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Exam Electromyography 2014-2015
May 26, 2015; 12:00 – 14:45

Six questions, all questions are equally weighted. The points per sub-question indicate a fraction of the points per question. The text boxes give an indication of the length of the expected answer. Write inside these boxes

1. The following is a quote from a paper on activation of knee muscles in patients with knee osteoarthritis: "Maximal electromyographic amplitudes were identified from three quadriceps, two gastrocnemius and two hamstring muscle sites for each exercise. The single highest EMG amplitude, regardless of trial and exercise was utilized to represent absolute maximum activity for each muscle. Activity levels for each exercise were normalized to this maximum amplitude and were reported as a percentage of Maximum Voluntary Isometric Contraction (%MVIC)."

a. Describe the main advantage and the main disadvantage of using the maximum EMG amplitude over the three attempts as a basis for normalization (1/3 points).

The main advantage of using the maximum over the three attempts is that this yields the best estimate of the true maximum level of activation, while an average would always be biased towards lower values. However, the disadvantage is that the maximum value is statistically the least precise and may well represent a measurement error.

The level of cocontraction of a pair of antagonistic muscles in this study was expressed by a cocontraction index (CCI) based on integrated EMG, defined as:

$$CCI = \int_{i=-100}^{peak} \frac{lowerEMG_i}{higherEMG_i} \times (lowerEMG_i + higherEMG_i)$$

in which *i* = the sample, starting at 100 ms before heel contact and ending at the instant of the peak knee moment, *lowerEMG* refers to the EMG amplitude of the muscle showing the lowest activity within the pair of muscles and *higherEMG* refers to the EMG amplitude of the muscle showing the highest actviting within that pair.

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b. Discuss the effect that slower walking would have on this CCI? (1/3 points).

Slower walking would lead a longer integration period, which would tend to increase the CCI. On the other hand, slower walking might coincide with lower muscle activation, which would tend to decrease the CCI. The net effect can therefore not be predicted.

c. Describe the effect of pain-related inhibition on this CCI, when the EMG amplitudes in this CCI are expressed as %MVIC (1/3 points).

Pain-related inhibition would lead to lower EMG amplitudes especially during maximal contractions. Hence the MVIC would be underestimated and as a result the CCI would be overestimated, since both the normalized values would be higher (divided by a lower number). It could be that the higher EMG during gait is more inhibited than the lower EMG, which would increase the ratio and hence increase the CCI further.

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2. The EMG amplitude during an isotonic and isometric contraction is expected to be constant. Obviously small fluctuations in the force and in the linear envelope of the EMG will be present.

a. Explain why the linear envelope of the collected EMG signal is more variable than the force during such contractions (1/5 points).

The EMG signal represents the summation of motor unit action potentials (MUAPs). MUAPs have both positive and negative phases. In addition, firing of MUs is somewhat irregular. Consequently, positive and negative superimposition of MUAPs occurs randomly, leading to variability even under constant activation. The force signal is a summation of MU twitches, which have a positive phase only. Alternative: Statistically estimating the EMG amplitude requires an estimate of the variance of the signal within a chosen time window (given the fact that its mean is zero). For estimating the force one could simply determine the mean over the same window. Estimates of variance are less reliable than estimates of a mean.

According to Clancy et al there are three methodological factors that determine the variability (SD_{amp}) of the amplitude of the EMG signal. These three factors are represented in the following equation:

$$SD_{amp} = C\sqrt{\frac{T}{B.N}}$$

b. In this equation N is the number of independent channels of EMG data. Which are the other two factors, here denoted as T and B? (1/5 points).

T is the temporal resolution B is the signal bandwidth

Factors T and B can be modified by high-pass or low-pass filtering of the EMG signal.

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c. Describe for each of these factors, which type of filter can be used and whether this filter is applied to the raw EMG or the rectified EMG. (1/5 points)

T can be decreased by low-pass filtering the rectified signal. B can be increased by high-pass filtering or whitening the raw signal.

d. Decreasing T by means of filtering has a disadvantage when applied to dynamic contractions. Describe this disadvantage (1/5 points).

