The surface electromyogram (EMG) comprises the sum of the electrical contributions made by the active motor units to the interference signal detected by electrodes placed on the skin overlying the muscle. Because it provides a global measure of motor unit activity, this signal is a valuable tool for assessing the level of muscle activation.

The analysis of the surface EMG in the frequency domain has been used in some instances, such as fatiguing contractions, to provide an indirect measure of the relative changes in average muscle fiber conduction velocity (19) or in the profile of the intracellular action potential (6). In addition to these applications, the spectral characteristics of the surface EMG have been used to infer motor unit recruitment strategies and the fiber-type composition of a muscle. Higher characteristic spectral frequencies are associated with a greater proportion of type II fibers (20, 21) and changes in EMG spectral variables are used to infer the recruitment of faster or slower motor units (3, 26).

The capacity of surface EMG spectral properties to provide information about motor unit recruitment or the proportion of fiber types is based on the rationale that higher threshold (and type I) motor units produce surface action potentials with larger relative energy at higher frequencies than lower threshold (and type II) motor units.

Because in these applications the main determinant of the frequency content of an action potential is assumed to be its conduction velocity (28), the crucial issue in this debate is the validity of two assumptions: 1) average conduction velocity of the active motor units is related to fiber-type proportions, and 2) changes in the spectral properties of the surface EMG are associated with changes in average conduction velocity.

Fiber-type composition and average muscle fiber conduction velocity. There are several physiological details that confound this association. First, the two main fiber types do not have distinct conduction velocities in humans, but rather conduction velocity has a continuous distribution with a single peak (25). Second, average conduction velocity of muscle fiber action potentials can differ among populations of motor units due to differences in fiber diameter and independent of changes in fiber-type proportions (4). Third, the number of muscle fibers innervated by a motor unit has a skewed distribution. For example, the first dorsal interosseus muscle comprises an equal number of type I and II fibers, but ~84% of the motor units have slow contraction times and are fatigue resistant (7). Fourth, the conduction velocity of muscle fiber action potentials can change by ~20% with variation in discharge rate (24) and the range of discharge rates varies with recruitment threshold in a population of motor units (2). Fifth, the conduction velocity of muscle fiber action potentials varies with fiber length (15).

Experimental evidence: fiber-type composition vs. muscle fiber conduction velocity. The significance of the physiological limitations discussed in the preceding paragraph can be underestimated due to observations of an association between fiber-type composition and muscle fiber conduction velocity (22). However, the weight of evidence argues against generalization of this association. For example, we observed a direct relation between the proportion of type I fibers identified by myosin heavy chain composition and average muscle fiber conduction velocity (9), which was contrary to the results reported by Sadoyama et al. (22). Moreover, average muscle fiber conduction velocity often does not differentiate among groups of subjects or muscles with expected differences in fiber-type proportions (e.g., 21).

Surface EMG spectral properties and muscle fiber conduction velocity. There are several biophysical details that mask this association. First, the power spectrum of a surface motor unit action potential depends on the distance between the fibers and the recording electrodes, in addition to the conduction velocity of muscle fiber action potentials (18). The power spectra of the action potentials of motor units with identical fiber membrane properties but located in different parts of the muscle may differ substantially (8). Furthermore, the spectral properties of the surface EMG are influenced by the thickness of the subcutaneous layers. Second, the power spectrum of the EMG signal depend on anatomical properties of the muscle fibers, such as length, position of the end plate, and fiber inclination (5), and on the profile of the intracellular action potential (6). Third, the spectral properties of the surface EMG also depend on the distribution of discharge rates of the active motor units and on their degree of synchronization (10, 30). These reasons indicate that the surface EMG power spectrum is influenced by factors other than the average conduction velocity of the action potentials and that these factors are independent of the method used to estimate the power spectrum.

Experimental evidence: surface EMG power spectrum vs. muscle fiber conduction velocity. The limitations discussed in the preceding paragraph are sometimes considered to be negligible (26). A study often cited to support this assertion is the observation by Solomonow et al. (23) that orderly stimulation of motor units in the cat gastrocnemius muscle via nerve electrodes gave rise to linearly increasing median frequency of the intramuscular EMG signal. As noted by the authors, however, “attempts to extend the findings . . . to data obtained from voluntary contractions require the consideration of several secondary but not unimportant factors” (23). These factors, which are common to other animal studies (17, 28), include differences between electrically evoked EMG signals and those detected during voluntary contractions, intramuscular (or over the muscle fascia) and surface recordings, and recordings of activity by discrete and mixed populations of muscle fiber types.

The orderly recruitment of motor units during a voluntary contraction in which force increases progressively (13) is accompanied by a gradual increase in average muscle fiber conduction velocity (1). Under these conditions, however, EMG characteristic spectral frequencies can either not change (12) or even decrease (29). For example, the mean frequency of

the surface EMG detected from the biceps brachii muscle did not increase between 40 and 100% of maximal force (10), although motor units are recruited up to ~80% of the maximal force in this muscle (16). The lack of consistency in experimental relations between force and EMG spectral variables (12) suggests that the biophysical issues described in the preceding paragraph are significant, although their influence may be reduced in some simulated conditions (27).

Because the relative proportions of active type I and II fibers change with varying force, the lack of consistency between force and EMG spectral variables also indicate that EMG spectral variables are, in general, not associated with the proportions of active fiber types and that results showing this association (11) do not generalize. For example, similar values of mean frequency were observed for surface EMG signals recorded from the vastus medialis, vastus lateralis, and rectus femoris (12), although these muscles have different fiber-type proportions (14).

Conclusion. The capacity to obtain information on motor unit recruitment and fiber-type proportions from a spectral analysis of the surface EMG is based on two assumptions about the associations of these two dependent variables with the average conduction velocity of muscle fiber action potentials. These assumptions lack general validity, however. Although it is possible to discuss details about motor unit recruitment and fiber-type proportions under some conditions, such interpretations are usually not appropriate.

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REBUTTAL FROM VON TSCHARNER AND NIGG

The Point and Counterpoint positions seem to be complementary. The Point position concentrates on task-specific aspects, the Counterpoint on within-task aspects.

The Counterpoint claims that von Tschcharner’s work (3) suggests that the “limitations” are negligible. Our Point position is that the limitations are not negligible. However, they are not limitations but opportunities and this has to be explained.

One basic assumption used in analyzing spectral properties of EMGs is the linear relationship between conduction velocity (CV) and the position of the power spectrum (mean fre-