Introduction to the hands-on sessions

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Introduction to the hands-on sessions

Hands-on sessions

- Participation is mandatory
- Shared material, including the list and composition of each team → *GitHub repository*
- Each team should fill-in a **daily report** (*Google form*) with the result(s) of each hands-on session (link to the report provided during each hands-on session) → **send before midnight** (only one for each group)

Introduction to the hands-on sessions

Hands-on Award

- Participation is optional
- Each team should:
  - Fill-in a **daily report** (*Google form*) with the result(s) of each hands-on session (link to the report provided during each hands-on session) → **send before midnight** (only one for each group)

  - Prepare a **presentation following the** *2023_GNB_School_Hands-on_template.pptx* (on the *GitHub repository)* → send before the midnight of Wednesday to gnbschool2023.bioengsport@gmail.com

Introduction to the hands-on sessions

Hands-on Award

- Five teams will be selected as finalists according to the daily report scores and will **present** their work **on Thursday** afternoon (6’ for each team presentation)

- Each presentation will be assessed by the Award Committee (prof. Burattini, prof. Knaflitz, prof. Camomilla) and the **three best** teams will be awarded (1st 500€, 2nd 300€, 3rd 200€)

STAR HORSE RIDING CARE

INNOVATIVE START UP

Hands-on session – Monday 11th

Quantifying and assessing movement in sport

#1 – In field signal processing in running

 # 2 – Extraction of muscle synergies in sport

#1 – In field signal processing in running

[https://www.youtube.com/watch?v=q1Osn6xugBg]

Rearfoot strike

Midfoot strike

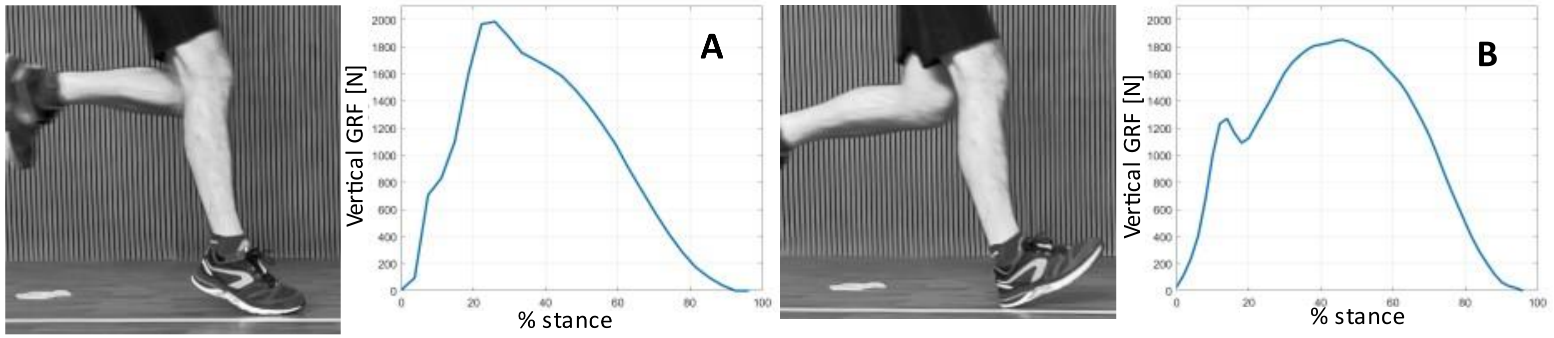
Forefoot strike

Performance

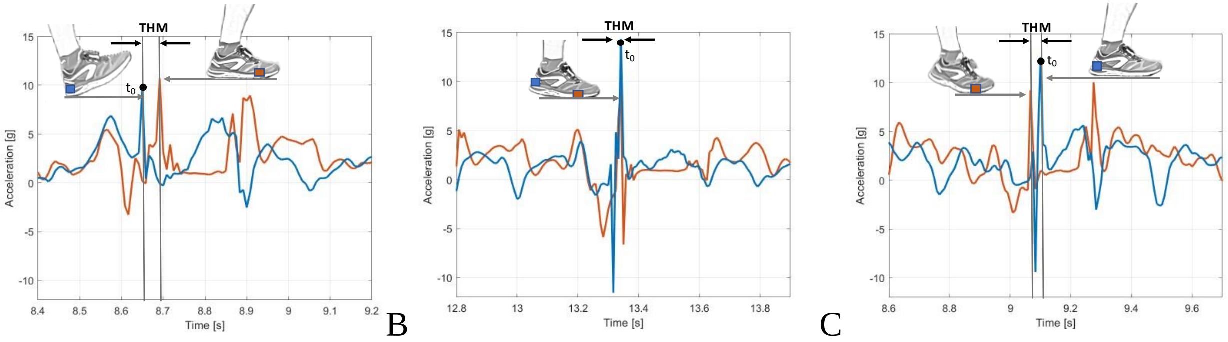
Injury

In field signal processing in running

Force plate



Wearable sensors



[courtesy of prof. Silvia Fantozzi, from The Bioengineering of Sport – 2023 Patron Editore]

The speaker

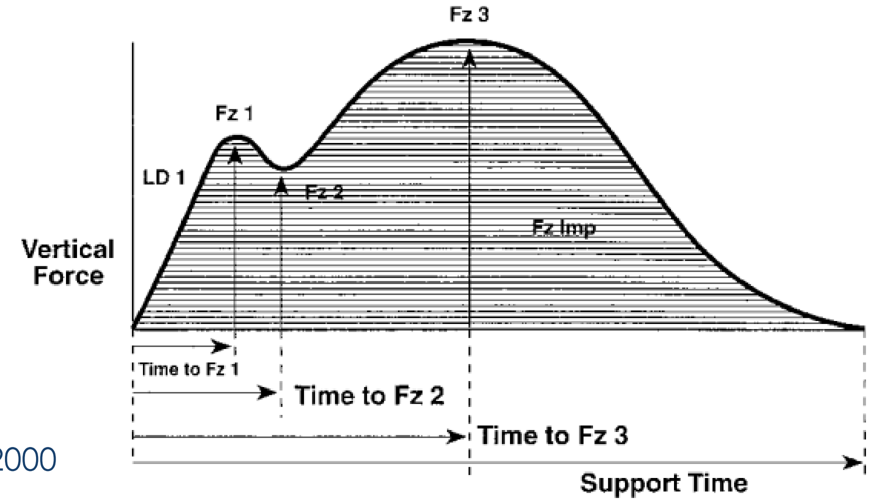
Prof. Silvia Fantozzi - *Associate Professor*

- M.S. degree in **electronical engineering** (1999) @University of Bologna
- **Ph.D.** in **Bioengineering** (2003) @University of Bologna

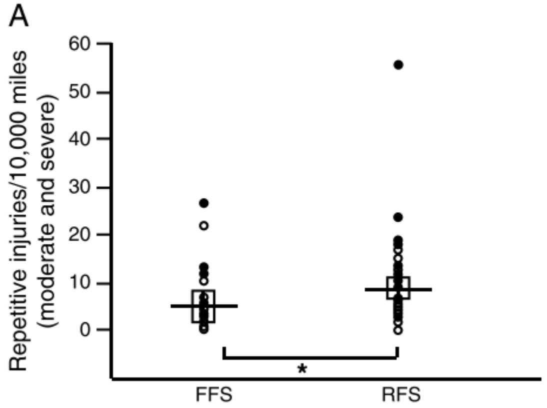
- Research activities:
  - human movement analysis (stereophotogrammetry, fluoroscopy, force platforms, inertial sensors, and electromyography)
  - clinical and sports science applications
  - board of directors of the Italian Society of Clinical Movement Analysis (2013-2017)
  - Associate Editor for Journal of Sports Sciences (2017-2020) and Sensors (2021-)
  - Co-authored >100 publications

Why foot strike patterns?

- **Magnitude** and **the rates of change of vertical impact forces** (Daoud 2012)
- Contribution to **running-related injuries** (Cavanagh & Lafortune 1980)
  - An **increased vertical loading rate of GRFs**
    → an **increased risk of tibial stress fractures** (Zadpoor & Nikooyan 2011)
  - Peak rearfoot eversion and rearfoot eversion
    → risk factors for **anterior knee pain** and **medial tibial stress syndrome**
    (Duffey 2000; Messier & Pittala 1988)
- **Different rates** of musculoskeletal injuries



