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CHAPTER 2

Reflections on EMG signal decomposition

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INTRODUCTION

During the past decade, considerable interest has been displayed by the clinical community in the concept of extracting as many motor unit action potentials (MUAPs) as possible from an EMG signal detected with needle electrodes. It was this very same interest that induced Adrian and Bronk (1929) to develop the first concentric needle electrode. In fact, they were directly interested in identifying both the shape and firing rate of the MUAPs. Sadly, the pursuit of assessing motor unit firing rate behavior has not flourished to the same extent as the pursuit of characterizing action potential shape. It is commonly suggested that technical limitations have hindered the interest in studies of firing rates; the complete truth embodies other factors. One is the complacency among practitioners to limit their quantitative measurements to behavioral aspects of the motor unit action potential (MUAP) shapes. Another is a lack of interest in the field of electromyography by individuals trained in signal processing techniques.

While the work of Buchthal and colleagues during the 1950s and 1960s paved the ground for quantitative measurements and application of the EMG signal, it also firmly established its painstaking manual approach of graphically measuring the morphological characteristics of individually detected MUAPs. The success this approach received among the clinical community overshadowed the need for a more comprehensive and more automated approach. Thus it was not by accident that the interest in accurately and automatically separating action potential trains in bioelectric signals originated not in the clinical community, but rather among researchers working to better understand the behavior of neuroelectric signals. The mid to late 60s produced a flurry of computer-based activity directed at identifying the individual action potentials and discharge times of neural activity by shape discrimination. Dominant among these pioneering attempts were the works of Gerstein and Clark (1964), Simon (1965), McCann and Ray (1966), Keehn (1966), and Glaser and Marks (1966). Applications to separation of EMG signals did not appear until a full decade later when the works of LeFever and De Luca (1978, 1982), Andreassen (1983), Guiheneuc et al. (1983) and Dorfman and McGill (1985) became known. Since those publications, the concept of automatically or semi-automatically deciphering the EMG signal has attracted the interest of and engendered contributions from researchers in many laboratories in several countries.

DESCRIPTION AND USEFULNESS

The term *decomposition* has been commonly used to describe the process whereby individual MUAPs are identified and uniquely classified from a set of currently active motor unit action potential trains (MUAPTs). The process of decomposition involves the breaking down of the superposition EMG signal that is recorded when more than one motor unit is active in the vicinity of the detection electrode. The concept of decomposition is depicted in Fig. 1. Identification refers to the categorization of the time of occurrences of the MUAP as well as the description of its morphological characteristics. From the above description it is apparent that the process of decomposing an EMG signal may range from a trivial task when only two MUAPTs with distinctly different MUAP shapes are present to a theoretical impossibility when many (say more than ten) MUAPTs with nearly similar and unstable MUAP shapes are present.

A decomposed EMG signal provides all the information available in the signal. The timing information provides a complete description of the interpulse interval, firing rate and synchronization characteristics; the availability of all the MUAPs which are discharged by a specific motor unit enables a more consistent expression of the shape by averaging the shape over a set of discharges.

The comprehensive, more accurate and more reliable information provided by decomposition finds applicability in both clinical and research environments. It is in fact a new tool which enables us to explore the workings of the nervous system in normal and dysfunctional modalities. In the field of neurology, the ability to measure the behavior of firing rates and synchronization of motor unit discharges holds the promise of more analytically

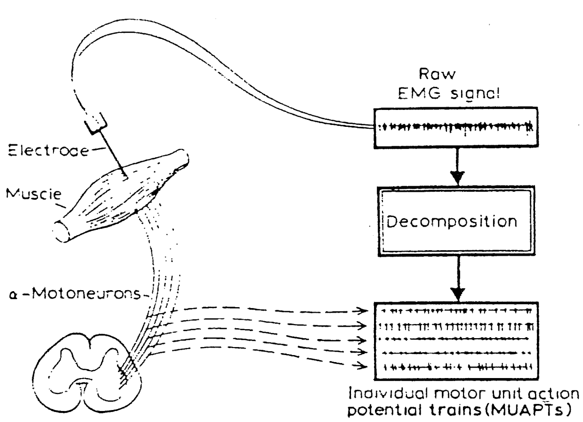

Fig. 1. A schematic representation of the decomposition of an EMG signal into its constituent motor unit action potential trains. (From De Luca et al., 1982)

classifying dysfunctions of CNS origin. Consider the potential advantages of diagnosing a CNS abnormality by inserting a needle into a muscle with no direct assault to the CNS. The ability to obtain more reliable representations of MUAP shapes by averaging over several correctly identified MUAPs of an individual motor unit provides a more accurate basis for diagnostics based on morphological measurements. Furthermore, the capability of storing and measuring numerous MUAPs makes more convenient the laborious process of obtaining normative data. In fact, it enables individual laboratories to obtain their own normative data, thus allowing them to develop improvements in methodologies and approaches for measuring the characteristics of the MUAPs.

