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Ministero dell'Università e della Ricerca
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Motion analysis with EMG sensors

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Getting acquainted: who are the teachers?

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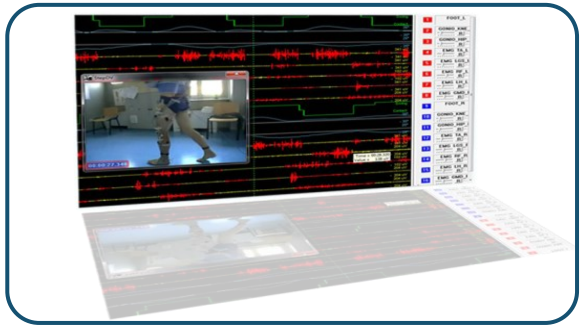
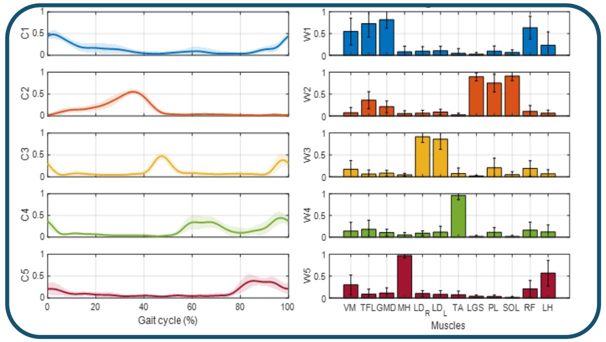
Introduction





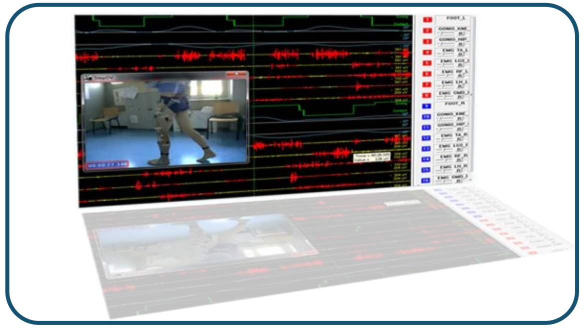
1. Statistical gait analysis and clinical applications

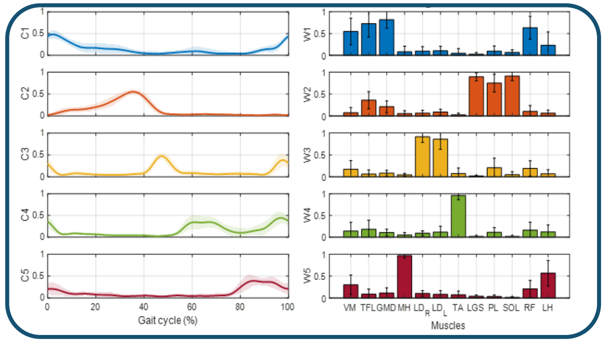
Valentina AGOSTINI

2. Study of motor control with muscle synergy analysis and clinical applications

Marco GHISLIERI

Introduction





1. Statistical gait analysis and clinical applications

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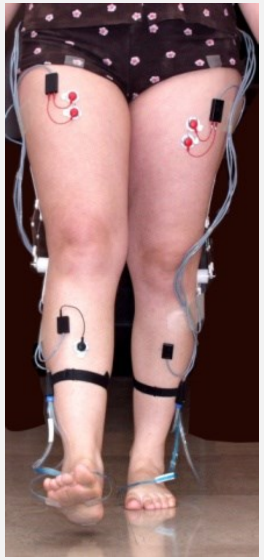
Statistical Gait Analysis (SGA)

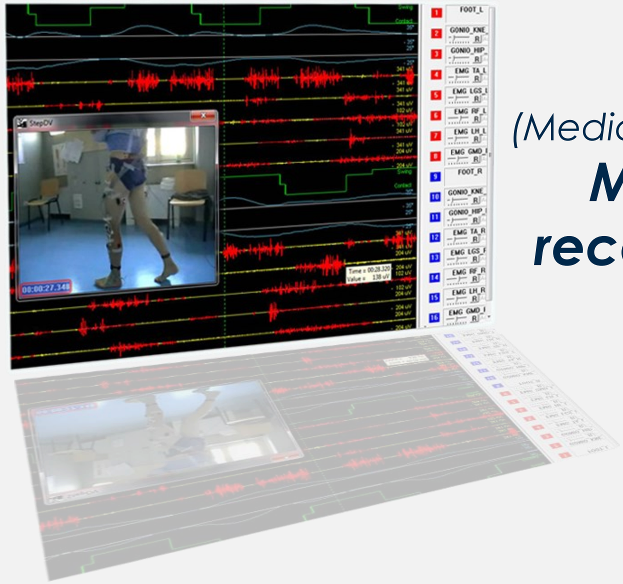
The analysis of human locomotion can be carried out taking into account hundreds of consecutive steps: this allows to describe gait from a statistical point of view. The results are accurate and highly repeatable.



Foot switches

Electrogoniometer

Surface electromyography (EMG) sensor



STEP32
(Medical Technology, Italy)
Multichannel recording system for SGA

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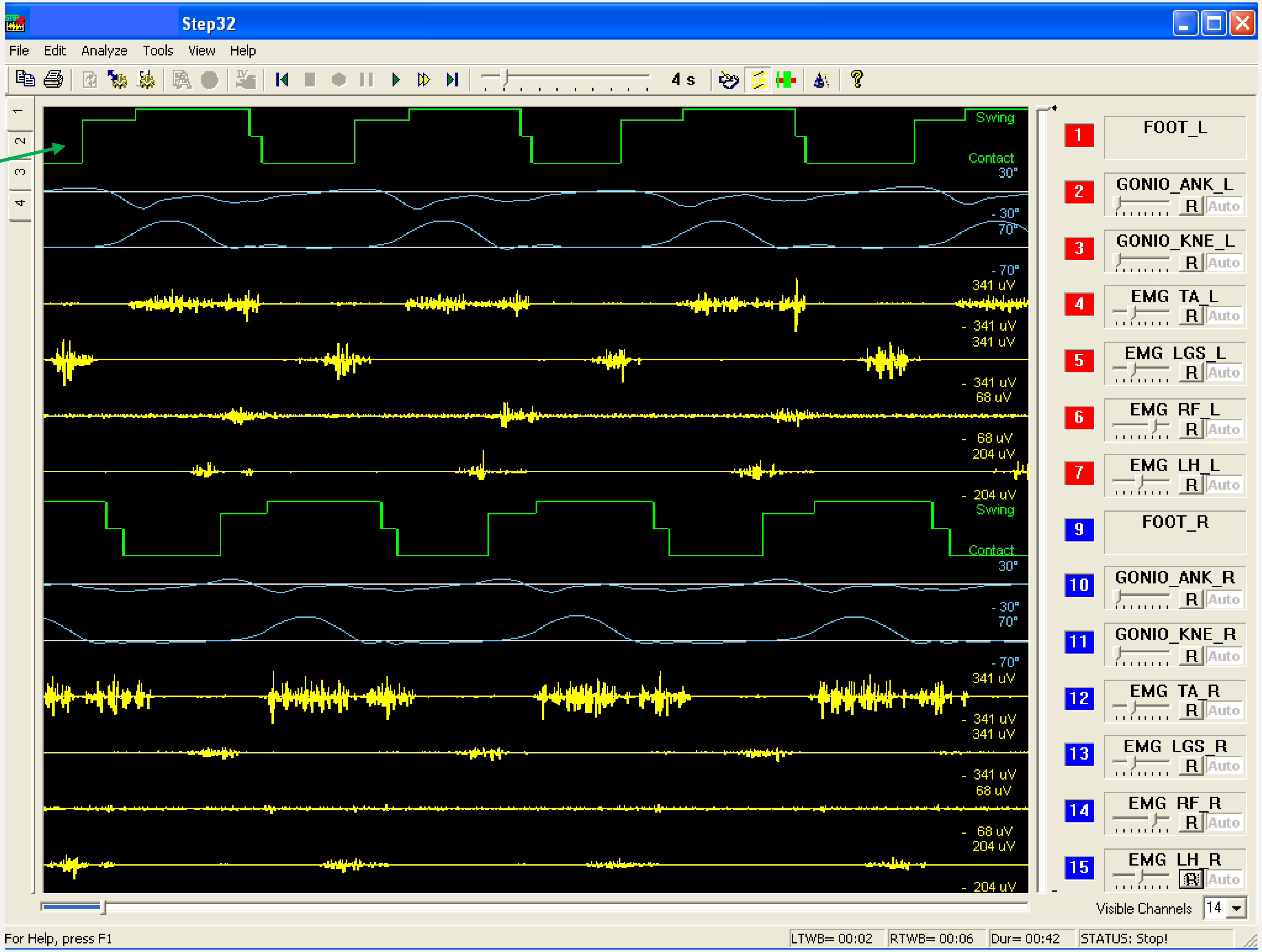
Examples of signals acquired during gait

Basographic signal (left foot)



Foot-switch signal

Foot-switches are useful to directly detect gait events, and study how the foot contact the ground (foot-floor contact sequence).

