Vibromyography for the assessment of voluntary muscle effort

The ability to non-invasively assess voluntary muscle effort has wide application in physiologic studies, sports and rehabilitation medicine, as well as movement science. Traditionally, surface electromyography (sEMG) has been used for such assessments, but sEMG has several significant limitations arising from the fact that an estimate of muscle mechanical effort is being obtained from an electrical potential measurement made at the skin surface. As a result, it can be difficult to compare recordings from different muscles on the same person, on the same muscle over a period of days or weeks, or between the same muscle on different individuals. In addition, muscle fatigue studies are difficult as EMG activity tends to increase with increasing fiber recruitment, even though muscle effort is decreasing[1].

To overcome the limitations associated with using sEMG recordings to evaluate muscle effort, an increasing number of investigators have come to rely upon vibromyography (VMG), or the recording of muscle fiber vibrations, to estimate muscle effort levels[2]. The development of microelectromechanical (MEMS) accelerometers has contributed greatly to this transition as extremely sensitive, very low noise sensors are now available at reasonable cost.

Translating VMG measurements into muscle effort, however, is still challenging due to the nature of muscle motor unit recruitment processes. To increase muscle force, the nervous system can increase the number of motor units activated, and/or increase the firing rate of each motor unit; in general, both occur simultaneously. Correspondingly, as muscle force increases, vibrations recorded from the muscle body appear to decrease in amplitude while increasing in frequency as fusion of the motor unit twitches occurs. This phenomenon is well known from classic *ex-vivo* muscle stimulus-response studies (c.f. Figure 1)[3].

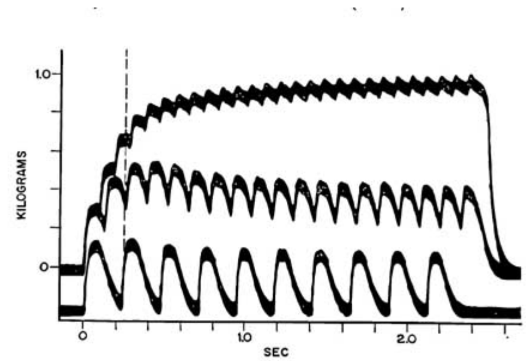

Fig. 3.6.3. Isometric tension responses of the soleus of a cat. Stimulation rates are (from bottom to top): 4.2, 7.5 and 10 per second. Adapted from ROSENBLUETH and RUBIO (1960). See text for explanation of vertical dashed line.

Figure 1 – Muscle vibrations decrease in amplitude and increase in frequency with increasing force output (from Rosenblueth & Rubio, 1960)

It is the complex summation of muscle fiber twitches which gives rise to macroscopic muscle force generation, yet these twitches are often masked by low frequency muscle body motions, physiologic tremor, and motion of the body part under study (Figure 2). If these low frequency components are included in the VMG recording, accurate muscle effort assessments cannot be obtained[4].

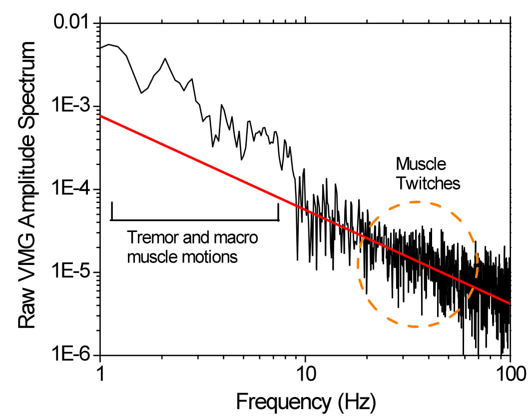

Figure 2. Frequency spectrum of raw VMG recording demonstrating intrinsic low frequency "noise", below approximately 10 Hz, which can mask muscle fiber twitch information.

The Sonostics BPS-II VMG transducer package, designed to work in conjunction with the BIOPAC MP-150 and MP-36 data acquisition systems overcomes these challenges of VMG application through the use of electronic bandpass filtering combined with wavelet packet analysis (WPA). The WPA algorithm weights the muscle fiber twitch information appropriately so as to provide a linear relationship between the VMG recording and muscle effort.

Sonostics BPS-II VMG Transducer Characteristics	
Sensitivity	50 V/g
Band Pass	20-200 Hz
Noise level	16 mV rms

The integral high sensitivity, low noise MEMS sensor, combined with the filtering characteristics and wavelet packet analysis results in a processed VMG signal which closely maps to voluntary muscle effort as assessed by dynamometer calibration studies (Figure 3).

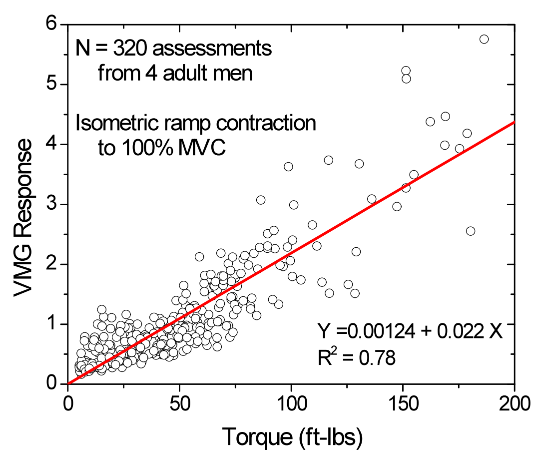

Figure 3. Correlation between processed VMG data and muscle effort as obtained from the vastus lateralis during dynamic contraction.

