Analysis of muscle coordination in sports

Perspectives from electromyography and elastography

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AUSTRALIA

Presentation summary

- **Introduction**
- Main drawbacks inherent to the surface EMG technique
- Analysis of the EMG signals
- Extraction of muscle synergies
- Elastography: toward the estimation of muscle force?

Muscle coordination

"Distribution of muscle activation or force among individual muscles to produce a given combination of joint moments"

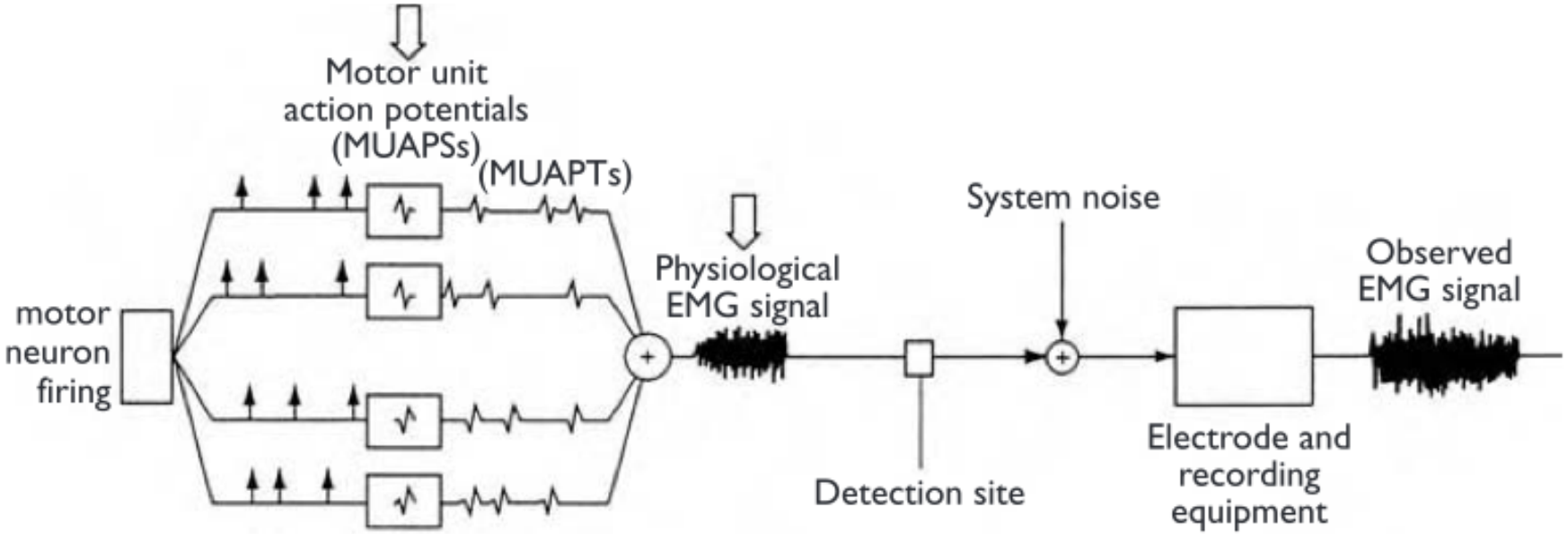
Prilutsky (2000 – Motor Control)

- Understanding of motor control
- Design robotic
- Improvement of rehabilitation/training programs
- …

Electromyography

« Electrical manifestation of the neuromuscular activation associated with a contracting muscle »

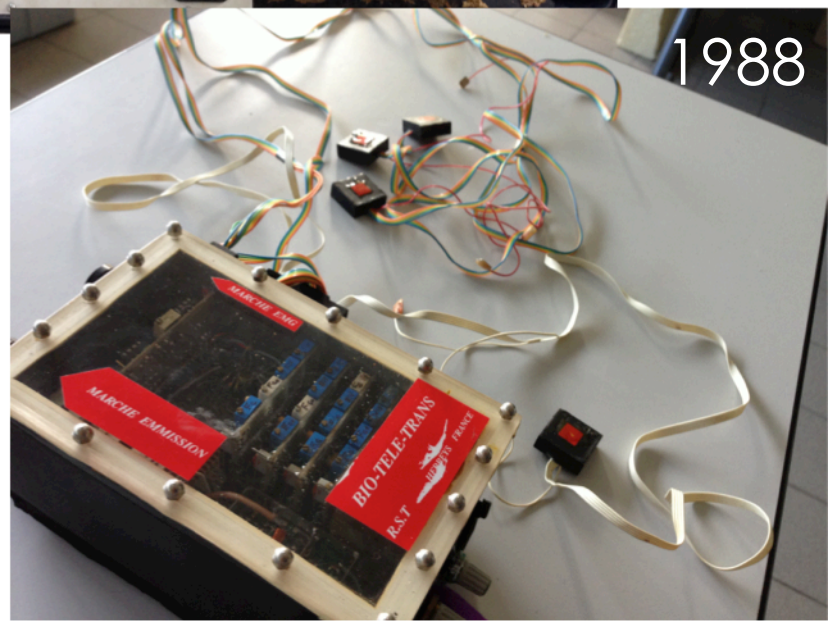
Basmajian and De Luca (1985 - Muscle Alive)



From Barlett (1997 – Introduction to sports biomechanics)

Electromyography

2013



Electromyography

Courtesy of the French National Institute of Sports (G. Guilhem)

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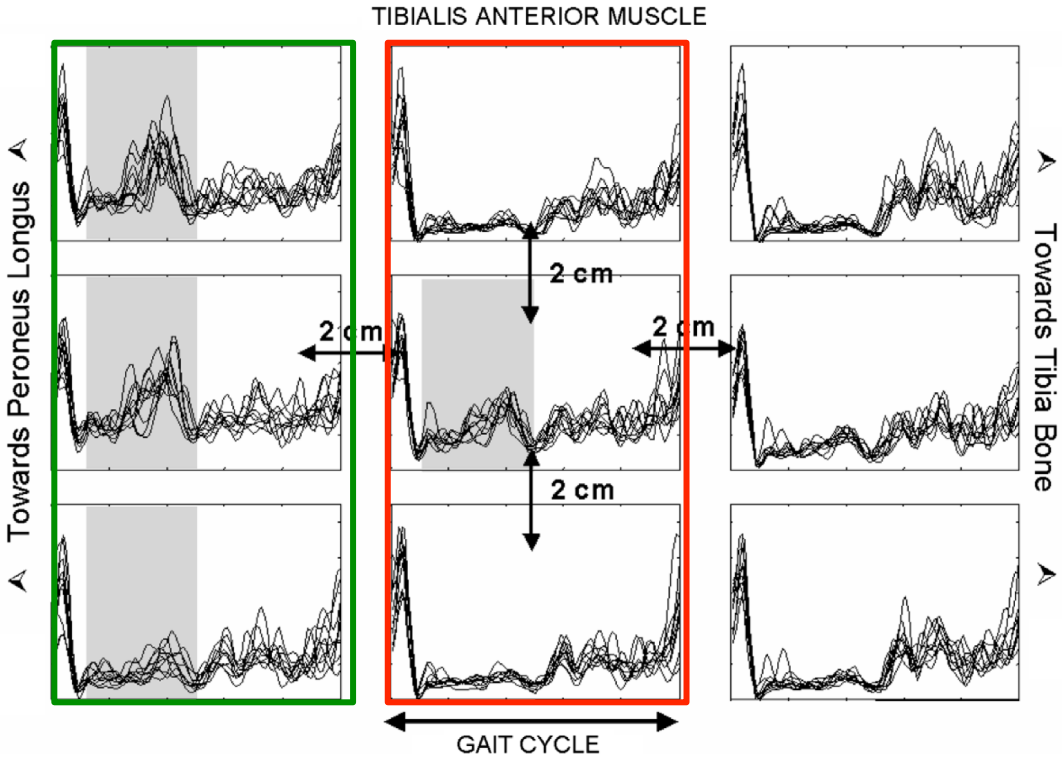
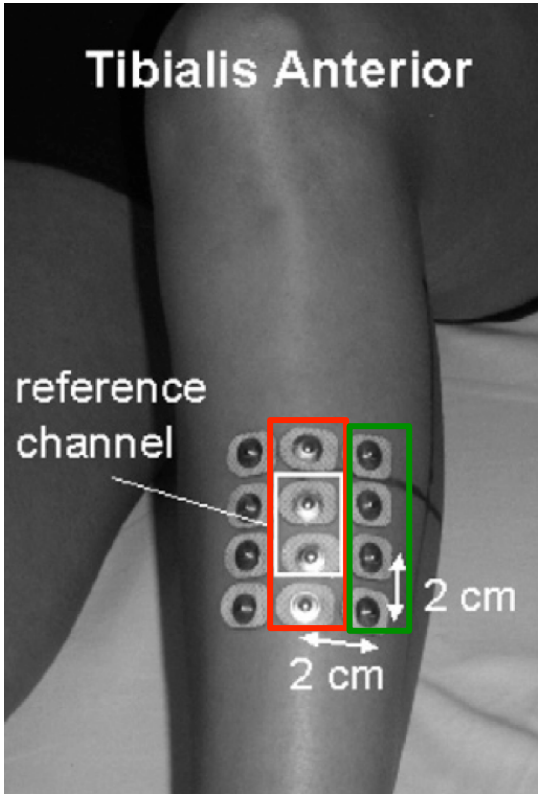
Electromyography

Drawbacks: crosstalk

Contamination of the EMG signal by a nearby muscle's electrical activity



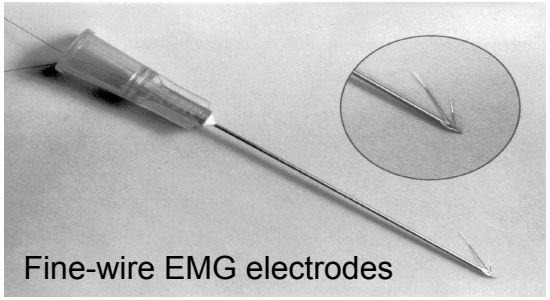


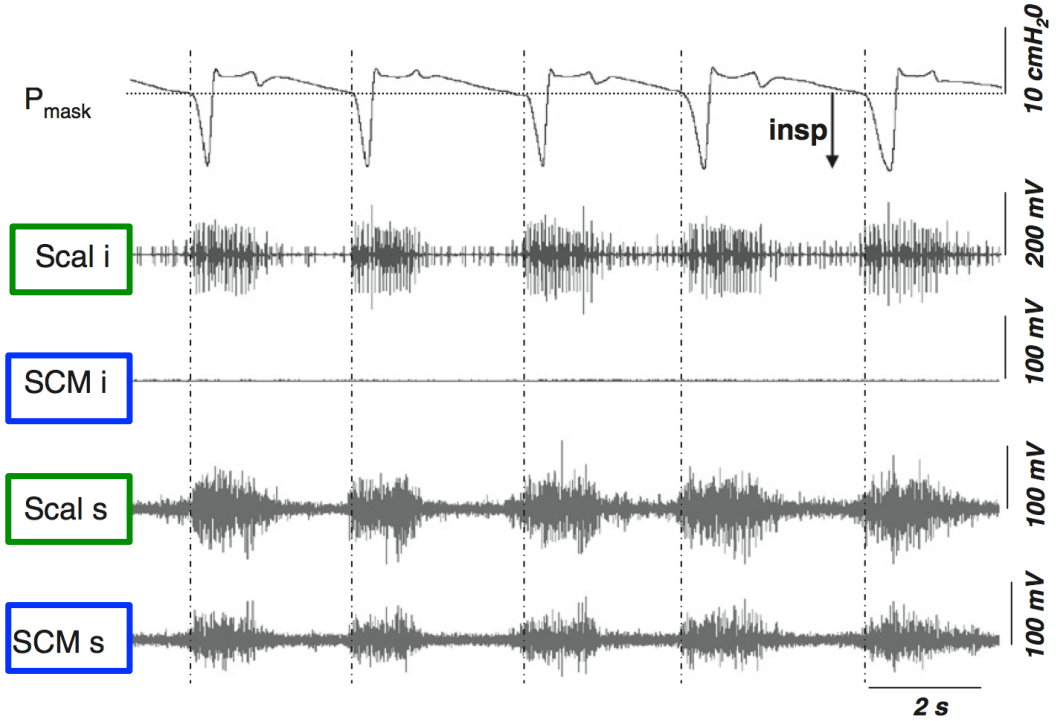
Campanini et al.
(2007 – J Electromyo Kinesiol)

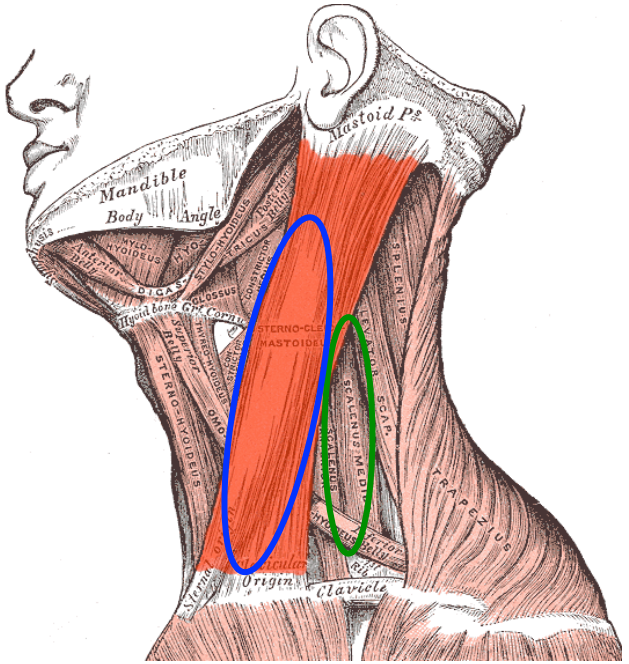
- Alteration of the shape of the EMG patterns

Electromyography

Drawbacks: crosstalk







Chiti et al. (2008 – Resp Physiol Neurobiol)

- In extreme cases: can make a muscle appear active while it is not

Electromyography

Drawbacks: crosstalk

Parameters influencing crosstalk:

- Electrode location
- Inter-electrode distance
- Muscle size
- Distance source/electrode
- Thickness of the subcutaneous layer …

No methodology to suppress crosstalk completely

Difficult to quantify

Electromyography

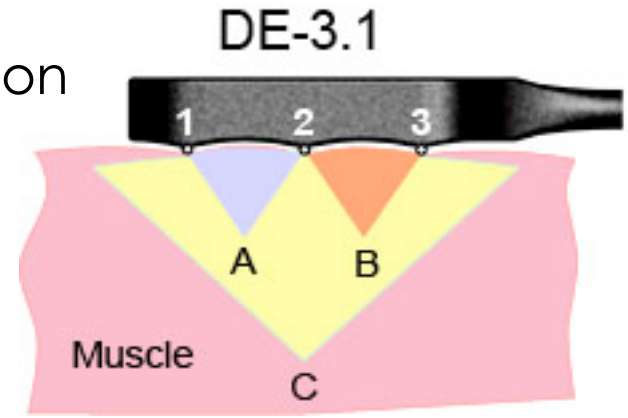
Drawbacks: crosstalk

How to minimize crosstalk?

