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# Piper rhythm of the electromyograms of the abductor pollicis brevis muscle during isometric contractions

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ABSTRACT

A temporal pattern coding, synchronization and rhythmicity form an integral part of central nervous system information controlling the muscle activation. Rhythmic oscillations of muscles at frequencies of 35–60 Hz were already noted in the electromyograms by Piper (1907). The purpose of this study was to resolve the Piper rhythm in the EMG of the APB muscle and report the pacing frequencies of the Piper rhythm. The Piper rhythm was identified using the power of the EMG signals extracted by a wavelet transform at higher frequencies (170–271 Hz). The results showed distinct power of the intensity extracted by the wavelets in a frequency band ranging from about 30–60 Hz. The band was reflected in the power spectra of the EMG intensity and in the first eigenvector of a principal component analysis of the power spectra. The fact that the Piper rhythm shown in this study for the APB muscle yielded a large contribution to the total power means that one can use the frequency and amplitude of the Piper rhythm in future analysis of EMG signals to monitor the influence and changes of the central command.

## 1. Introduction

A general framework that views temporal pattern coding, synchronization and rhythmicity as an integral part of central nervous system information processing seems to form the bases for muscle activation (Farmer, 1999). Rhythmic oscillations of muscles at frequencies of 35–60 Hz were already noted in the electromyograms by Piper (1907). Stochastic models used in ergonomics and kinesiology consider the surface EMG to be generated by a stochastic process whose amplitude is related to the level of muscle activation and whose power spectral density reflects muscle fiber conduction velocity (McGill, 2004). Other models represent realizations of zero mean, nonstationary, mutually uncorrelated, random processes (Farina et al., 2008). However, other models include synchronization of motor unit action potentials (MUAP) which may induce rhythms (Stegeman et al., 2000). Rhythms seem to be present as well at low and high forces. Piper rhythms are not dependent on the presence of strong stretch reflexes (equally prominent in muscles with brisk, weak or absent stretch reflexes) and seem to depend on some kind of pace-maker in the spinal cord or the cerebrum which tends to entrain and synchronize motor impulses (Hagbarth et al., 1983).

The brain's control center for synchronizing the muscle activation is the motor cortex. The rhythmicity between and within muscles was detected in the in the frequency ranges of the alpha (7–13 Hz), beta (17–23 Hz) and gamma (35–41 Hz) bands of the brain activity (Farmer et al., 1993; Conway et al., 1995; Salenius et al., 1996, 1997) The spectra of rectified EMG occasionally revealed a band at 20 and at 40 Hz and satisfactory coherence between the brain activity and the EMG was often obtained indicating a rhythmicity in the EMG but not showing it explicitly. Various approaches can be taken to measure rhythmicity in the EMG. Forces with respect to the maximum voluntary contraction are often considered by researchers interested in rhythmicity (Andrykiewicz et al., 2007; Brown, 2000; Conway et al., 1995; Mima et al., 1999) whereas, measures of EMG amplitude were usually not explicitly quantified. If one wants to measure the rhythm in an EMG one should concentrate on higher frequencies only, because they will be present whenever a motor unit (MU) is activated but will not interfere with the lower frequency bands associated with electroencephalograms (EEG) or magnetoencephalograms (MEG). The decomposition of the EMG's power in time and frequency is preferably done using a wavelet transform because time resolution is kept short (Beck et al., 2008; Coorevits et al., 2008; von Tscharner, 2000). Time and frequency resolutions are critical if one wants to address rhythmicity. The non-linearly scaled wavelets that are used in this study have the advantage of having an appropriate time resolution and a narrower bandwidth of the

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wavelets at higher frequencies than classical linearly scaled wavelets (von Tscharner, 2000).

We previously studied the decay of conduction velocity and mean frequency of the abductor pollicis brevis (APB) muscle with fatigue but without paying special attention to rhythmicity (Barandun et al., 2009). Results indicating the change in frequency of rhythmicity with fatigue are contradictory (Yang et al., 2009; Tecchio et al., 2006). A decay of conduction velocity and mean frequency also results from muscle atrophy associated with carpal tunnel syndrome (Kulick et al., 1986; MacDermid and Wessel, 2004; Rainoldi et al., 2008). It follows that rhythmicity is always present in one of the frequency bands due to the pulse-based manner in which muscles are controlled. However, the gamma band activity was less frequently observed than the beta band activity. During a static force condition the well-documented beta-range corticomuscular coherence (15–30 Hz) with the contralateral sensorimotor cortex was reported (Andrykiewicz et al., 2007). Gamma band corticomuscular coherence (30–45 Hz) occurred in both small and large dynamic force conditions without any significant difference between both conditions. In the right forearm a rhythmicity of 45 Hz and a down shift from the gamma to the beta band activation was observed when reducing the force levels from the maximum voluntary contraction to around 20–40% (Brown et al., 1998). The Piper band (30–60 Hz) was most evident during strong isometric contractions and correlated to the brain activity during movement (Brown, 2000). For the APB muscle under investigation in this study, a rhythmicity of 40 Hz was typically observed during strong contractions (Mima and Hallett, 1999; Mima et al., 2001). It was thus shown that there were rhythms in the EMG which correlate with rhythms in the brain activity but the amplitudes and frequencies of the rhythms in the EMG were not explicitly resolved.

