Application Note 250  Vibromyography for the assessment of voluntary muscle effort

The ability to noninvasively 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.

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. 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 theoretically 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).

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.

The Sonostics BPS-II VMG transducer package, designed to work in conjunction with the BIOPAC MP160/150 and MP36R 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.

<table>
<thead>
<tr>
<th>Sonostics BPS-II VMG Transducer Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>Bandpass</td>
</tr>
<tr>
<td>Noise level</td>
</tr>
</tbody>
</table>

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 either dynamometer calibration studies (Figure 3).
Muscle effort consistent with maintenance sessions, as well as relatively constant recordings over repeated 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). 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.

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 fact that sEMG is an electrical recording, so that as the nervous system recruits additional motor units (motor unit rotation) when 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 activity, VMG accurately tracks muscle effort throughout a fatiguing exercise, as seen in Figure 5.

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 30 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