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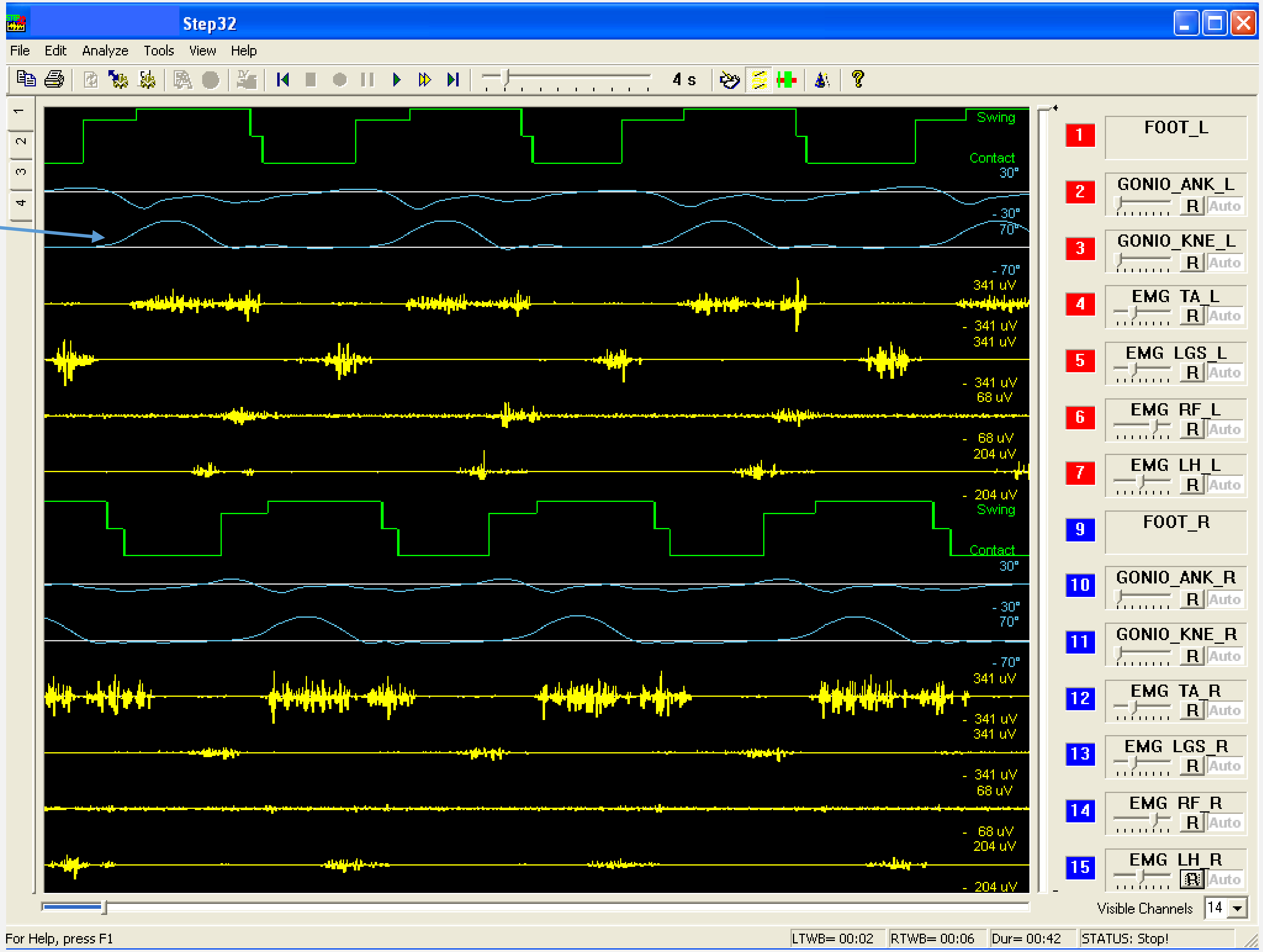
Flexo-extension angle of the knee joint in the sagittal plane

Joint kinematics

Electrogoniometers are useful for measuring joint kinematics during locomotion.

Examples of signals acquired during gait

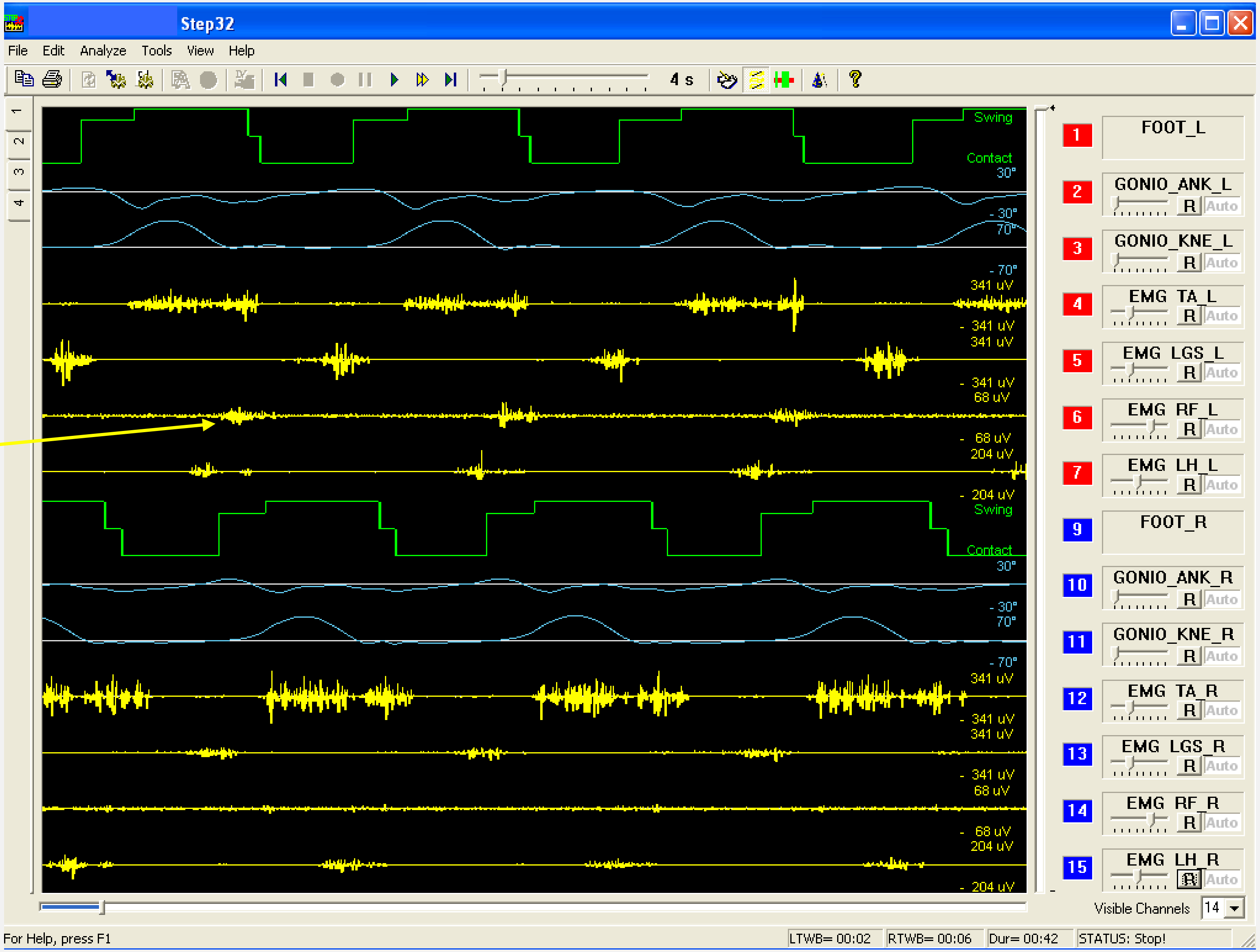


Surface EMG signal

EMG signal of the Rectus Femoris muscle (left)

Surface EMG electrodes are useful to acquire the electrical signal of the muscles non-invasively, during locomotion.