In the field of neurophysiology, the decomposition technique provides a fresh new investigatory tool to a current investigatory armamentarium which is growing stale and fruitless. It is now possible to study the behavior of several concurrently active motor units and determine their characteristics beyond those relating to individual motor units and to discharge-to-discharge occurrences. It is now possible to search for information transmission within the nervous system beyond individual neuron-to-neuron interaction. We can now explore more comprehensively and more effectively the orchestration of neuronal activation within and among muscles. It will be possible to execute these studies in the cooperative human performing voluntary contractions and without destroying the environment of the system under investigation. Furthermore, any enhancement of knowledge obtained from fundamental studies on the normal CNS can only augment the clinical armament for performing diagnoses.

APPROACHES TO DECOMPOSITION

Due to the technical complexity of the methodology involved in developing decomposition algorithms, two different approaches have evolved. One will be referred to as *limited decomposi-*

tion and the other as *complete decomposition.* As implied by the name, complete decomposition consists of attempts at extracting all the temporal and morphological information from the signal. Limited decomposition settles for less; generally it consists of attempts at extracting as much morphological data as possible and whatever temporal information which may be available as a secondary effort in the process. Limited decomposition has the obvious advantage of requiring far less computational time, approaching real-time analysis. It may also be applied to partially decipher the EMG signals detected by standard concentric needle electrodes commonly used in clinical laboratories. These advantages present obvious attractions to the clinical practitioner. However, the convenience and attractiveness of limited decomposition presents the potential of tempting the developers and use of such techniques into overextending the proper usage and interpretation of the forthcoming data. For example, it is often tempting to classify MUAPs with relaxed identification criteria in order to speed up the decomposition procedure. Such approaches present an increased probability of false classification. The limited decomposition procedure is inherently unable to provide a continuous, accurate expression of the firing rates of the motor units because either no attempt is made to identify all the discharges of each contributing motor; or if an attempt is made, the accuracy of the identification is less than reliable, yielding erroneous information.

The complete decomposition approach requires much more involved algorithms and possibly novel approaches for detecting the EMG signal. A generic procedure would embody the following concepts:

(1) sample and store the EMG signals;
(2) resolve superposition of MUAPs;
(3) identify individual MUAPs;
(4) classify each MUAP to a particular motor unit;
(5) measure temporal and morphological information of the MUAPTs;
(6) verify the accuracy of the procedure.

Sufficiently intricate algorithms are not yet available to decipher the EMG signal in real time or at a sufficiently fast speed to make them useful in a clinical environment. It is certainly true that the efficiency of currently used algorithms could be improved by more effective coding. Also, the speed of the algorithms will inevitably increase with ever-evolving faster computers. However, there are inherent physiological and bioelectric limitations which pose challenging hurdles that have not been resolved satisfactorily to date and which, unfortunately, have not received much attention. There are: (1) the discharge-to-discharge variability of a MUAP belonging to a specific motor unit may vary dramatically when the MUAP contains contributions from only two or three muscle fibers. This behavior is due to the well known jitter phenomenon. (2) The shape of the MUAP will be modified if the detection needle moves with respect to the active fibers. This relative movement need only be minor; a displacement of 0.5 mm will cause dramatic modifications. The problem of movement is further accentuated by the fact that it is more likely to occur during relatively higher-force level contractions when higher-threshold motor units are active or, in general, when a larger population of motor units is active. Decomposition techniques yield particularly interesting and useful results when applied to these types of contractions. Algorithms that will be able to deal effectively with these disturbances require considerably more sophistication than is present in the current state-of-the-art methods. Approaches that have been successful in applications of artificial intelligence should be explored. Broman (1986), working in collaboration with our Center, has begun to study such an approach and has achieved some encouraging success.

