

EMG: advanced issues on data processing

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Introduction

The usefulness of EMG in a context of gait analysis has been a matter of debate ever since instrumented gait analysis was introduced in clinical practice (Kleissen et al 1998). The appreciation of its information is strongly related to a style of gait analysis. A more neurological approach reasons from the muscles to the movement, seeking to understand what the cause of a disturbed movement pattern is, from a motor control perspective. This approach tends to underexpose the importance of musculoskeletal mechanisms, like a lever arm dysfunction. Alternatively, the biomechanical approach focuses on musculoskeletal mechanisms, taking the muscular interplay to create the net moments for granted. Such an approach tends to underexpose the importance of pathological motor control, like increased co-contraction.

Different textbooks take different approaches. In the end it is the usefulness to the clinician, and hopefully its clinical success, that matters most. Since the biomechanical approach focuses on mechanisms that can be restored in some part, (e.g. lever arm dysfunctions, muscle length) this approach is not widely followed. Motor control is very hard to change, though the selective dorsal rhizotomy (SDR) can be effective when disturbed motor control is the main cause of gait disorders. So with a context of biomechanical based gait analysis it might be questioned what the use of EMG measurements is.

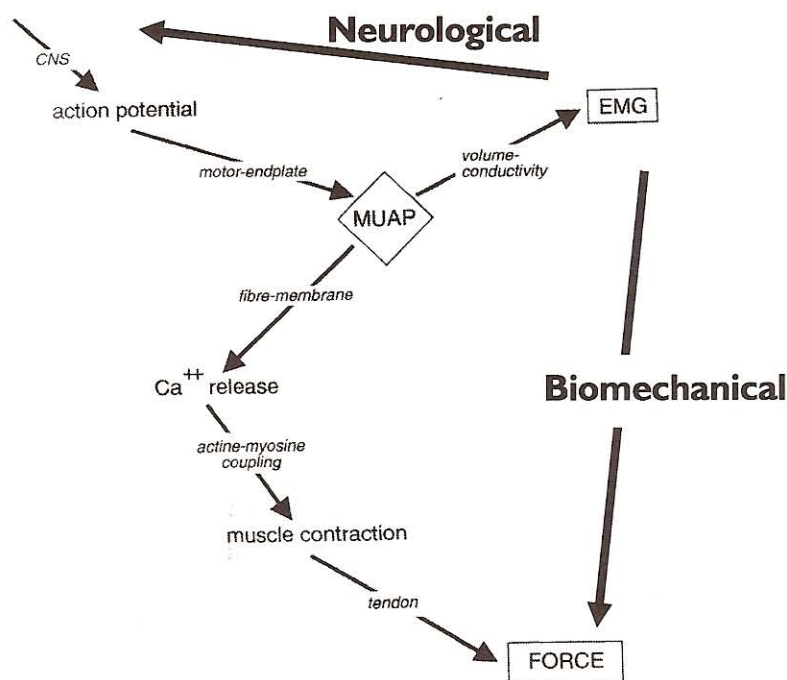


Figure 1. Pathways related to the EMG signal. Neurological versus biomechanical interpretation requires (implicit) modelling of different physiological pathways.

A second point on the use of EMG is how the information from its direct measurement, should be interpreted. The ElectroMyoGraphic signal is an electrical signal, picked up by either indwelling or surface electrodes. The interpretation of this signal is not straight forward. How this electrical signal relates to something meaningful for movement analysis requires a clear concept of the approach of interpretation: either neurological or biomechanical. In figure 1 the two pathways that are related to each approach are shown.

Neurological approach

The neurological interpretation focuses to quantify the mechanisms of motor control.

On/off

For many purposes muscular control is regarded as an on/off signal to the muscles. Quantifying an/off signals from the EMG signal is not without problems. First of all; ON-OFF not a likely as a control strategy of the CNS. So, to impose either the ON or OFF status on a signal that is gradually increasing, requires an arbitrary threshold. Secondly, even if the EMG is behaving like ON-OFF in some way, detecting either status from a noise signal requires again a threshold. Above the threshold the signal is ON, below threshold it is OFF. It is clear that such dichotomisation is very sensitive to the (arbitrary) threshold.

A statistical criterion to describe ON-OFF was developed by Staude and Wolf (1999), based on the Approximated Generalised Likelihood Ratio (AGLR) being more reliable than the standard threshold criterion. It is based on an abrupt change in the (time-varying) parameters of a statistical process model adapted to the measured signal, i.e the EMG. It was introduced in gait analysis by Roetenberg et al, (2003) and applied by Buurke et al (2004) to demonstrate changes in coordination after hamstrings lengthening in CP, and the effect of walking with a cane in patients with stroke (Buurke 2005).

