the muscle during contraction [3]. Vibromyography (VMG) is a technique of using low-mass accelerometers to record the radial vibration of the muscle fibers. VMG offers a low cost, single-point measurement alternative to EMG assessment which has the potential to acquire more reproducible assessments of muscle force.

VMG offers several advantages to EMG including simple reliable assessment of contractile muscle force, insensitivity to skin condition such as electrical resistance and single point measurement. Here we use Vibromyography paired with wavelet packet decomposition [4,5] to resolve voluntary contractile force in the brachioradialis during elbow flexion.

II. Methods and Materials

A. Approval

The study protocol was approved by the Human Subjects Research Review Committee at the State University of New York, Binghamton. During screening, subjects' age, height, weight and pertinent medical history were obtained.

B. Subjects and Study Design

Inclusion criteria for this study were healthy adult men with no current fractures, bone disease, neuromuscular disease or systemic illness and the capability of providing informed consent. After removing jewelry and arm coverings, subjects stood with their backs flat against a wall. The subjects' left elbow was positioned near the body and against the wall (long axis of the body vertical and parallel to the surface), and the forearm was anti-parallel to the wall (10° from supine, open palm). An accelerometer (Kistler Corporation, model 8304B2) was placed on the skin above the belly of the brachioradialis using 1 inch wide double sided adhesive tape (3M Corporation, United Kingdom PLC). For stability, the lead was also taped to the skin and a wide elastic band was placed around the forearm over the electrode.

C. Protocol

Mechanical resistance was suspended from the wrist and loads were increased from 0% to 100% of the subject's MVC in 4.45 Newton increments. We define 0% MVC as only the force of gravity acting on their forearm and 100% MVC is the maximum load that the subject could hold while maintaining the posture described above, allowing subjects to serve as their own controls. Recovery time was allowed between lift to avoid unnecessary introduction of fatigue (at the discretion of the subject). A VMG recording was taken consisting of 2^{14} data points, corresponding to 2^n data points required by the wavelet analysis algorithm, during each lift beginning when the subject was stable and in position. All contractions were attempted-isometric and wrist motion > 5 cm in any direction invalidated the lift; data for each subject was collected during a single session.

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D. Data Acquisition and Analysis

Analog VMG signals were collected using a Kistler K-beam capacitative accelerometer (Model 8304B2), pre-amplified by a K-Beam 5210 power supply then passed through a 1/1,000 voltage divider. Signals were then digitized using a Biopac MP35 data acquisition unit (Biopac Systems, Inc., Goleta, CA) sampling at 5 kHz with an anti-aliasing filter at 1.0 kHz (24 bit A/D resolution, DC coupled, 5k gain). Post processing of the digitized signals was performed on blinded samples using customized software code in Mathematica V 5.2 (Wolfram Research, Inc., Champaign, IL) and results confirmed with Origin V 6.1 (OriginLab Corporation, Northampton, MA).

VMG signals from each subject exhibited similar, non-monotonic relationship between the RMS of the VMG signal and force including a "tailing off" of the signal beyond ~ 65% MVC. This behavior was expected and in agreement with the findings of other studies involving similar muscles under voluntary control [6,7,8,9,10].

Ability of RMS values of *single* sub-lists to monotonically represent force over the entire range of attempted-isometric contractile force for each subject was compared. Pooled data was used to build a multiple regression model and examine the RMS values of the wavelet sub-lists in physiologically relevant frequency ranges (i.e. 10~150 Hz).

III. RESULTS

The experiments included twenty-four healthy male volunteers (mean age 26.6 ± 9.8 years).

Frequencies between 40 and 120 Hz consistently tended to have superior ability to indirectly measure force and a one-way ANOVA showed no statistical difference in the algorithms resolving power ($P < 0.001$) for sub-lists associated with the three highest correlation coefficients (wavelet levels seven sub-list 3 (7.3), 8.4 and 8.5, R^2 value based on second order polynomial model). Standard errors associated with these sub-lists were small (Figure 1 a, b).

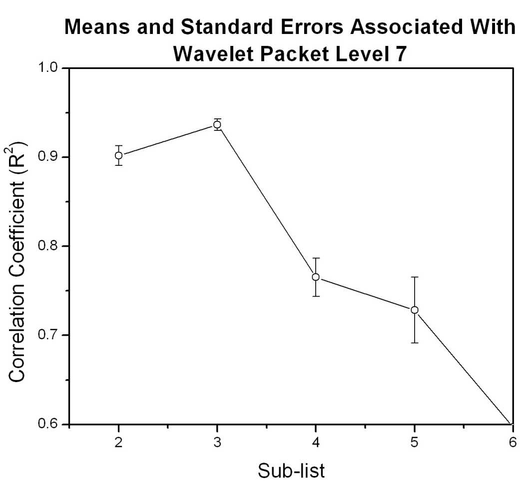

Figure 1a: Means and standard errors represented as error bars on their associated with the ability of RMS values from single sub-lists of wavelet coefficients to represent absolute force produced by a muscle during isometric contraction over the entire range of force the muscle is capable of producing. Notice the very small standard errors in the sub-list 2-4 region. Standard errors are associated with regression coefficients (RMS vs. muscle force) of sub-lists in wavelet level 7