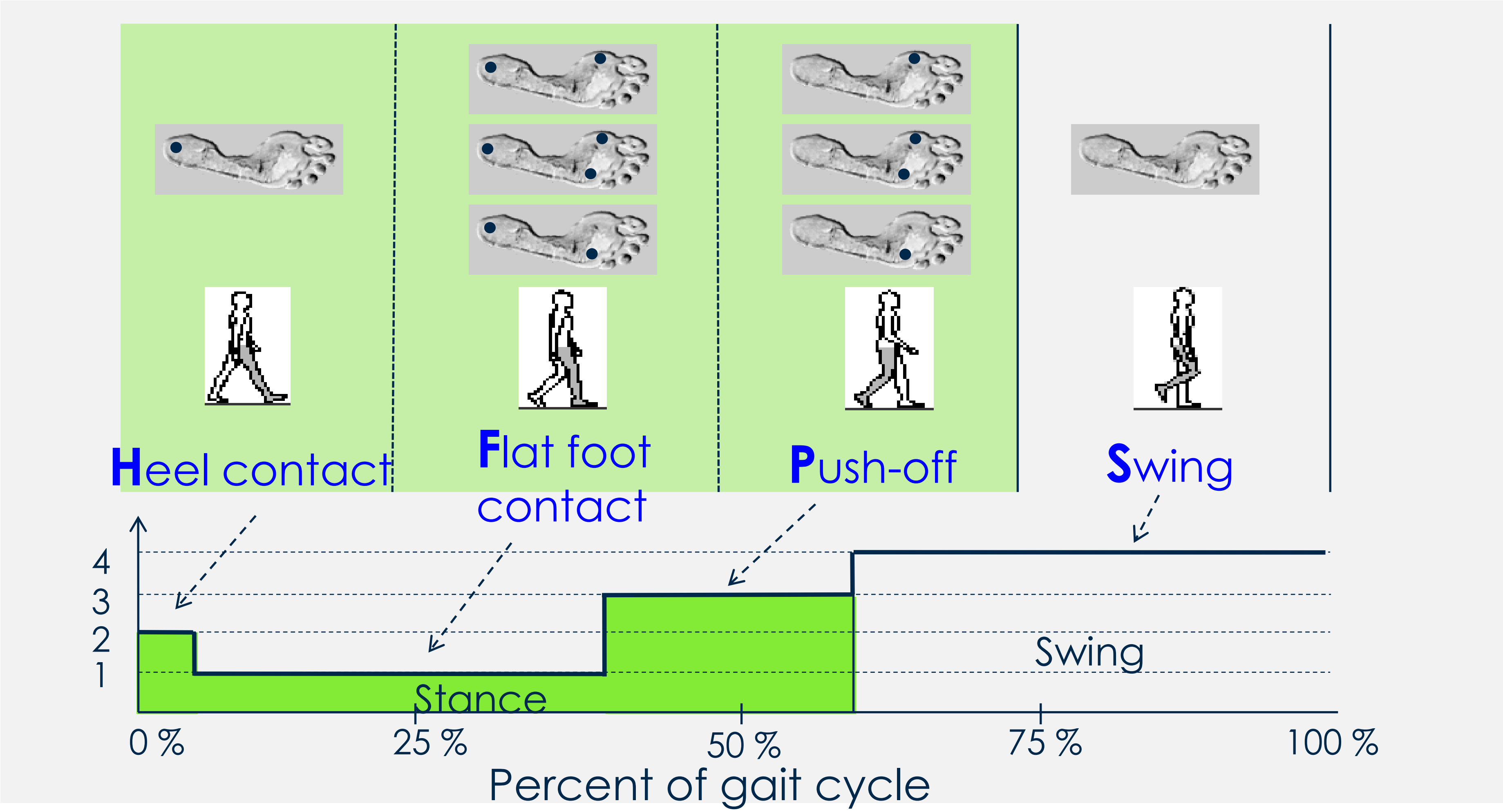
Examples of signals acquired during gait



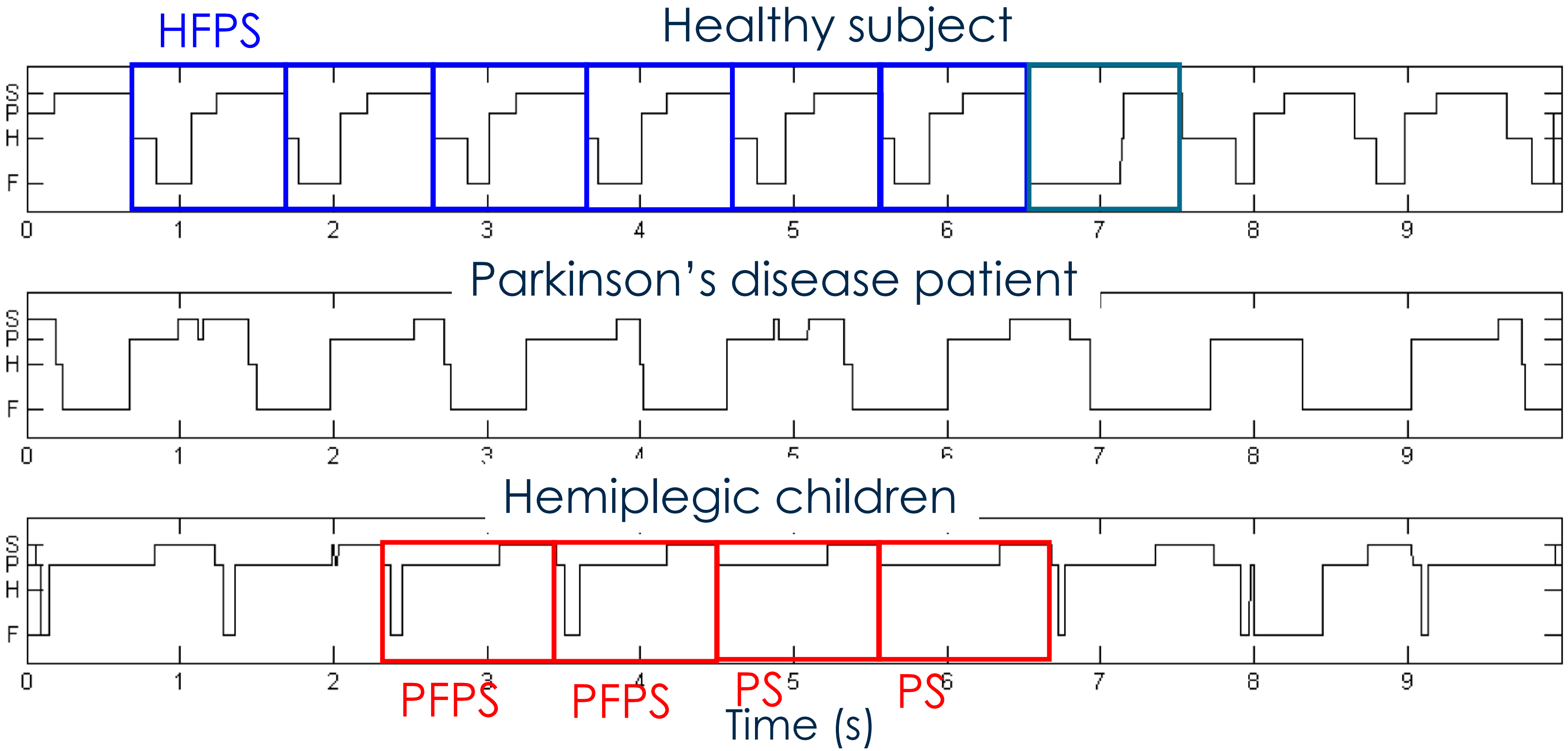
Typical or «normal» gait cycle

Considering the foot-switch signal, the most common gait cycle, in healthy subjects, shows the sequence of gait phases:

H-F-P-S.