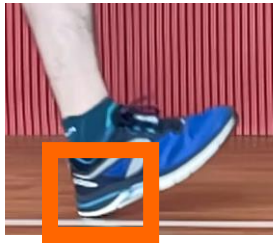
Duffey 2000

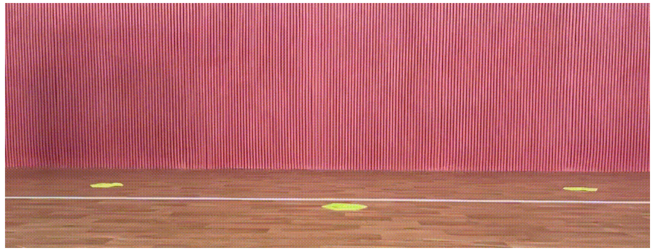


Daoud 2012

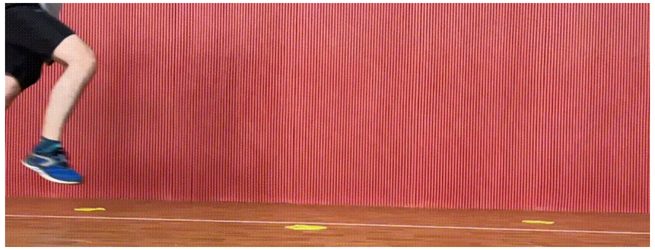
Definition

REARFOOT
RFS

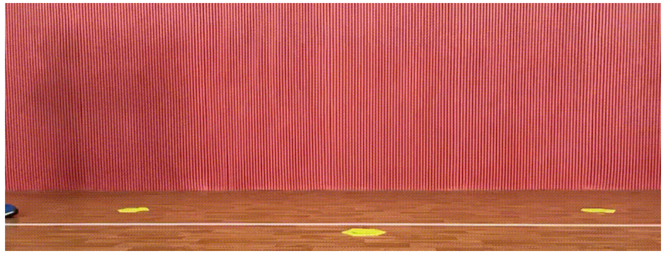




MIDFOOT
MFS

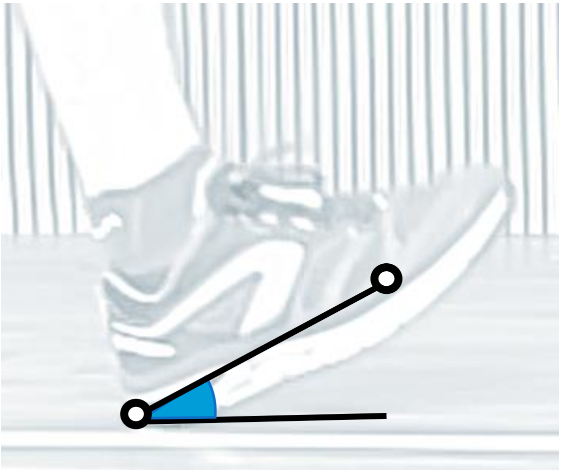


FOREFOOT
FFS



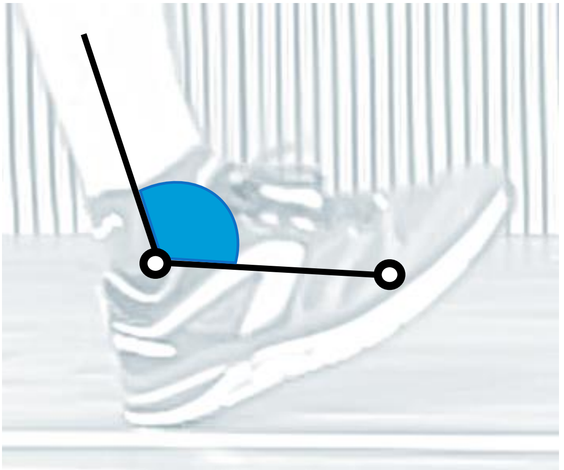
Classification

Foot Strike Angle

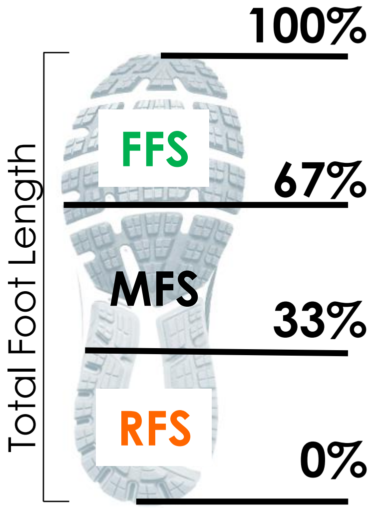


FFS: FSA < -1.6°
MFS: -1.6° < FSA < 8.0°
RFS: FSA > 8.0

Ankle dorsi-plantarflexion



Strike Index

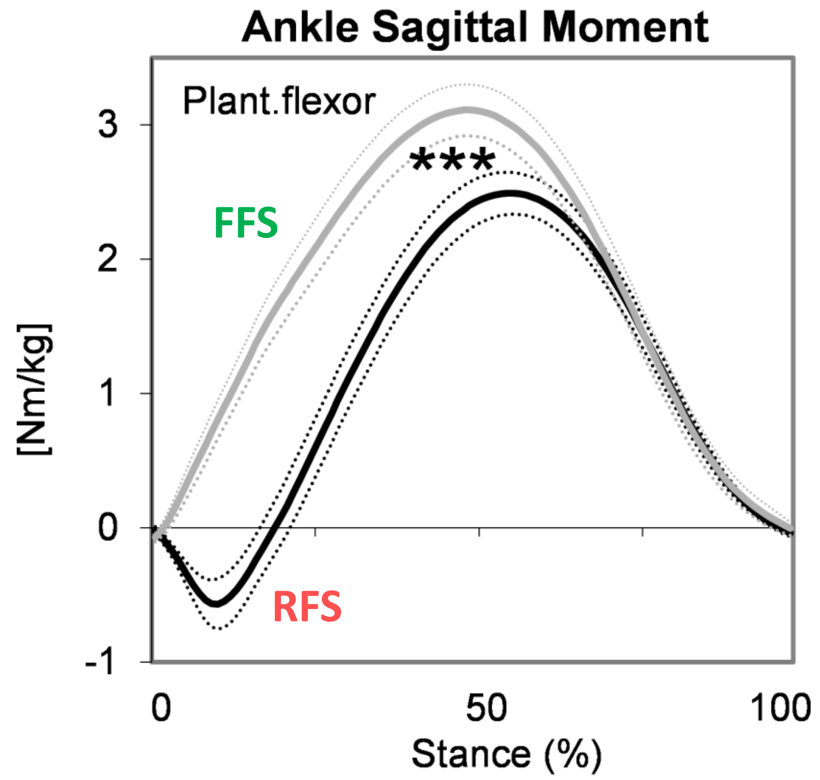


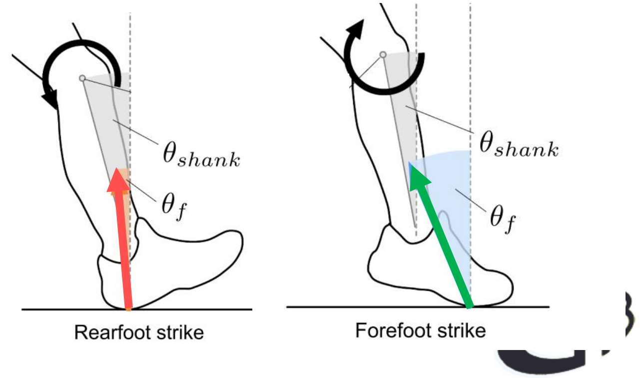
Center of Pressure

Kulmala 2013

Kinematics- Kinetics

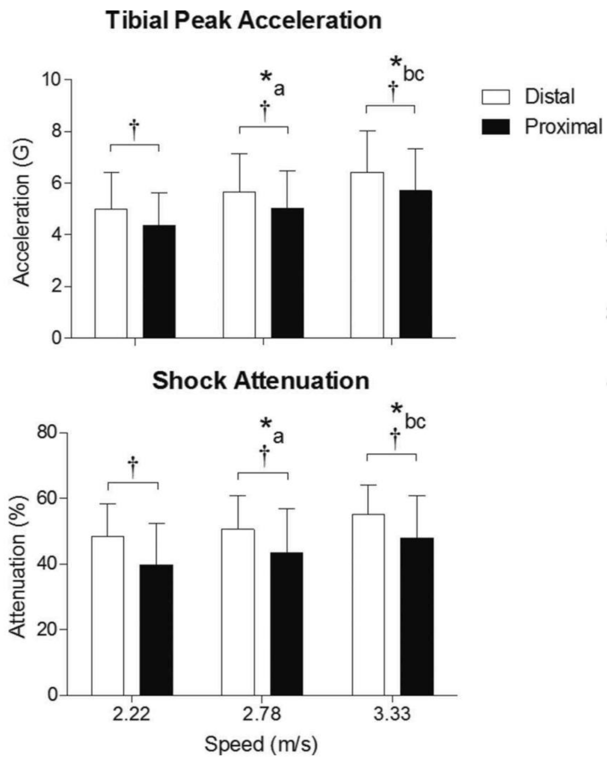
- Cadence and step/stride length: no difference
  (Ardigo 1995; Shih 2013)
- **RFS** (dorsiflexed) and **FFS** in (plantarflexed): ~ 16°
  (Almeida 2015)
- **Ground Reaction Force**: larger vertical loading rate and first impact peak in **RFS** with respect to **FFS**. Second active peak was increased in **FFS**
  (Cavanagh & Lafortune 1980; Lieberman 2010)
- **Ankle joint moment**: greater plantar flexor in **FFS** during the first 50% of stance. Greater triceps surae **muscle forces** in **FFS** and increased tibialis anterior force in **RFS** runners during the first 20% stance
  (Rooney & Derrick 2013)



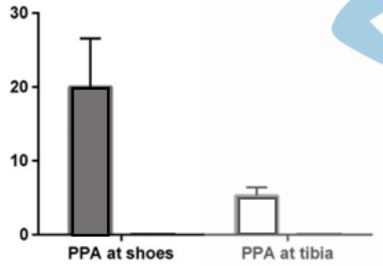


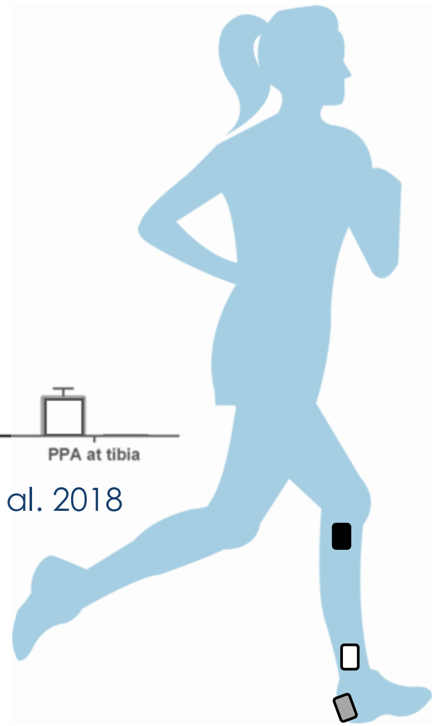
Wearable inertial sensors: SELECTION & LOCATION

- Small dimension and mass; range (16g; 2000°/s); sampling frequency (200-500Hz)
- Tibia most frequent location (32%) often distal anteromedial aspect (fatigue fractures)



Lucas-Cuevas et al. 2016

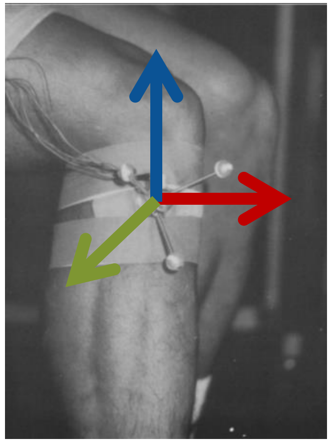


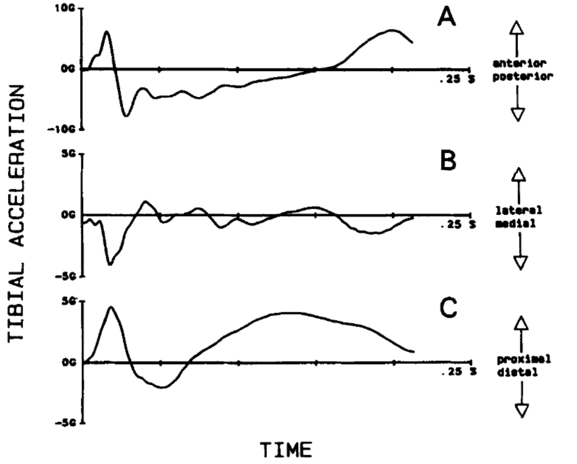


Cheung et al. 2018

Tibial accelerations occur in 3D

4.7m/s





7.6g

4.5g

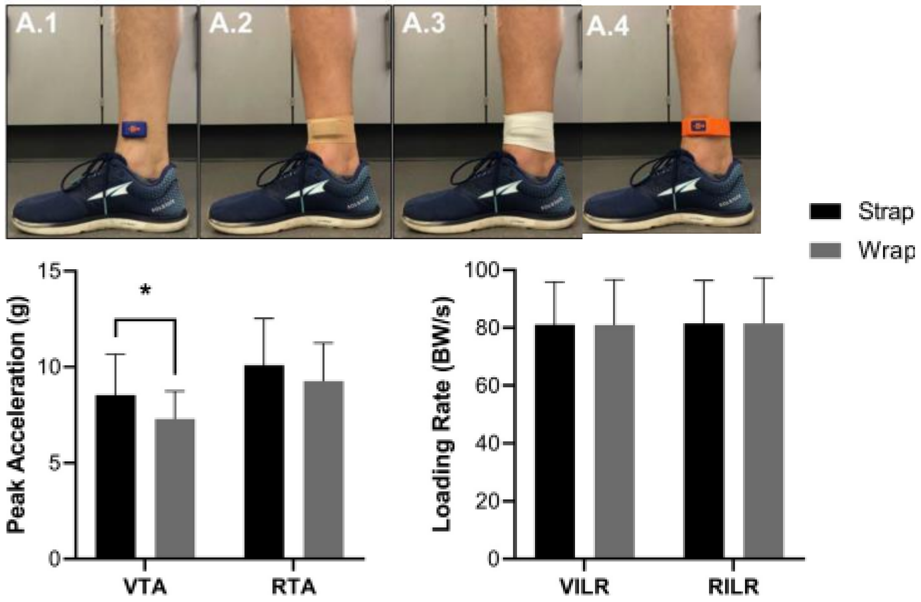
5.0g

Lafortune 1991

Wearable inertial sensors: FIXING TECHNIQUE & SIGNAL PROCESSING

- Skin-mounted ~ 2 * bone-mounted devices (Lafortune 1995)
- **Oscillations**: resonance frequency matches the frequencies of ground impact (4-20Hz)
- **Recommendations**: device attachments tensioned (preload force as tight as tolerable); no areas close to joints and with soft tissues "wobbling"; low mass; preference for combination of tape & elastic wraps than strap

(Clarke 1985; Johnson 2020; Preatoni 2022)



Johnson 2020

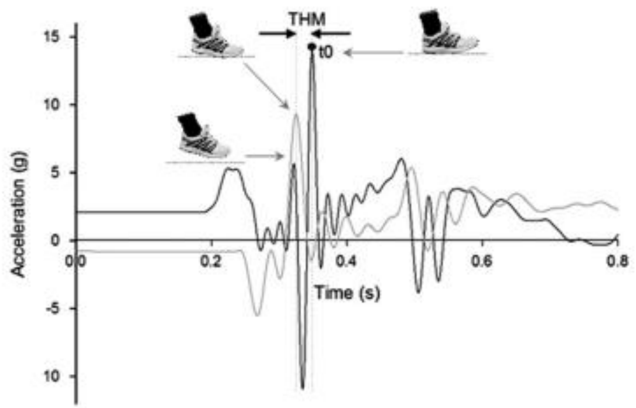
- **Filtering:** low-pass cut-offs between 40 Hz and 100 Hz
  - <u>Low-frequency</u> (4-8 Hz): *voluntary leg motion and the acceleration of the center of mass*,
  - <u>High-frequency</u> (10-20 Hz): *rapid deceleration of the lower extremity upon contact with the ground*