Decreasing T means that temporal resolution is lost, dynamic changes in the EMG amplitude at frequencies above the cut-off frequencies can no longer be observed.

Muscle fatigue is associated with a slowing of the propagation of the motor unit action potentials.

e. Describe and explain the effect that this will have on the variability of the EMG amplitude and explain your answer (1/5 points)?

Slower action potentials lead to a lower frequency content and hence lower B, thus more variability. Alternative: Slower action potential propagation leads to more overlap of MUAPs and hence more effect of random positive and negative superimposition.

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3. Averaging amplitudes of multiple monopolar EMG signals collected with electrodes distributed over the muscle does usually not improve precision of estimates of muscle activation compared to the conventional approach in which only one (usually bipolar) channel is used.

a. Explain why this is the case (1/3 points).

Monopolar signals from nearby electrodes contain a lot of common information, i.e. the signals are highly correlated. The precision of estimates of the average over channels is only improved by the uncorrelated information in these channels as also implied by the equation in question 2 in which N is the number of independent channels.

In contrast to what is described above, averaging the amplitudes of a number of bipolar EMG channels does usually yield a more precise estimate of the muscle activation than a single bipolar channel.

b. Explain this observation (2/3 points).

Taking bipolar derivatives creates signals that are spatially more selective, because the common information in the two channels is discarded. Remote sources cause very similar potentials at two nearby electrodes and hence information from remote sources is lost by the bipolar derivation. (This effect holds in particular for the stationary potentials caused by the dipole source at the end of the muscle fiber, i.e. the far-field potentials.)

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4. Each panel in Figure 4.1 (from E.R. Mulder et al., JEK 21, p.384, 2011) contains a force profile (upper traces) and four selected traces of EMG from the agonist muscles soleus (SOL), gastrocnemius medial (GM), gastrocnemius lateral (GL) and the antagonist tibialis anterior muscle (TA). They represent a plantar flexion at 1/5 of maximal voluntary force (20%MVC). The upper panel is measured before, and the second panel after a long (8 weeks) period of strict bed rest (BR) of a (healthy) subject. The bed rest study was undertaken to estimate effects of long space flights.