- Proper localization of the electrodes

www.seniam.org/

- Double differential electrode configuration



http://www.delsys.com/

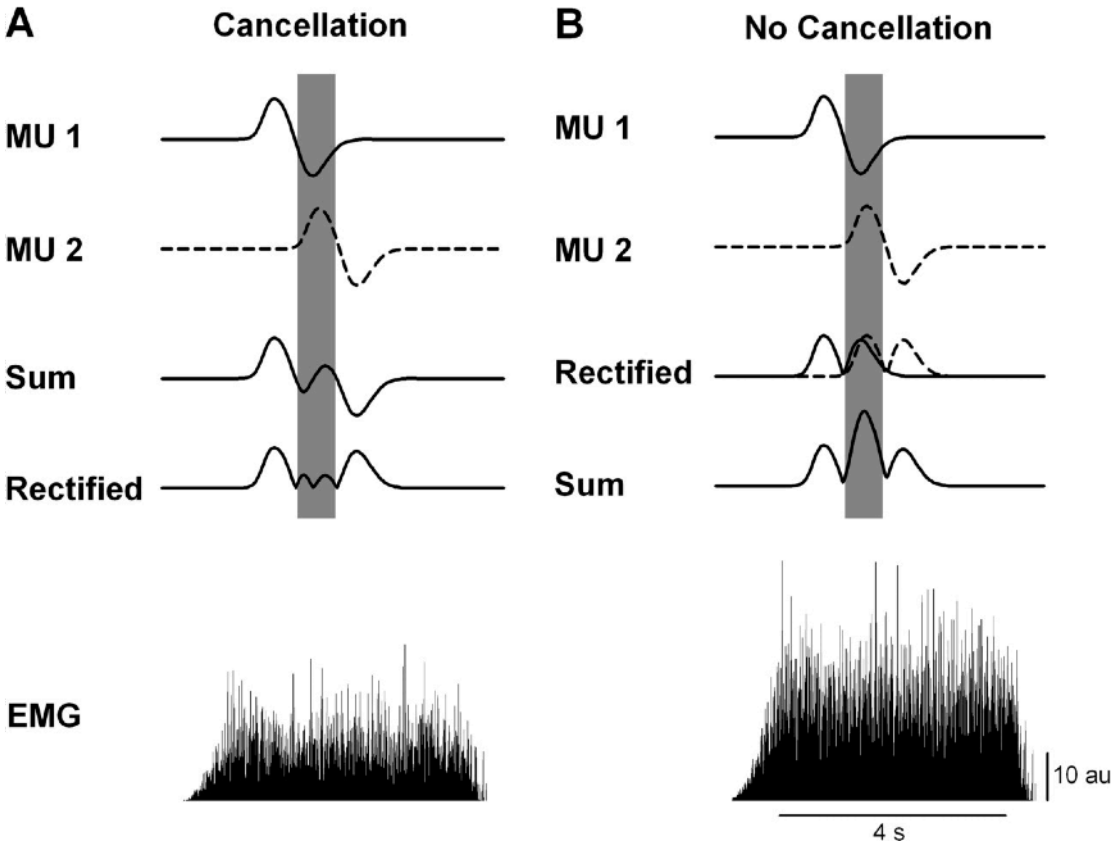
- Low skin-electrode impedance

Mesin et al. (2009 J Electromyo Kinesiol)

Electromyography

Drawbacks: amplitude cancellation

Cancellation of positive and negative phases of motor unit action potentials



Keenan et al. (2004 - J Appl Physiol)

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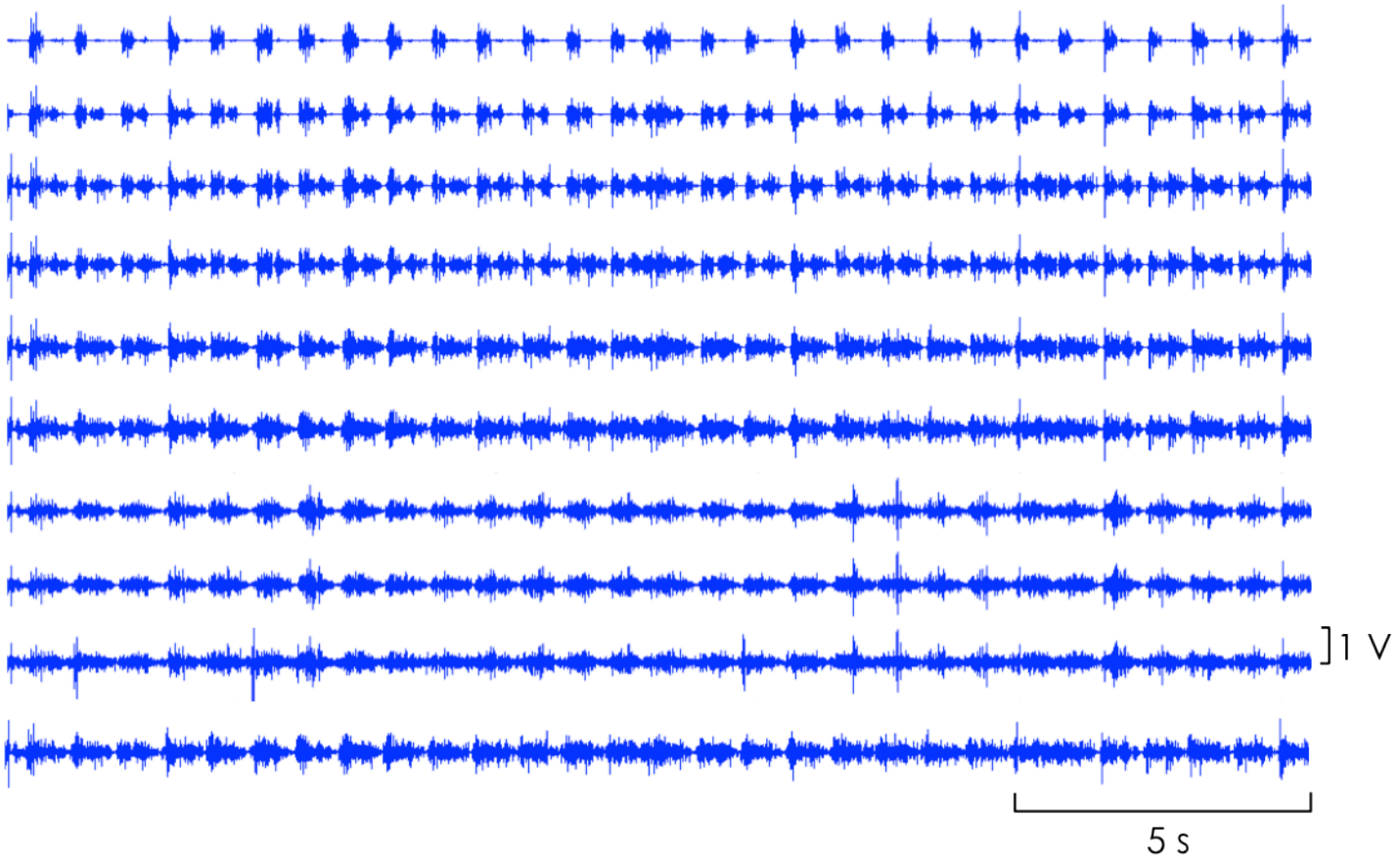
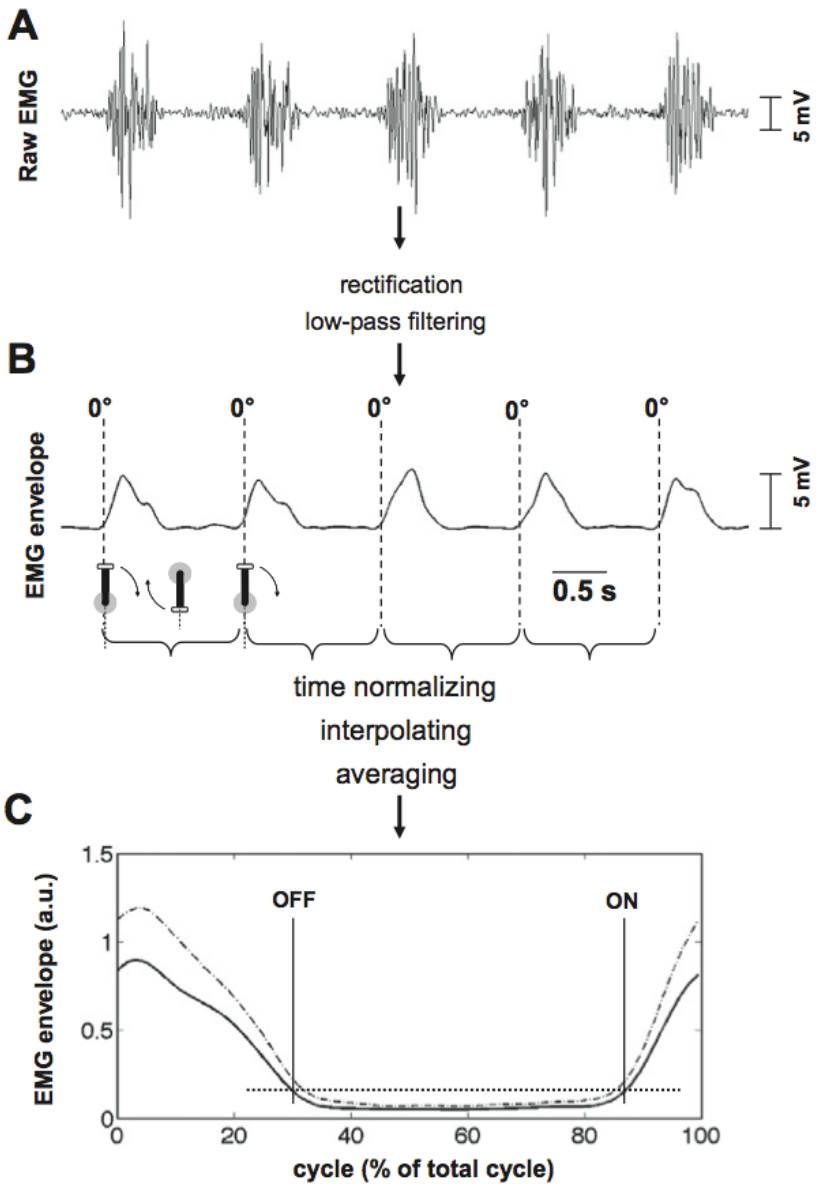
Electromyography

What useful information can we extract from raw EMG signals?



Electromyography

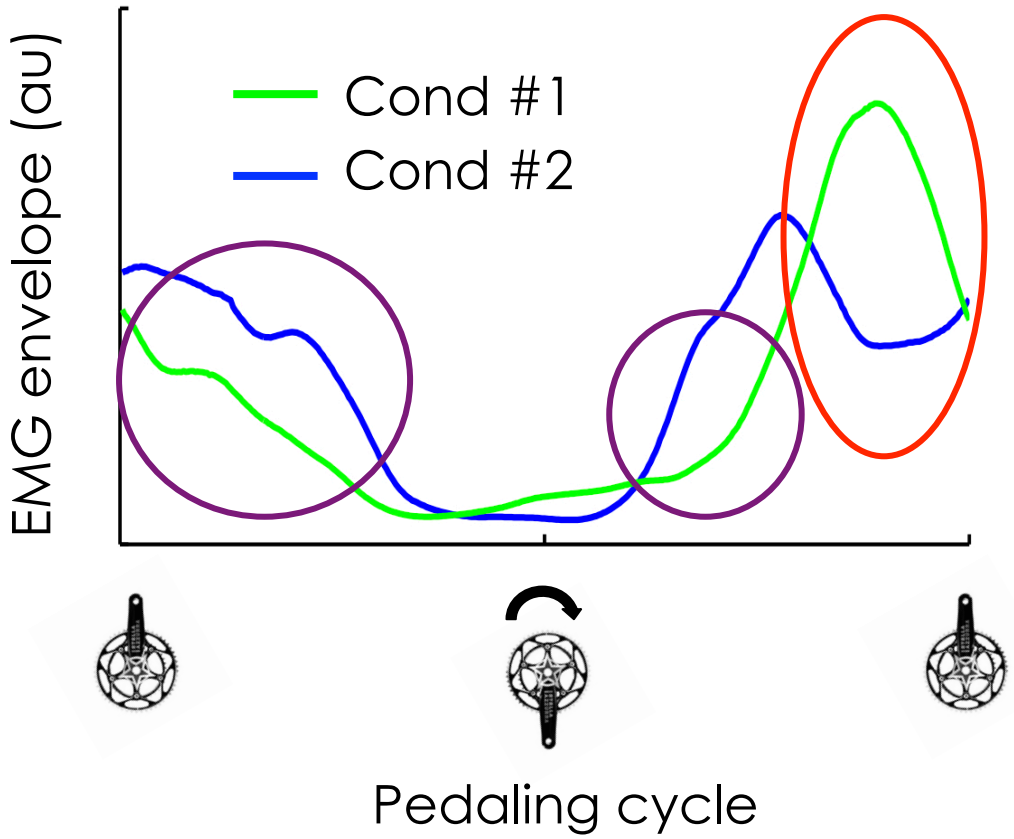
- Muscle synergies
- Muscle activity level
- Timing of activation
- Shape of the EMG pattern



Hug (2011 – J Electromyo Kinesiol)

Electromyography

EMG patterns should be considered for a better understanding of muscle coordination



Mean EMG amplitude over the cycle is not different

BUT …

Electromyography

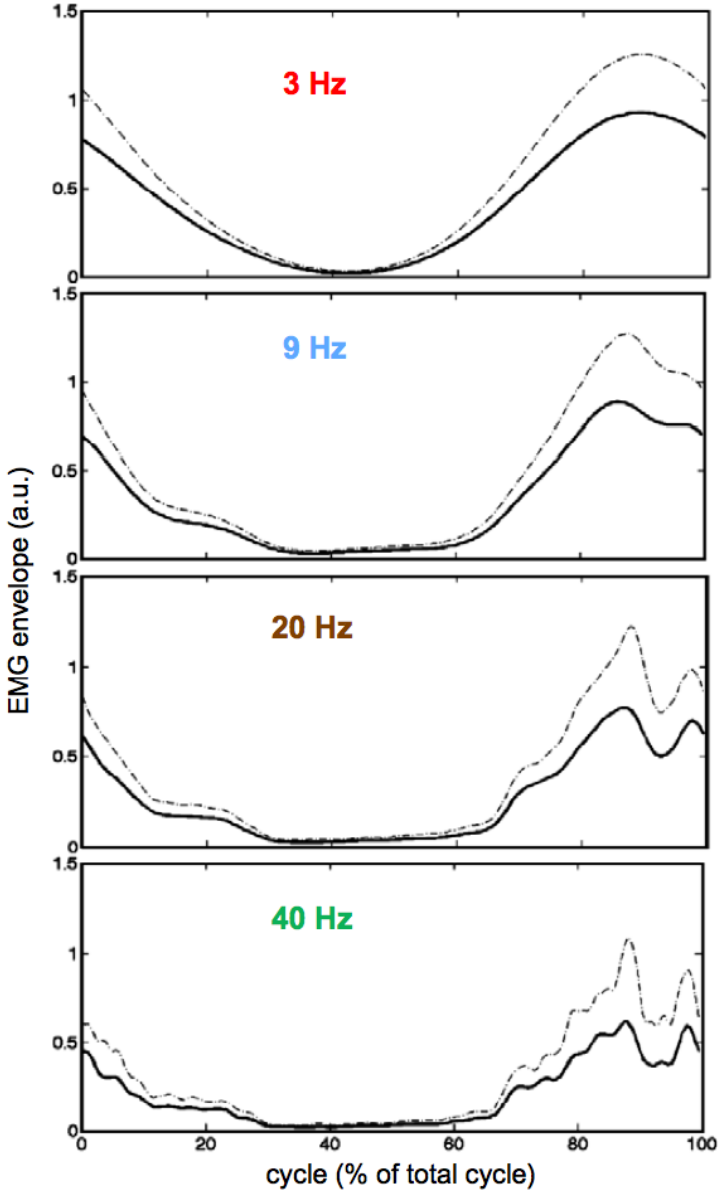
Smoothing the EMG signal

- Depend on the cut-off frequency of the low-pass filter

- But also depend on the number of averaged cycles

What is the "ideal" filter and, thus, the "ideal" waveform?

