MAXIMISING THE RESOLUTION OF EMG CHARACTERISTICS FROM DYNAMIC CONTRACTIONS BY COMBINING A MUSCLE MODEL AND WAVELET ANALYSIS

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INTRODUCTION

When utilising surface electromyography (EMG) the amplitude and / or frequency content of the processed EMG signals can be used to investigate neural aspects of muscle function (De Luca, 1997). However, signal interpretation is complicated by the influence of a number of factors in addition to neural strategy and remains the subject of ongoing debate (Farina *et al.*, 2004). This is particularly true for dynamic contractions (Beck *et al.*, 2006), where the signals are non-stationary and require processing with a combined time–frequency approach.

The purpose of this study was to develop methods to improve the measurement and understanding of EMG signal characteristics from dynamic contractions. Based on a continuous wavelet transform (CWT) time–frequency analysis, the methods comprised of: (i) a muscle model to estimate the fibre kinematics beneath the recording electrodes; and (ii) selection of wavelet parameters to give the required resolution properties of the instantaneous amplitude (IAMP) and mean frequency (IMNF) estimates. Given the added dimension in resolution provided by the CWT, neglecting the muscle model would hamper the interpretation of time dependent EMG as the length, velocity and position of the fibres would be unknown.

METHODS

Eight strength trained male volunteers (age 27.5 ± 5.0 yrs, body mass 81 ± 11 kg, height 1.77 ± 0.05 m) gave informed consent prior to performing maximal effort knee extensions. Eccentric–concentric contractions at velocities ranging from ±50 to ±300° s^{-1} (Yeadon *et al.*, 2006) were conducted on a Cybex NORM dynamometer (CSMI, USA).

EMG signals from the rectus femoris (RF), vastus medialis (VM), and vastus lateralis (VL) were recorded using active bipolar electrodes (Biovision, Germany). Synchronous dynamometer and EMG signals were recorded at 2 kHz. The dynamometer data were used in a Hill-type muscle models, scaled to each subject, to give the force, length and velocity characteristics of the VM, VL and RF.

EMG signals were processed using a CWT analysis to provide estimates of the IAMP and IMNF. This employed a complex Morlet wavelet function (Wavelet Toolbox in Matlab):

$$\Psi(t) = \frac{1}{\sqrt{\pi f_B}} \times \exp\left(2i\pi f_C t\right) \times \exp\left(\frac{-t^2}{f_B}\right) \quad \text{eqn. 1}$$

where the wavelet shape is described by the bandwidth parameter, f_B and the central frequency parameter, f_C. The value of $f_C\sqrt{f_B}$, the wavelet shape factor, sets the resolution properties of the IAMP and IMNF estimates.

The influence of the wavelet shape factor on resolution was examined based on specifying time, angle and frequency resolutions for the knee extension task.

RESULTS AND DISCUSSION

The muscle model illustrated that the fibre kinematics could deviate markedly from those of the joint. Across eccentric and low concentric velocities the fibre velocity was up to 50% lower than that of the muscle-tendon complex for extended knee angles and up to 50% higher at flexed knee angles. Across concentric velocities the fibre length showed marked non-linearity with the length up to 12 mm shorter across mid-range joint angles. These differences were greater for the RF than the vastii.

For investigating time-based events a single velocity independent value of the wavelet shape factor gave the optimal time and frequency resolutions of the IAMP and IMNF estimates. Resolutions of better than 100 ms and 10 Hz were achievable across all trials using a wavelet shape factor of 4 (Figure 1). For investigating angle-based events wavelet shape factor selection was velocity dependent; at low velocities a high value provided the optimal angle and frequency resolutions, and vice versa at high velocities. Setting resolution limits of 10° and 10 Hz, and the requirement to minimise their sum, the optimal wavelet shape factor was 6 in the low velocity trial, and 3 in the high velocity trial (Figure 1). Individual values for f_B and f_C, were found by minimising the entropy of the resulting wavelet coefficients; giving f_C, of 1.5 and f_B, obtained from the optimised shape factor values given above.

Thus, through careful selection of the wavelet shape factor, the IAMP and IMNF can be estimated with resolutions specific to the investigation, and thereafter directly related to the instantaneous muscle fibre kinematics predicted by the muscle model.

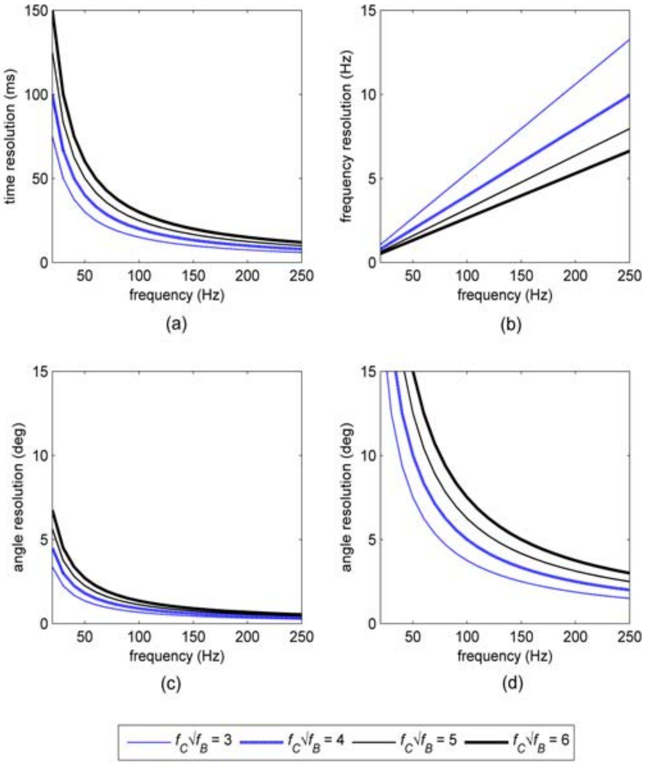

Figure 1 – Time, frequency and angle resolutions as a function of frequency. (a) time; (b) frequency (c) angle, (velocity = ±45° s^{-1}); (d) angle, (velocity = ±250° s^{-1}).

CONCLUSIONS

Combining the muscle model and CWT results allowed for a substantial improvement in measuring and interpreting time dependent EMG data since the length, velocity and position of the muscle fibres are known at the same time as specific frequency and amplitude events.

REFERENCES

Beck *et al.* (2006). *J Electromyography Kinesiol.*, **16**, 531–539.
De Luca, C.J. (1997). *J. Appl. Biomech.*, **13**, 135–163.
Farina *et al.* (2004). *J. Appl. Physiology*, **96**, 1486–1495.
Yeadon *et al.* (2006). *J. Biomech.*, **39**, 476–482.