Application 1: VMG in the assessment of knee muscle balance

One limitation of sEMG is poor reproducibility. The irreproducibility results from the EMG being a differential voltage measurement, and therefore two electrodes must be attached to the skin. This means that small changes in sensor positioning as well as variations in skin preparation can significantly influence the magnitude of the recording. Consequently, comparisons between absolute muscle effort levels obtained during different recording sessions, between different muscles on the same individual, or between individuals are of questionable value.

The single sensor aspect of VMG recording, combined with the minimal influence of skin condition serves to significantly improve both reliability and reproducibility of VMG muscle effort recordings between muscles and between individuals. One benefit of being able to compare recordings between muscles and between people is the ability to undertake muscle balance assessments. For example, risk of anterior cruciate ligament (ACL) tears is strongly influenced by the level of imbalance between quadriceps muscle effort and hamstring muscle effort during knee extension (i.e. Q/H ratio)[5]. VMG analysis permits real-time assessment of muscle effort during functional activity. Figure 4 shows the peak Q/H ratios obtained from 35 young female athletes performing a side lunge. Note that two individuals demonstrate Q/H ratios greater than 4, a level associated with high risk of ACL injury[6].

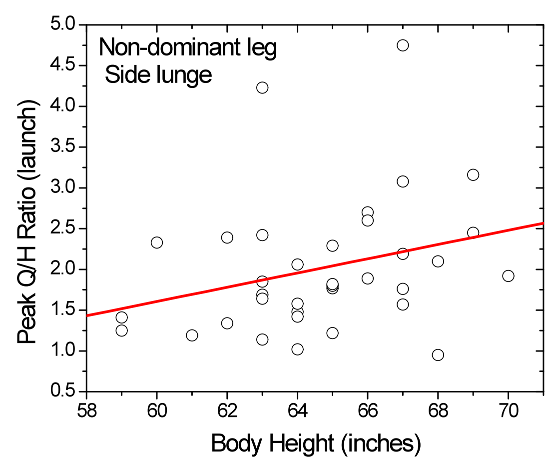

Figure 4. Knee muscle effort assessed by VMG during the push-off phase of a side lunge (average of 3 repetitions; 35 young female athletes). A significant dependence on body height is observed as well as very high Q/H ratios in two individuals.

Application 2: VMG in the assessment of muscle effort during fatiguing exercise

Another limitation of sEMG recordings is their general inability to track muscle effort during fatigue. This is a result of the sEMG being a recording of the electrical activity of a muscle, so that as the nervous system recruits additional motor units (motor unit rotation)[7] as previously activated units fatigue, the sEMG signal increases, even though muscle effort is decreasing or staying constant. Because VMG is a recording of the mechanical activity of the muscle motor unit, VMG accurately tracks muscle effort throughout a fatiguing exercise, as seen in Figure 5.

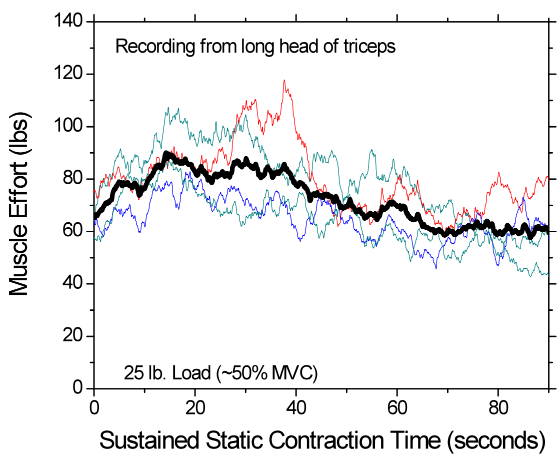

Figure 5. VMG recordings obtained during sustained static contraction (50% MVC) of the triceps. Four recordings (color) were obtained over a four week period of time. The black line reflects the average of the four recordings. Note consistency of recordings over repeated recording sessions, as well as relatively constant muscle effort consistent with maintenance of constant load.

Conclusions

Vibromyographic analysis utilizing the Sonostics BPS-II in combination with a BIOPAC data acquisition system provides a simple and reproducible means for assessing absolute muscle effort. The features of VMG analysis may be of particular interest to investigators interested in making muscle effort comparisons over time, comparisons between muscles (i.e. muscle balance), or comparisons between individuals. With a temporal resolution of 16 ms, the dynamics of muscle activation can readily be studied, including not only estimation of peak effort but time to peak effort. Moreover, when combined with kinematic analysis, calibration data can be utilized to provide estimates of the actual forces being generated by the muscle under study.

References

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