Comment on Point:Counterpoint: Spectral properties of the surface EMG can characterize/do not provide information about motor unit recruitment strategies and muscle fiber type

MOTOR UNIT RECRUITMENT THRESHOLD

TO THE EDITOR: Motor unit activity can be characterized either with direct physiological measurements or with indirect estimates that are based on the association of another parameter with the physiology. Key physiological properties include contractile characteristics, discharge rate modulation, and recruitment threshold. Classic indirect assessments of motor unit physiology include quantifying the level of myosin ATPase activity and determining the myosin heavy chain composition of muscle fibers, both of which are used as indexes of contractile speed.

Von Tscharner and colleagues (5) propose an alternative indirect index of motor unit activity, one based on a spectral analysis of the surface EMG. According to this scheme, a wavelet approach can be used to identify the response time of muscle twitches in the interference EMG and thereby infer the recruitment patterns of motor units (3). On the basis of the rationale that rapid contractions should involve the preferential recruitment of faster motor units, they report exceptions to the pattern of motor unit recruitment predicted by the size principle (6). This rationale is flawed, however, because it ignores the decrease in recruitment threshold that occurs with an increase in contraction speed (1; see Fig. 1 in Ref. 2), which renders a strategy to bypass lower threshold motor units unnecessary. Indeed, low-threshold motor units are recruited during rapid contractions (4). In the absence of a convincing rationale for a change in recruitment order, the purported recruitment patterns of motor units determined with the wavelet analysis require a more rigorous validation.

REFERENCES


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RECRUITMENT ORDER OF MOTOR UNITS CANNOT BE DETERMINED FROM SURFACE EMG

TO THE EDITOR: Von Tscharner and Nigg (5) separate motor units by their force-generating capacities and task specificity. It is true that each motor unit has a specific force-generating capacity; but task specificity of each motor unit is not a defined physiological parameter. Task-specific recruitment of groups of motor units does occur in many muscles; however, each task group comprises slow and fast motor units and orderly recruitment occurs within each task group (2, 4). No one has shown the existence of a task group that is composed exclusively of one motor unit type.

Surface EMG records low-pass filtered version of muscle-fiber action potentials; the amount of filtering of each action potential depends on the distance of the muscle fiber from the recording electrodes and on the total electrical activity generated by other active muscle fibers. It is well known that the muscle fibers of different motor units within a muscle have a complex distribution and that there is a wide range of shapes of motor unit territories and muscle fibers of different types interdigitate in a normal muscle (1). Due to such complexities, it is difficult to assign a “filtering” weight to the action potential of each muscle fiber of each motor unit recorded by surface EMG electrodes. As a result, one has to agree with the compelling arguments made by Farina (3) against using frequency composition of surface EMG to identify motor unit types during different movements.

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SPECTRAL PROPERTIES OF THE SURFACE EMG CAN CHARACTERIZE MOTOR UNIT RECRUITMENT STRATEGIES

TO THE EDITOR: A critical issue in the Counterpoint argument is the assumption that changes in spectral properties of the sEMG are associated with changes in average muscle fiber conduction velocity (1). The Point argument explains that spectral properties and conduction velocity are independent, and being able to break free from this assumption actually provides an “opportunity” for understanding the recruitment process (4). This issue can be resolved by providing physiological evidence that spectral properties of the EMG are associated with motor unit recruitment, a point raised by the Counterpoint argument (1). Such evidence has been demonstrated using both histochemical and contractile measures of fiber type (2–3, 5): these findings were from fine-wire EMG studies and it is appropriate to consider whether they would also apply to surface EMG signals. A recent simulation study (6), that incorporated distributed end-plate zones (4), volume conductor effects, and
continuously distributed conduction velocities (1), found associations between the spectral properties of sEMG and motor unit recruitment strategies: changes in spectral properties were associated with the level of activation when motor units were recruited in an orderly fashion (single-task manner); however, when recurrent inhibition changed the recruitment pattern (as could happen for multi-task actions) then more pronounced changes in sEMG spectra were observed.

The evidence demonstrates that sEMG certainly can characterize MU recruitment strategies and active fiber types. However, it is likely that this will not necessarily be the case for all physiological situations and restricted recruitment tasks.