Foot-switch signal during gait



Examples of foot-switch signals acquired during gait (10 s extracted From the original signals)

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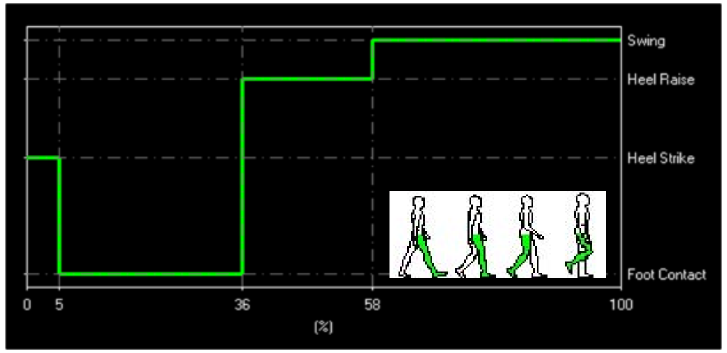
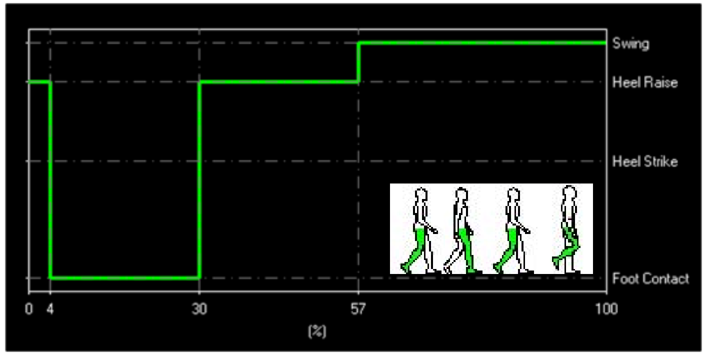
Agostini et al. "Segmentation and classification of gait cycles" IEEE Trans Neural Syst Rehabil Eng. 2014
doi: 10.1109/TNSRE.2013.2291907

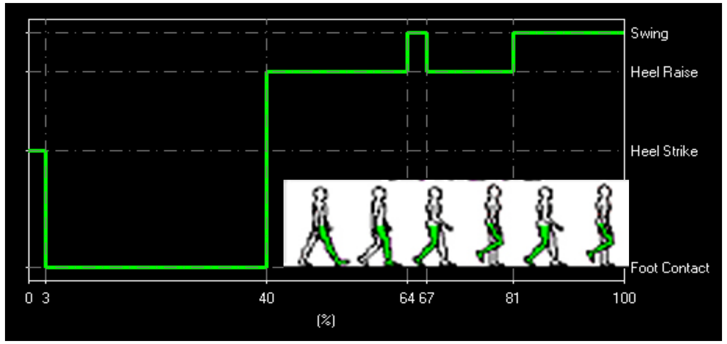
Different gait cycles…



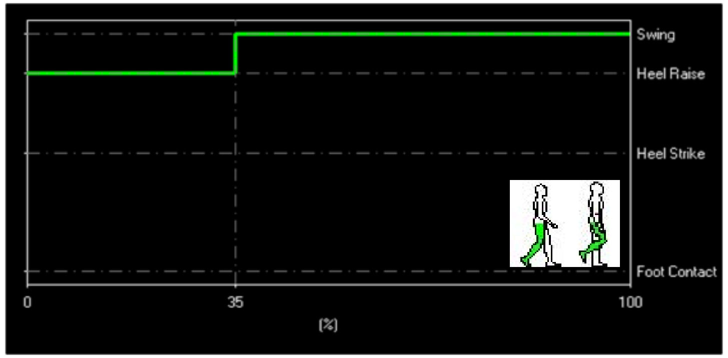
Cycle HFPS (normal)



Cycle PFPS



Cycle HFPSPS

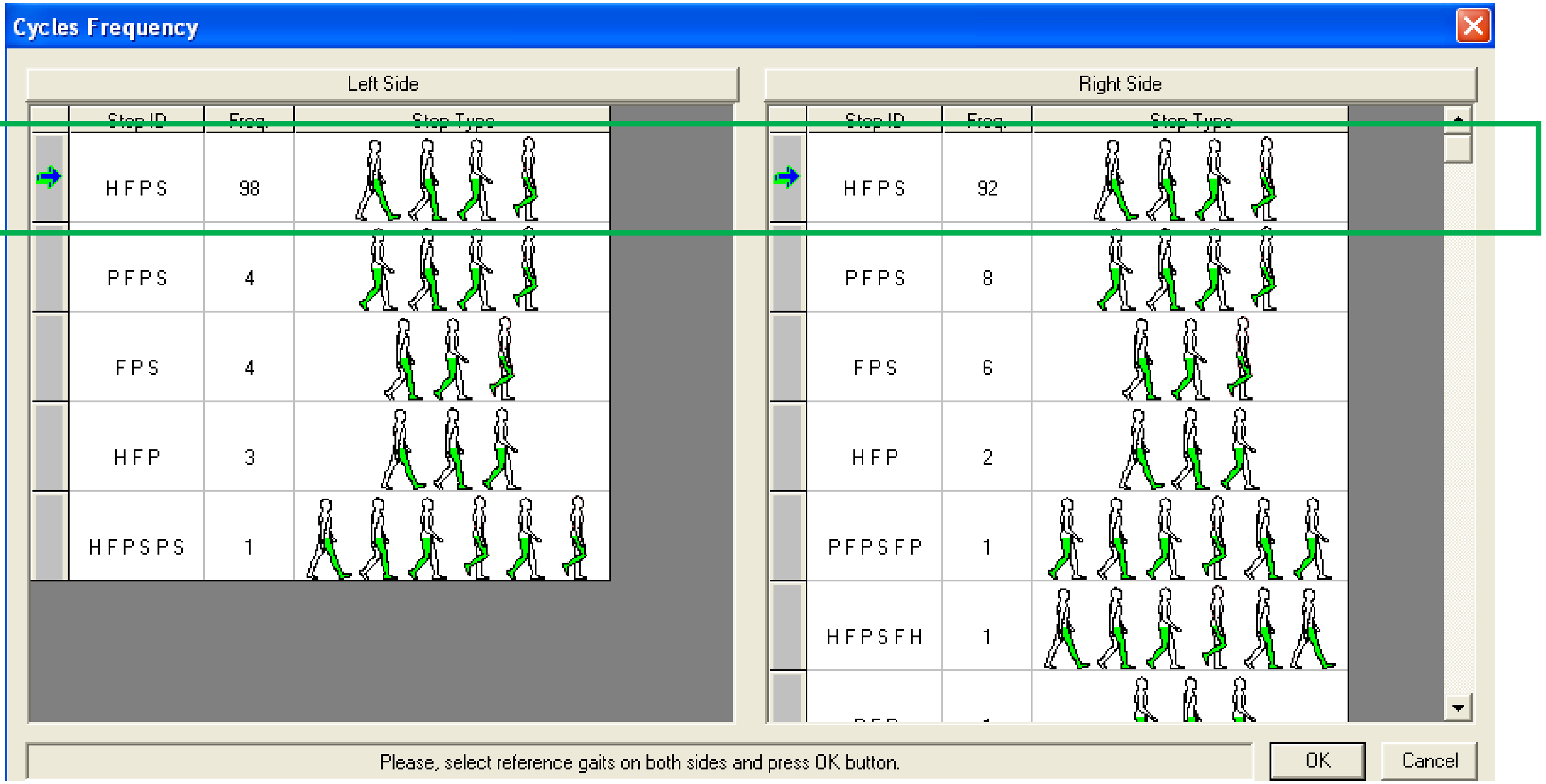


Cycle PS

- Different types of gait cycles can be observed in both normal and pathological subjects.
- Increased % of atypical cycles → increased fall risk
- Different gait cycles → different patterns of muscle activation: muscle activation should be studied after selecting similar walking cycles.