Also, we should direct our attention to alternative configurations for detection surfaces in the needle electrodes. The simple concentric needle electrode, with its fixed architecture and geometry, has served as a useful reference instrument by which different groups or laboratories could obtain comparable data. However, it should not be allowed to stand as an impediment to the evolution of electrode geometries more suitable to decomposition requirements.

THE IDEAL DECOMPOSITION

It is reasonable to speculate when considering the advances being made in software engineering, computer engineering, neurophysiology and electrode technology, that in the near future it will be possible to develop a decomposition technique which will satisfy all the critical needs of the clinician and the researcher. Such a technique should embody the following functions:

(1) it should be able to decipher EMG signals detected at all levels of muscle contraction; contraction level should no longer be an impediment to neurological diagnosis and neurophysiological investigation;
(2) the decomposition should be completely reliable and accurate; that is, all of the identified MUAPs should be classified to the proper motor unit;
(3) all the discharges of a motor unit should be identified; this task requires the ability to resolve superpositions;
(4) as many as possible MUAPTs should be identified; at least five motor units should be decomposed in a 30% MVC contraction;
(5) the ability to sustain identification of MUAPTs should be maintained during slight needle movement;
(6) the decomposition should occur in real time if possible; and certainly in less than ten times real time; slower times become impractical in a clinical or otherwise busy environment;
(7) for the sake of compatibility with current standard practice, the decomposition technique should be able to employ conventional concentric needles; however, in the future, such a limitation need not apply.

Verification of accuracy

Given that an algorithm and technique are conceived to perform according to the required specifications, there remains the confounding issue of verifying its accuracy. This is a fundamental problem because the process of decomposing a stochastic signal into a unique set of pulse trains, in the presence of indeterministic disturbances presents a serious problem.

Any approach for measuring the performance of a decomposition technique by relying on modelled behavior of MUAPTs must be considered inappropriate at the present time, because no model exists which comprehensively describes the behavior of MUAPTs. It is often tempting to generate mathematical models of MUAPTs and synthesizing EMG signals by superimposing the trains, and subsequently testing the decomposition technique on the synthesized signal. Such tests are considered to have the advantage of knowing the exact nature and composition of the MUAPTs, and therefore would provide an objective means of comparing the outcome of the decomposition with the source. Unfortunately, such an approach is deceptive. The conceivable mathematical models could not capture the intricacies of the MUAPT behavior to properly challenge the algorithm. Such an attempt would fall short of its intended objectives; it would only prove the algorithm's ability to systematically execute a programmed procedure.

Approaches whereby the time history of decomposed MUAPTs is compared to that which is obtained by visual, manual procedures also lack conviction. Such approaches can only be executed on EMG signals which contain two or three MUAPTs. Algorithms which successfully decompose relatively simple EMG signals provide no assurance that correct decomposition will be obtained on more complex signals.

One infallible approach would be to use two EMG signals detected from two locations in the muscle during the same contraction. By placing two needle electrodes lengthwise along the muscle fibers so that the two electrodes detect some signals in common and some signals which are not shared. Now by decomposing the EMG signals from each electrode and comparing the time occurrences of all the MUAPs of each MUAPT common to both signals, it is possible to obtain an objective evaluation of the accuracy of the decomposition algorithm. If the signals are at least 10 s long, the probability that two identical MUAPTs (containing approximately 200 MUAPs) from each signal are both incorrectly decomposed is extremely slight. For completeness, this procedure should be repeated for various signals obtained during various force-varying paradigms. The importance of such objective evaluations cannot be overemphasized.

CONCLUSION

The concept of EMG signal decomposition has taken firm roots in clinical neurology and to a lesser, but nonetheless significant extent, in the field of neurophysiological research. This new tool has opened, and will continue to open new vistas. It will provide an objective means for evaluating muscle and CNS dysfunction much more powerful and penetrating than any current electrophysiological tool available today. In the research arena it will allow us to perform experiments which were unthinkable a few years ago. We can design non-invasive experiments on human volunteers which, in their own distinct way, will be more scientifically penetrating than neurophysiological experiments invasively performed on animals.

We must not let the dramatic pay-off of the decomposition approach affect the correct and proper maturation of developments in this area. Those of us working in this exciting area would do well to remember that we must not over-promise the abilities of our current techniques and should faithfully explain the limitations of our work to those less experienced in this art. Let us be cautious with our developments and control our exuberance. We will all be the better for it.