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THE MOST CONSISTENT FINDING IN SEMG IS INCONSISTENT FINDINGS

TO THE EDITOR: Our paper was cited by Farina (1) to support the lack of relationship between surface electromyographic (sEMG) spectral variables and motor unit behavior. We reported no significant increase in mean power frequency (MF) with increases in isometric elbow flexion force from 40 to 80 percent of maximal voluntary contraction (MVC) (2). However, it is possible to find other studies wherein the increase in MF is moderate but others demonstrate a large increase in MF across force levels. For example, Sbriccoli et al. (4) demonstrated a large increase in median power frequency (MDF) and muscle fiber conduction velocity during ramp increases in isometric elbow flexion force. It has been suggested that MDF increase reflects the recruitment of higher threshold motor units. It also generally accepted that firing rate characteristics of isometric elbow flexion force. It has been suggested that MDF depend upon speed of isometric force generation. J Electromyogr Kinesiol 13: 139–147, 2003.


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IT IS NOT A WAVELET ANALYSIS

TO THE EDITOR: von Tscharner and Nigg (6) argue that the orderly recruitment of motor units can be revealed from the intensity pattern generated by a so-called “wavelet” analysis. However, the “wavelet” analysis of Ref. 5, which possesses none of the properties of a wavelet analysis (2), cannot resolve the subtle changes in the EMG recordings that could separate the different types of motor units. Aside from the common, but incorrect, assumption that there exist distinct types of motor units (1, 4), the interpretation of the “wavelet” coefficients defined in (4) is obfuscated by several factors. First, the “wavelet” transform has a poor time resolution. Because the wavelets are computed by taking the inverse Fourier transform of a series of overlapping bumps, the resulting functions have an infinite extent and are imprecise in the time domain. Second, the frequency resolution is poor because any frequency in the range [0:50] Hz is covered by many bumps, and an oscillatory signal, such as the surface EMG, has its energy spread across many different “wavelet” coefficients. This well-established limitation of wavelet analysis (3) is aggravated here because of the ad hoc design of the wavelets. Third, the mathematical interpretation of the so-called “intensity in time space” is completely unclear. As a result, von Tscharner and colleagues cannot assess the statistical significance of the “wavelet intensity” and have resorted to anecdotal visual inspection of the data as validation of the approach.

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NEURAL DRIVE STRATEGIES FROM SHORT-TERM SPECTRAL CHANGES IN SURFACE EMG

TO THE EDITOR: Von Tscharner and Nigg (6) claim that EMG spectral changes directly reflect (de-)recruitment of distinct motor unit populations and of distinct fiber types. Farina (2) rightly tackles this narrow interpretation, although it is not farfetched. Van der Laarse et al. (5) showed a strong inverse relationship between muscle fiber oxygen consumption and fiber diameter. Both parameters vary over a 100-fold range in nature’s species. But regrettably for the argument, human muscle fiber-type properties are largely overlapping (2, 3). We could show recruitment of fiber type populations only in a precisely tuned protocol (3).

Then how to explain the results by Von Tscharner and coworkers? Referenced work (6, e.g. Refs. 17, 19), show very low mean frequencies (<20–40 Hz), coinciding with the lowest EMG amplitudes. An obvious explanation for these results is cross-talk from distant agonists or antagonists. It is remarkable that this notion did not show up in this Point: Counterpoint discussion. But then, if cross-talk was or will be ruled out, which neural drive mechanisms could be involved? We argued that animal results should be taken with care, but a functionally relevant topographical shift in recruited fiber population during rat walking is described (e.g., Ref. 4). In the large human muscles this could be reflected in spectral shifts. And with respect to motor unit firing properties, especially the indirect influence of the firing interval (1, 2) should be taken seriously. Firing synchronization, also mentioned (2) would mean a frequency decrease with increasing force demands and EMG amplitude, contrary to what is reported.