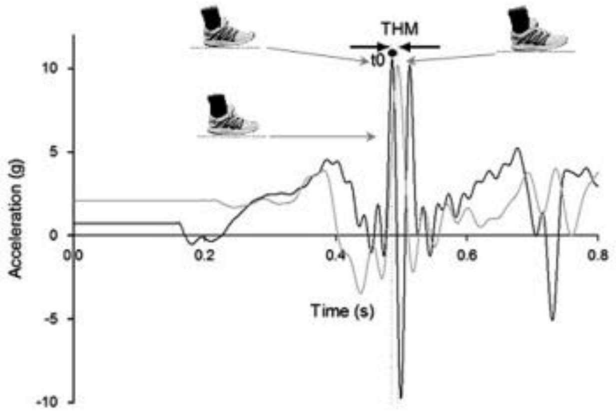
  (Shorten and Winslow 1992)

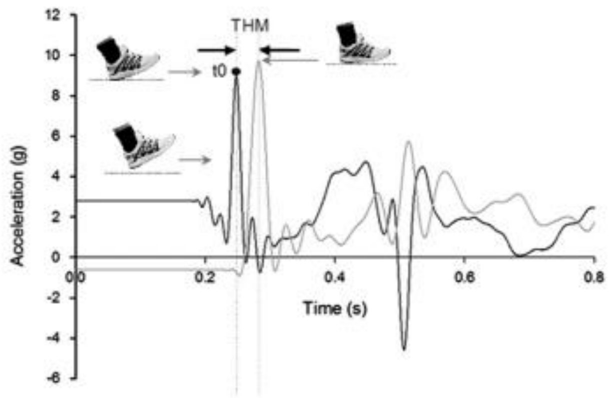
IDENTIFICATION WITH INERTIAL SENSORS (1/3)

- *Heel* and *metatarsal accelerations*
- **Time between the two events determined the type of contact**
- Reliable for a wide range of speeds and slopes (r=0.916) except for 'toe running'
- Less reliabe for MFS identification

FFS < 5.49 ms < **MFS** < 15.2 ms < **RFS**





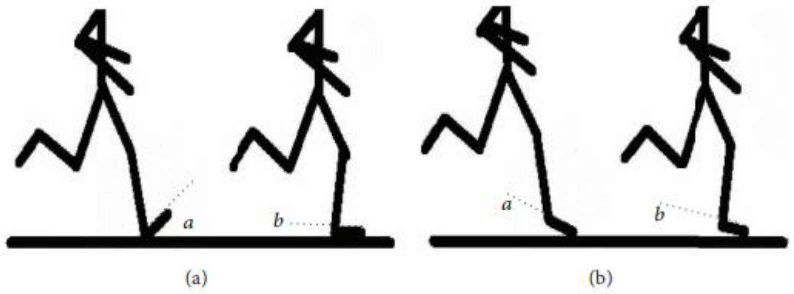


Giandolini 2014

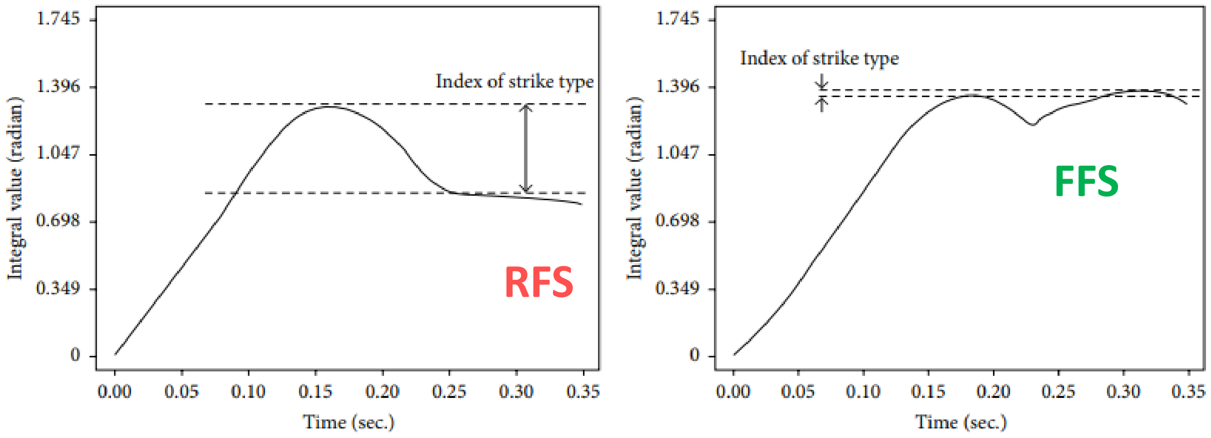
IDENTIFICATION WITH INERTIAL SENSORS (2/3)

- *3D accelerometer & 3D gyroscope* attached on the *dorsal side of the shoe*
- **Integral of the angular velocity**

  interval of integration fixed to the foot contact (-0.15s : 0.2s)
- Correlation with stereo (r=0.98)
- MFS not considered



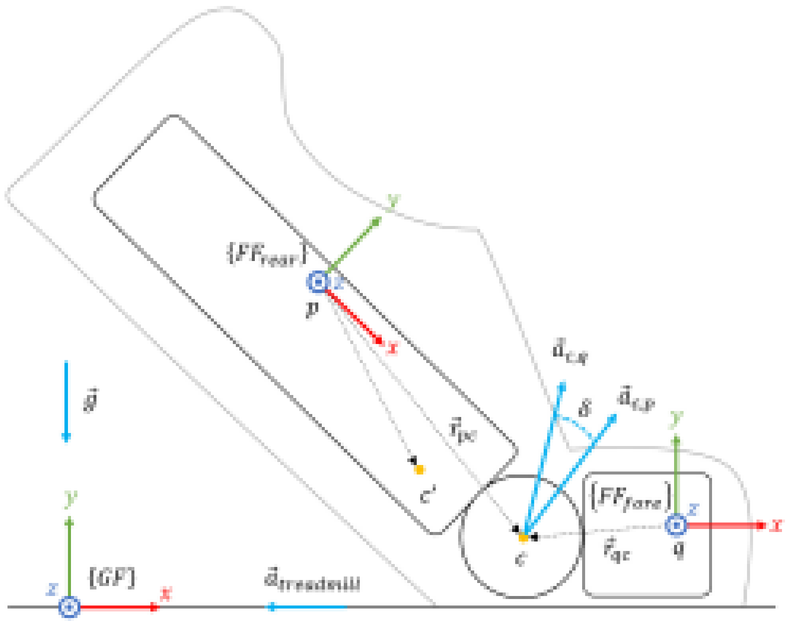
RFS FFS

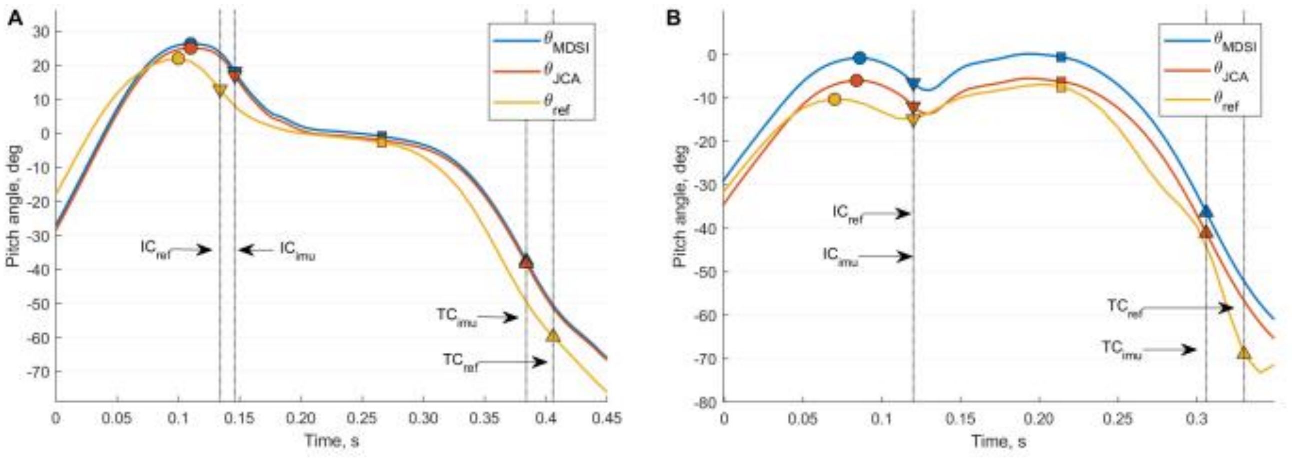


Shih 2013

IDENTIFICATION WITH INERTIAL SENSORS (3/3)

- *One IMU for each foot*
- **Two-segmental model + bidirectional strap-down integration**
- Three phases: in the first the RFS was assumed, than all the possible foot strike patterns
- Accuracy 2 ± 5.9°, precision 1.6 ± 1.1° (treadmill at different speed)

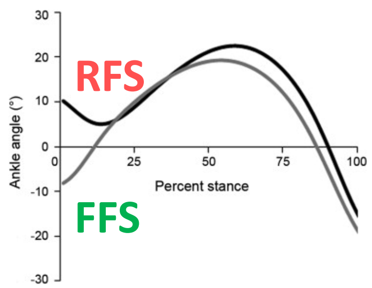


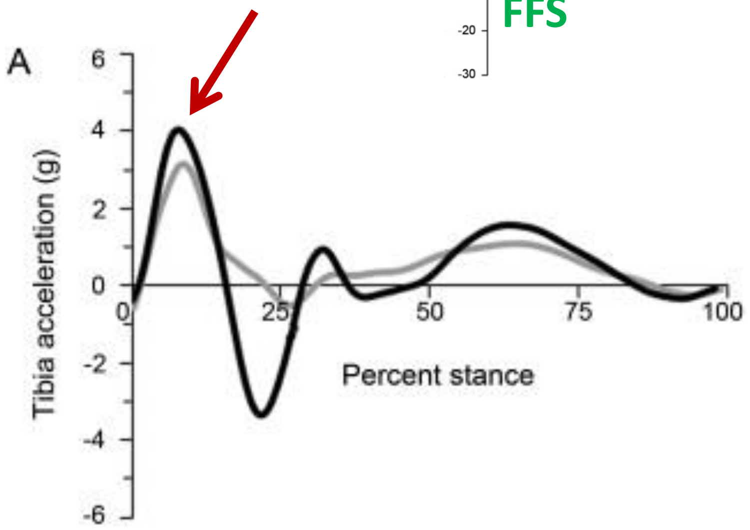


Falbriard 2020

ACCELERATION PEAK IMPACT (time domain)

- Relationship between tibial acceleration and bone strain: **uncertain**
- Axial tibial acceleration **different** in runners:
  - with/without tibial fatigue fractures (Pohl 2008)
  - injured and uninjured limbs (Zifchock 2008)
- Risk of experiencing a tibial fatigue fracture increase by **a factor of 1.4 for every 1 g increase in axial tibial acc**





Gruber at al. 2014

- <u>Parameters</u>: *peak, time to peak positive, slope and the loading rate* (Sheerin 2019)
- Normalize the acceleration data expressing the value in relation to the average value observed at the slowest running velocity: "shock ratio" (Clarke 1985)

SHOCK-ATTENUATION (frequency domain)

- Sequence of events occur during foot-ground contact → *impact shock*; to prevent excessive head acceleration: necessary to *attenuate the impact shock*