Envelope detection

Envelope processing is a common technique in gait analysis. When the detection of motor control patterns is aimed for, the low-pass cut-off frequency of the envelope should be high (i.e > 10 Hz). in order not to smoothen away quick transition or introduce an unwarranted delay. Some advanced algorithms have been proposed by Bogey et al. (1993,1994).

Decomposition of the EMG signal

Modern techniques like continuous wavelet analysis (eg Gazzoni et al 2004) have made it possible to decompose the EMG signal into its building blocks: the motor units. This technique makes it possible to unravel the coding of the neural strategy that is used by the CNS in terms of recruitment and firing rate to activate the muscle. (Farina et al 2004)

Biomechanical approach

The biomechanical approach focuses on estimation muscle force from the EMG signal. From the pathway of figure 1 it can be concluded that, besides the volume conductivity, also the muscle physiology must be taken into account. Effects of muscle physiology are dominated by the length dependency of the force generating capacities of the muscle as well as the time delay between EMG and muscle force (electromechanical delay, eg. Vos et al 1991)

Envelope detection

When envelope detection is aimed at the estimation of muscle force, the dynamics of the envelope should match those of the muscle force. A second order low-pass filter of 2 or 3 Hz to process the rectified EMG, will mimic the dynamics of the muscle physiology: the time constant of the depolarisation of the membrane, followed by the interaction of actin-myosin coupling with the series elastic component of the musculo-tendon unit. The resulting signals are usually interpreted without any meaning to the absolute value. However it has been shown that even without normalisation, EMG profiles are very reliable, even between laboratories (Kleissen et al 1997). Hof et al (2002) showed that for a group of young male subjects absolute gain ranges within a factor four.

Normalisation of EMG envelopes

Normalisation of EMG envelopes is usually done by taking a percentage of the envelope mean or envelope maximum, to minimize inter-individual differences. This has been shown to be a very successful method (Yang & Winter 1984). However also true biological variance is eliminated in this way. An external criterion (i.e isometric MVC) is principally more valid. Unfortunately MVC as a measure for maximum activation is not very reliable (Yang & Winter 1983).

EMG to force processing

In 1981 it was shown by Hof that EMG to force processing for the m. triceps surae is feasible, but too laborious for clinical practice. Doorenbosch et al (1998) suggested a simple model (for muscles around the knee), based on isokinetic calibration contractions. It has been proven to be accurate for some movements (but not for gait) and has strong potential for selected clinical applications.

Instead of the classical envelope, limiting the EMG signal to the top 1% (!) of its bandwidth, yields more accurate estimates of muscle force (Potvin and Brown, 2004). This method has not yet been shown to be applied in movement analysis.

Another way of EMG to force processing is to include the EMGmax as unknown parameter to estimation muscle force from the EMG. Subsequently, these parameters can be estimated from optimisation, to match the net joint moments from inverse dynamics analysis. This has been shown successful for back muscles (Granata & Marras 1993; vDieën & Kingma 2005)

EMG standardisation

The SENIAM guidelines for standard EMG measurements are added to this chapter, just for reference.

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Appendix: Recommendations of the SENIAM working group on EMG

Electrode selection

- Electrode shape: circular, rectangular
- Electrode size 10 mm
- Inter electrode distance
 - Global view
 - large muscles 20 mm
 - small muscles $\frac{1}{4}$ of fibre length
 - Selective view 3-6 mm