Gait: 9Hz *(Shiavi, 1998 - Med Biol Eng Comput)*

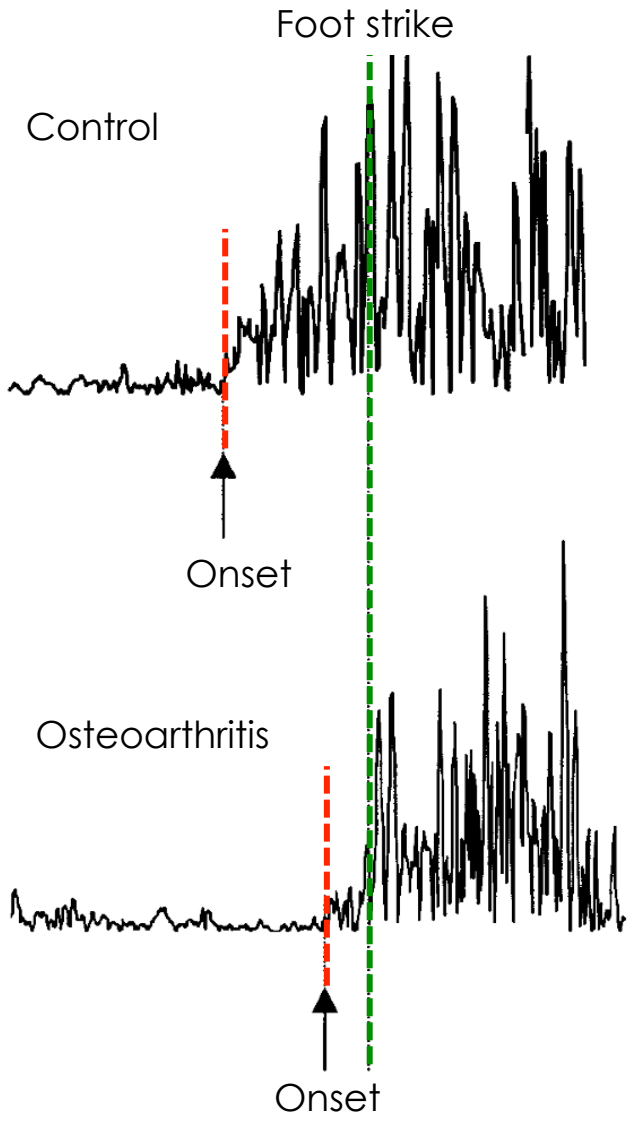


Hug, 2011 (J Electromyo Kinesiol)

Electromyography

Onset/offset detection

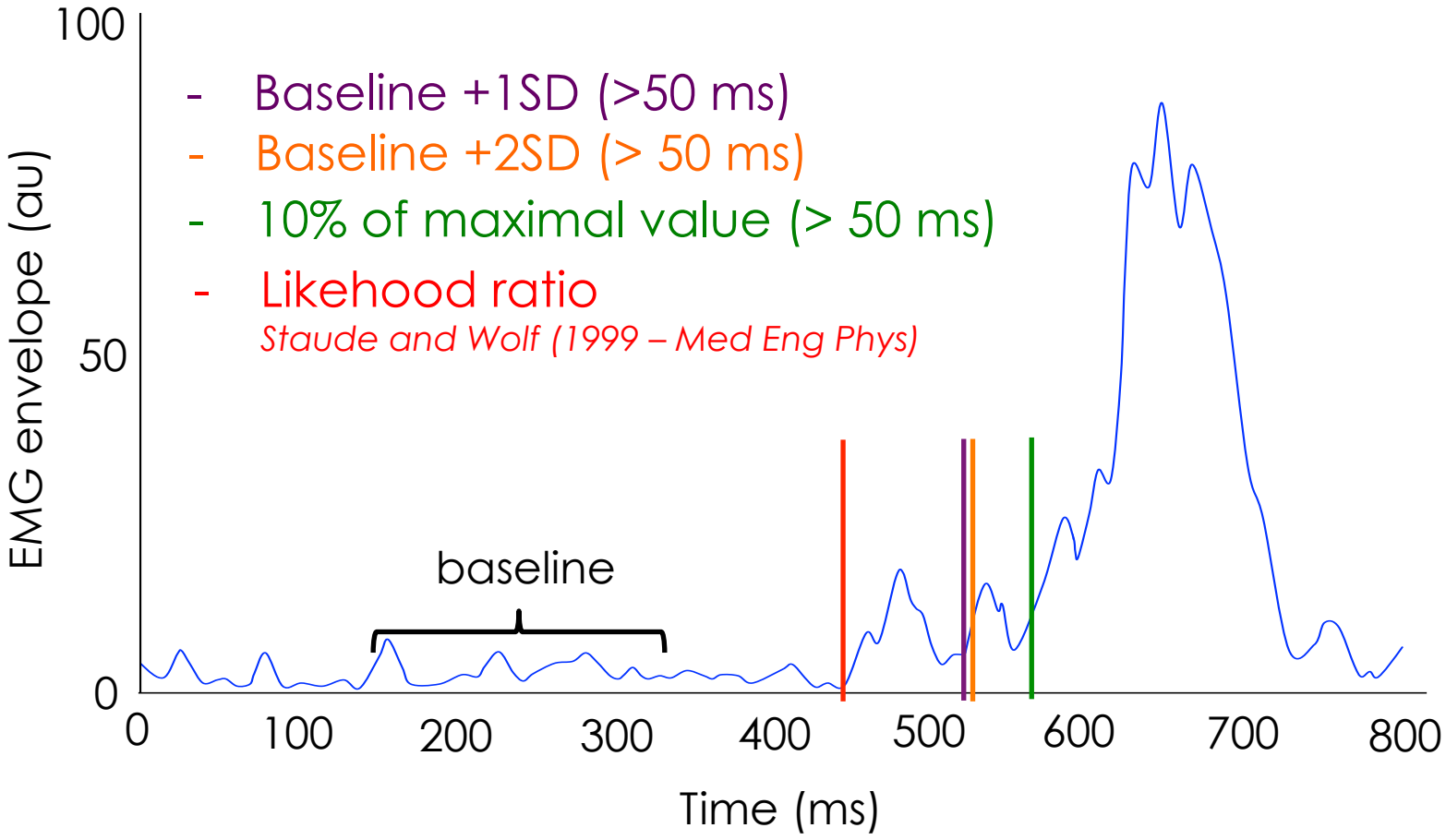
Clinical interpretation of EMG signals is usually based on the assessment of the onset of muscle activation



Hinman et al. (2002 – Arch Phys Med Rehab)

Electromyography

Onset/offset detection



Important to visually check !

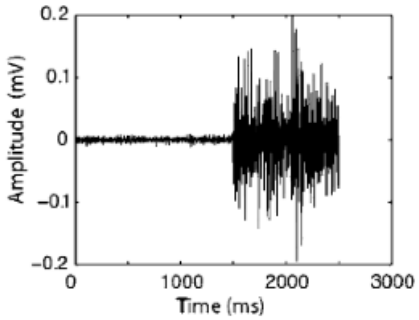
Hodges and Bui (1996 – Electroencephalogr Clin Neurophysiol)

Electromyography

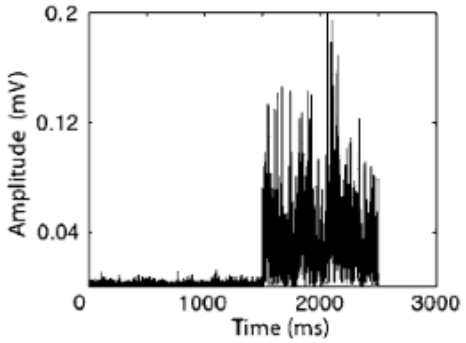
Onset/offset detection

Teager-Kaiser energy operator

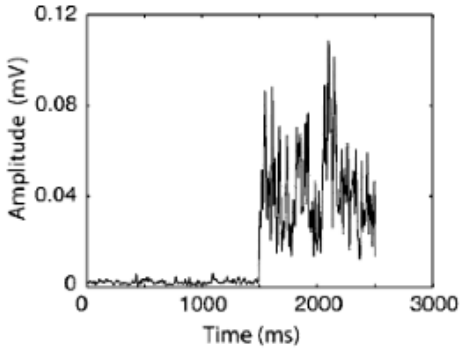
Raw signal



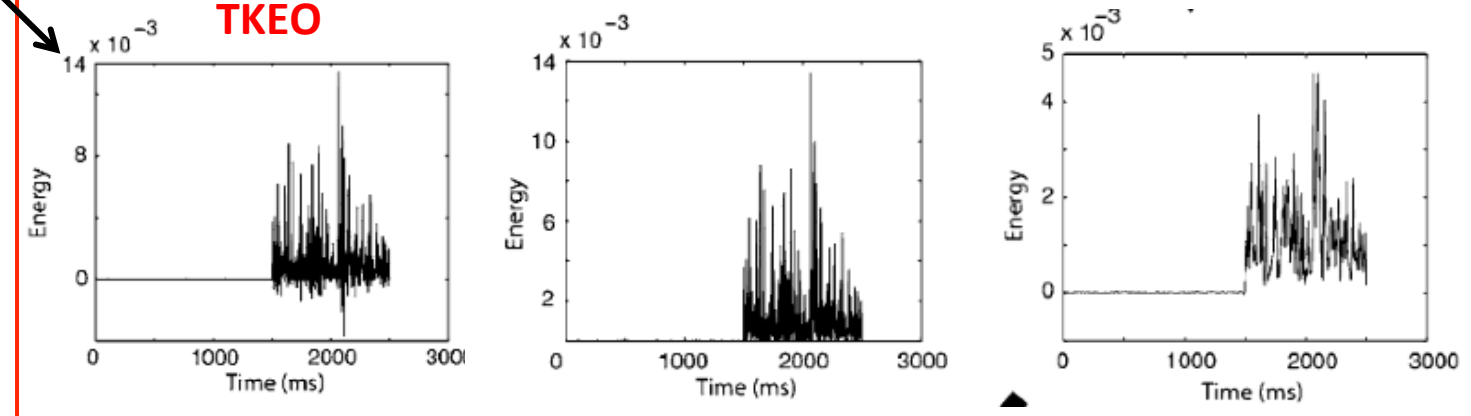
Rectification



Low-pass filter



TKEO



Adapted from Solnik et al. (2010 – Eur J Appl Physiol)

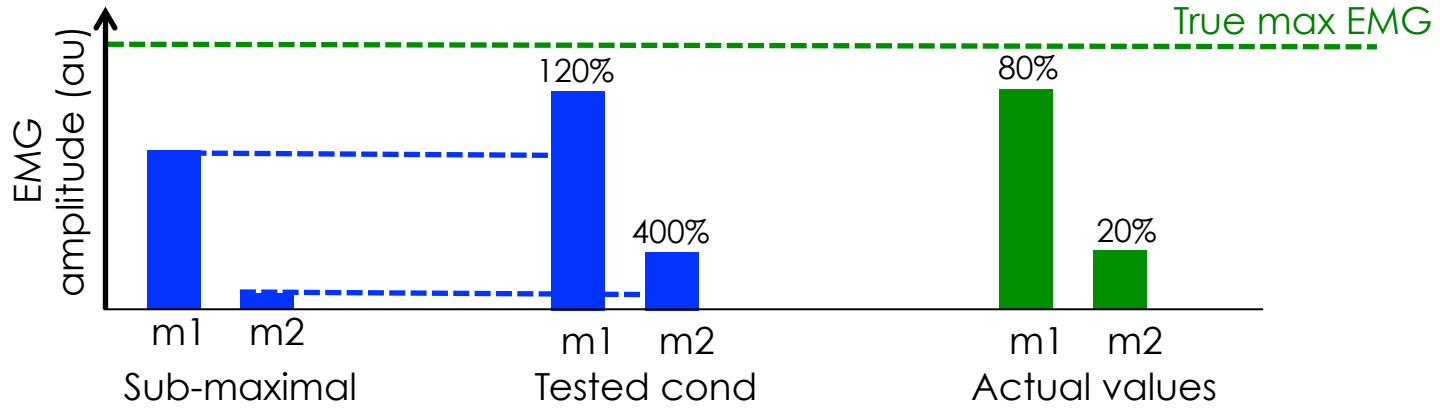
Electromyography

Amplitude normalization

Different methods:

- Isometric maximal voluntary contraction
  - -> Maximal neural drive during dynamic contractions?
  - -> Values >100% are often reported
  - -> Time consuming when numerous muscles are recorded

- Submaximal contraction
  - -> Not a direct information



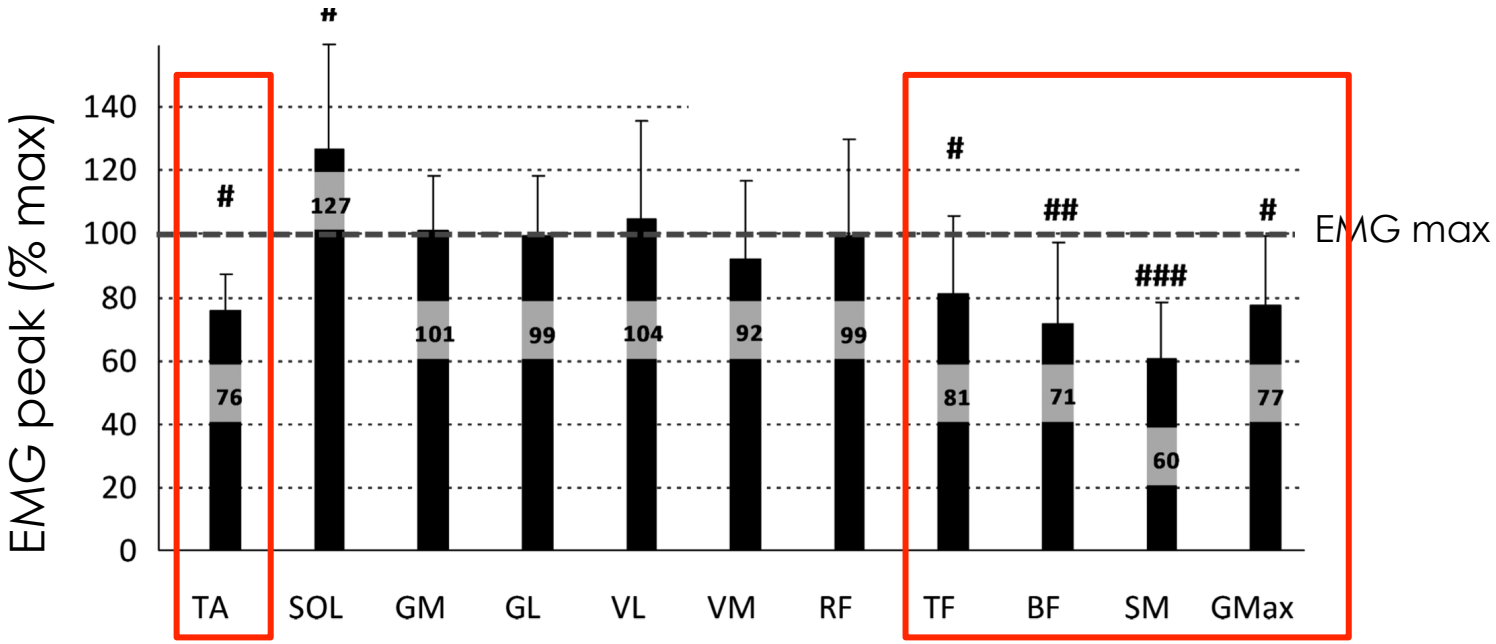
Electromyography

Amplitude normalization

- Maximal dynamic task (e.g., all-out pedaling sprint)

  -> Is maximal activation reached for all the muscles?