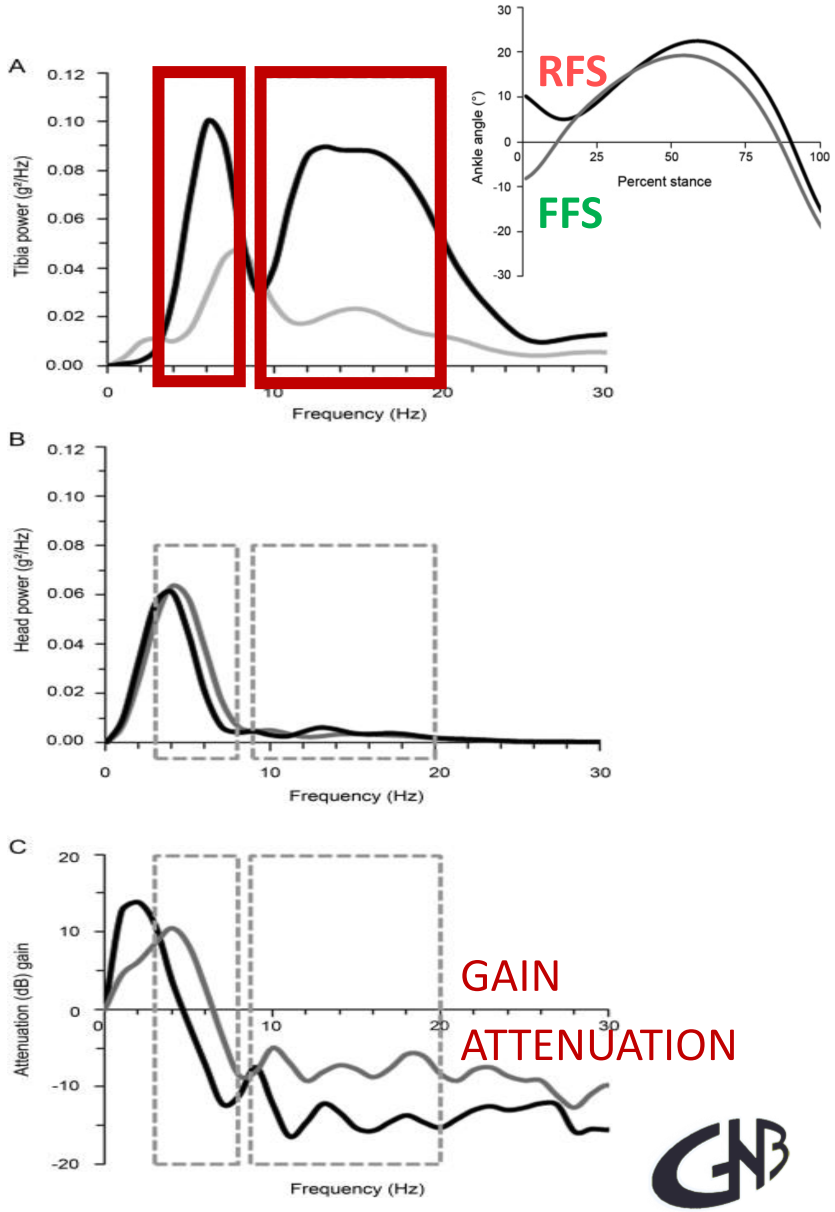
(Derrick 1998; Hamill 1995)

- **2 acc** (proximal/distal): **power spectral density** of tibia/head and **transfer function** (gain/)

(Hamill 1995)

- Frequency ranges:
  - Low-frequency: *voluntary lower extremities motion and the acceleration of the center of mass,*
  - High-frequency: *rapid deceleration of the lower extremity during initial ground contact and associated with the impact peak of the GRF*

(Derrick 1998; Hamill 1995)



Gruber at al. 2014

In field signal processing in running

Hands-on session

Each team will be provided with **MATLAB® routines** to evaluate **foot strike pattern using inertial sensors data from three athletes**.

The team should **analyze the athletes** and **establish the type of foot strike** and **comment on tibia acceleration in time domain** and **shock attenuation in frequency domain**.

Hands-on session guidelines and **data** are available
in the **GitHub repository**

#1 – Foot strike patterns with wearables in running

silvia.fantozzi@unibo.it Cambia account

Non condiviso

Analysis of Athlete A

Type of foot strike

Scegli

Scegli

Rear foot

Mid foot

Fore foot

Tibial Peak Acceleration

Comment the results abou ... on the time-domain analysis

La tua risposta

Shock Attenuation (frequency-domain) **Max 100 words**

Comment the results about the schock attenuation based on the frequency-domain analysis

La tua risposta

Indietro Avanti Cancella modulo

Analysis of Athlete B

Analysis of Athlete C

Type of foot strike

Scegli

Tibial Peak Acceleration (time-domain) (**Max 100 words**)

Comment the results about the tibial peak acceleration based on the time-domain analysis

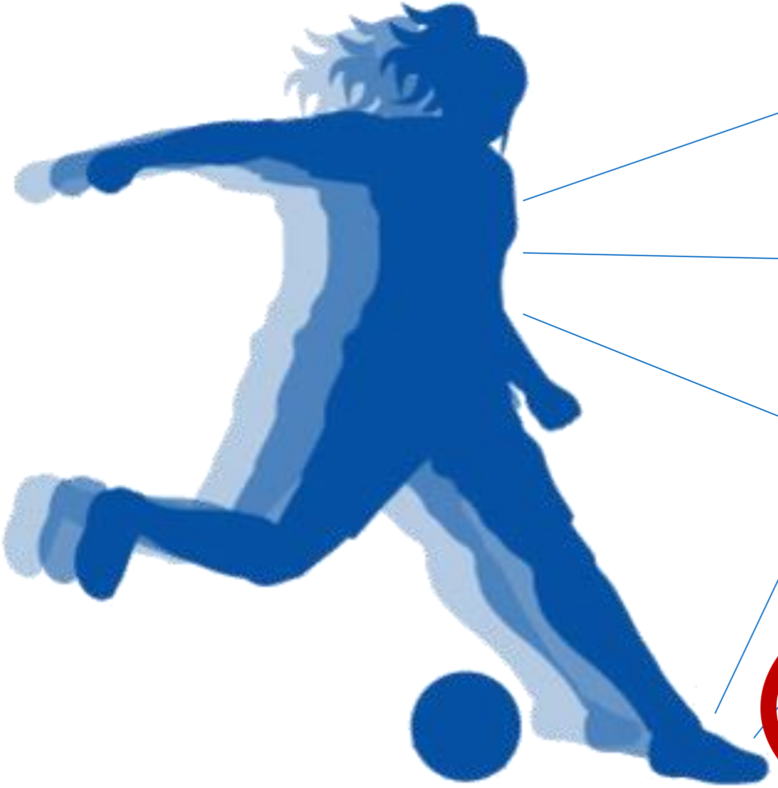
La tua risposta

Shock Attenuation (frequency-domain) (**Max 100 words**)

Comment the results about the schock attenuation based on the frequency-domain analysis

La tua risposta

Athlete's Passport



Cardiovascular: ……… [s]

Respiration: ……… [ml/kg/min]

Glycemic variability: ……… [%]

Ankle instability: …… [num. synergies]

Foot strike type: ……… [RFS/FFS]

Athlete A

Performance feedback:

…………………………………………

…………………………………………

…………………………………………

…………………………………………

…………………………………………

Risk of injury information:

…………………………………………

…………………………………………

…………………………………………

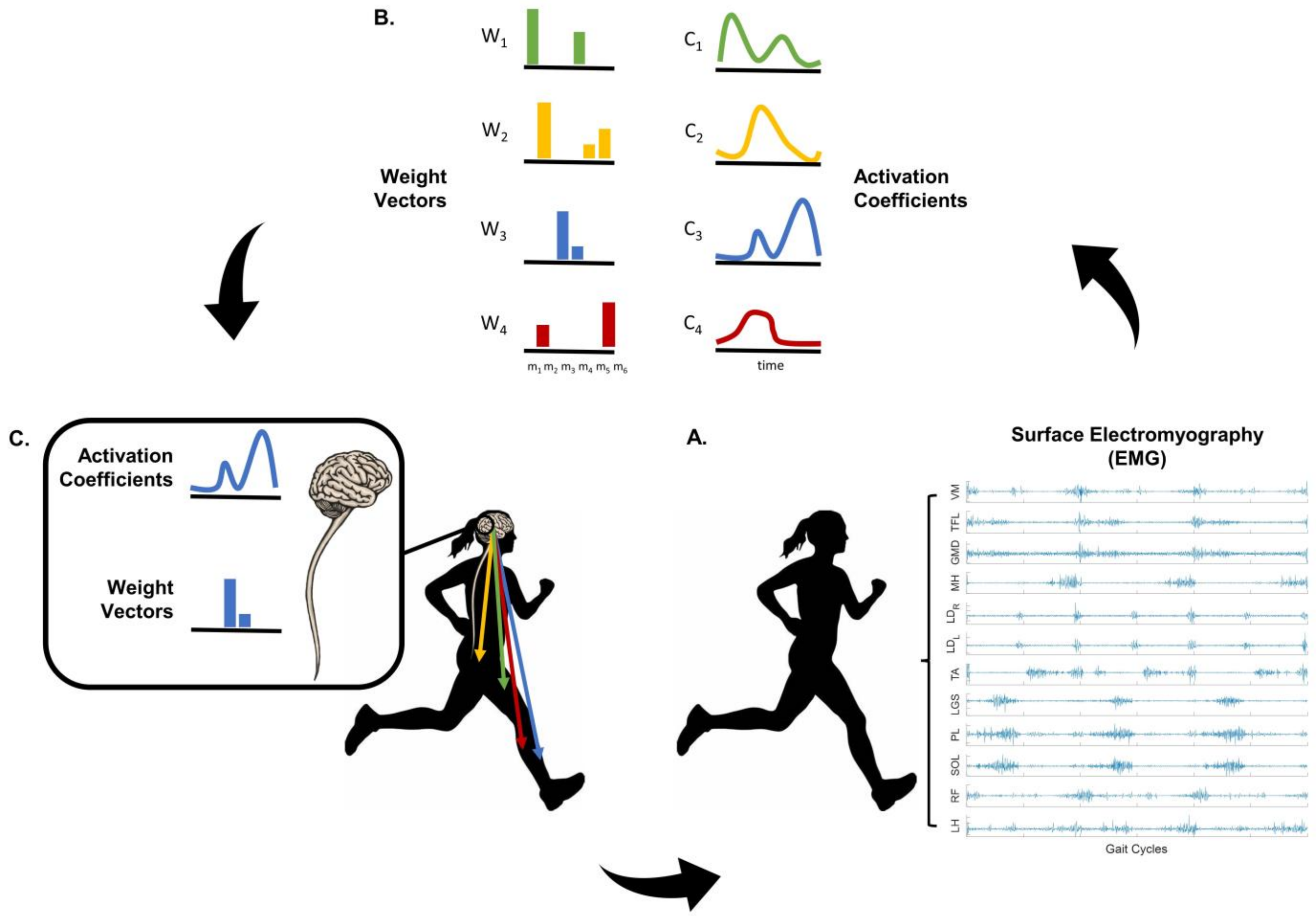
…………………………………………

…………………………………………

2 – Extraction of muscle synergies in sport

The study of **muscle synergies** can provide an in-depth understanding of **how the Central Nervous System** (CNS) **controls many muscles to perform a specific motor task** or an athletic gesture. This tool can be used to evaluate:

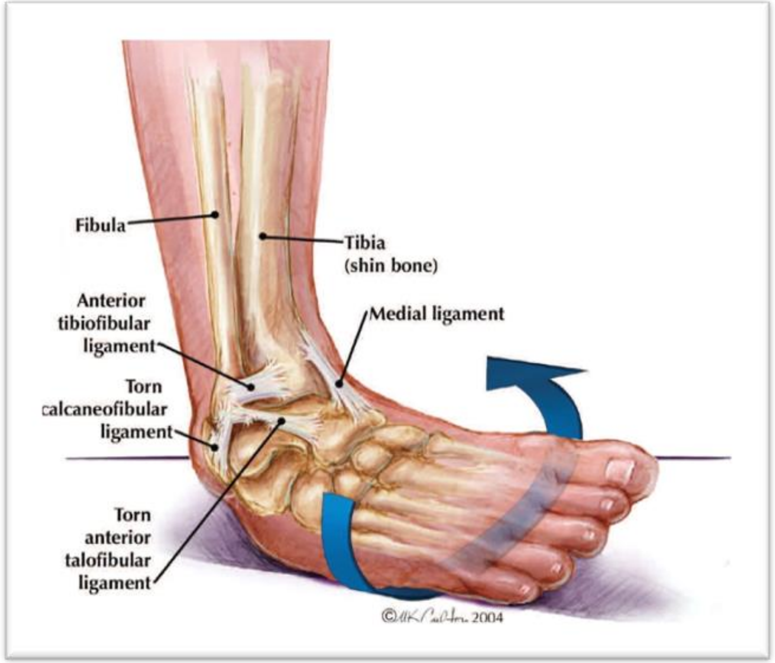
- Motor skill competencies & intermuscular coordination of athletes with different levels of expertise, before/after specific training programs
- Motor biomarkers for injury and re-injury prevention & assessment of Return-To-Sport.



