Surface EMG Decomposition Requires an Appropriate Validation

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TO THE EDITOR: A major constraint in the analysis of motor unit activity in humans is that relatively few active motor units can be detected concurrently due to the high selectivity of needle electrodes commonly used for electromyographic (EMG) recordings. Furthermore, the accurate decomposition of intramuscular EMG signals is usually not possible at high muscle forces due to the many motor unit action potentials that overlap in time. De Luca and Hostage (2010) appear to have developed a noninvasive solution to these problems. They assert that it is possible to decompose surface EMG signals and detect with confidence the concurrent activity of 20–30 motor units at contractions up to the maximal force. Moreover, their decomposition method requires only four surface EMG channels.

The main difficulty associated with processing surface EMG recordings is the greater number of overlapping action potentials than that in intramuscular EMG. For example, the second discharges of motor units #17 to #24 in their Fig. 10 occur at a similar instant in time and thus the action potentials of these eight motor units must partially overlap. Indeed, close inspection of Fig. 10 suggests that even more action potentials overlap at this point in time and at other times throughout the recording, as can also be appreciated from the interference surface EMG signal (see their Fig. 8). This is not surprising given the many action potentials that contribute to the surface EMG signal at each instant in time. Consequently, relatively few action potentials of each unit are detected as isolated in time from those of other units (Nawab et al. 2010).

In principle, the overlapping action potentials can be disentangled by estimating the likelihood of each event in the multiple possible sets of matching templates. However, the global optimization of overlapping action potentials is a nondeterministic polynomial–type hard problem that cannot be solved by polynomial complexity algorithms (Ge et al. 2010). The maximal number of overlapping potentials that can be distinguished in each segment is practically limited by the size of the search space. A potential solution is to limit the search space to the most likely combinations and to include some constraints on the estimated discharge pattern (Nawab et al. 2010), but the likelihood of finding the correct solution decreases with the size of the search space (Ge et al. 2010). Consequently, the results achieved by De Luca and Hostage (2010) to decompose surface EMG signals are impressive. Such a remarkable achievement, however, requires an extremely convincing validation of the decomposition results.

The results of the study by De Luca and Hostage (2010) were tested with an approach called the reconstruct-and-test procedure (Nawab et al. 2010), which they suggest is superior to the two-sensor method (Mambrito and De Luca 1984). The new validation approach involves generating a synthetic signal from the decomposed trains of action potentials and reapplying the same decomposition method to this synthetic signal to which noise is added with a power similar to that of the residual in the first decomposition (see their Fig. 9 and detailed description by Nawab et al. 2010). The accuracy in the identification of each train of action potentials is then estimated in the same way as in the two-sensor method; that is, as the percentage of action potentials that are identified by the two decompositions with respect to the total. We beg to differ that such an approach provides a valid demonstration of the accuracy of the decomposition algorithm.

One of the problems with the reconstruct-and-test procedure is that missed discharges do not influence the index of accuracy. If the first decomposition does not detect a discharge time, the absent discharge will not be used to build the synthetic signal for the second decomposition. It is thus very likely that the second decomposition will not detect that missing discharge and thus will corroborate the error introduced in the first decomposition. Consequently, a disagreement in the results of the two decomposition methods is biased toward discharges detected by the first decomposition and not by the second, whereas there were no converse cases of discharges detected by the second decomposition and not by the first (their Fig. 10). This result differs from that obtained with the two-sensor validation method, where either of the two decompositions can miss a discharge time with respect to the other. Contrary to the two-sensor method, the reconstruct-and-test procedure is biased in that the signal used in the second decomposition depends on the result of the first decomposition and may lead to an estimation of 100% accuracy for a train of action potentials, even when a substantial number of discharge times are not identified.

Besides the failure to assess missed discharges, the reconstruct-and-test approach is not an appropriate validation method due to a more general issue. As reported by Nawab et al. (2010) and similar to many other decomposition methods, the decomposition algorithm used by De Luca and Hostage (2010) is data-driven, in that its output is identical when applied to identical signals. When the power of the residual signal from the original decomposition is low and the noise added to the synthesized signal is small, the original and synthesized signals will be relatively similar and thus the results of the two decompositions will be in close agreement, independent of the decomposition accuracy. As an extreme case, the accuracy index used by De Luca and Hostage will necessarily be equal to 100% for each train of action potentials when the residual signal is equal to zero. In practice, low power in the residual signal results in the algorithm being applied to two signals that are almost identical (as can be seen in Fig.
in De Luca and Hostage 2010), so that their decompositions will be necessarily very similar, which is incorrectly associated with high accuracy. It is worth noting that the issue of high similarity between signals is not only relevant for the reconstruct-and-test procedure, in which it is most critical, but also for the two-sensor validation method when applied to two surface EMG signals recorded concurrently from close locations, which will also be very similar. For this reason, appropriate application of the two-sensor method for validation of surface EMG decomposition needs to be performed with intramuscular EMG as the reference.

The decomposition method described by De Luca et al. (2006), improved by Nawab et al. (2010), and used by De Luca and Hostage (2010) has not been validated systematically with approaches other than the reconstruct-and-test procedure. In previous studies, De Luca et al. (2006) reported the results of only one decomposition analysis of surface EMG validated relative to an intramuscular EMG recording and, similarly, Nawab et al. (2010) described only one validation based on two surface EMG sensors (with the issues described earlier for the latter approach). It is surprising that De Luca and Hostage (2010) did not apply these classic validation methods to evaluate their results. Rather, the authors asserted that the classic validation approaches provide “a less rigorous and a less complete test” than the reconstruct-and-test procedure (Nawab et al. 2010).

The absence of a convincing validation for the decomposition method detracts from the impact of this work. The claim that the algorithm can identify 20–30 motor units per contraction with an accuracy >90% up to maximal force and using only four surface EMG signals suggests that the approach is far superior to even the most optimistic expectations in the field and that important theoretical problems in the discrimination of surface action potentials (Farina et al. 2008) have been solved. This accomplishment, however, requires a more convincing validation than that reported by De Luca and Hostage (2010). To allay our concerns and those of other investigators in the field, we propose that De Luca and Hostage decompose a set of synthetic surface EMG signals that we generate with a model and for which we know the discharge times of all the involved motor units. Although De Luca et al. (2006) have expressed reservations about the use of simulated signals to test the accuracy of a decomposition algorithm because simulated signals do not sufficiently challenge the algorithm, we would be more convinced by a successful outcome with this approach than by the more limited reconstruct-and-test procedure. If their algorithm can perform as well as they claim in this simple test, we would enthusiastically welcome such an advance in technology for this field.

REFERENCES