Analysis of gait cycles

Healthy subject



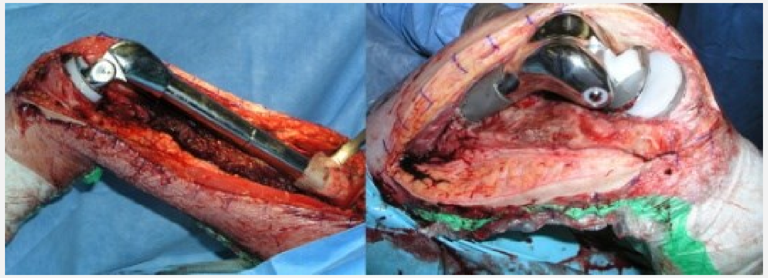
Typical cycles

The first step towards the Statistical Gait Analysis is the identification of all the different cycles that can be found in a walk. This task can be performed automatically, without user interaction.

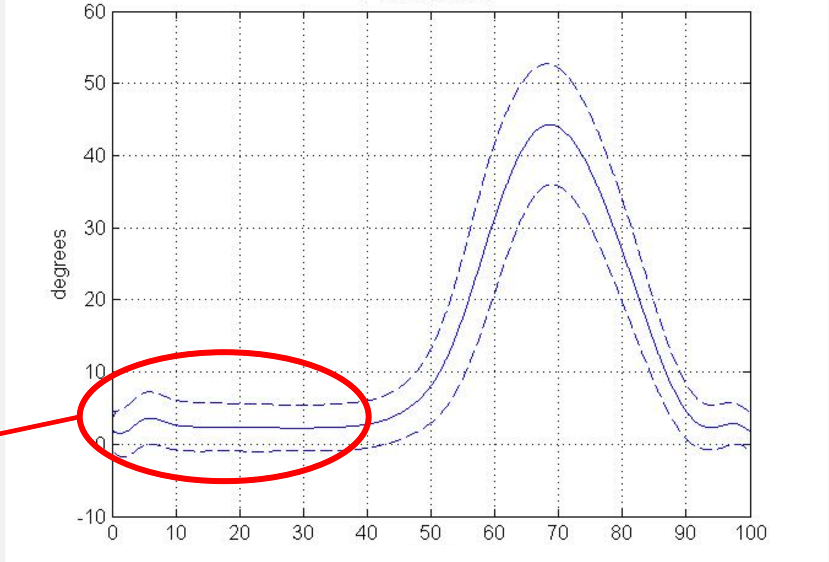
Knee mega-prosthesis

Reduction of knee flexion during the load acceptance phase of gait, on the prosthetic side with respect to the contralateral side.

17 patients with knee megaprosthesis after limb saving surgery for osteosarcoma (age: 40 ± 18 years)

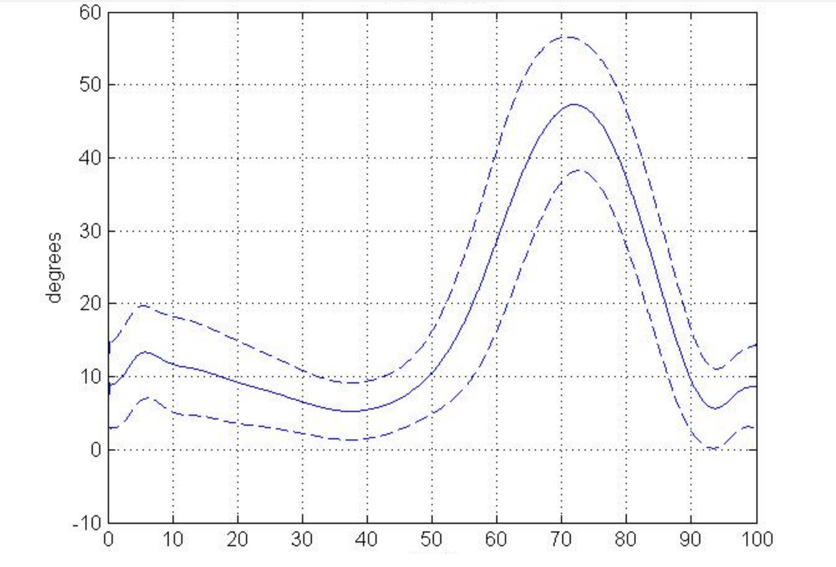


Prosthetic side



Gait cycle (%)

Sound side

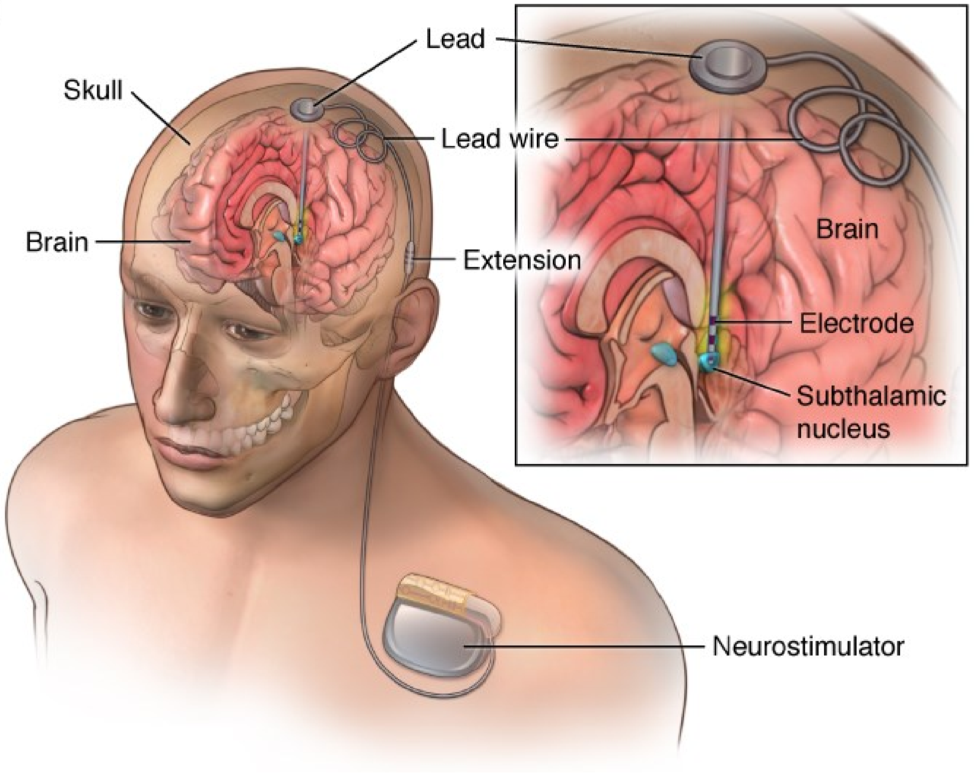


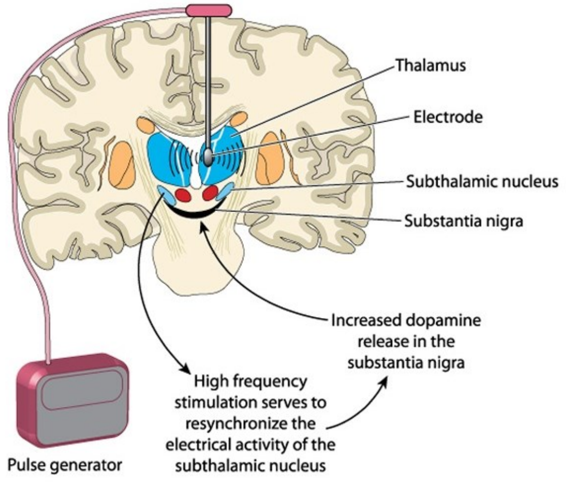
Gait cycle (%)