[Courtesy of Dr. Marco Ghislieri, from The Bioengineering of Sport – 2023 Patron Editore]

Chronic Ankle Instability (CAI)

- **Ankle sprain** is the most common lower limb injury in athletes and accounts for 16%-40% of all sports-related injuries.
- Individuals involved in the first episode of ankle sprain frequently undergo further injuries, developing **CAI**, a condition characterized by recurrent ankle sprain episodes, perception of ankle "giving-way", reduced ROM, self-reported function, weakness, & pain, that can persist for more than 1 year after the first episode.
- The persistence of **ankle instability** can alter the athlete **proprioception** (and it may also lead, in the long term, to joint degenerative pathologies, e.g. osteoarthritis).



Ankle sprain

Chronic Ankle Instability (CAI)

The genesis of CAI has been identified in both **mechanical** and **neural** factors:

- <u>MECHANICAL</u>: The first episode of ankle sprain causes damage to the structures of the foot-ankle complex (ligaments, nerves, tendons, & muscles), increasing ankle joint laxity.

- <u>NEURAL</u>: Spinal and supraspinal alterations which persist over time cause maladaptation in the control of movement. During the performance of balance tasks, individuals suffering from CAI show a proximal muscle excitation strategy.

The speaker

Dr. Marco Ghislieri – *RTD-A researcher*

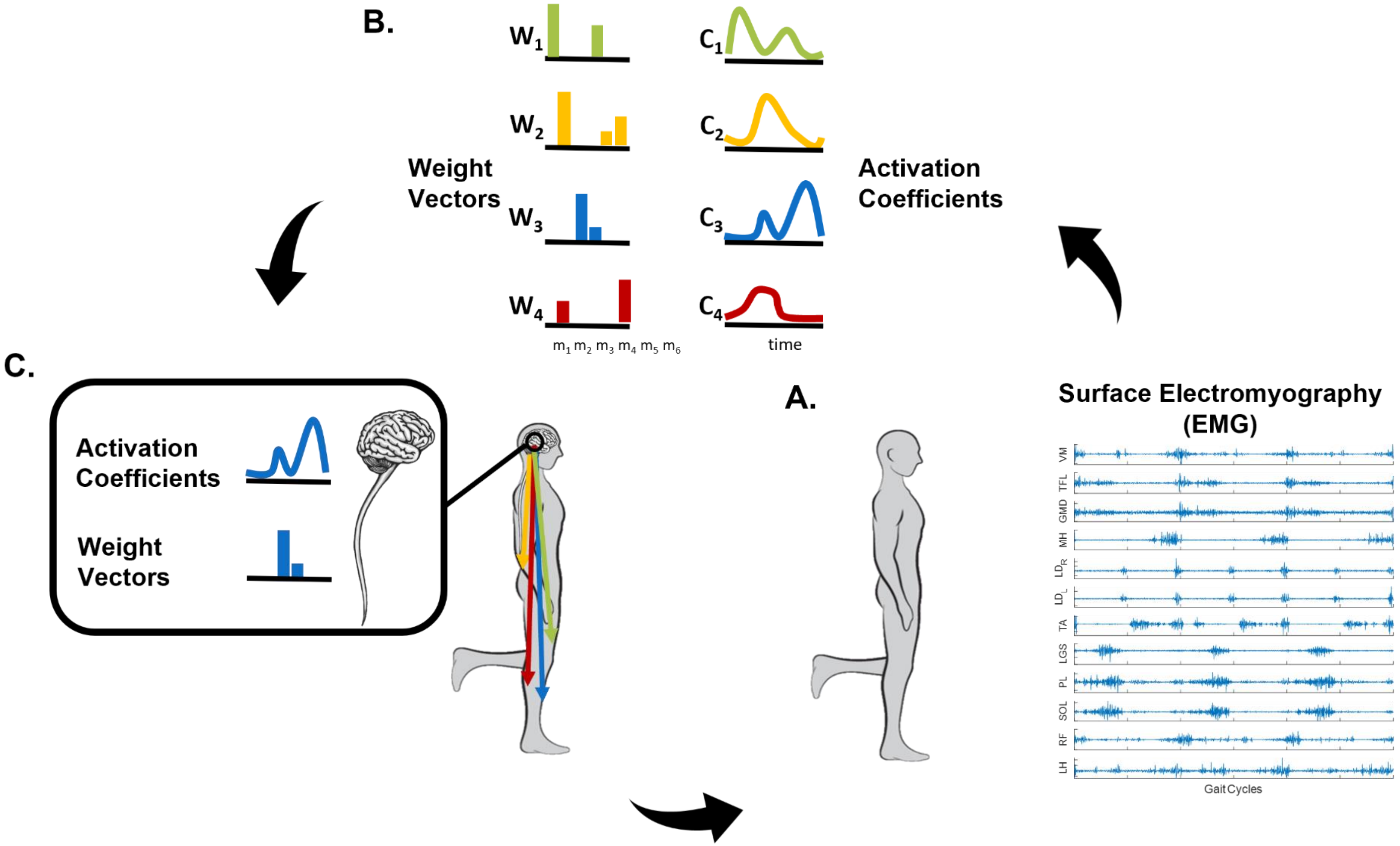
Politecnico di Torino

- M.S. degree in **Biomedical Engineering** (2016)@Politecnico di Torino
- Ph.D. **Bioengineering and Medical and Surgical Sciences** (2021) @Politecnico di Torino

- His research mainly focuses on understanding how the CNS manages motor control during movements, in both healthy and impaired individuals.

- For his contributions to technological advances in EMG acquisition and signal processing, he received the 2022 Carlo J. DeLuca Award from the International Society of Electrophysiology & Kinesiology (ISEK).

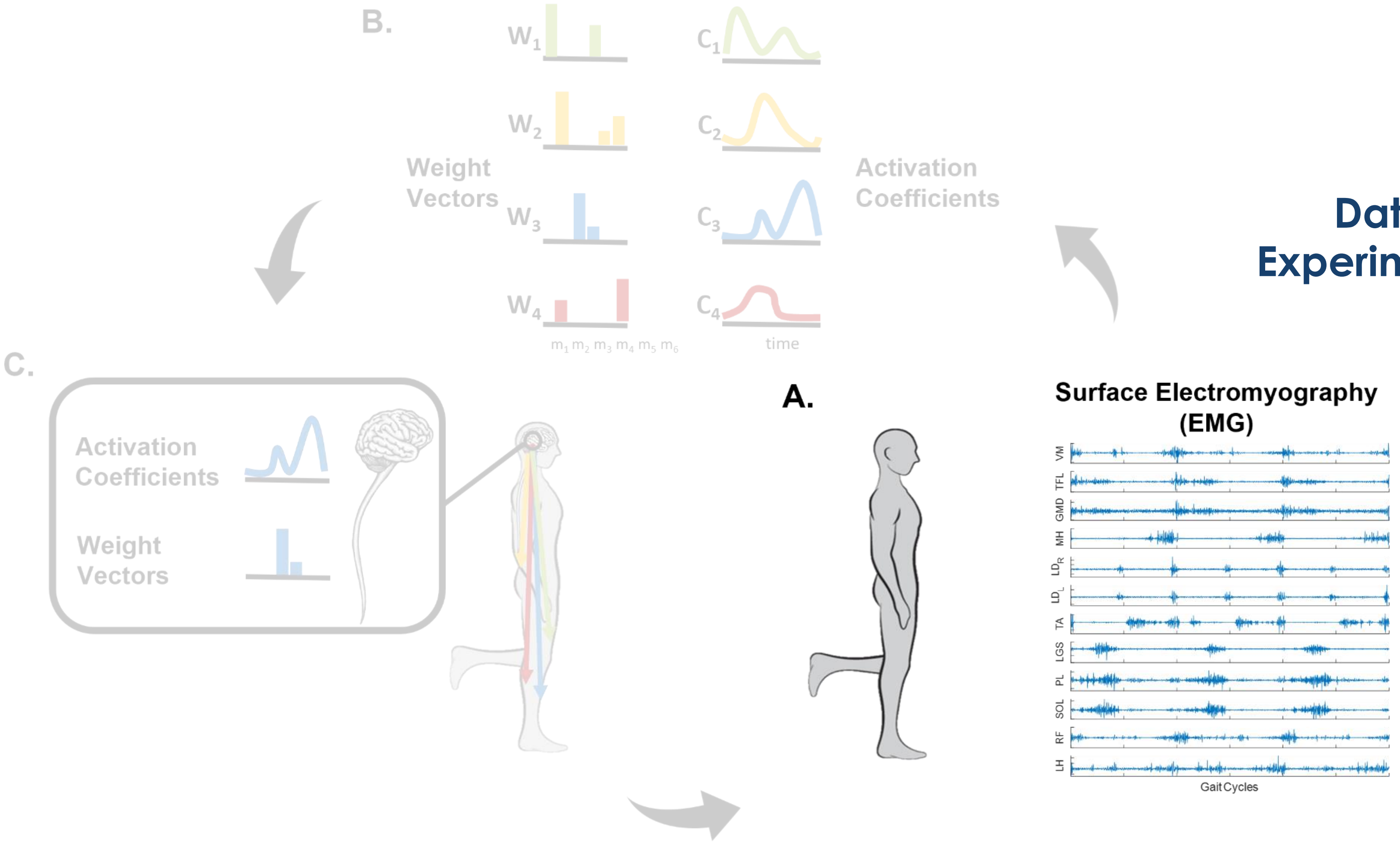
Evaluation of Chronic Ankle Instability



[Courtesy of Dr. Marco Ghislieri, from The Bioengineering of Sport – 2023 Patron Editore]

Evaluation of Chronic Ankle Instability

Data acquisition & Experimental protocol

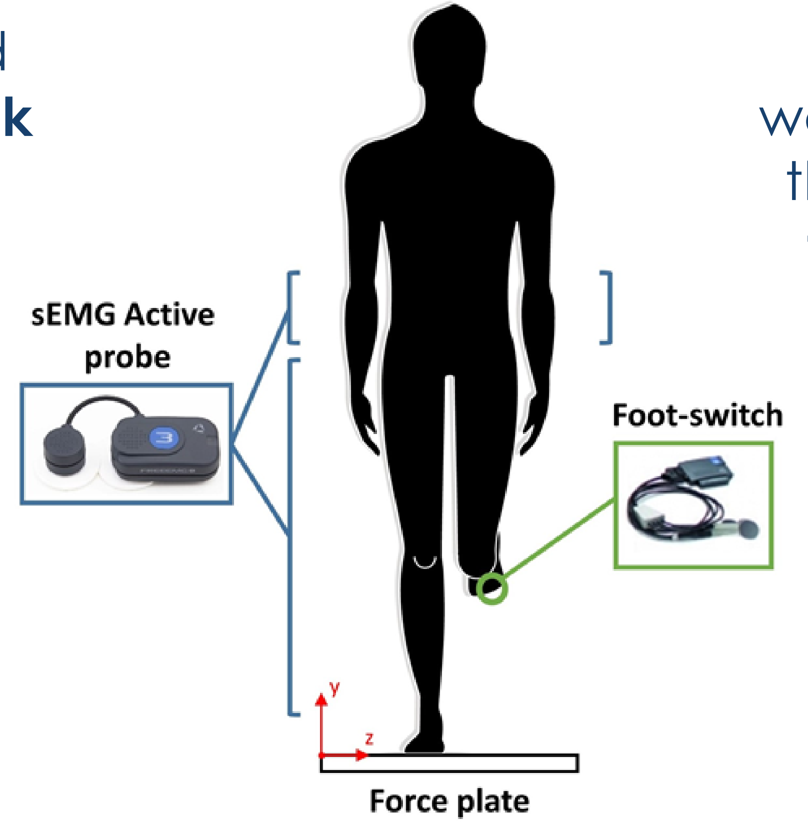


[Courtesy of Dr. Marco Ghislieri, from The Bioengineering of Sport – 2023 Patron Editore]

Evaluation of Chronic Ankle Instability

Acquisition system

EMG signals were acquired from **13 lower-limb and trunk muscles** of the affected (or dominant) side