Electrode placement

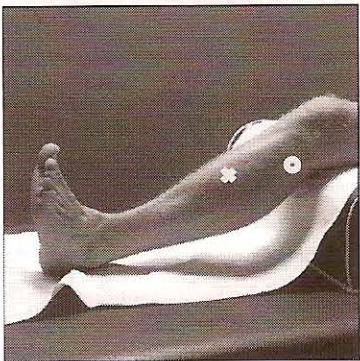
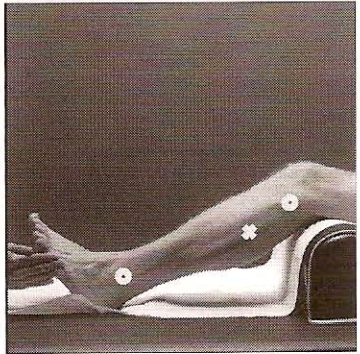
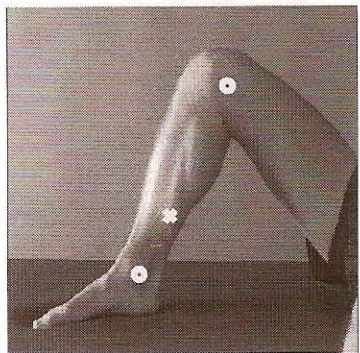
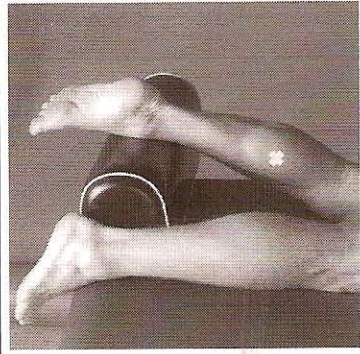
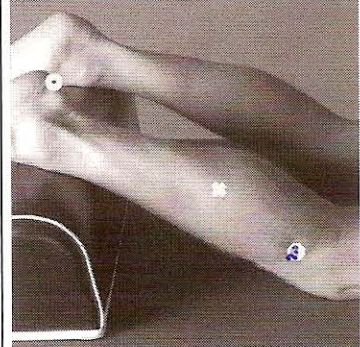
- Skin preparation
 - shaving
 - cleaning with alcohol
- Electrode placement
 - if possible between end plate and tendon
 - avoid end plate region
 - use standard recommendations for individual muscles (> workshop)
- Fixation of cables
- Check your signal

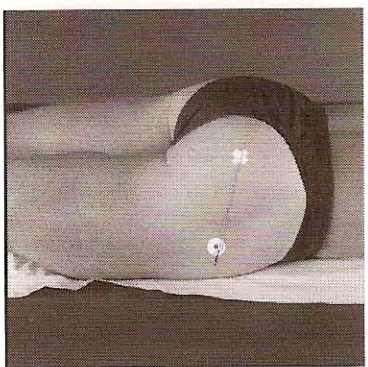
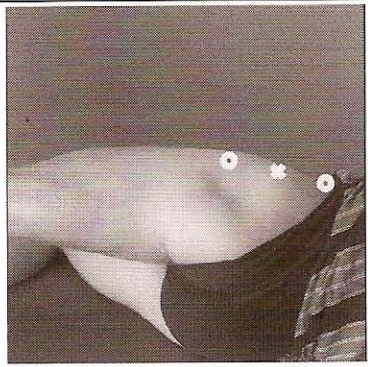
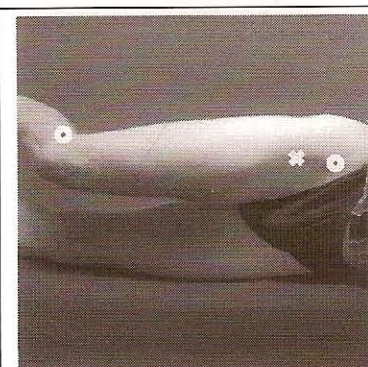
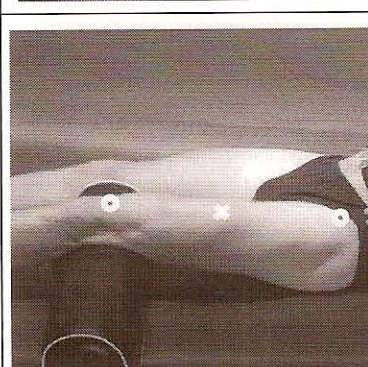
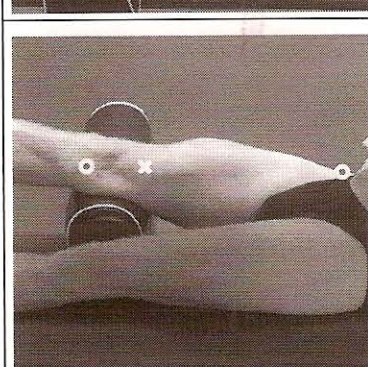
On-line signal processing