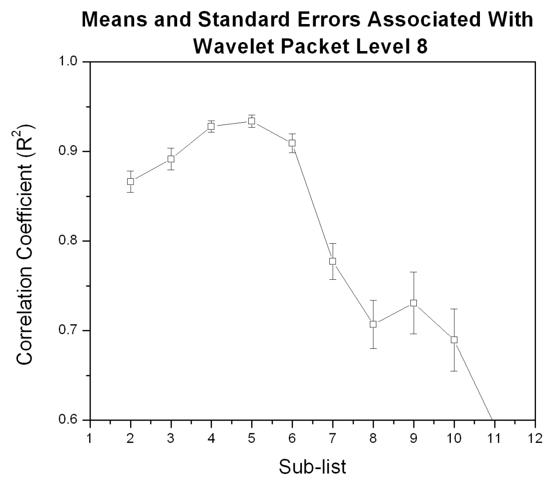

Figure 3b: Means and standard errors represented as error bars on their associated wavelet level (similar to Figure 1a). Notice the very small standard errors in the sub-list 2-6 region. Standard errors are associated with regression coefficients (RMS vs. muscle force) of sub-lists in wavelet level 8.

Multiple regression models identified the two most significant factors (sub-lists) contributing to overall R^2 (Figure 2).

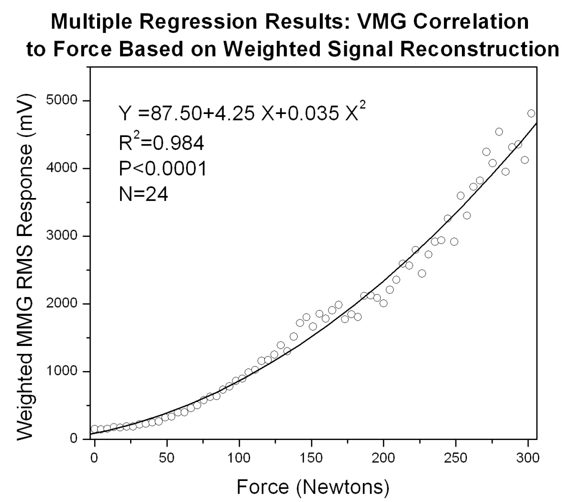

Figure 2: Multiple regression results based on weighted RMS values of wavelet level 9 sub-list 7 (9.7) and 9.9.

IV. DISCUSSION

This study is the first to correct for a known non-monotonic correlation to force from a skin surface myogram during voluntary contraction. This may be due to several factors: 1) Most studies have modeled myographic signals from muscle contractions as stationary. Clearly this model does not reflect the true nature of these signals and we have applied a wavelet analysis technique designed specifically for non-stationary signals. 2) We used a 24-bit A/D converter, which has significantly better resolution than the devices used in many other studies. This allowed us to examine parts of the VMG spectrum that would be considered noise when using 10 to 16-bit systems commonly used in other labs. 3) We used an accelerometer (Frequency response flat to 300 Hz) to record VMG signals which are more sensitive to high frequency vibrations than other commonly used MMG devices such as piezoelectric contact sensors, velocity meters, laser position sensors and air or fluid coupled microphones. 4) Current theory regarding muscle fiber recruitment strategies does not lead researchers or practitioners to believe that tracking isolated frequency bands will result in a measure of muscle force. 5) The legacy that previous research has left includes the idea that the frequency spectrum of the VMG signal shifts with changing levels of effort, leaving no historical support for the idea that narrow frequency bands might contain enough information to be an indirect measure of muscle force.

Despite the remarkable correlations between observed frequencies and force in our sample population, further study will be required to ascertain the degree to which this relationship holds true for specific age/athletic ability/ethnic groups. Future studies involving other muscles, will address the well-known problems of varying joint angles and the introduction of fatigue and expect to identify different signal components that are relatively unaffected by either as well as assess repeatability of the measure.

Although the myographic responses observed here were in response to controlled stimuli and resulted in limited movement, muscles under less controlled motion are known to present more complex dynamics which will pose a significant challenge to future studies. We also recognize that motion limits signal acquisition time and wavelet analysis (especially of higher wavelet levels) requires a significant number of data points. This presents a problem similar to one commonly encountered when using Fourier analysis, however wavelet decompositions offer considerably more flexibility than Fourier transforms including, but not limited to the location of frequency components in time.

Although these results are supportive of our initial hypothesis, certain aspects of the experimental design limit the interpretation of these results. First, forces were incrementally increased and although time was allowed in-between lifts in an effort to minimize fatigue, it remains a possibility that fatigue was introduced to some degree. Second, MVC is subjective and very dependent on the motivation/desire of the subject to perform. Thirdly, to an extent, subjects self-selected for the study, with knowledge that maximal exertion levels would be required on their part, which may suggest a selection bias based on subjects' subjective opinion of their own strength.

V. Conclusion

We suggest that these initial findings using wavelet analysis are consistent with the hypothesis that limiting components of myographic signals can reveal a resultant signal with significant force resolving power, particularly in the 80 to 100% MVC region. We have identified components of myographic signals collected from the brachioradialis with an accelerometer during attempted-isometric contraction that exhibit a reliable, non-monotonic correlation to force. Further, this relationship is based on *absolute* force and is *not* normalized to 100% MVC of the subject, making it ideal for use when conditions do not allow for collection of a representative 100% MVC signal.

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