MVC in isometric and isokinetic modes



Dorel et al. (2012 – Med Sci Sports Exerc)

Electromyography

Amplitude normalization

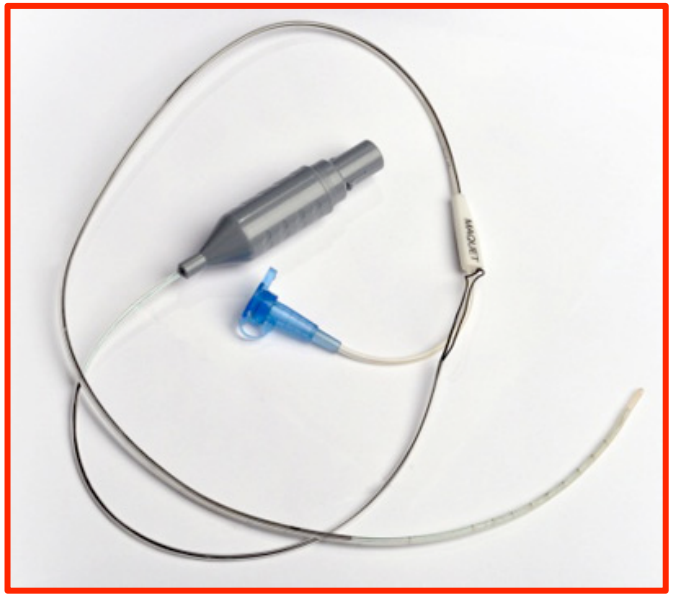
No agreement on the best normalization procedure to be used

Burden and Bartlett (1999 – Med Eng Phys)

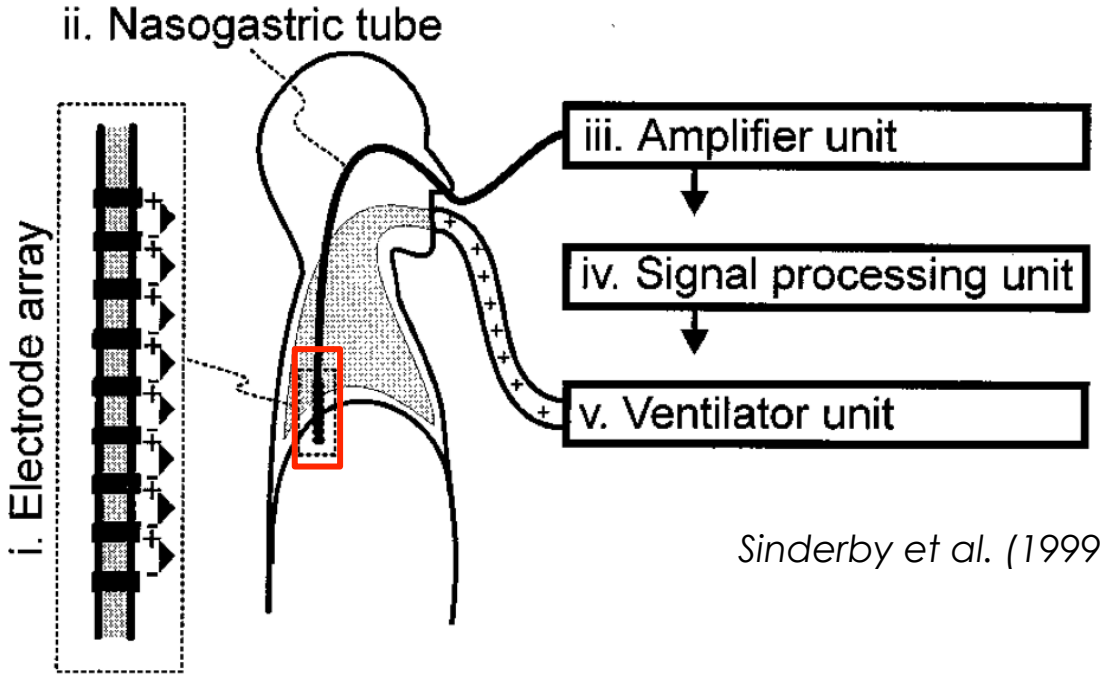
- Amplitude normalization is not always necessary:
  - Feedback
  - Quantification of changes within a session
  - Determination of onset/offset times
  - …
- Other cases:
  - Keep in mind the relatively low accuracy

Electromyography

Example of application



Neurally adjusted ventilatory assist (NAVA)



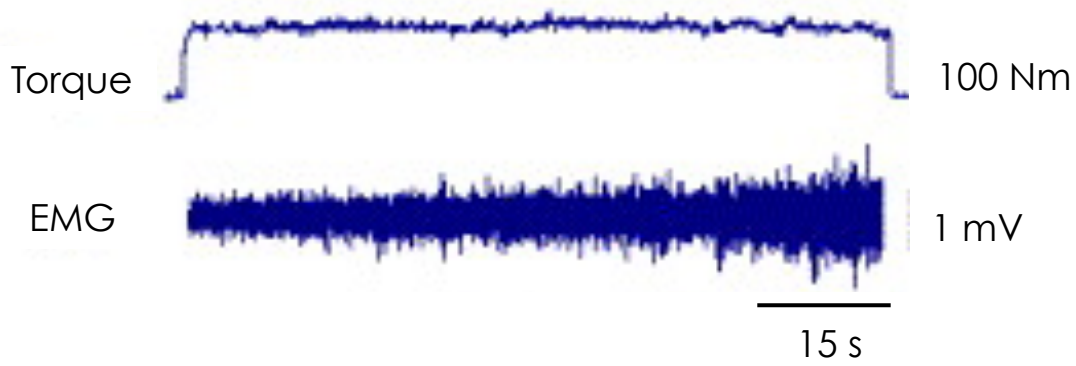
Sinderby et al. (1999 – Nat Med)

- Improvement of patient–ventilator interaction

Electromyography

Example of application

Change in muscle coordination with fatigue

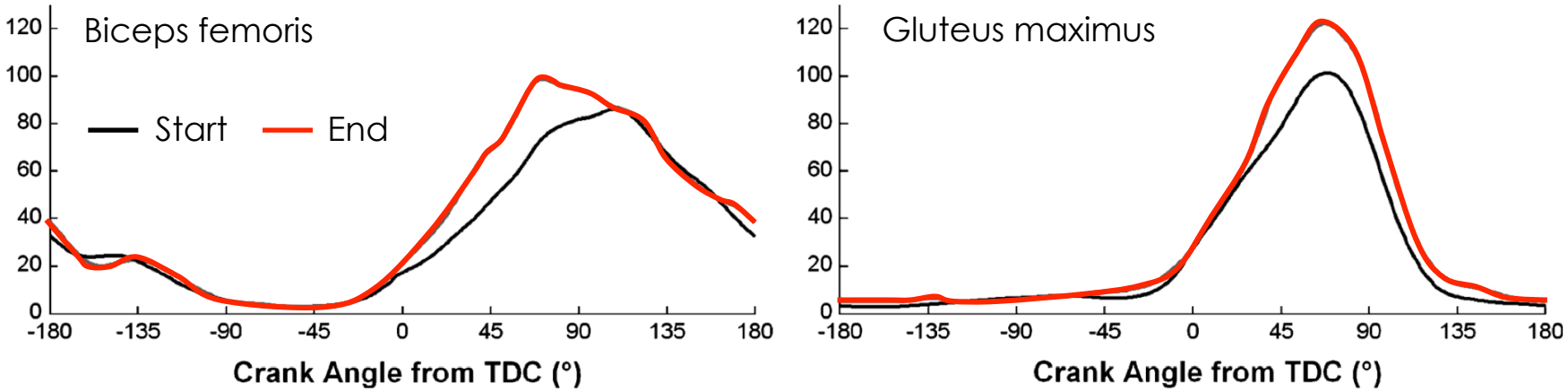


- Recruitment of additional MUs to compensate for the decrease in force of the fatigued fibers *(Edward and Lippold, 1956 – J Physiol)*
- Slowing of muscle fiber action potential conduction velocity *(Lindstrom et al. 1970 - Electromyogr)*

Electromyography

Example of application

More complicated to interpret in a complex system



Dorel et al. (2009 – Med Sci Sports Exerc)

Pedaling at a constant power output and pedaling rate until exhaustion

- Fatigue (same force but higher activation)?
- Compensation (higher activation to increase force production)?
- Both?

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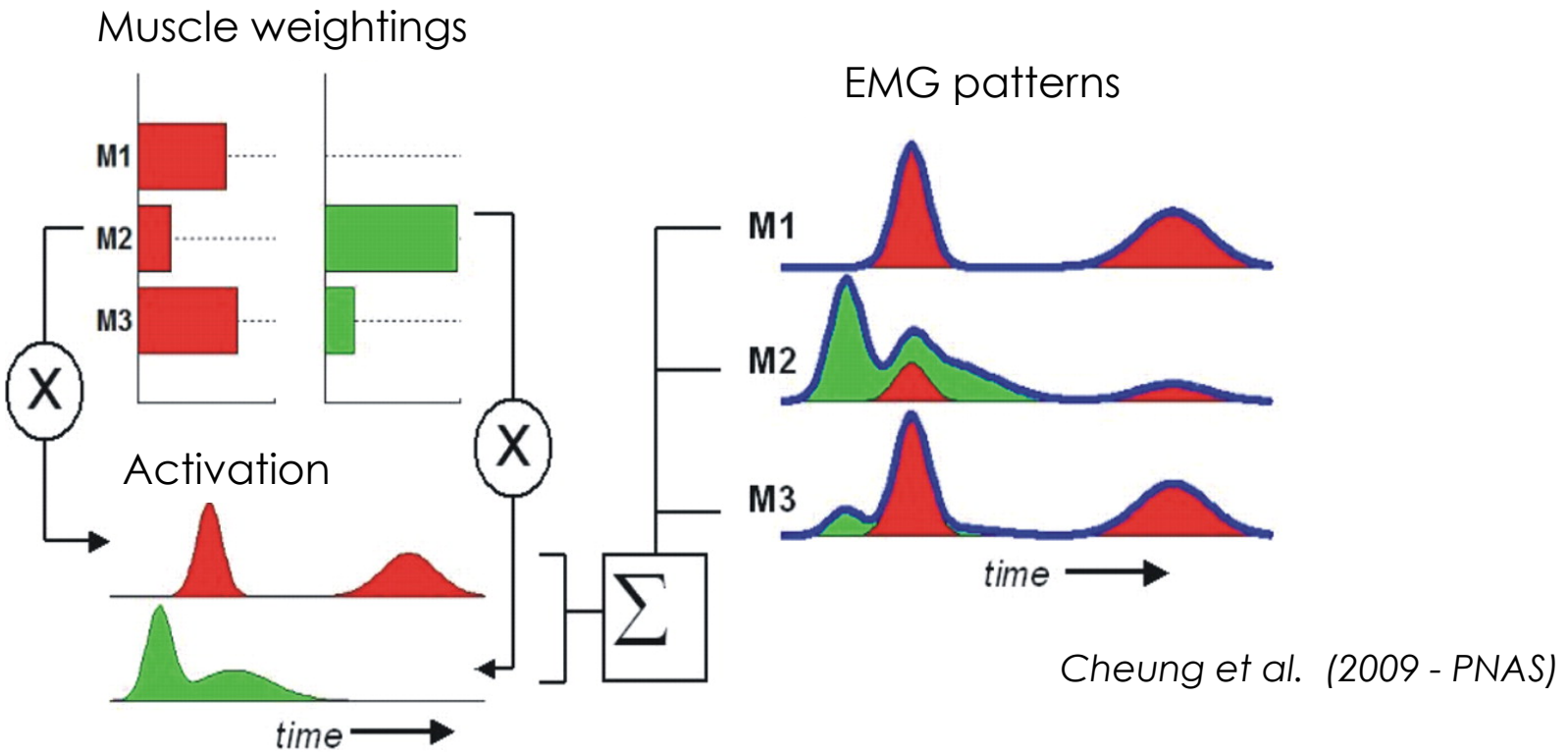
Electromyography

Muscle synergies

"Modules formed by muscles activated in synchrony, named muscle synergies, have been proposed as building blocks that could simplify the construction of motor behaviors"

d'Avella and Bizzi (2005 - PNAS)