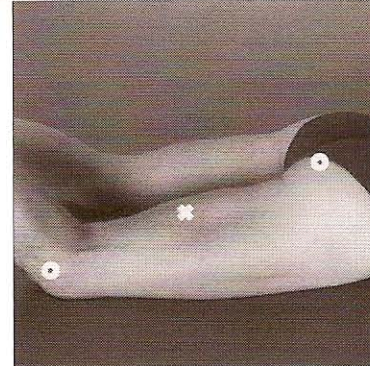
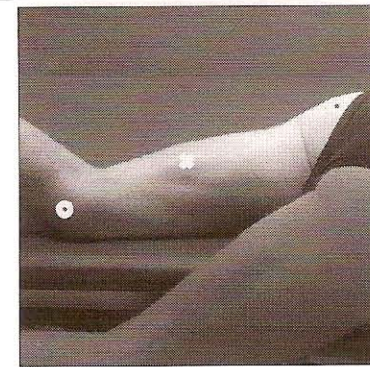
- Preamplifier (bipolar configuration)
 - use high quality electrode cables
 - noise < 1 microVrms
 - CCMR > 100 dB
 - Input impedance > 100 MOhm
- Filter setting
 - low pass 500 Hz
 - high pass 5-20 Hz
- Sampling
 - 2000 Hz
 - 16 bits (or 12 bits: < 1 microV/bit)

Envelope detection

- Rectification or RMS processing
- Non-dynamic signals
 - < 50 % MVC ; average: 1 - 2 second epoch
 - > 50 % MVC ; average: .25 - .5 sec. epoch
- Dynamic signals during gait
 - 2 Hz 2nd order low-pass filter
- Ensemble averaging (report number of cycles and Standard Error of the Mean)

	<p>M. Tibialis Anterior</p> <p>at 1/3 on the line between the tip of fibula and the tip of the medial malleolus</p>	<p>Testcontraction:</p> <p>apply resisted pressure and ask for dorsiflexion and inversion</p>
	<p>M. Peroneus Longus</p> <p>at 1/4 on the line between the tip of fibula and the tip of the lateral malleolus</p>	<p>Testcontraction:</p> <p>apply resisted pressure and ask for eversion</p>
	<p>M. Soleus</p> <p>at 2/3 on the line between the tip of medial femoral condyle and the tip of the medial malleolus</p>	<p>Testcontraction:</p> <p>manually push the (flexed) knee downwards and ask to lift the heel up</p>
	<p>M. Gastrocnemius Med.</p> <p>at the most prominent point of the muscle bulge</p>	<p>Testcontraction:</p> <p>ask plantar flexion of the foot (heel rise) under resistance</p>
	<p>M. Gastrocnemius Lat.</p> <p>at 1/3 of the line between the tip of the head of the fibula and the heel</p>	<p>Testcontraction:</p> <p>ask plantar flexion of the foot (heel rise) under resistance</p>

	<p>M. Gluteus Maximus</p> <p>at 1/2 of the line of the sacrum and the greater trochanter</p>	<p>Testcontraction:</p> <p>lifting the leg against resistance</p>
	<p>M. Gluteus Medius</p> <p>at 1/2 of the line of the iliac crest and the great trochanter</p>	<p>Testcontraction:</p> <p>Side lying: hipabduction against resistance at the ankle</p>
	<p><u>Tensor Fasciae Latae</u></p> <p>at 1/6 of the line of the ASIS and the lateral femoral condyle</p>	<p>Testcontraction:</p> <p>Lift and abduct the leg against manual resistance</p>
	<p>M. Rectus Femoris</p> <p>at 1/2 of the line of the ASIS and superior edge of the patella</p>	<p>Testcontraction:</p> <p>apply resisted pressure at the ankle and ask for knee extension (avoid thigh rotation)</p>
	<p>M. Vastus Medialis</p> <p>at 4/5 of the line of the ASIS the anterior border of the medial ligament in the kneejoint</p>	<p>Testcontraction:</p> <p>apply resisted pressure at the ankle and ask for knee extension (<u>avoid thigh rotation</u>)</p>

	<p>M. Vastus Lateralis</p> <p>at 2/3 of the line of the ASIS and the lateral side of the patella</p>	<p>Testcontraction:</p> <p>apply resisted pressure at the ankle and ask for knee extension (avoid thigh rotation)</p>
	<p>M. Biceps Femoris</p> <p>at 1/2 of the line of the ischial tuberosity and the lateral epicondyle of the tibia</p>	<p>Testcontraction:</p> <p>apply resisted pressure at the ankle and ask for knee flexion</p>
	<p>M. Semitendinosus</p> <p>at 1/2 of the line of the ischial tuberosity and the lateral epicondyle of the tibia</p>	<p>Testcontraction:</p> <p>apply resisted pressure at the ankle and ask for knee flexion</p>

Final remarks

- There is a lot of inter-individual variation
- NOBODY IS PERFECT
- Take anatomy lessons
- discuss with your colleagues
- try to establish your reproducibility...



SENIAM: Surface EMG for non-invasive assessment of muscle

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