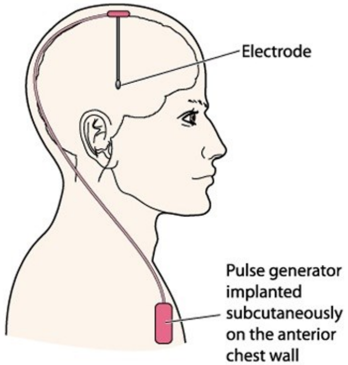
Deep Brain Stimulation

Parkinson’s disease (PD)

- DBS help to control **tremors** and **chronic movement disorders**, like Parkinson’s disease
- Electrodes produce **electrical impulses** that regulate abnormal brain function







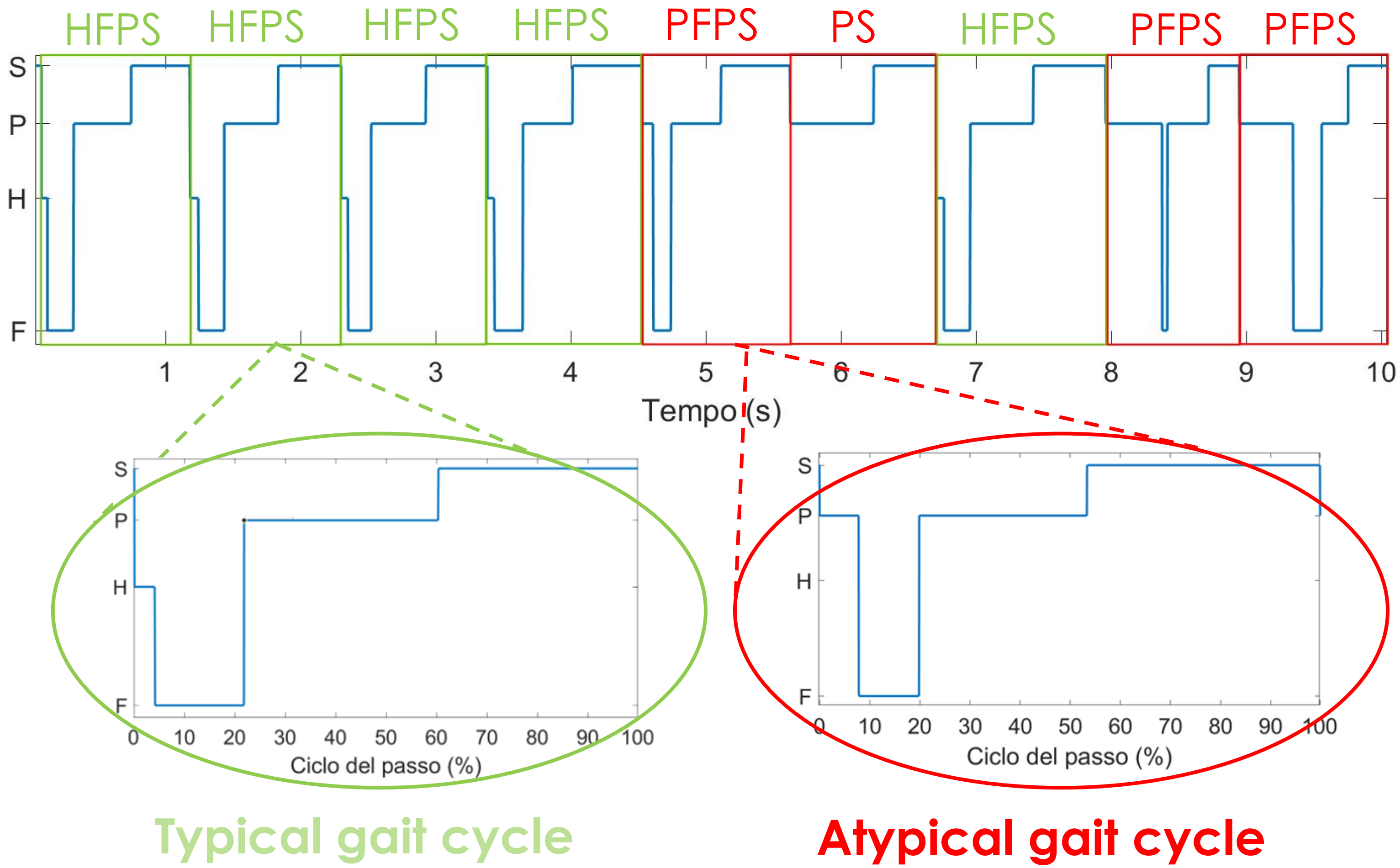
This study was carried out in collaboration with the Department of Neuroscience “Rita Levi Montalcini” of the University of Turin, Turin, Italy.

Population and signal acquisition (foot-switches)

- 35 PD patients (70% males – average UPDRS-III : 18.5 ± 8.3)

3 time points: baseline (T0), 3 months (T1) and 12 months (T2) after DBS

- 35 age-matched healthy controls (~ 60 years)



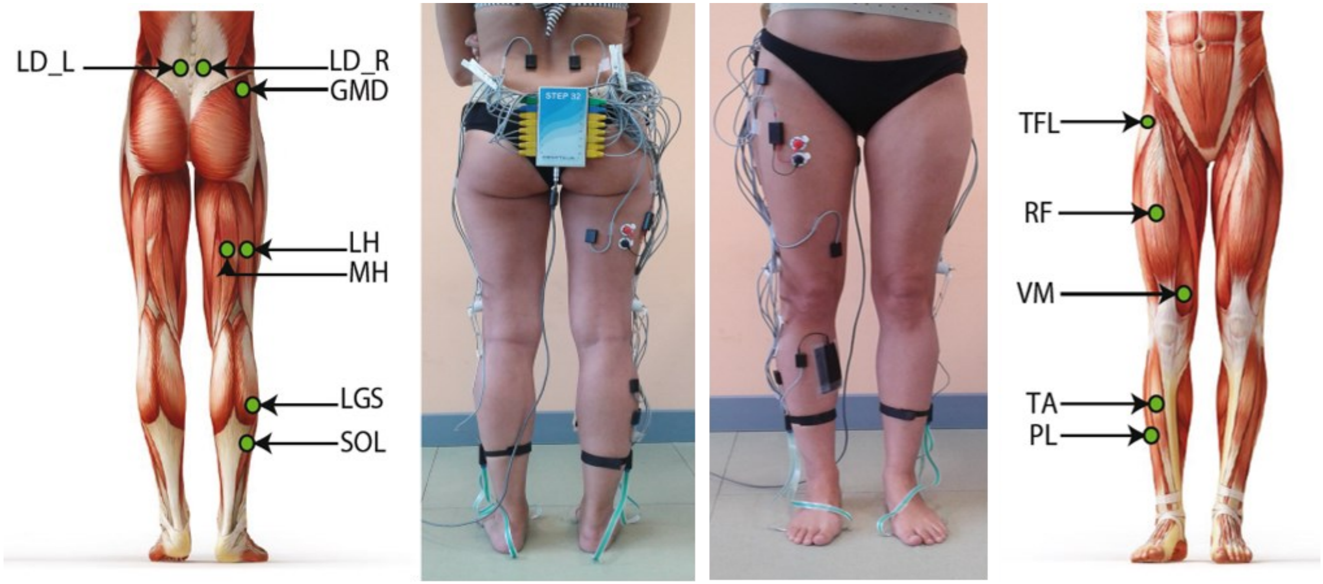
Population and signal acquisition (EMG)