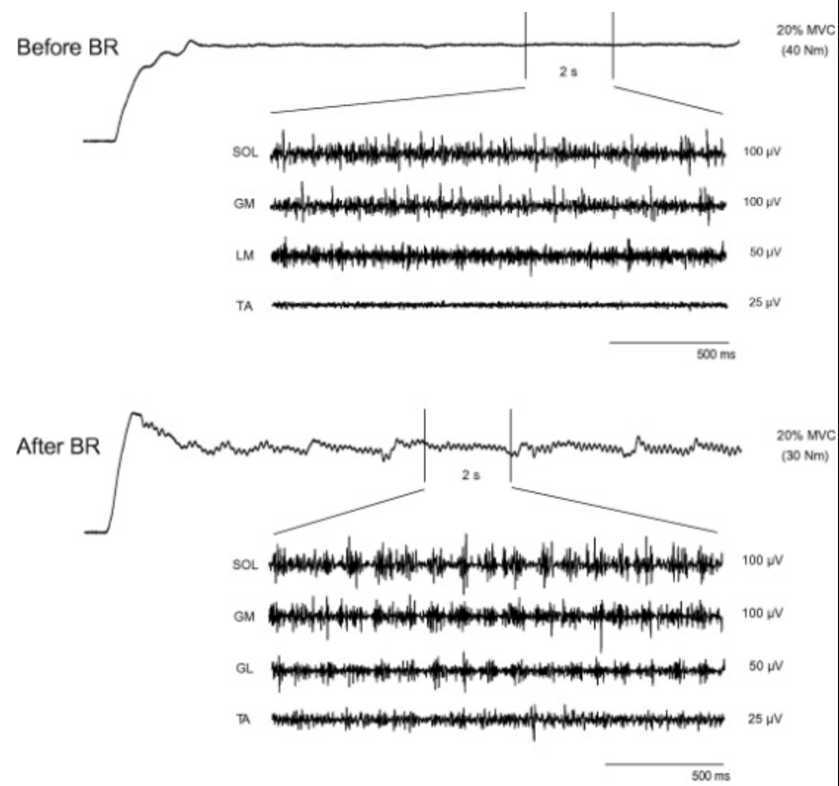

Figure 4.1

a. As shown Figure 4.1, the mean MVC force measured after bed rest was lower. Discuss based on the EMG signals, why the MVC measured was lower after bed rest and provide a reason other than a decreased force capacity of the plantar flexor muscles. (1/3 points).

The lower force measured can be due to higher coactivation of the antagonistic TA muscle. The figure shows a higher amplitude of TA activation in the recording after bed rest. Of course this may be due to random variations between measurements. Alternative: fatigue as inferred from tremor, atrophy inferred from higher EMG at lower abs force.

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Apparently a constant fluctuation of the force is present after BR. The fluctuation is called a tremor.

b. How can you estimate the frequency of the tremor without using its reflection in the force signal (1/3 points)?

The spectrum of the raw EMG signals and even of the EMG linear envelopes of the agonist muscles might reveal a peak at the tremor frequency.

c. Does the tremor originate peripherally in the muscles or centrally in the nervous system? Motivate your answer (1/3).

Tremor originates in the nervous system. The firing behavior of MUs is all or none, implying that only interactions between neurons can affect firing behavior.

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5. The sources of the electrical activity of the heart (ECG) are very strong compared to those of skeletal muscles. These ECG sources together can fairly well be described as a very large current dipole compared to the EMG sources. Its potential field can be observed all over the body.

a. Explain why an ECG signal measured with a conventional EMG electrode pair (bipolar derivation) is relatively small despite this strong source? (1/2 points)

The dipole source will cause very similar potentials at both electrodes. A bipolar derivative will reject this common information.

b. Explain why a bipolar EMG configuration with electrodes aligned with muscle fibers is useful in reducing cross-talk from other muscles as compared to monopolar EMG. Consider in your answer the fact that sources of muscle fiber action potentials have both of a quadrupole and a dipole characters. (1/2 points).

Cross-talk from remote muscles consists mainly of the far-field potentials caused by the stationary dipole sources at the end of the muscle fiber, as these potentials drop off less fast with distance from the source than the potential caused by the quadrupole source of the propagating action potential. The bipolar electrodes will therefore pick-up more or less the same potential from distant dipole sources, while the propagating potential will be time-delayed between the two electrodes, leading to rejection of the dipole source and maintaining the information from nearby quadrupole sources.

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6. Figure 3.1 represents a raw EMG signal. Several commonly observed contaminations of the EMG signal can be seen here.

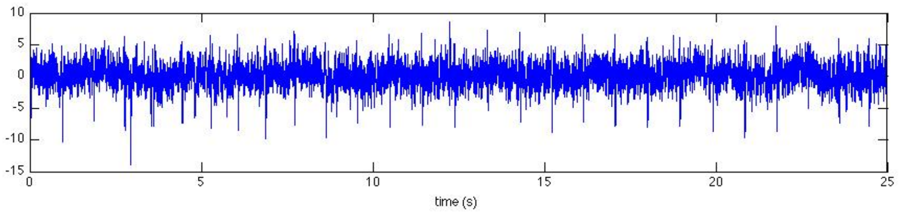

Figure 6.1

a. Identify two types of contamination in Figure 6.1 and describe for each how it can be recognized in the figure? (1/5 points)

The figure suggests that movement artefacts are present. These are visible as low-frequency waves or deviations from the baseline from zero over a time-window of up to seconds.
The figure suggests that ECG contamination may be present. The fairly regular spikes occurring a rate of slightly above 1 Hz are most likely ECG waves.