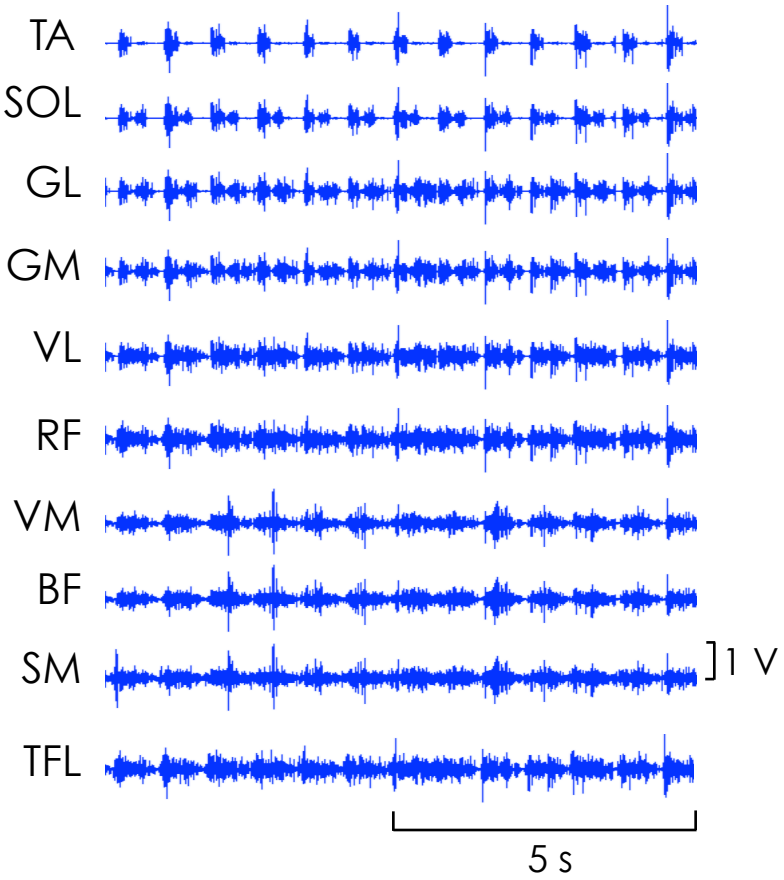


Cheung et al. (2009 - PNAS)

Electromyography

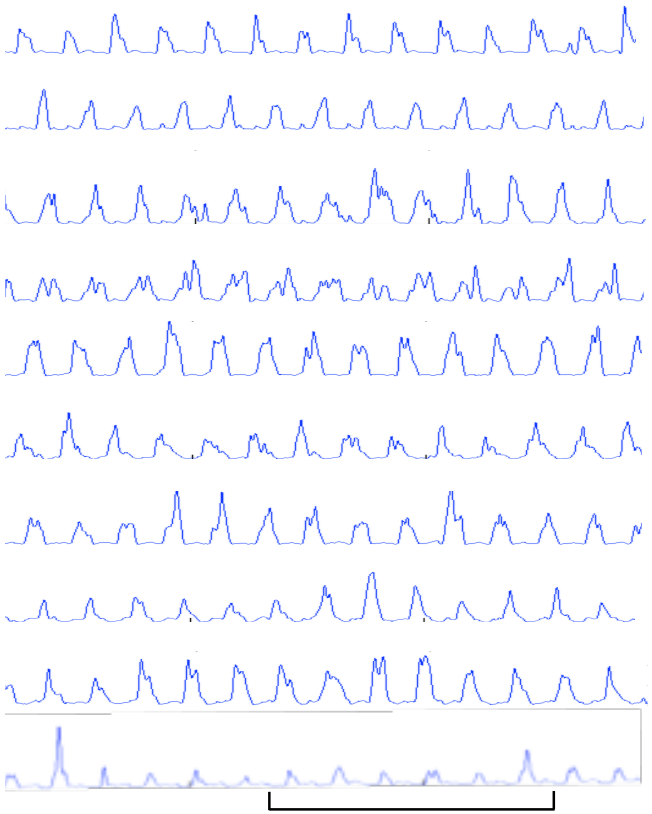
Muscle synergies

Raw EMG signals



Example of extraction (pedaling)

Step 1: filtered EMG + normalization



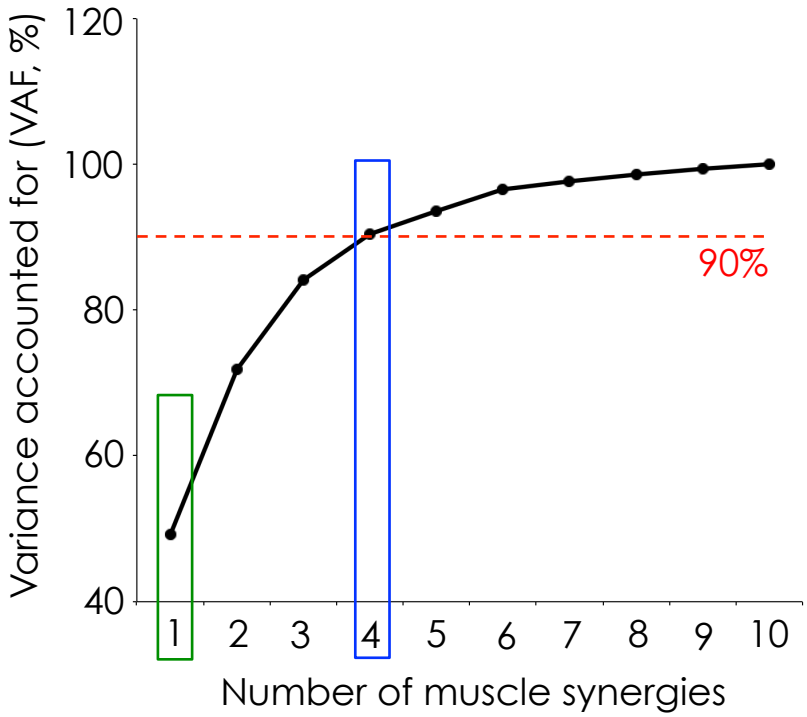
Electromyography

Muscle synergies

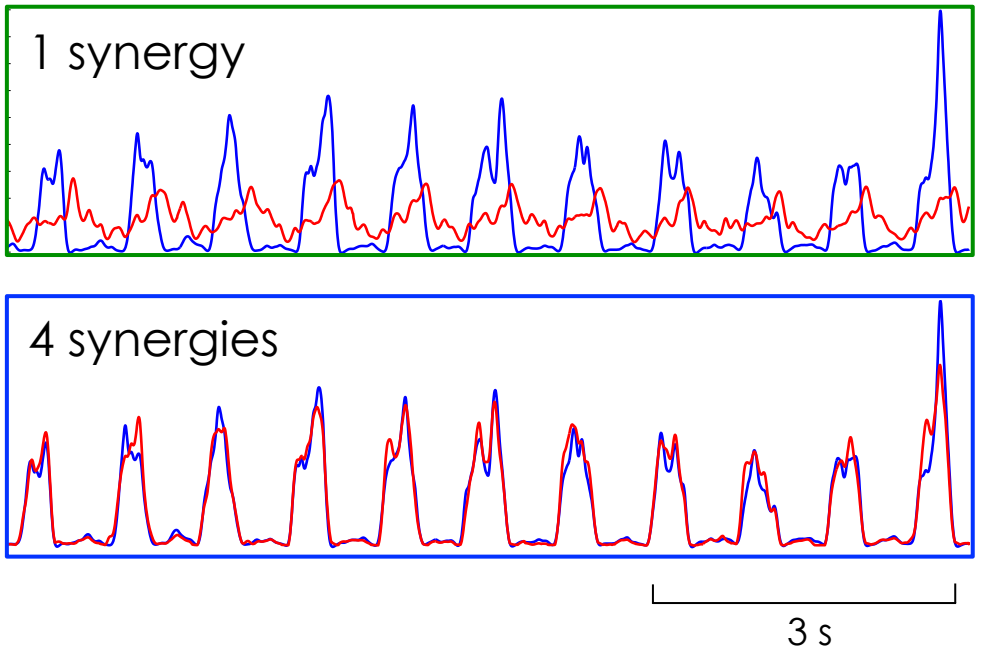
Step 2: extraction using non-negative matrix factorization

Lee and Seung (2001 - Nature)

Selection of the number of muscle synergies

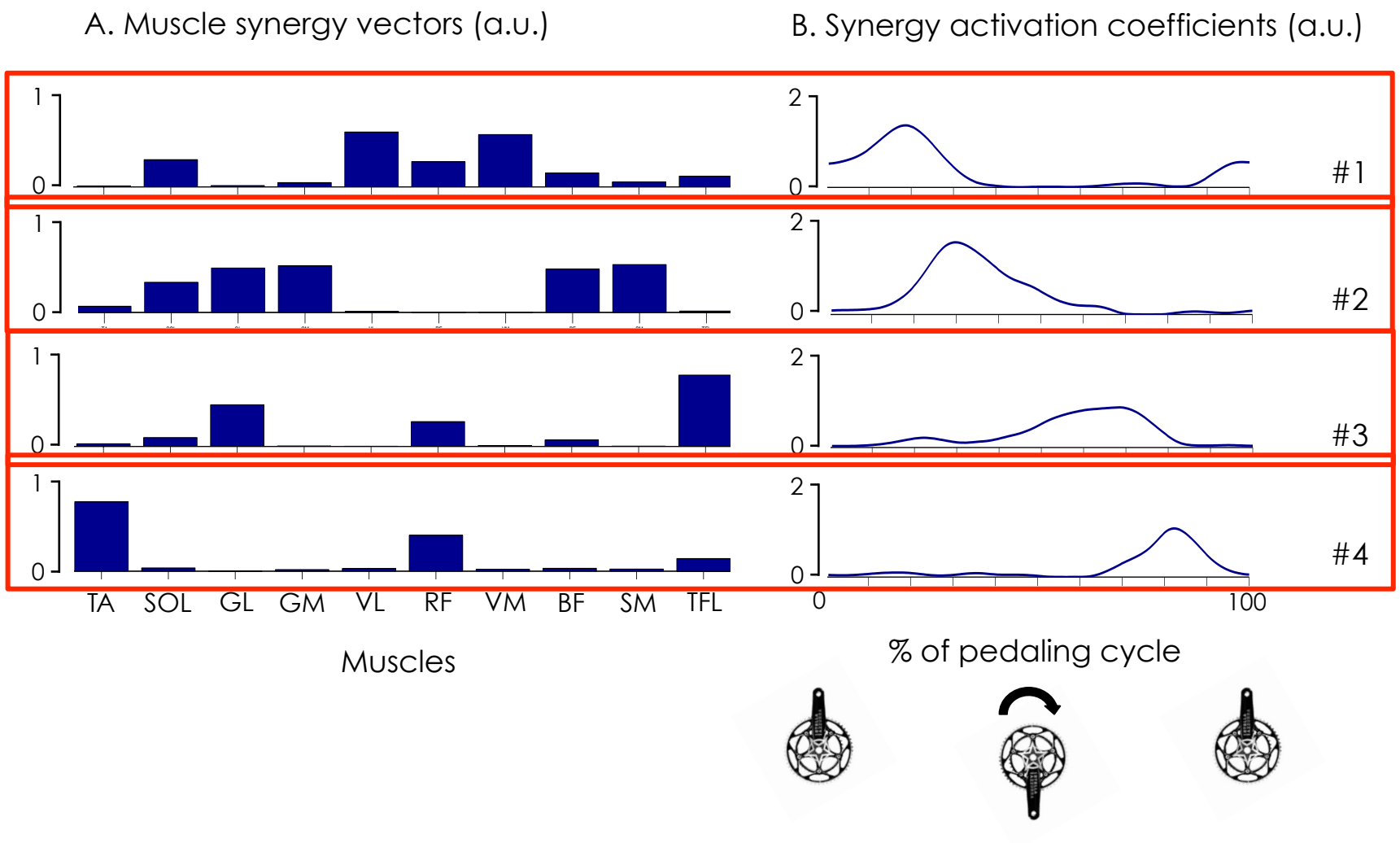


Example of VL reconstruction:



Electromyography

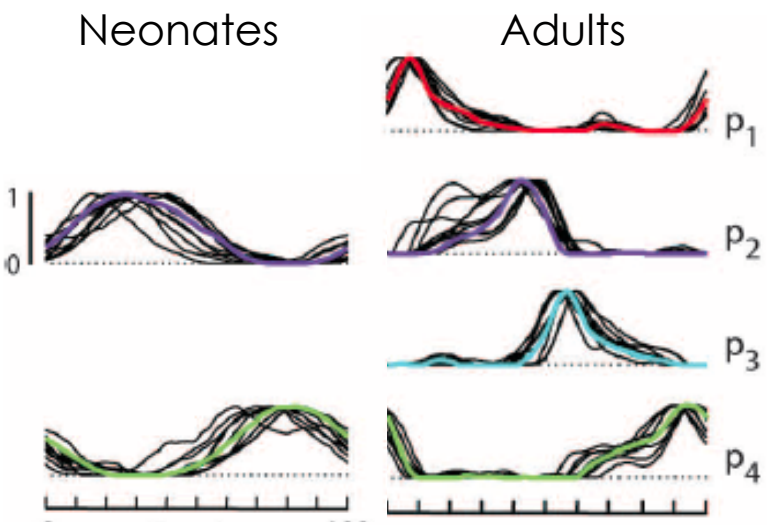
Muscle synergies



Electromyography

Muscle synergies

Number of synergies as an indicator of the complexity of the task



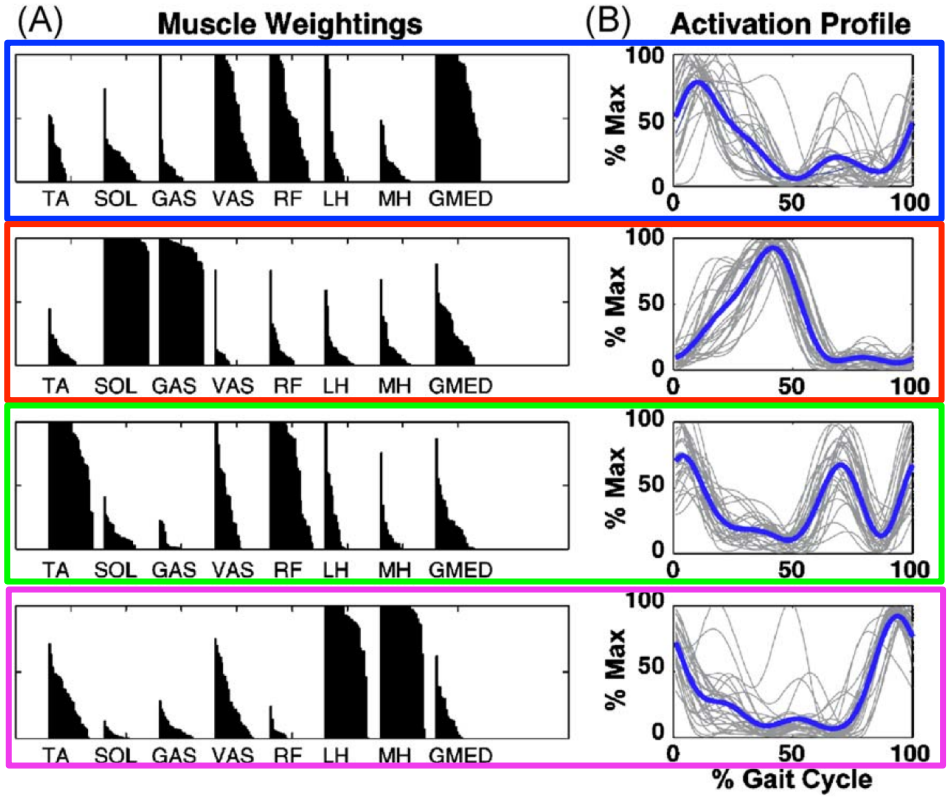
Two muscle synergies of stepping neonates are retained through development, augmented by two new synergies first revealed in toddlers