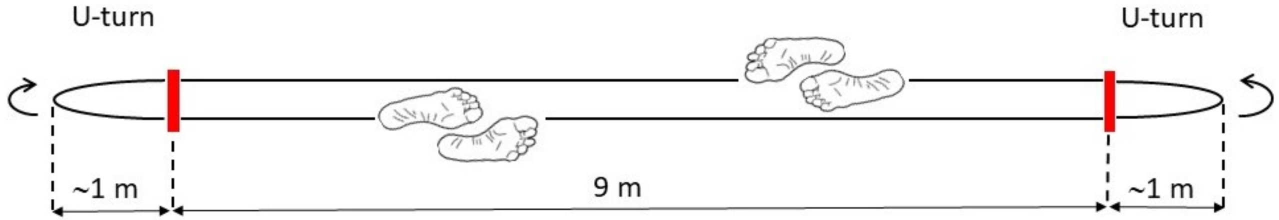
- 35 PD patients (70% males – average UPDRS-III : 18.5 ± 8.3)

3 time points: baseline (T0), 3 months (T1) and 12 months (T2) after DBS

- 35 age-matched healthy controls (~ 60 years)

This study was carried out within the «PD-DBS» project (“Effect of bilateral subthalamic nucleus deep brain stimulation on gait analysis and muscle synergy patterns of patients affected by Parkinson’s disease during dual-task walking”, protocol N° 2022KWSJJT) – funded by European Union – Next Generation EU within the PRIN 2022 program (D.D. 104 - 02/02/2022 Ministero dell’Università e della Ricerca).





5-minute overground walking at self-selected speed

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STEP32: protocol of acquisition of EMG signals for the study of muscle synergies

Atypical gait cycles in PD at baseline (T0)

sensors MDPI

Article

Atypical Gait Cycles in Parkinson's Disease

Marco Ghislieri [1,2,*], Valentina Agostini [1,2], Laura Rizzi [3,4], Marco Knaflitz [1,2] and Michele Lanotte [3,4]

2021

Link: https://doi.org/10.3390/s21155079

Traditional gait parameters

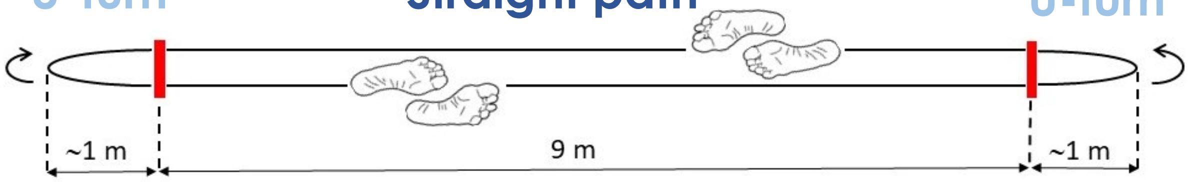
	PD Patients	Control Subjects	Wilcoxon Test (p-Value)
Walking speed (m/s)	1.01 ± 0.25	1.08 ± 0.17	0.31
Cadence (cycles/min)	55.7 ± 5.9	54.6 ± 3.3	0.53
Double support (%GC)	11.9 ± 5.5	14.2 ± 3.9	0.13

Percentage of atypical gait cycles (%)

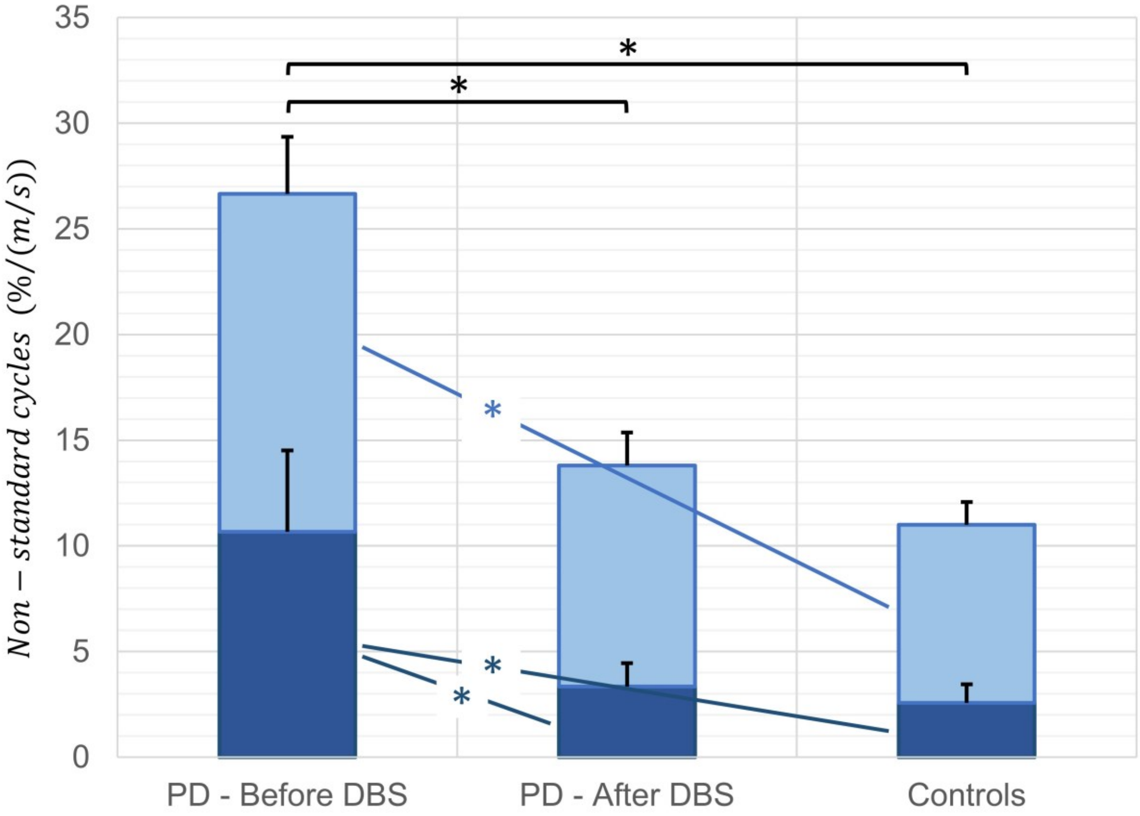
Percentage of *atypical* GC (%)	PD Patients		Control Subjects		2-way ANOVA (p-Value)	
	More-Affected Side	Less-Affected Side	Dominant Side	Non-Dominant Side	Group	Side
Straight walking	12.3 ± 18.3	4.8 ± 7.8	2.0 ± 2.5	2.5 ± 3.4	0.007	0.12
U-turning	13.1 ± 6.1	10.7 ± 4.4	6.1 ± 4.1	6.3 ± 3.0	<0.0001	0.36

Atypical gait cycles in PD (T0 vs. T1)

Effects of bilateral Deep Brain Stimulation



Results demonstrated the **validity of atypical gait cycles in the evaluation of the effects of the DBS**, at 3 months after the implant.
The segmentation of straight-path and U-turning epochs provided supplemental information, that can be useful in the management of PD patients.



M., Ghislieri et al. "Straight-path and U-turn gait biomarkers in PD patients before and after deep-brain stimulation" in Gait & Posture (2023). Doi:10.1016/j.gaitpost.2023.07.288.