REFERENCES

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TO THE EDITOR: A huge number of studies tried to correlate EMG variable estimates with muscle fiber-type composition. No consensus can be found in the literature about the power of spectral properties in such a task. Spectral properties of EMG signals are influenced by an incredible high number of confounding factors (1); moreover they represent not a physiological variable directly related to CNS, as happens in the case of muscle fiber conduction velocity, that is however influenced by many other confounding factors. Some works found such correlation associated to muscle biopsies (2, 3), others missed such a finding for mean frequency and found it for conduction velocity (4) or vice versa in case/control studies (5). My opinion is that the proposed Point (6) sounds too far from the recent developments in methodology for recording and analyzing EMG signal. The complexity of the system under study, in fact, requires extreme caution in extracting correlations which sometime can be due to randomness and/or to specific experimental setups. Findings about this issue are quite always obtained in protocols aimed to study fatigue. Differences in EMG manifestations of fatigue are actually physiologically mediated by differences in fiber type composition, but not exclusively. Thus, even if “any changes in the EMG signals during a contraction task can be considered an expression of myoelectric fatigue,” it is not always possible to solve the inverse problem associating to a modification of a single variable (i.e., spectral properties) the value of a set of parameter (fiber-type composition).

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THE RESULTS OF “DIRECT EXPERIMENTS” SHOULD BE ACCEPTED WITH CAUTION

TO THE EDITOR: To support their Point, Von Tscharner and Nigg (5) used the results of animal experiments, in which an original elegant method of orderly electrical stimulation of nerve fibers of different diameter was applied (4). However, the results of such “direct experiments” should be accepted with caution. The linear increase in median frequency of power spectrum (PS) of intramuscularly detected M-responses was related to corresponding increasing of muscle fiber propagation velocity (MFPV) in larger motor units (MU). As the nerve stimuli were applied a few centimeters from the muscle, the delay of M-responses used for estimating the MFPV was affected considerably by propagation velocity along the corresponding nerve fibers, whose diameters differed. As a few nerve fibers
were stimulated simultaneously in such experiments, desynchronization of individual motor unit potentials (MUPs) in 
M-responses was larger under stimulation of slower nerve fibers. The effect of desynchronization on EMG signals is more 
considerable under intramuscular detection (2) when duration of MUP is shorter than under surface detection. The larger 
MUP desynchronization under stimulation of slower nerve fibers artificially induces a stronger shift of PS of their M-
response toward lower frequencies. Thus the PS shift in “direct 
experiments” has to be affected by differences in velocities 
along nerve fibers. The effect depends on distance of the 
stimulating electrode from the motor point.

I support arguments represented by Farina (3) in the Coun-
terpoint. However, one should pay special attention to the 
effect on PS of intracellular action potential that can change considerably especially under fatigue (1).

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3. Farina D. Counterpoint: Spectral properties of the surface EMG do not provide information about motor unit recruitment strategies and muscle

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SPECTRAL PROPERTIES OF THE SURFACE EMG CAN NOT 
PROVIDE RELIABLE INFORMATION ABOUT 
RECRUITMENT STATE

to the editor: The potential produced by motor units (MUs) can be considered (2, 3) as a convolution of the input signal 
(IS) and corresponding transfer (T) function. IS reflects intracellular action potential (IAP). T function reflects (2) relation
between recording electrode position, MU anatomy, volume conductor properties, and muscle fiber propagation velocity 
(MFPV). In accordance with Borel’s convolution theorem, Fourier’s transform of convolution is a product of Fourier’s transform of both functions.

The widely spread opinions on linear relationship between 
MFPV and the position of the power spectrum (mean frequency) (6) and on MFPV as mean determinant of the frequency content (4) are misleading. There is a linear relationship between MFPV and spectral characteristics of T function, but the property of one term cannot be accepted as a property of the product (3).

Reducing MFPV through muscle cooling or muscle fatigue, it was found (1) that change in MFPV required to generate 
equal spectral shift toward lower frequencies was ∼10 times greater under reduction of muscle temperature than under fatigue. Irrespective of similar effects of fatigue and muscle temperature reduction on IAP, such drastic difference was due to considerable decrease of the IAP after-potential (5) that neutralized the effect of MFPV reduction.