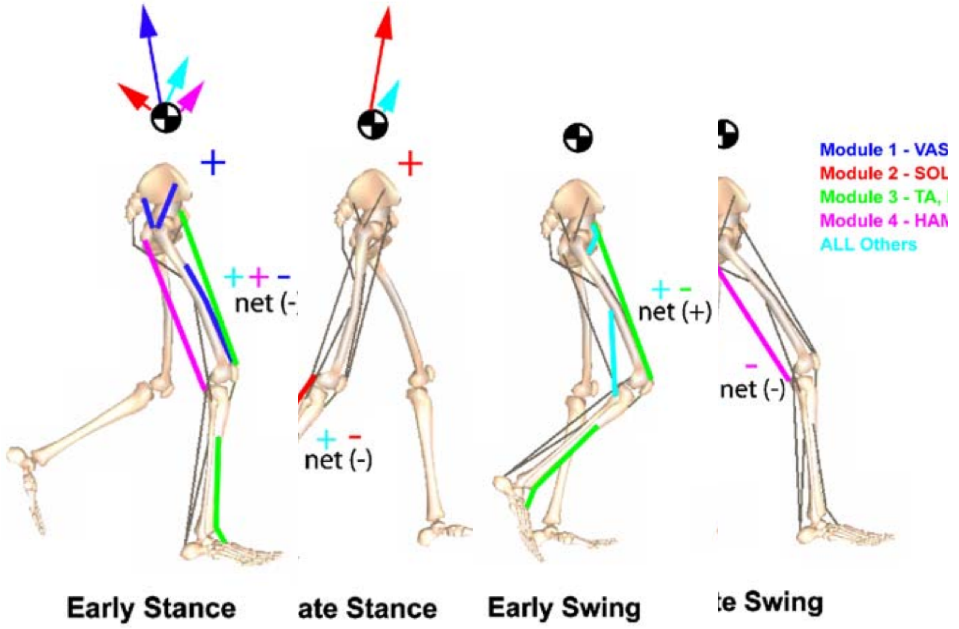
Dominici et al. (2011 - Science)

Electromyography

Muscle synergies

Synergies as functional motor sub-tasks





Neptune et al. (2009 – J Biomech)

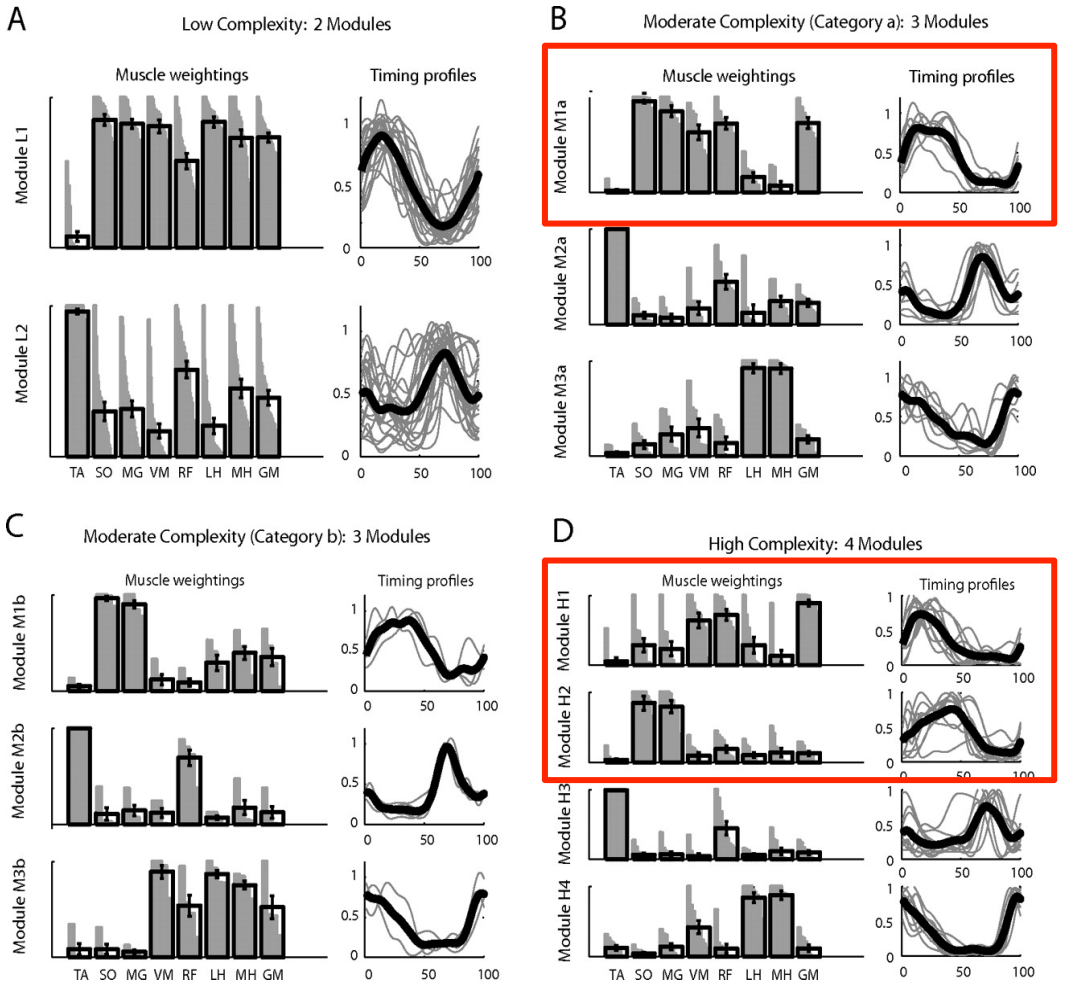
Walking results from a simple neural control strategy involving muscle synergies to perform the basic sub-tasks of gait

Electromyography

Muscle synergies

Number of synergies as a predictor of the degree of impairment

Patients with post-stroke have fewer muscle synergies related to impaired walking performance



Clark et al. (2010 – J Neurophysiol)

Electromyography

Muscle synergies

Do they really reflect the neural command?

- Experimental works support this idea

e.g., Overduin (2012 - Neuron)

- Reflect the biomechanical constraints of the task

e.g. Kutch and Valero-Cuevas (2012 – PloS Comp Biol)

Whatever their origin, muscle synergies can be useful to describe muscle coordination in a more integrative way, especially when numerous muscles are recorded

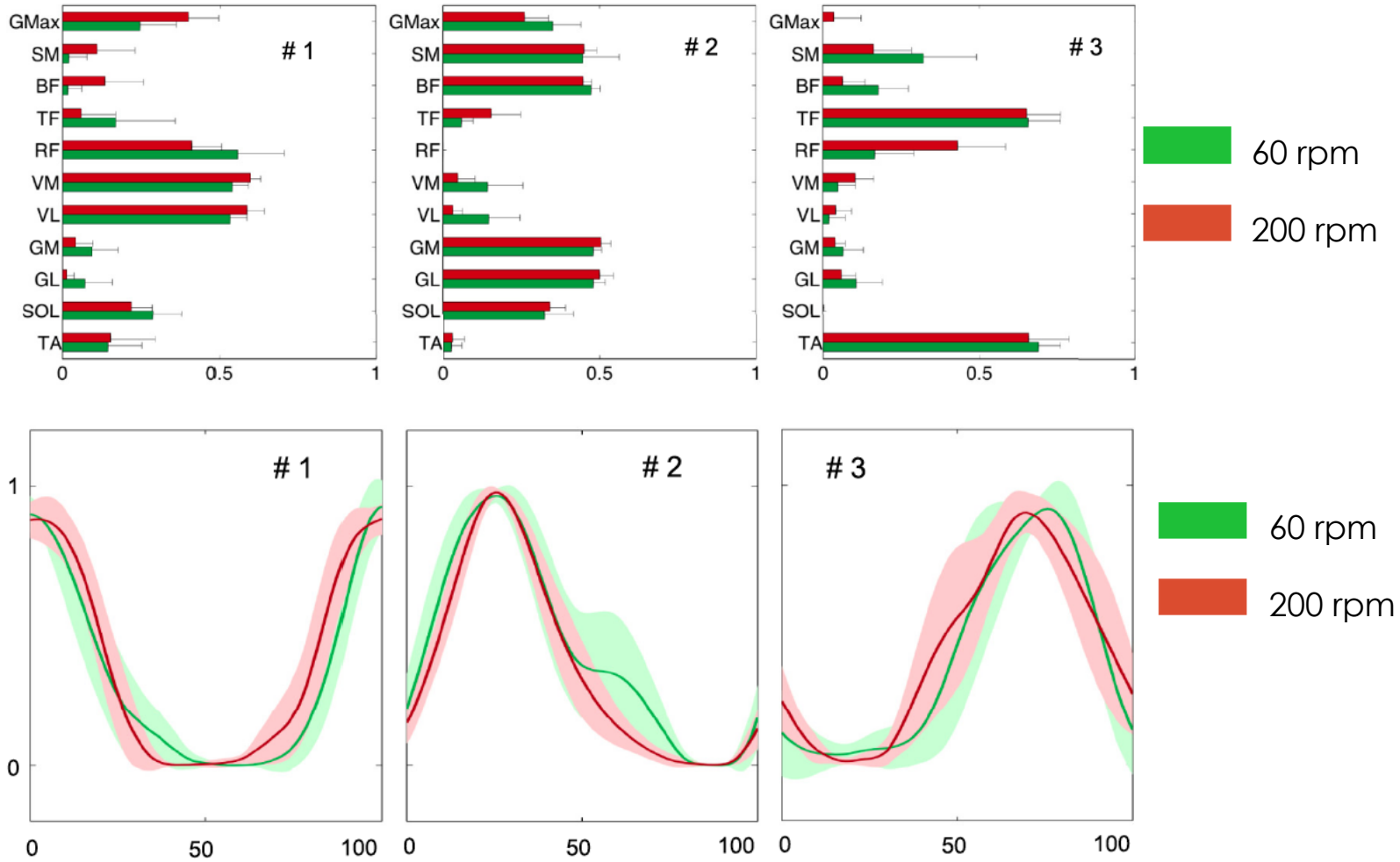
Electromyography

Muscle synergies: example of application

What are the effects of the mechanical constraints on muscle coordination during an all-out pedaling sprint?

Electromyography

Muscle synergies: example of application

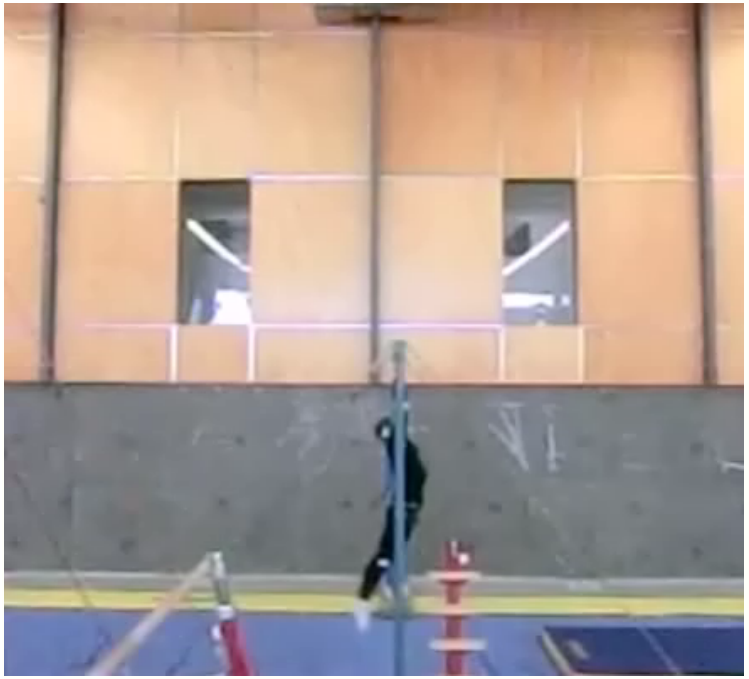


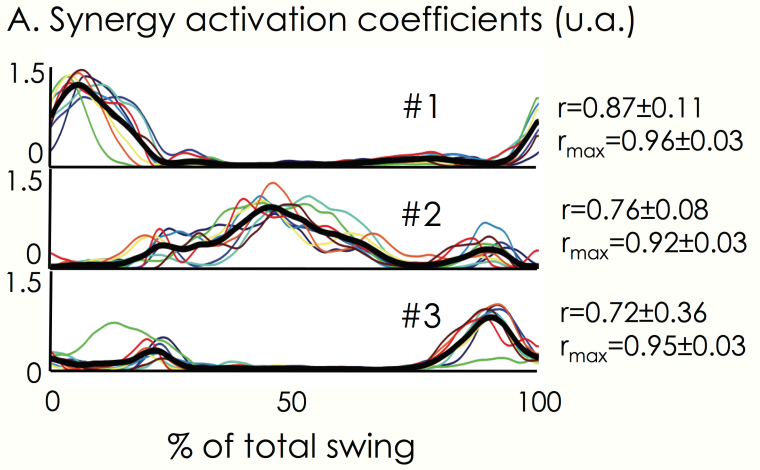
Hug et al. (2011 – J Neurophysiol)

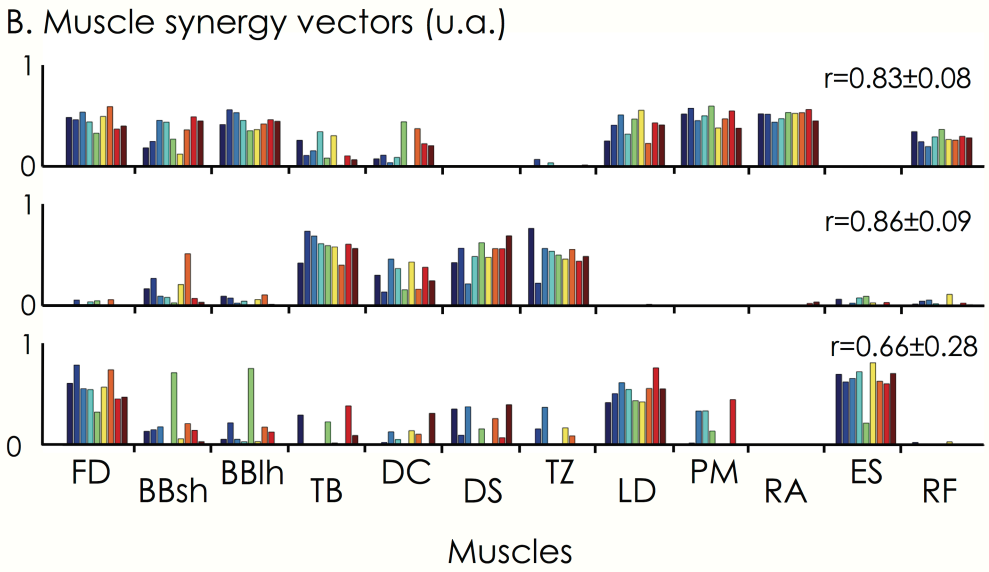
Electromyography

Muscle synergies: example of application

Backward giant swings on the high bar







Frère and Hug (2012 - Front Comp Neurosci)

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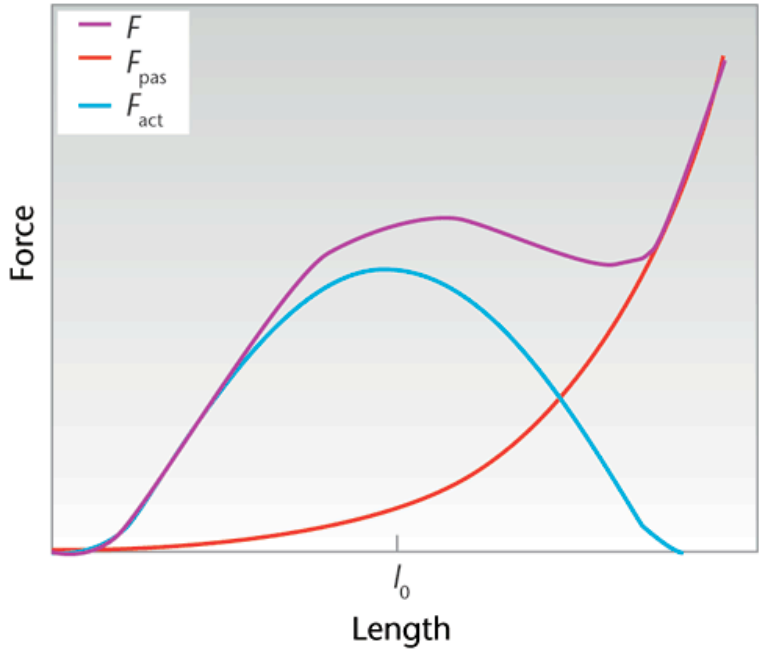
Muscle activation or muscle force?