The purpose of this study was to explicitly resolve the rhythmicity (Piper rhythm) in the EMG of the APB muscle. The rhythms were defined as repetitive (non random) bursts of MUAPs creating oscillations of the power of the EMG signal. The oscillations were identified using the power of the EMG signals extracted by the wavelet transform at higher frequencies. This technique has, to our knowledge, not been used previously and yields a signal reflecting the rhythm.

A measurement of the rhythm in the EMG will allow observing the effects of one aspect of central control, the pacing of the muscles, independently of measuring brain activity. It will provide an alternative to using EMG amplitude measurements that have been questioned (Farina et al., 2004). The intensity of the EMG signal obtained by the wavelet analysis may provide an alternative signal to the rectified EMG for measuring corticomuscular coherence and thus help in neurophysiologists in their research.

## 2. Methods

### 2.1. The subjects

The study was approved by the Conjoint Health Research Ethics Board of the University of Calgary. Informed consent was obtained from 14 healthy, right handed subjects (7 females and 7 males, average age 43 years) who participated in this study. Of these only those 13 were used where both hands yielded 6 trials of analyzable data (26 hands).

### 2.2. Experimental setup

Details of the experimental setup were reported previously (Barandun et al., 2009) and the essential parts for this study are summarized below. The skin covering the APB muscle was washed with water and soap, lightly abraded and cleaned with alcohol. A linear array of five Ag-electrodes (inter electrode distance 6 mm; diameter 2 mm) placed above the muscle belly parallel to the muscle fibers allowed EMG signals to be recorded at 10 kHz (bandwidth 10–700 Hz) from four adjacent electrode pairs. Two adjacent electrode pairs (3 electrodes) were selected if the two bipolar EMG recordings showed a clear correlation thus indicating that they were placed between the innervation zone and the muscle tendon interface. The EMG signal from the electrodes that were closer to the innervation zone was used for the analysis. Force and EMG measurements from a hand placed in an intrinsic plus position were displayed on a screen and recorded during maximal voluntary contraction. Subjects performed six trials with a rest interval of 2 min in between. From the measurement a period lasting 1.64 s was selected for analysis (sub dividable in 4 sequences of 4096 points) starting 0.3 s after maximal voluntary contraction was reached. This time was short enough to consider the signal as stationary and not significantly affected by fatigue.

### 2.3. Estimation of a mimicked MUAP and simulation of an EMG

The EMG is often explained as superposition of multiple MUAPs that occur at random instances (interference EMG). A simulated EMG is computed by convolving a modeled MUAP with a pulse train reflecting the random instances (Hermens et al., 1992). The power spectra of a modeled MUAP and the resulting simulated EMG are identical in shape, however, the power spectrum of the simulated EMG contains additional noise. In this study, we reversed this procedure to compute a mimicked MUAP from a recorded EMG. The power spectrum from the raw EMG signal was computed using the sequential Fourier transform (using 32 sequences of 512 points each) (Rosenberg et al., 1989). An inverse Fourier transform of its square root multiplied by *i* yielded a symmetric, mimicked MUAP. A new, simulated EMG was then computed by convolving the mimicked MUAP with a randomly distributed pulse train of 2000 pulses. Its amplitude was adjusted to recover the energy of the raw EMG signal. If there was any rhythm in the raw EMG, this rhythm will be eliminated in the simulated EMG. However, the general characteristics of the raw EMG will be closely reproduced and the power spectra of the measured and simulated EMGs will be identical. A simulated EMG was created for each measured EMG and was used as a reference signal containing no rhythmicity.

### 2.4. Intensities of the EMG signal extracted by the wavelet transform

A set of non-linearly scaled slightly modified Cauchy type wavelets were used to extract the EMG intensity (von Tscharner, 2000; Barandun et al., 2009). The wavelets were characterized by their center frequencies (cf: 7, 19, 38, 62, 92, 128, 170, 218, 271, 331, 395, 466 and 542 Hz). The wavelet transform yields the power of the EMG signal at each time point subdivided into the frequency bands covered by each wavelet. In this study the power recovered by the wavelets with the center frequencies 170–271 Hz were used to measure the EMG intensity representing the presence of the EMG signal. The low frequencies were eliminated because the long time resolutions of the corresponding wavelets may mask shorter rhythms. The higher frequencies were eliminated because they recover increasing amounts of power from the noise. From each hand and for each trial the intensities were computed for the EMGs and the simulated EMGs.

The power spectrum of the EMG intensity was computed by a sequential Fourier Transform using 4 sequences of 4096 points yielding a 2.44 Hz frequency resolution. The resolution was selected to allow discriminating alpha and beta bands if they were present. The power spectrum of one hand was obtained by averag-