The fast-twitch fibers are fatigable. Thus, in addition to arguments noted in (4), the increased after-potentials typical for fatigue induced, for example, by long-distance running (6), should neutralize the effect of higher MFPV on the EMG spectral characteristics and compromise information about recruitment strategies and muscle fiber type.

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SPECTRAL VARIABLES DO NOT NECESSARILY REFLECT 
HISTOLOGICAL TYPES OF RECRUITED MOTOR UNITS

to the editor: Mean power frequency (MNF) and muscle fiber conduction velocity (CV) are related exclusively when a stable pool of MUs decline their CV with N0 other change. Otherwise, MNF changes no longer reflect only changes of CV but other phenomena as well. CV is related to fiber diameter, which is not necessarily associated to fiber type.

Consider case 1: some small (type I) superficial MUs are active. A few new larger and deeper MUs (type II) are then recruited. The MNF of the surface EMG likely decreases because of the greater depth of the newcomers. Shall we then conclude that type I MUs have been recruited?

Consider case 2: some deep MUs (of either type) are active. New small and superficial (type I) MUs are then recruited. The MNF of the surface EMG increases because of the small tissue filtering affecting the newcomers. Shall we then conclude that type II MUs have been recruited?

Although extreme, cases 1 and 2 are not unrealistic. Changes produced by other factors, such as synchronization or MUAP shape changes, may not be distinguishable from those produced in case 1 or 2. Of course recruitment of superficial type II MUs would increase MNF but many other phenomena would produce the same result. An increase of MNF does NOT necessarily imply recruitment of type II MUs and EMG spectral features are not reflecting percentage of active type I or type II fibers or MUs unless the role
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played by other factors in determining such features is known.

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MOTOR UNIT RECRUITMENT BEHAVIOR IS NOT READILY IDENTIFIABLE FROM EMG SPECTRAL CHANGES

TO THE EDITOR: von Tscharner and Nigg (4) lay foundation to their argument that spectral properties of surface EMG do provide information on motor unit recruitment and muscle fiber type, on the basis of experimental results from running studies (5, 6). They relate time-related changes in frequency components of the surface EMG signal to the recruitment strategy of low- and high-threshold motor neurons during the different phases of the gait cycle.

Farina (1) rightly argues that the link between the spectrum and motor unit behavior is flawed, as no direct measurements were made at times in the stride cycle to identify the recruitment behavior of motor units contributing to the surface signal. A dilemma exists in the fact that in experiments where an orderly recruitment of motor units is expected, such as during ramp contractions (2) or submaximal fatiguing contractions (3), the spectral properties of the surface EMG signal appear to rarely reflect the underlying changes in motor neuron recruitment and rate coding, but are more influenced by some of the confounding factors pointed out by Farina (1). I do not believe it is acceptable to discount many of these concerns on the basis of task specificity and therefore side with the persuasive arguments made by Farina (1).

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SPECTRAL PROPERTIES OF THE SURFACE EMG DO NOT CHARACTERIZE MOTOR UNIT RECRUITMENT AND RATE CODING

TO THE EDITOR: The surface EMG has been used effectively to qualify and quantify skeletal muscle recruitment patterns during a variety of single- and multi-joint tasks. The tendency to conclusively link the spectral profile of the surface EMG to motor unit activation (temporal and spatial patterns) is attractive as it implies the presence of a non-invasive cause-and-effect measurement technique. On the basis of the available data in the scientific literature, the argument outlined by Farina (3) is not just simply compelling, but is factual. Although our own previous investigations demonstrated synergistic muscle differences in the contraction-intensity-dependent change in the EMG median frequency (4, 5), it is improbable, at best, to derive specific motor unit recruitment patterns from this spectral measure.
This fact is additionally exemplified by weak correlations that were demonstrated between the surface-, and needle-detected MUAP during submaximal contractions (1). It is also well understood that technical factors alone, such as skinfold thickness (2), have a significant influence on shaping the surface EMG interference pattern. Notwithstanding the valid suggestion by von Tscharner and Nigg (6) that muscle fiber type will contribute to the shaping the surface EMG signal, it is unlikely that the commonly used median (center) frequency spectral index can be used to distinguish motor unit activation subtleties.

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