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A Novel Approach to the Analysis of Muscle Synergies Based on the Average Threshold Crossing Technique

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Purposes

This work aims to investigate the application of the Average Threshold Crossing (ATC) technique in the analysis of muscle synergies.

First the ability of the technique to approximate different modulations of the electromyographic (EMG) data was assessed via simulations.

Then muscle synergies from ATC envelopes were extracted from on real EMG data collected during over ground walking and compared to the ones obtained from the standard envelopes.

ATC Technique

The ATC technique evaluates the muscle activity integrating on a time window of fixed length the number of times the EMG signal exceeds a threshold.

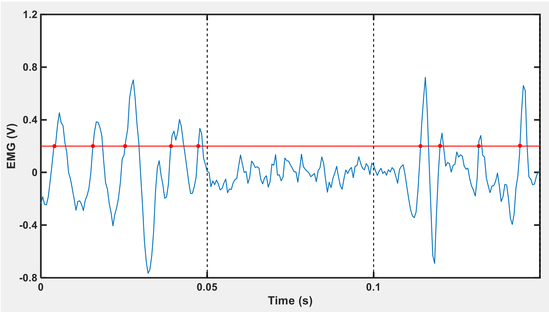

Figure 1. ATC Extraction. The **blue** line represents the EMG signal, the **red** horizontal line the threshold level abd the **black** dashed vertical line the beginining and the end of the ATC Windows.

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Simulation

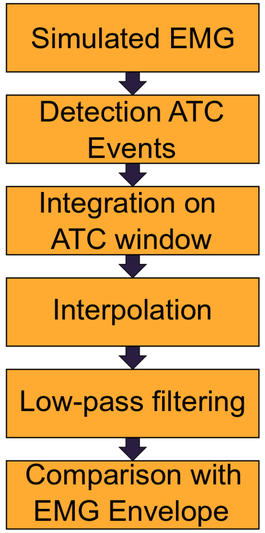

Figure 2. Simulation Flow Chart

Five hundred different modulations were generated by synthesizing EMG data, produced by multiplying colored noise by a Gaussian waveform, and adding white noise to obtain a SNR of 10 dB.

For each of these modulations, the EMG envelope was extracted by applying a cascade of a high pass filter, a rectifying stage, and a low pass filter.

The ATC envelope was computed using three different window lengths (10, 20 and 50 ms) and three different threshold values (2.5, 3 and 3.5 the RMS noise level). The ATC envelope was then resampled to have the same number of points as the initial signal, and low-pass filtered to smooth the discontinuities.

Finally, the R2 between the ATC envelope and the portion of the EMG envelope above the threshold level used to estimate the ATC was computed.

Due to the stochastic nature of the simulated timeseries, multiple repetitions with the same parameters, provided slightly different outputs. For this reason, each one of the modulations was generated 100 times and the effect of averaging a different number of epochs on the ATC envelope was evaluated.

The results of the simulation are shown in Table I

		ATC Threshold Value		
ATC Window Length	**Epochs Averaged**	**2.5 x RMS Noise**	**3 x RMS Noise**	**3.5 x RMS Noise**
10 ms	1	0.51 (0.35)	0.74 (0.21)	0.81 (0.16)
20 ms	5	0.71 (0.13)	0.87 (0.10)	0.94 (0.04)
50 ms	10	0.75 (0.09)	0.90 (0.06)	0.96 (0.02)
10 ms	1	0.51 (0.34)	0.74 (0.20)	0.82 (0.14)
20 ms	5	0.70 (0.12)	0.87 (0.08)	0.94 (0.04)
50 ms	10	0.74 (0.08)	0.90 (0.05)	0.96 (0.02)
10 ms	1	0.46 (0.36)	0.72 (0.22)	0.81 (0.17)
20 ms	5	0.67 (0.14)	0.85 (0.09)	0.94 (0.04)
50 ms	10	0.71 (0.09)	0.88 (0.06)	0.96 (0.03)

Table I. R2 values obtained from the simulation (mean (std))

Test on EMG Data

The EMG data collected during over ground walking of 8 healthy subjects were analyzed using a 20 ms ATC window, with threshold value equal to 3 times the noise RMS value.

The data was averaged over 5 gait cycles. This set of parameters to estimate the ATC envelope appeared to provide a good trade-off between the quality of the reconstruction and the need to use a low threshold value to fully capture the amplitude modulation of the EMG data.

The average cosine similarity between the weights of the muscle synergies derived from ATC and the ones extracted using the traditional envelopes was 0.92 (±0.05), while the average value of ZLCC for the temporal coefficients was 0.93 (±0.06).

Below an example of synergies extracted from ATC envelopes (window length 20 ms, 5 steps average). and standard EMG envelopes.

Muscle List:
1. *Gastrocnemius*
2. *Soleus*
3. *Tibialis Anterior*
4. *Peroneus*
5. *Vastus Lateralis*
6. *Vastus Medialis*
7. *Biceps Femoris*
8. *Semitendinosus*

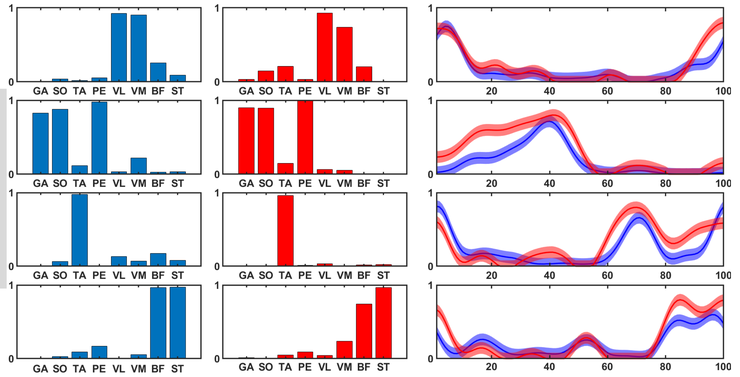

Figure 3. Synergy Comparison. In blue the decomposition from the classic EMG envelopes and in red the results obtained using the ATC.

Conclusion

1. Selecting the proper threshold and window length, it is possible to obtain R^2 similarity values above 0.8 between ATC and EMG envelopes. This result improves by averaging the ATC envelopes over multiple epochs.
2. The synergies extracted using the ATC technique showed high similarity with the ones obtained with a standard approach using the EMG envelopes for both weights and temporal activations.