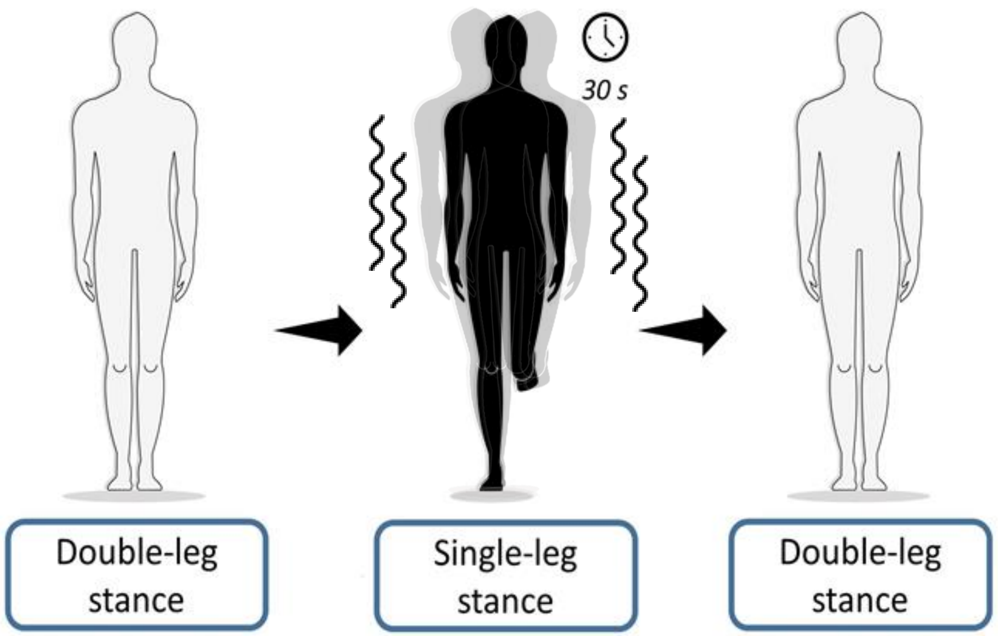
Foot-switch was placed under the foot of the limb raised from floor to **time-segment SLS epochs**

[Ghislieri et al., Muscle synergy assessment during Single-Limb-Stance, IEEE Trans. Neural Sys. Rehab. Eng., 2020. Doi: 10.1109/TNSRE.2020.3030847]

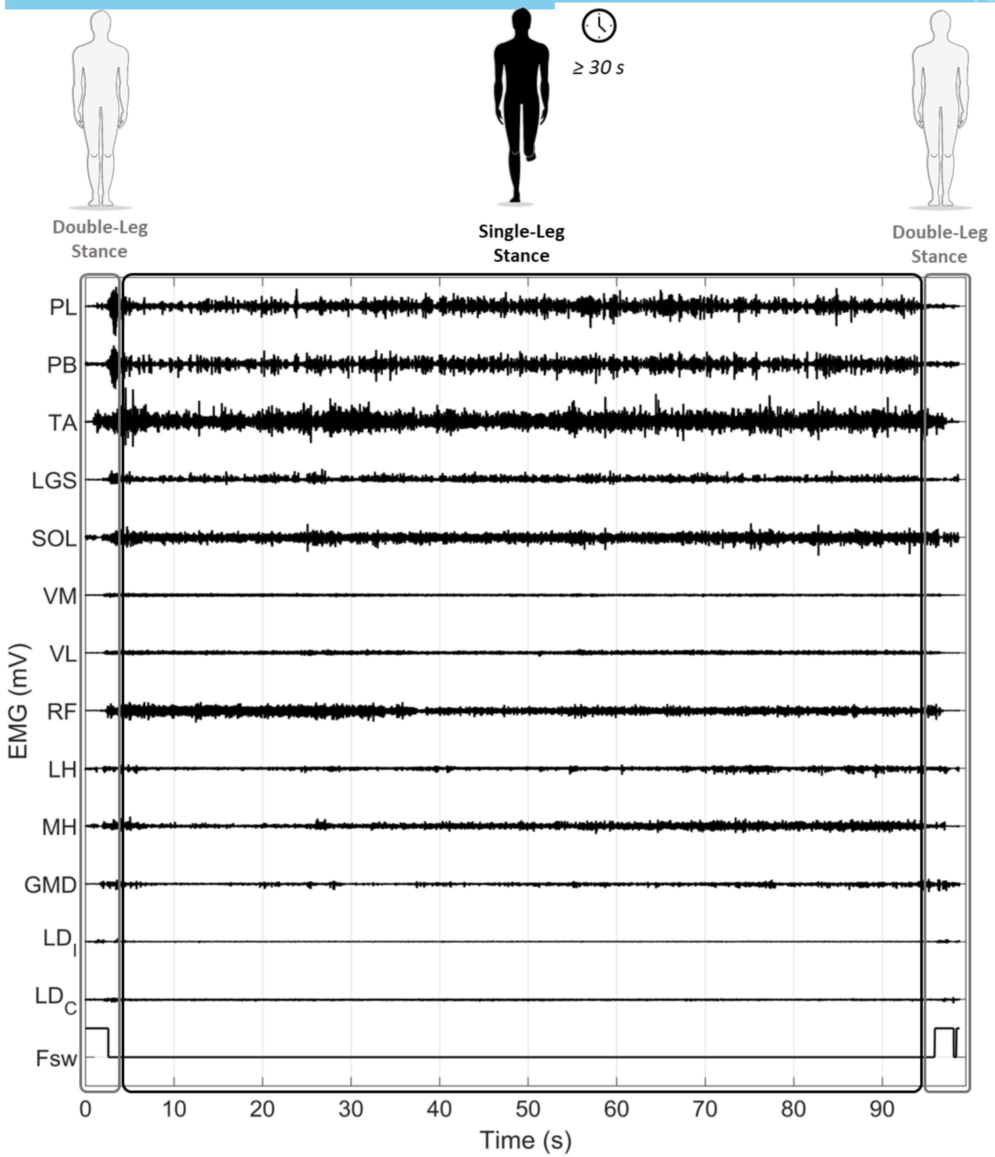
Evaluation of Chronic Ankle Instability

Experimental protocol

Subjects were asked to **maintain SLS balance** with their injured (CAI) or dominant (control) lower limb for at least **30 seconds.**



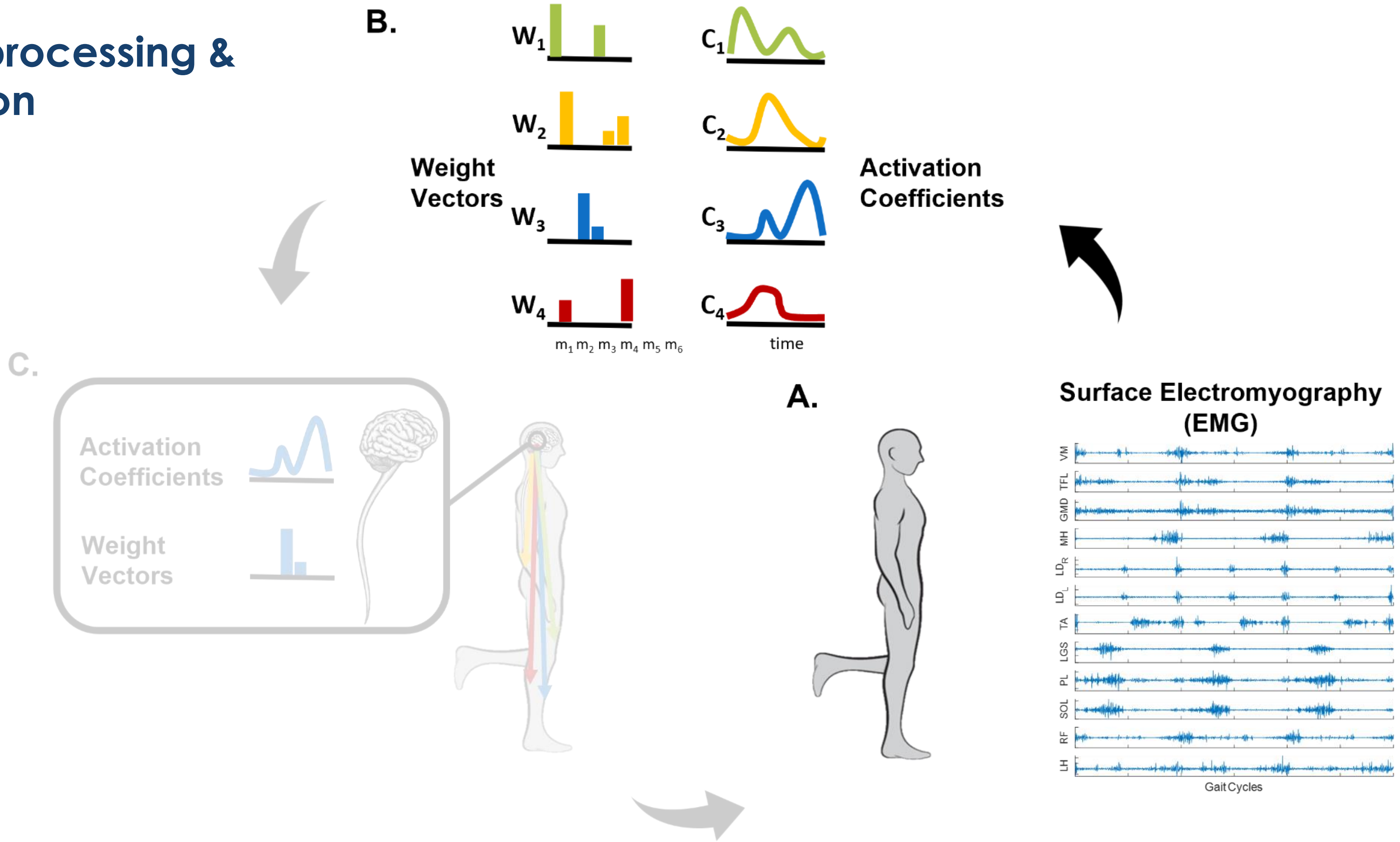
[Ghislieri et al., Muscle synergy assessment during Single-Limb-Stance, IEEE Trans. Neural Sys. Rehab. Eng., 2020. Doi: 10.1109/TNSRE.2020.3030847]



[Courtesy of Dr. Marco Ghislieri, from The Bioengineering of Sport – 2023 Patron Editore]

