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Introduction: Epoch-based electromyogram (EMG) amplitude estimates have not incorporated signal whitening, even though whitening has demonstrated significant improvements for stream-based estimates. Epoch-based algorithms are necessary, for example, when functional electrical stimulation (FES) of one muscle is controlled by voluntary EMG recorded from another muscle, since the voluntary EMG is interrupted (blanked) to remove the stimulus artefact. This paper presents new epoch-based algorithms, for both single- and multiple-channel EMG, which include an adaptive whitening stage.

Methods: The adaptive whitening stage is sequentially comprised of a fixed whitening filter, an adaptive Wiener filter, and an adaptive gain corrector. These processes are cascaded with the noise-rejection stage, present in all EMG amplitude estimators, and then realized using the least squares filter design method. Current stream-based algorithms are implemented using the window filter design method. Since the least squares design method creates optimized filters (which tend to require fewer coefficients), the startup transients associated with the realized filters can be minimized. In epoch-based applications, each data segment can be as short as 13 ms (e.g., FES at 30 Hz, with a 20 ms blanking interval). Applying existing stream-based algorithms is not possible, since the length of the filter startup transients can exceed the duration of the epoch. These transients must be discarded, and the remaining EMG data used to form an amplitude estimate. Therefore, the startup transients must be as short as possible so that enough data remain to produce a valid amplitude estimate.

To evaluate the performance of epoch-based EMG amplitude estimates, biceps and triceps EMG amplitudes were related to elbow torque during force-varying, constant-posture, non-fatiguing contractions via a dynamic linear relationship. Presumably, better EMG amplitudess would yield lower root mean square (RMS) errors in estimating joint torque from the EMG. In all cases, an EMG amplitude-to-torque model was fit (trained) on one contraction trial, then model error tested by applying the model to a separate contraction trial.

Results: Whitening single-channel EMG data provided a 9.1–12.5% improvement in RMS torque error over unwhitened single-channel estimates. Multiple (four) channels of EMG without whitening yielded an 11.5–14.3% improvement over unwhitened single-channel estimates. Multiple-channels with whitening provided an 18%–22% reduction in average error when compared to single-channel unwhitened estimates; and, at a FES stimulation rate of 12.5 Hz (using a 20 ms blanking interval), the average RMS error (at the best filter order) was 7.85% of maximum voluntary contraction. Filter orders ranged from 12–18 using the least squares filter design method (compared to 60 using stream-based algorithms).

Discussion: These results suggest that whitening can be used to improve EMG amplitude estimation for systems that require epoch-based estimates, such as FES. Approximately half of the reduction in error is due to whitening, while the other half can be attributed to the use of multiple-channel EMG. Also of note is that computing whitened single-channel estimates yielded roughly the same average error as multiple-channel estimates without whitening. Filter design via the least-squares design method might also be beneficial in stream-oriented algorithms when lower filter orders are beneficial (e.g., to reduce computational load in real-time applications).