*"Distribution of **muscle activation or force** among individual muscles to produce a given combination of joint moments"* *Prilutsky (2000 – Motor Control)*



- Passive force
- Same force (stress) can be achieved by different activation levels

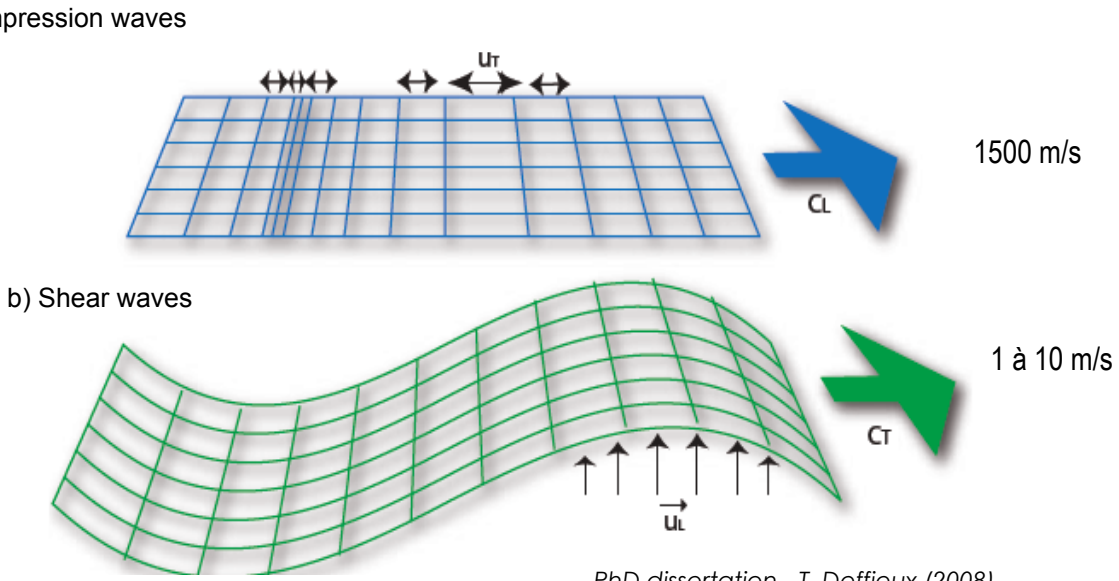
Altenburg et al., (2009 – J Appl Physiol)

Elastography

Principle

Mechanical perturbation

=> Propagation of mechanical waves



PhD dissertation - T. Deffieux (2008)

The propagation velocity of shear waves is directly linked to the elastic modulus (stiffness):

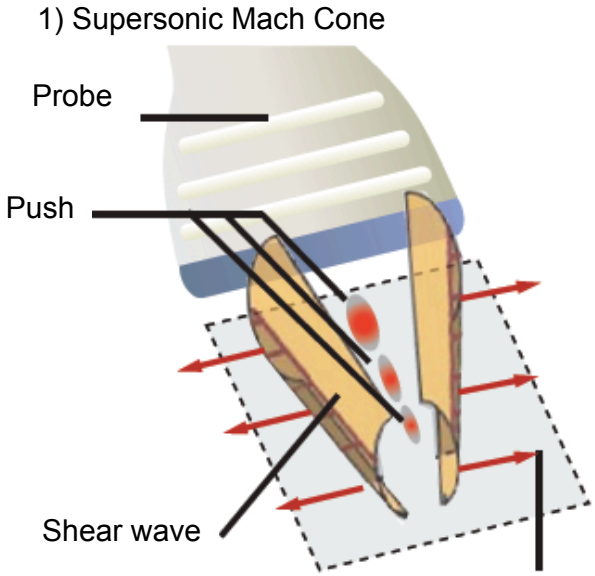
$\mu = \rho C^2$

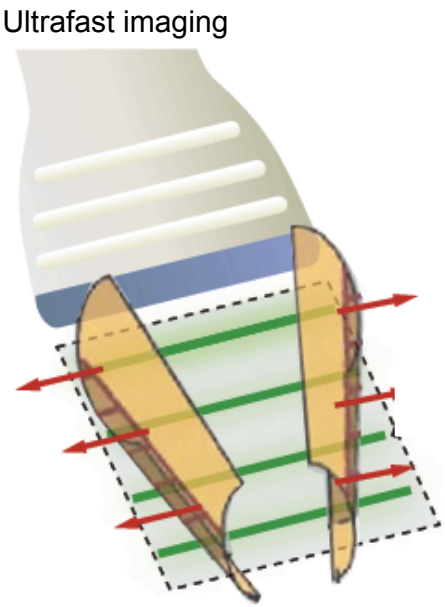
(where μ is the shear elastic modulus, ρ is the muscle mass density and C is the shear wave velocity)

Elastography

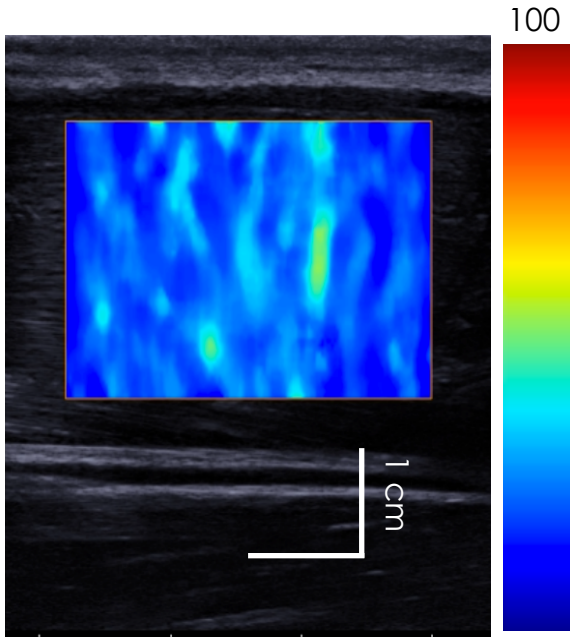
Principle

Supersonic Shear Imaging (SSI)





PhD dissertation (Deffieux, 2008)

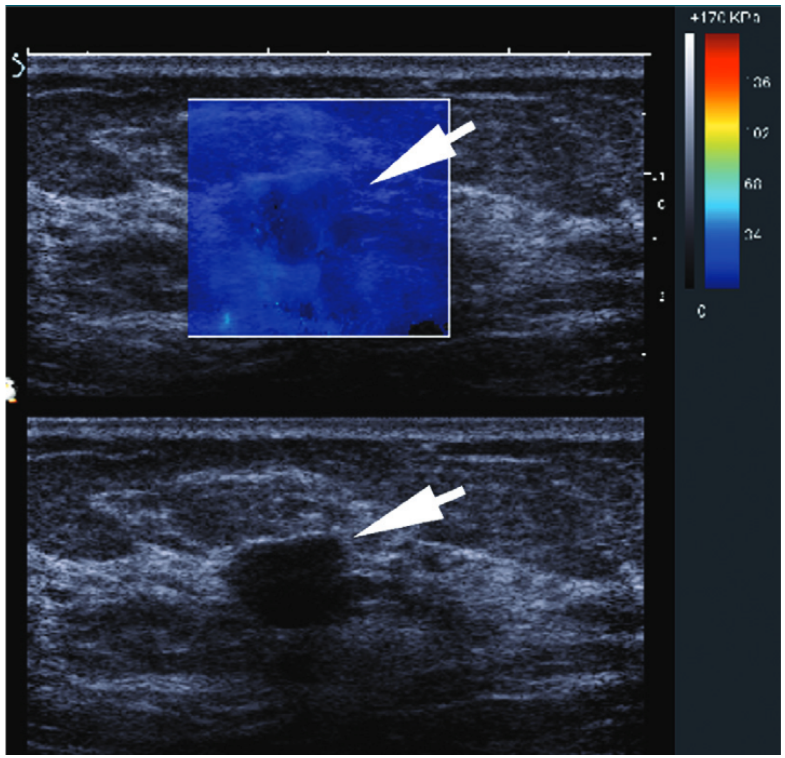


Elastography

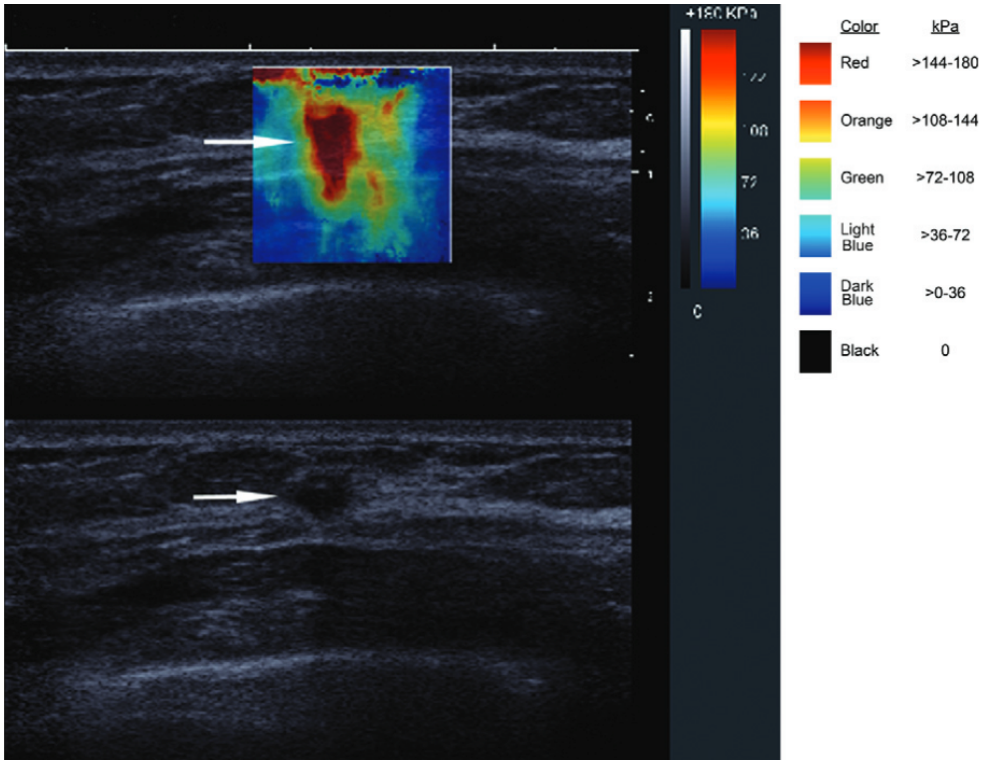
Example of clinical application

- Breast mass assessment

Benign



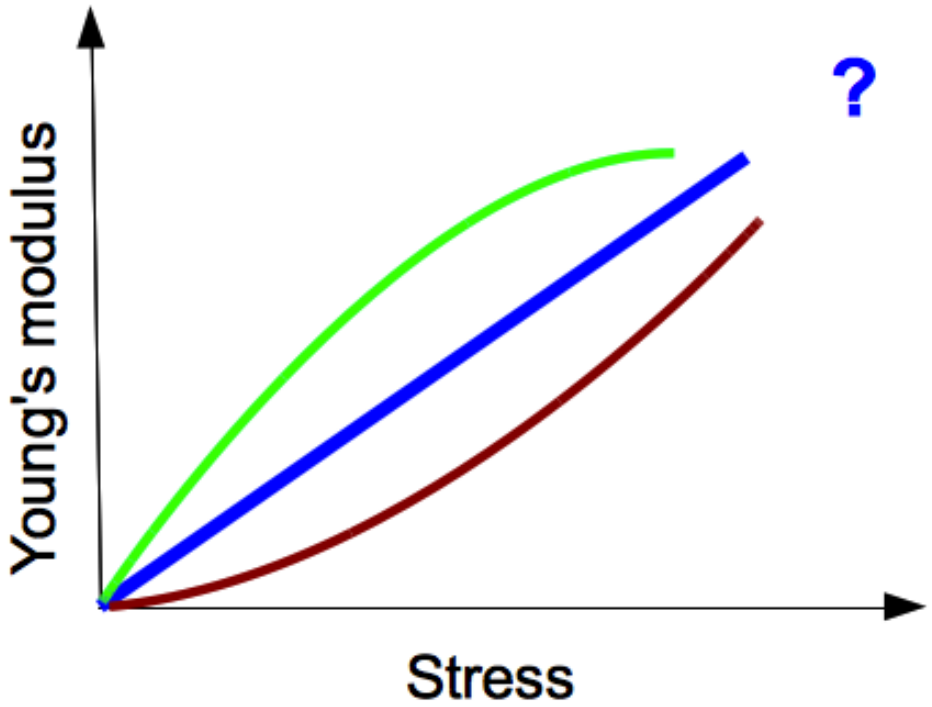
Malignant



Berg et al. (2012 – Radiology)