Evaluation of Chronic Ankle Instability

EMG pre-processing & factorization



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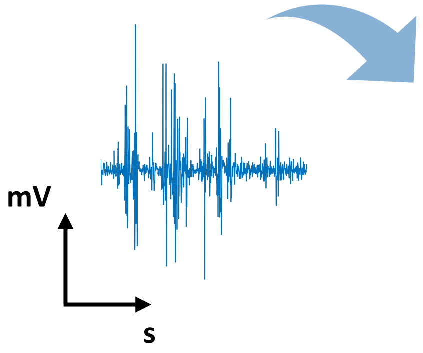
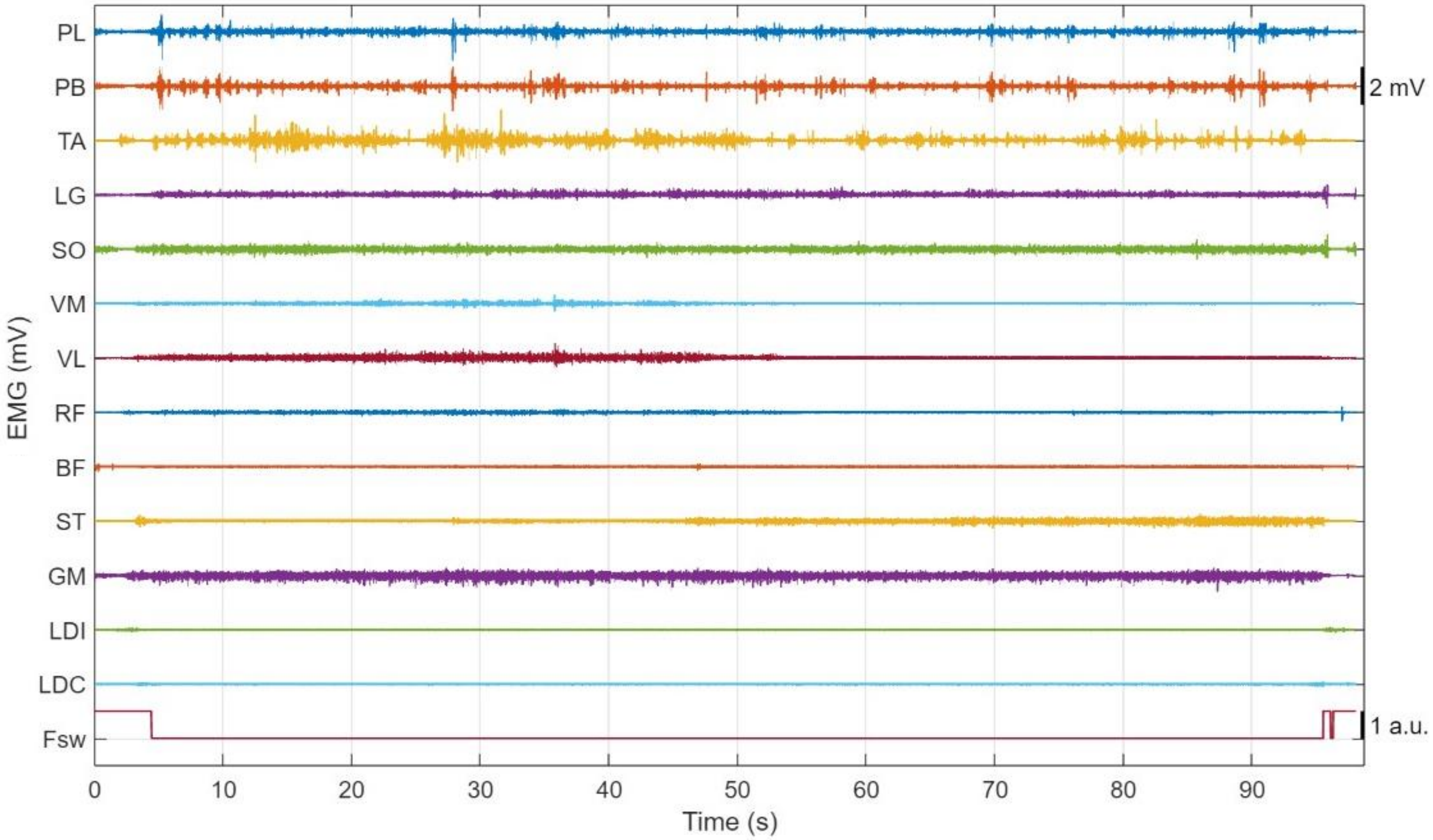
Evaluation of Chronic Ankle Instability



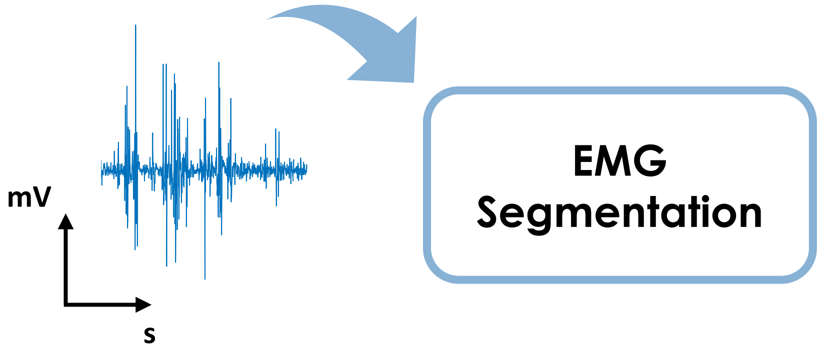
EMG Segmentation

SLS epoch is defined as the **longest 0-level epoch**, excluding **2 seconds following the Double-Leg to Single-Leg Stance transition** and **2 seconds preceding the Single-Leg to Double-Leg Stance transition.**

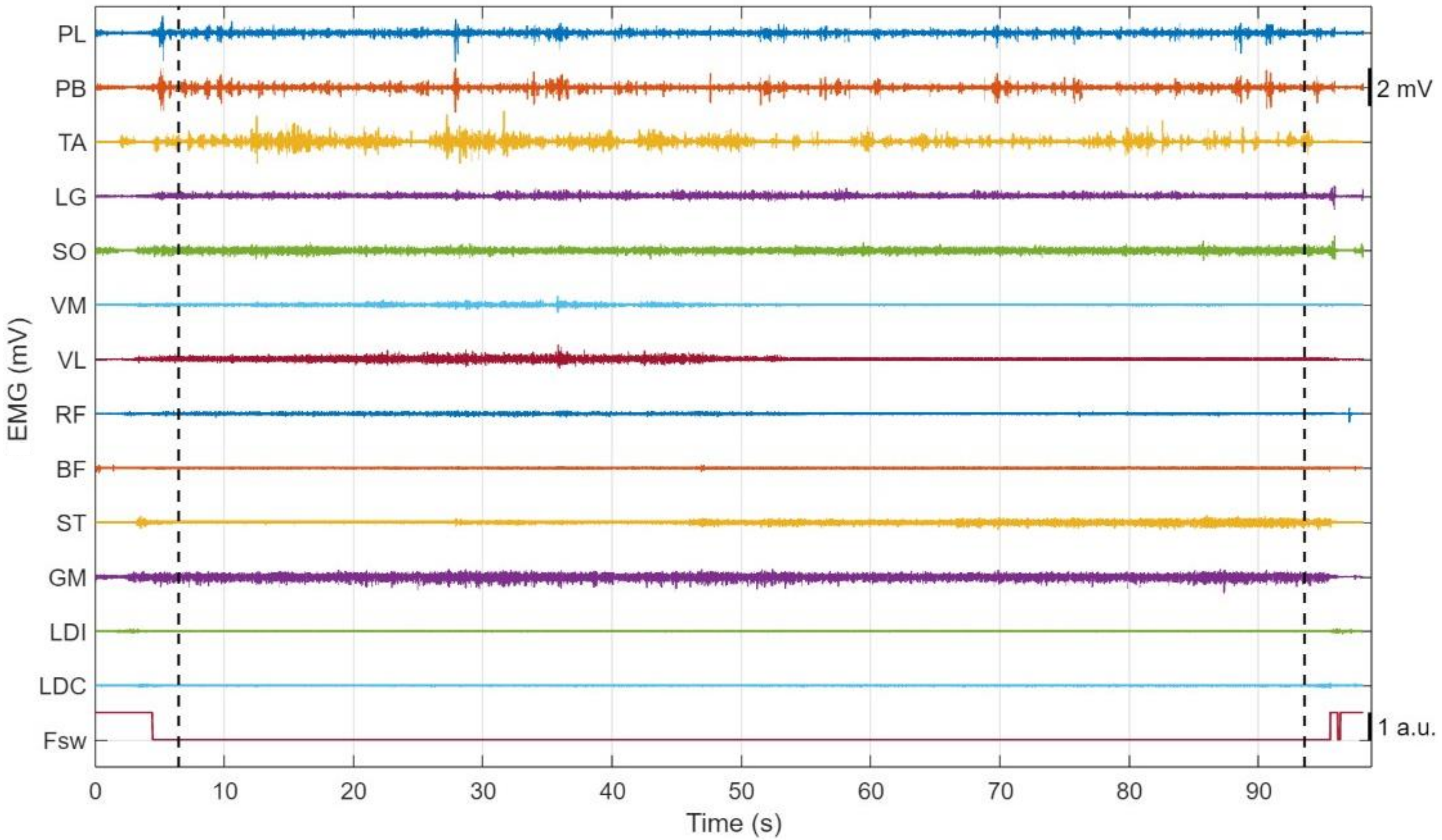


Raw EMG and Fsw signals acquired from a representative healthy subject.

Evaluation of Chronic Ankle Instability



SLS epoch is defined as the **longest 0-level epoch**, excluding **2 seconds following the Double-Leg to Single-Leg Stance transition** and **2 seconds preceding the Single-Leg to Double-Leg Stance transition.**



Raw EMG and Fsw signals acquired from a representative healthy subject.

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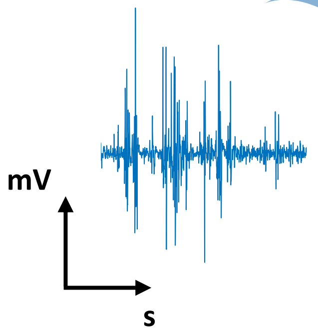
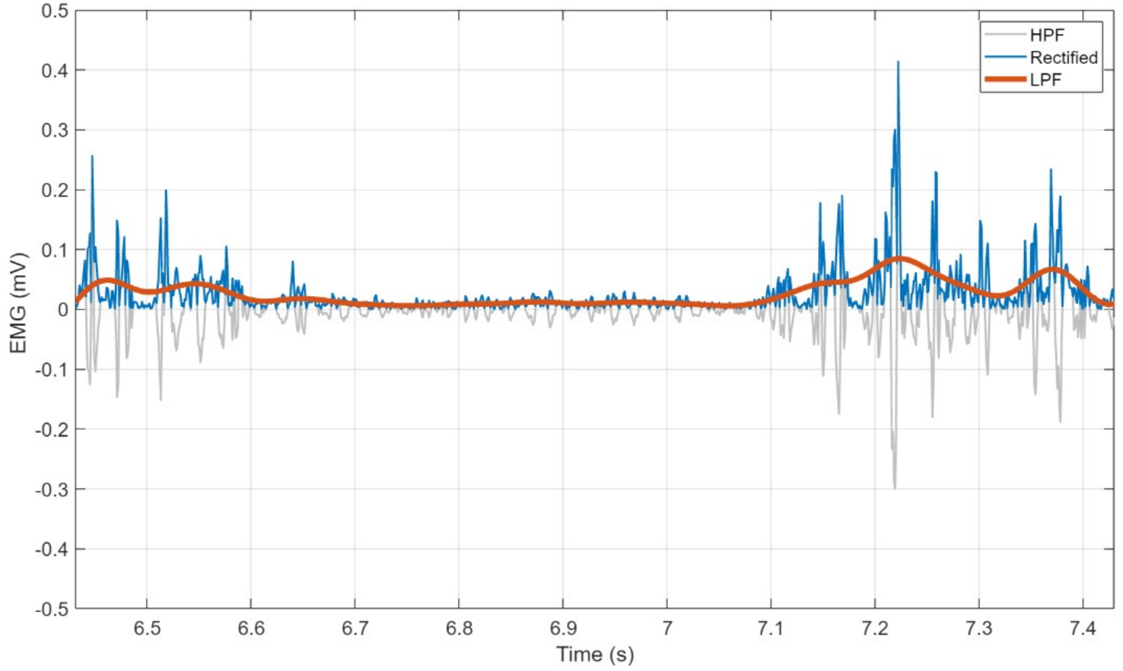


EMG Segmentation → **EMG Pre-processing**

EMG Pre-processing

High-pass filter @35Hz → EMG Rectification → Low-pass filter @12Hz → Amplitude Normalization

Filtered EMG signals acquired from Tibialis Anterior muscle of a representative healthy subject.