b. Assume that the EMG signal has been digitized at 2000 samples/s and has been low-pass filtered prior to digitization at 500 Hz. Draw a power spectrum of a clean EMG signal and add appropriate frequency values for the lowest and highest frequency contained in the signal as well as an appropriate value of the frequency at which the highest power is expected on the x-axis. (1/5 points)

Power density mV^2/Hz

Frequency (Hz)

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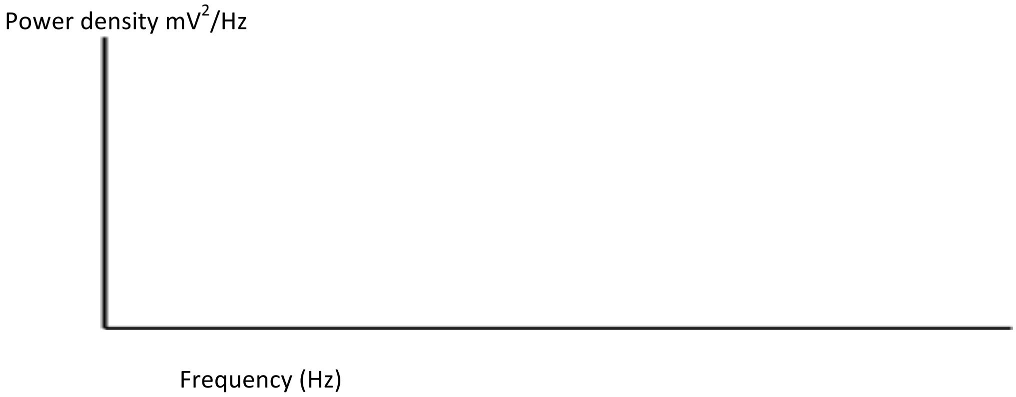
c. Draw a spectrum of the same signal now with the contaminations observed in Figure 6.1 and describe the approximate frequency bands where compared to the clean signal changes of the power density are expected due to each of the two contaminations. (1/5 points)



The movement artefacts are expected to cause signal power between 0 and 5 Hz, most likely at approximately 1 Hz.
ECG has power mainly between 20 and 30 Hz, so a higher power is expected in this band due to the ECG contamination.

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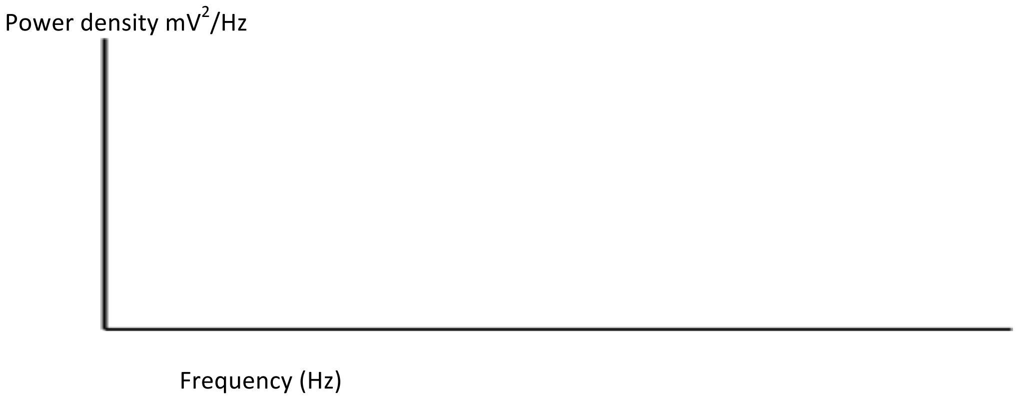
d. Draw the spectrum of the unfatigued clean signal as in question 6b and add a spectrum reflecting an EMG signal of the same muscle in a fatigued stated producing the same level of force. Describe the changes that are expected to occur and describe the cause of each of these changes. (2/5 points)



The spectrum is shifted to the right due to the slower propagation of motor unit action potentials.

A peak at around 10 Hz can occur due to synchronization of the firing of motor units

The power density is increased because to achieve the same level of force the muscle has to be activated more.