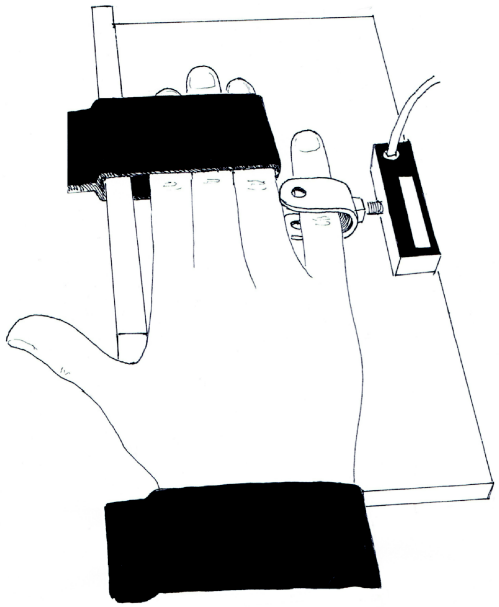
Elastography

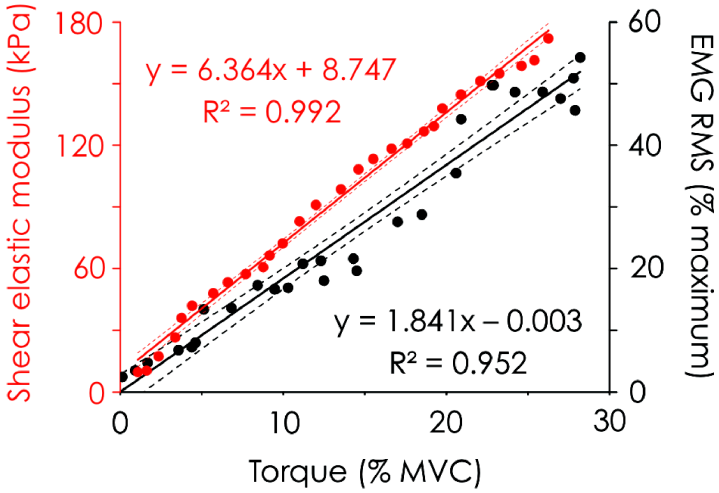
Toward the estimation of muscle force



Elastography

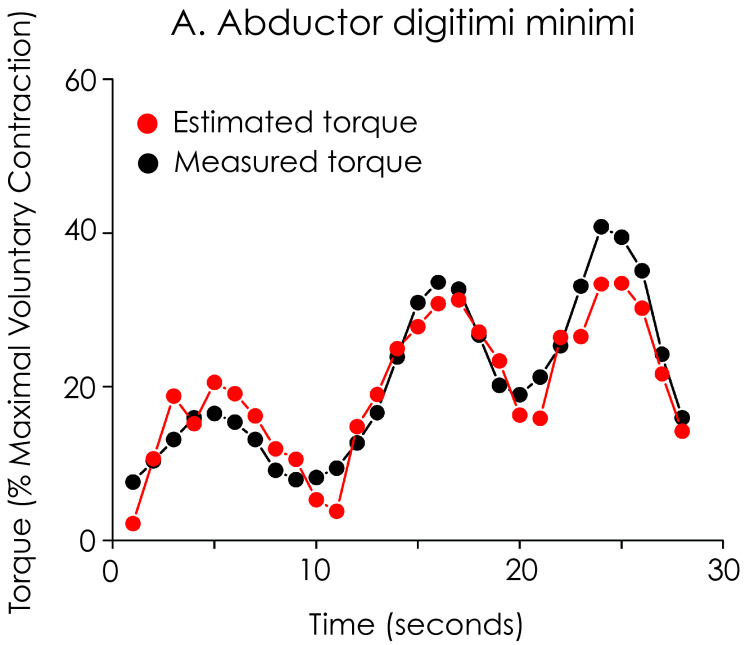
Toward the estimation of muscle force





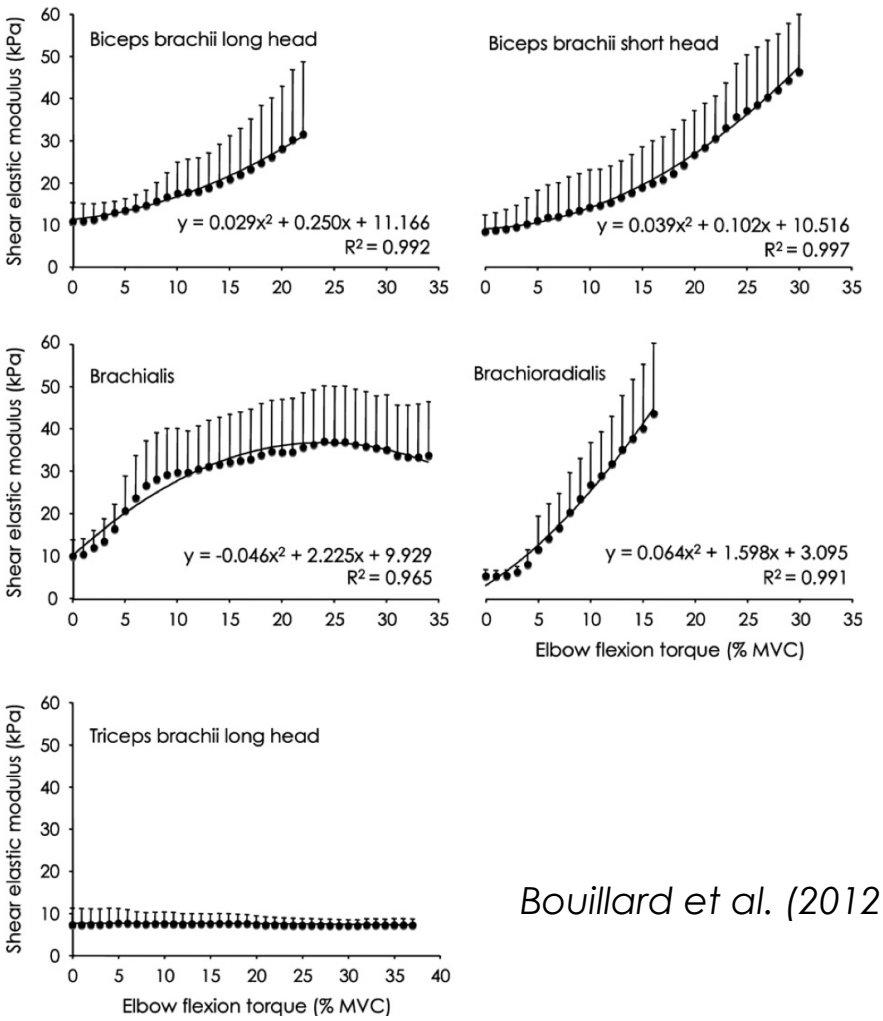
The shear elastic modulus measured using SSI can provide an accurate estimation of individual muscle force

Bouillard et al. (2011 – PloS ONE)

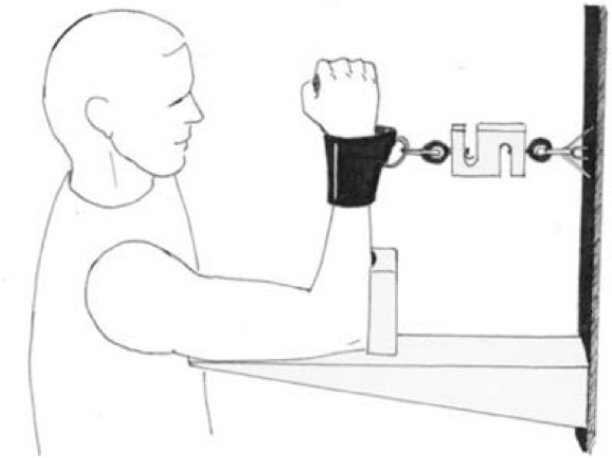


Elastography

Toward the estimation of muscle force



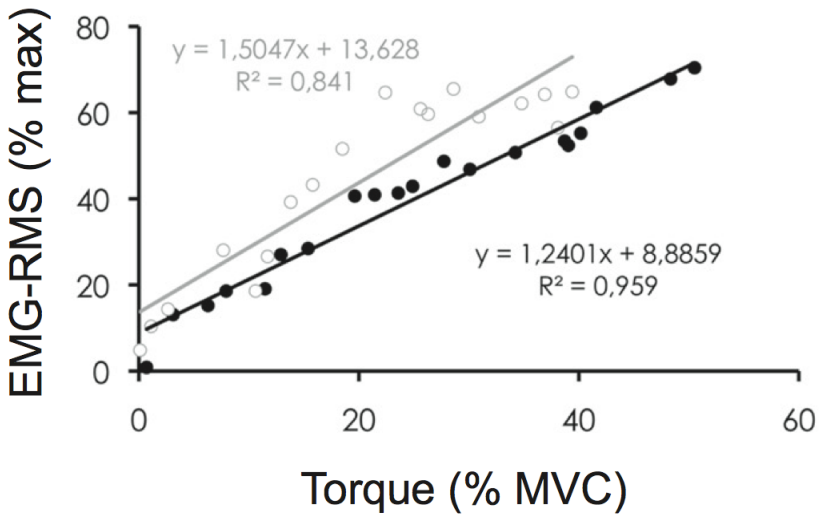
Load sharing among the elbow flexors

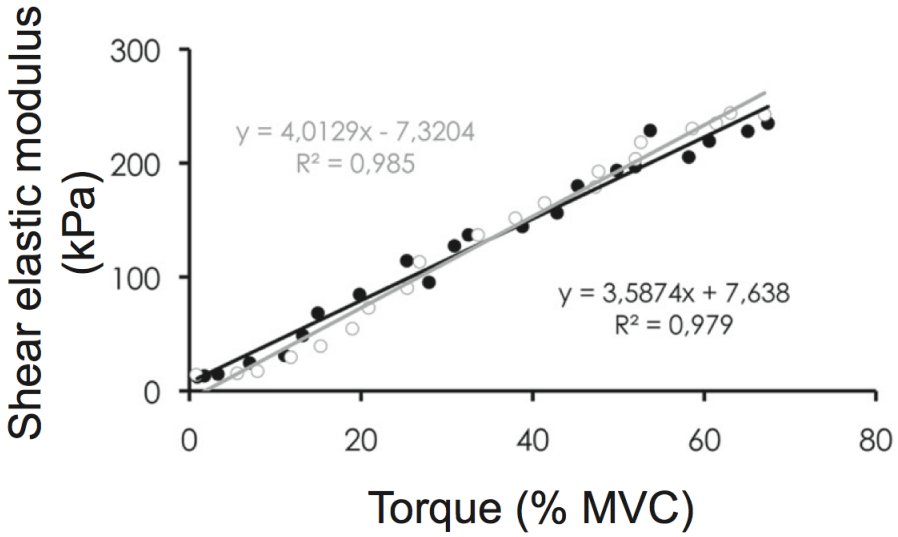


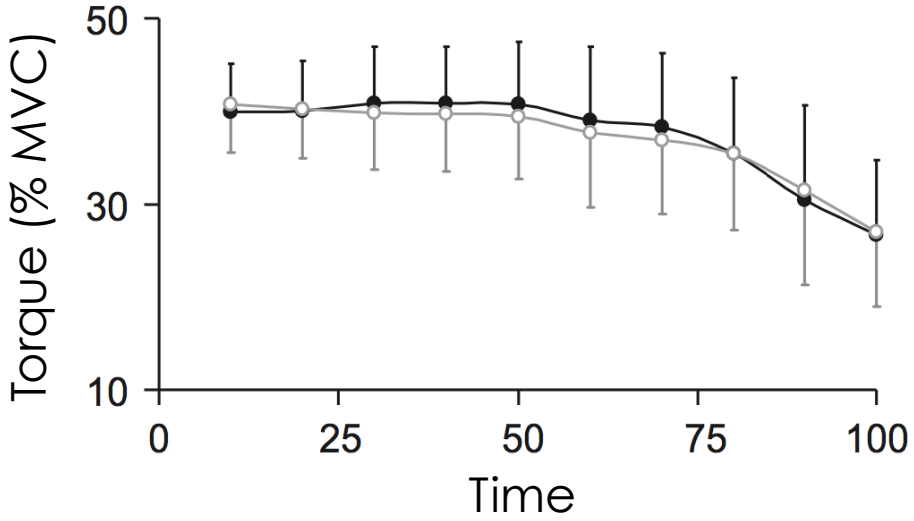
Bouillard et al. (2012 – J Biomech)

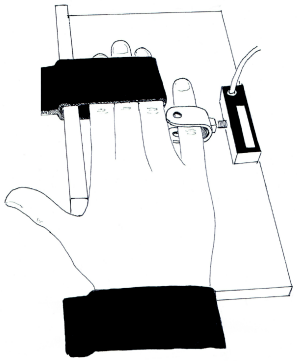
Elastography

Toward the estimation of muscle force





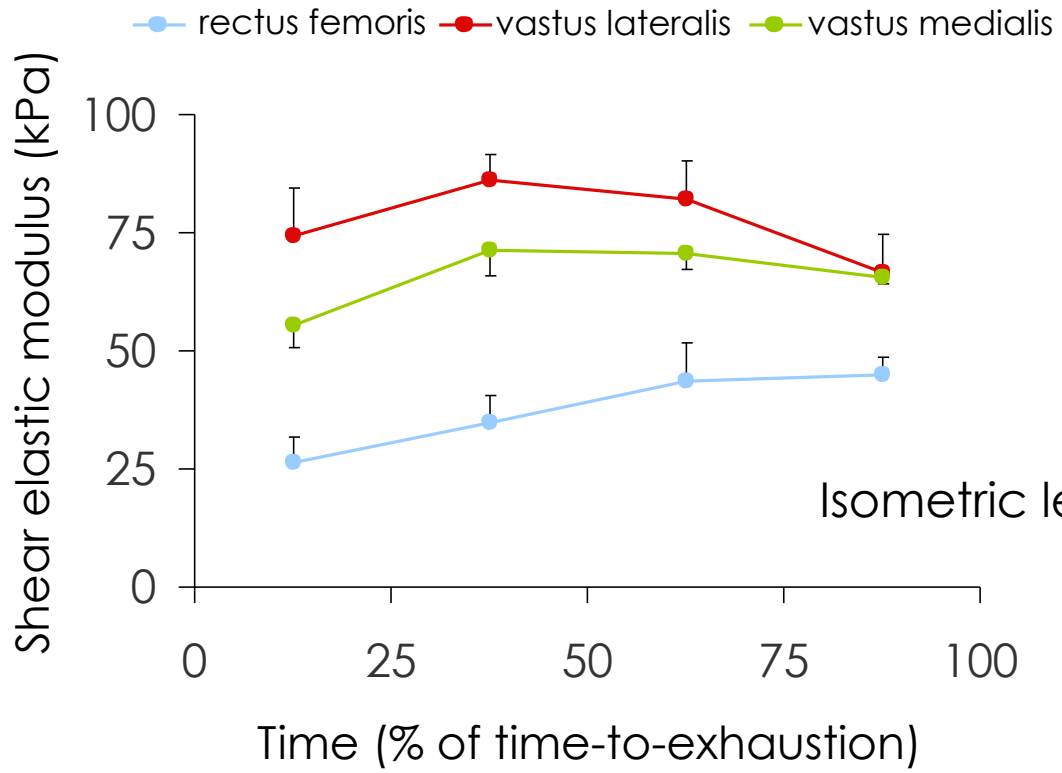




Bouillard et al. (2012 – J Appl Physiol)

Elastography

Toward the estimation of muscle force



Isometric leg extension at 20% of MVC

Bouillard et al. (submitted)

- Not always observed (50% of the participants)
- When it was observed, participants did not exhibit the same strategies

Elastography

Toward the estimation of muscle force

Limitations:

- Index of individual muscle force (≠ force)
- Force levels < 50% of MVC
- Map of shear elastic modulus at 1 Hz => isometric tasks
- Difficult to get reliable measurements in deep muscles

Perspectives:

- Hardware/software improvements => 5/10 Hz
- Stiffer tissues
- New probes

Thank you for your attention

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