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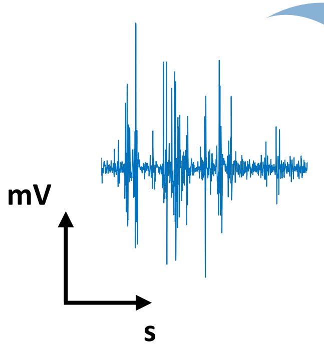
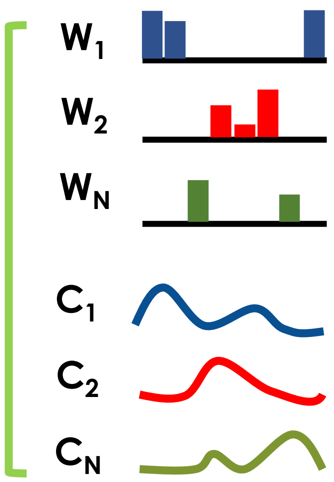


EMG Segmentation → **EMG Pre-processing** → **Muscle Synergy Extraction** (NNMF)



EMG Pre-processing

High-pass filter @35 Hz → EMG Rectification → Low-pass filter @12 Hz → Amplitude Normalization

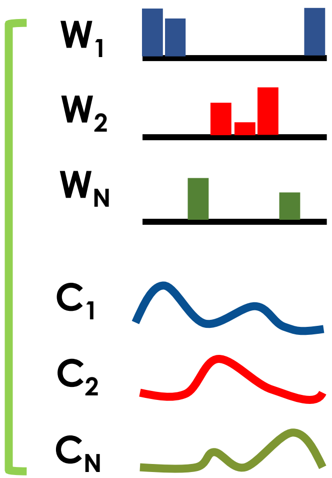
Muscle Synergy Extraction (NNMF)

$$M(t) = \sum_{k=1}^{N} C(t)_k \cdot W_k + e$$

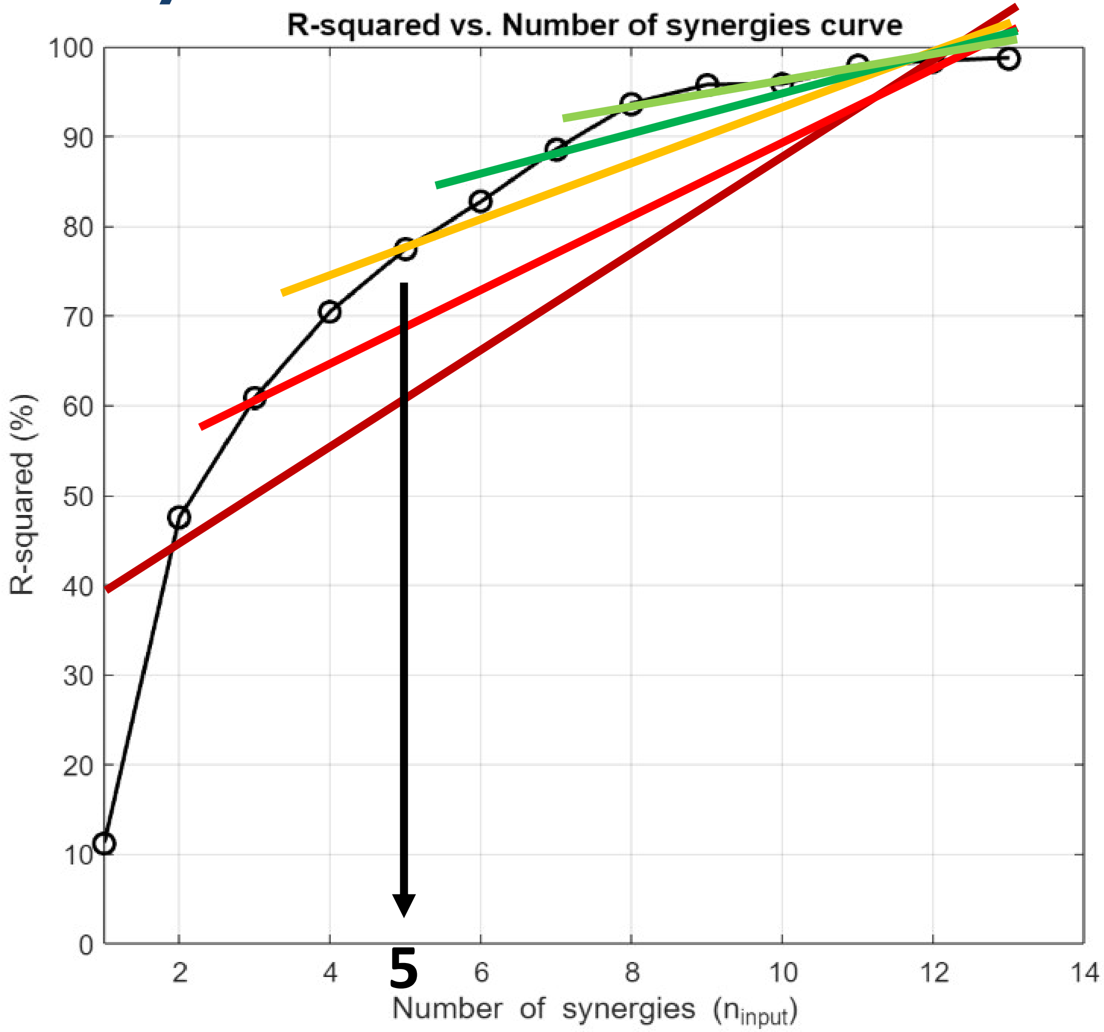
- **Activation coefficients (C):** temporal activation pattern of each synergy (temporal information)
- **Weight vector (W):** contribution of each muscle to a specific synergy (spatial information)

Evaluation of Chronic Ankle Instability

Selection of the number of muscle synergies (N)



Coefficient of determination (R-squared) is computed the quantitatively assess the **percentage of variability accounted for by the muscle synergy model.**



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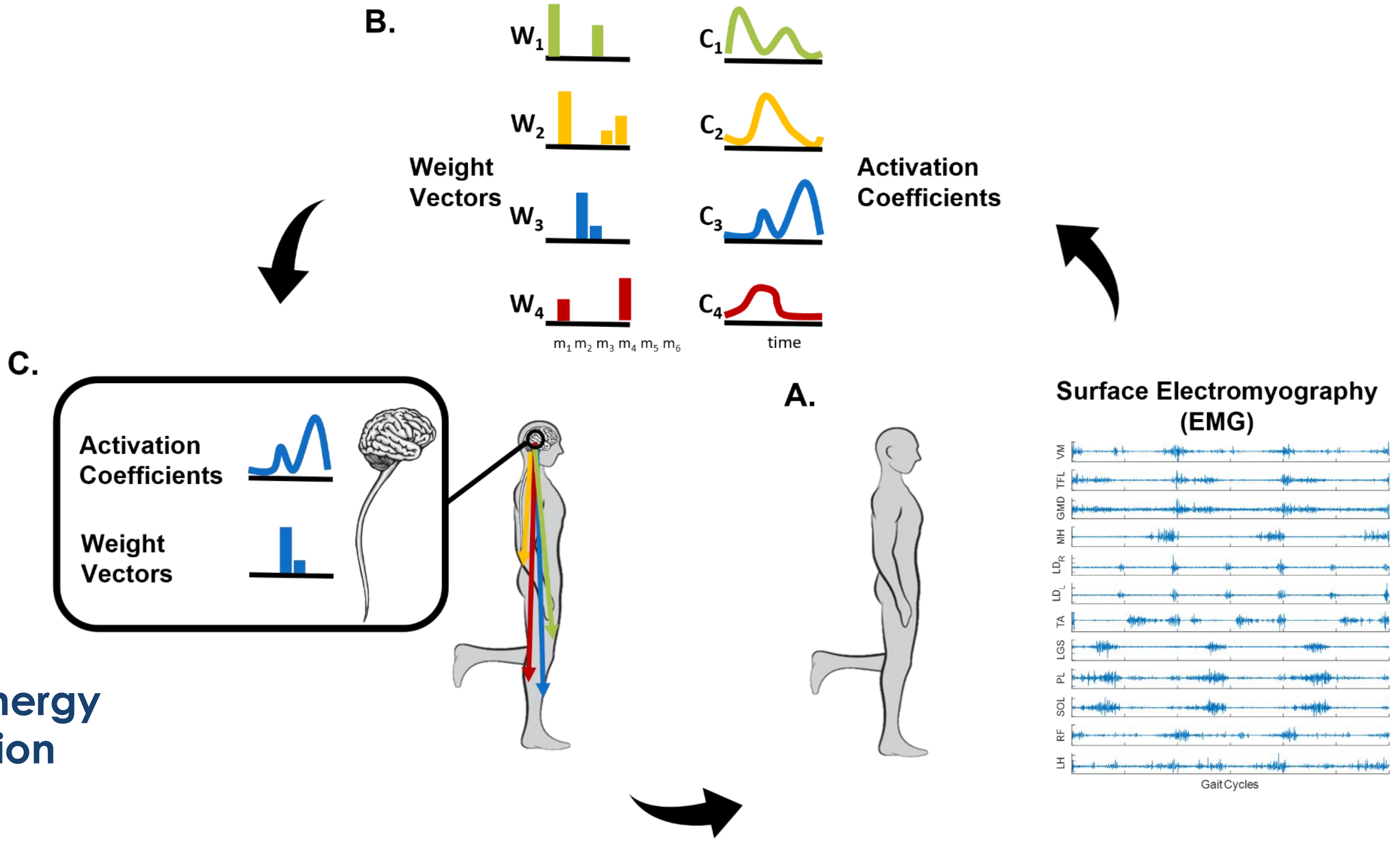
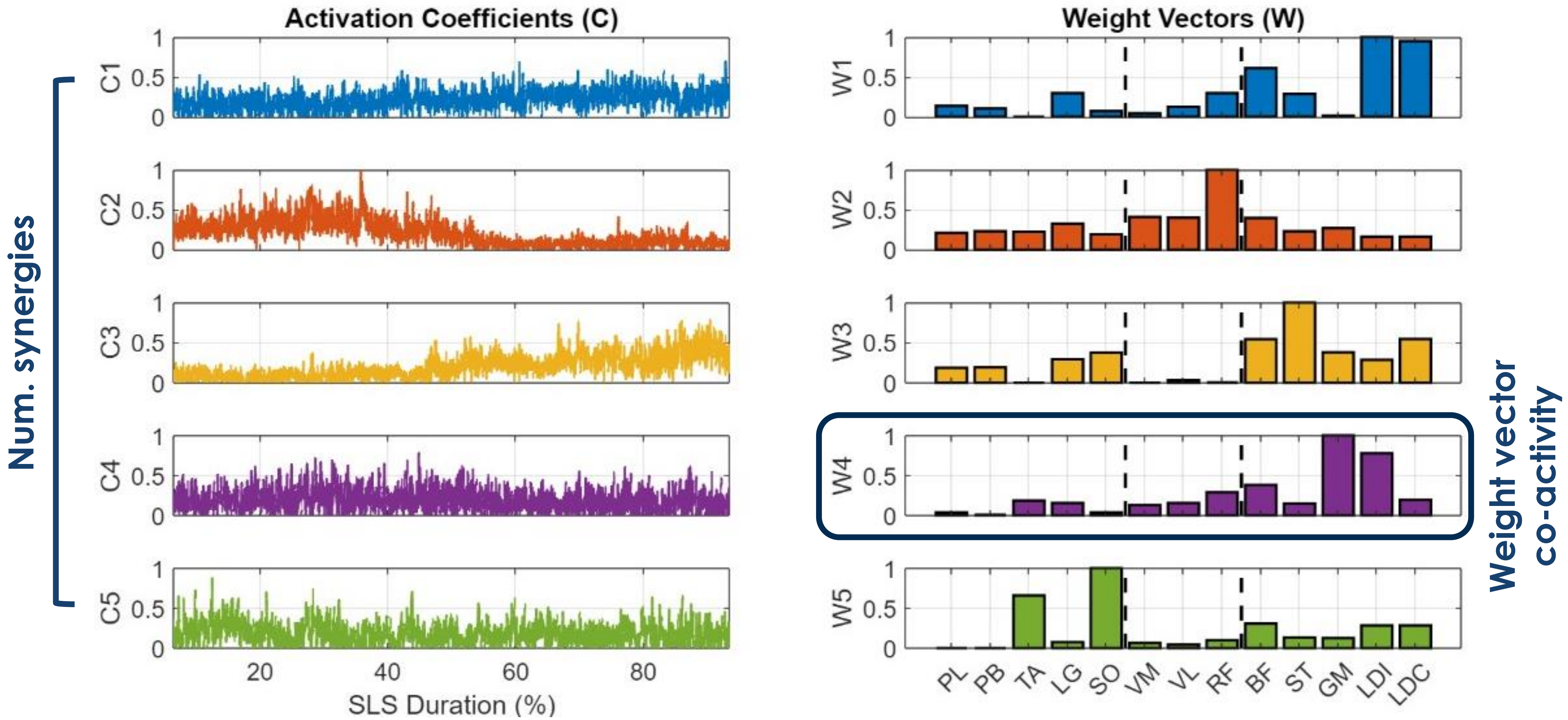


Muscle synergy interpretation

[Courtesy of Dr. Marco Ghislieri, from The Bioengineering of Sport – 2023 Patron Editore]

Evaluation of Chronic Ankle Instability



Muscle synergies extracted from a representative healthy subject.

Evaluation of Chronic Ankle Instability

Hands-on session

Each team will be provided with **MATLAB® routines** to extract muscle synergies and **surface EMG data from two subjects** (one of which is affected by CAI).

The team should **compare the two subjects** and **establish which one shows ankle instability and which one shows the better ankle stability**.

Hands-on session guidelines and **data** are available in the **GitHub repository**