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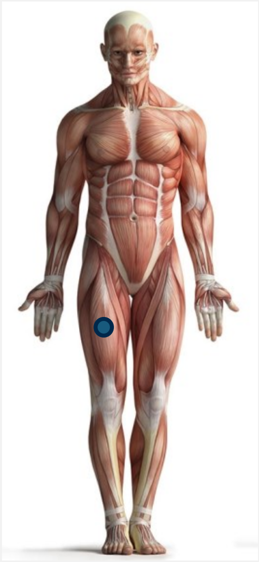
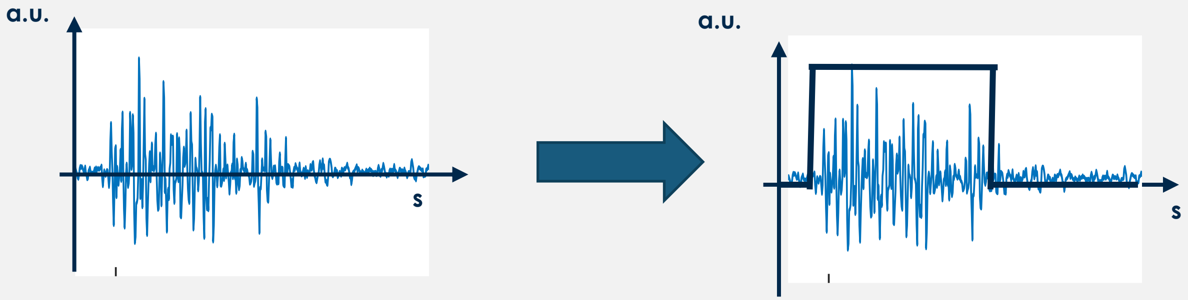
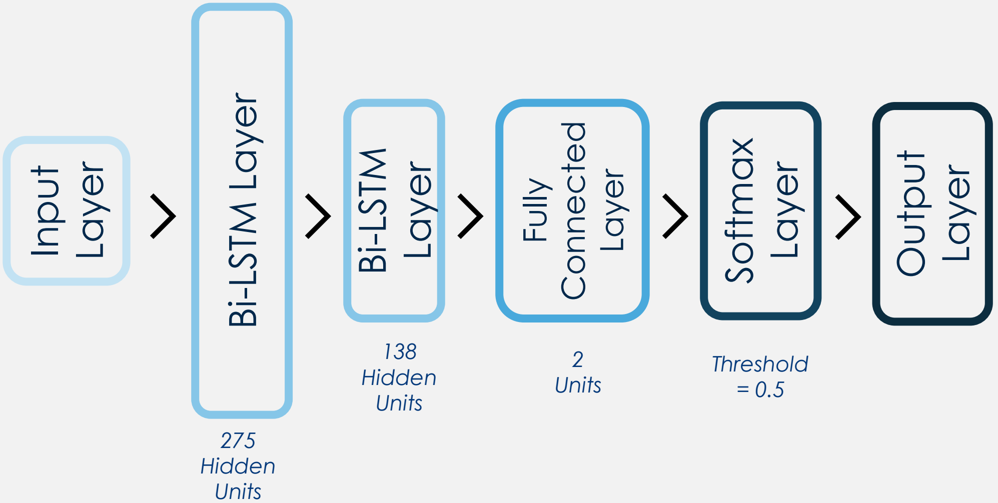
Artificial Intelligence for Muscle Activity Detection (MAD)

A Deep Learning (DL) approach was used (LSTM)







> J Neuroeng Rehabil. 2021 Oct 21;18(1):153. doi: 10.1186/s12984-021-00945-w.

Long short-term memory (LSTM) recurrent neural network for muscle activity detection

Marco Ghislieri [1, 2], Giacinto Luigi Cerone [3, 4], Marco Knaflitz [5, 3], Valentina Agostini [5, 3]

Affiliations + expand

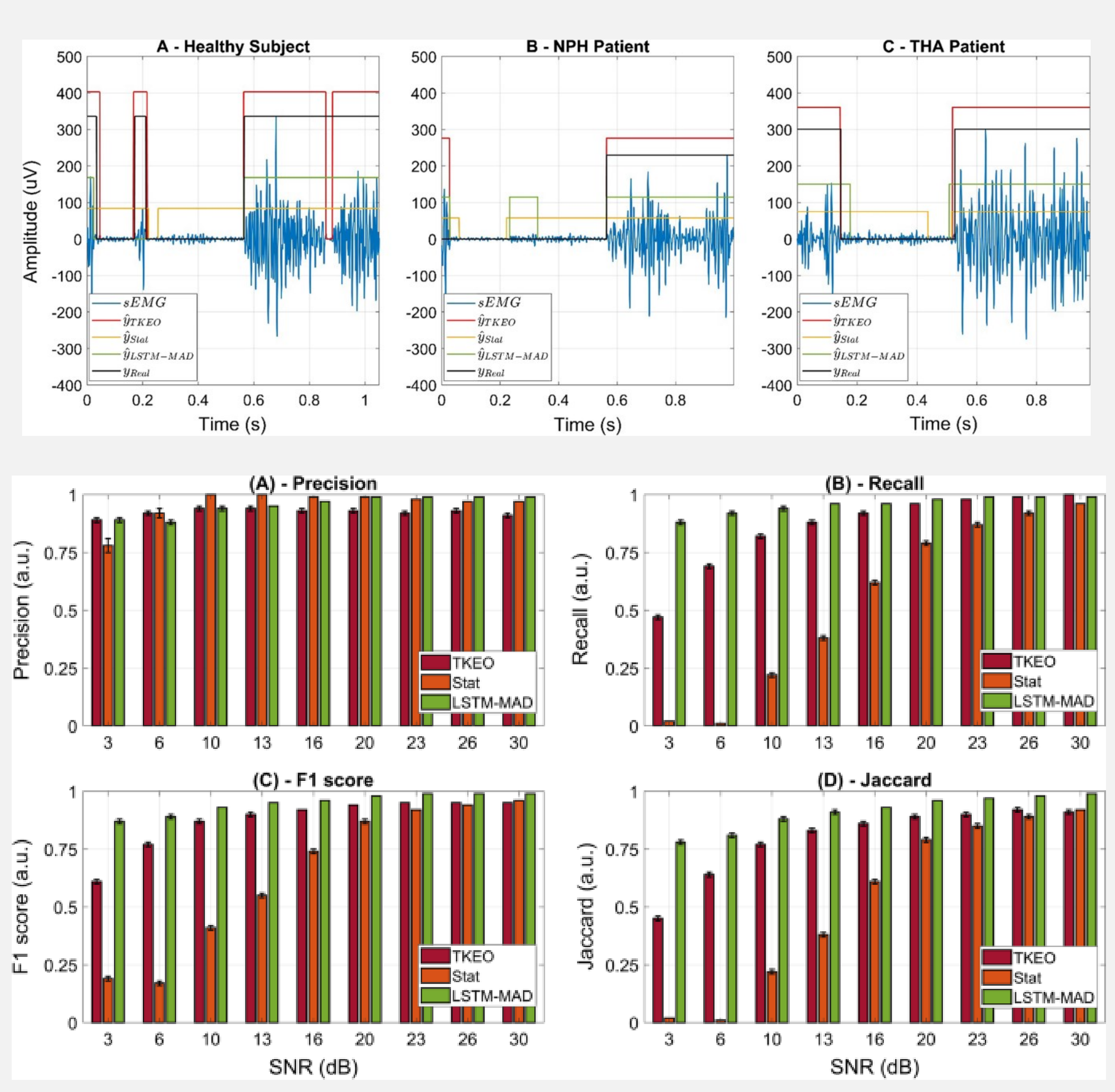
PMID: 34674720 PMCID: PMC8532313 DOI: 10.1186/s12984-021-00945-w

2021

Link: https://doi.org/10.1186/s12984-021-00945-w

EMG detector

- EMG detector “LSTM-MAD” overcomes the main limitations of the other tested approaches since it works directly on EMG signals, without the need for background-noise and SNR estimation (as in Stat).
- LSTM-MAD outperforms the other tested approaches (higher values of F1-score (>0.91) and Jaccard similarity index (>0.85), and lower values of onset/offset bias (average absolute bias < 6 ms), both on simulated and real EMG signals.
- Advantages of LSTM-MAD are particularly evident for signals with low to medium Signal-to-Noise Ratio (SNR).



Potential clinical applications of the EMG detector:

- Extraction of reliable motor biomarkers to evaluate:
  1) **muscle asymmetry**
  2) **co-contraction of antagonist muscles**

  e.g. to study jumping tasks in ahtletes, for a better assessment of Return-to-sport time after Anterior-Cruciate Ligament (ACL) surgery and rehabilitation.
- Human-machine interfaces (HMI): myoelectric control of upper- or lower-limb prostheses

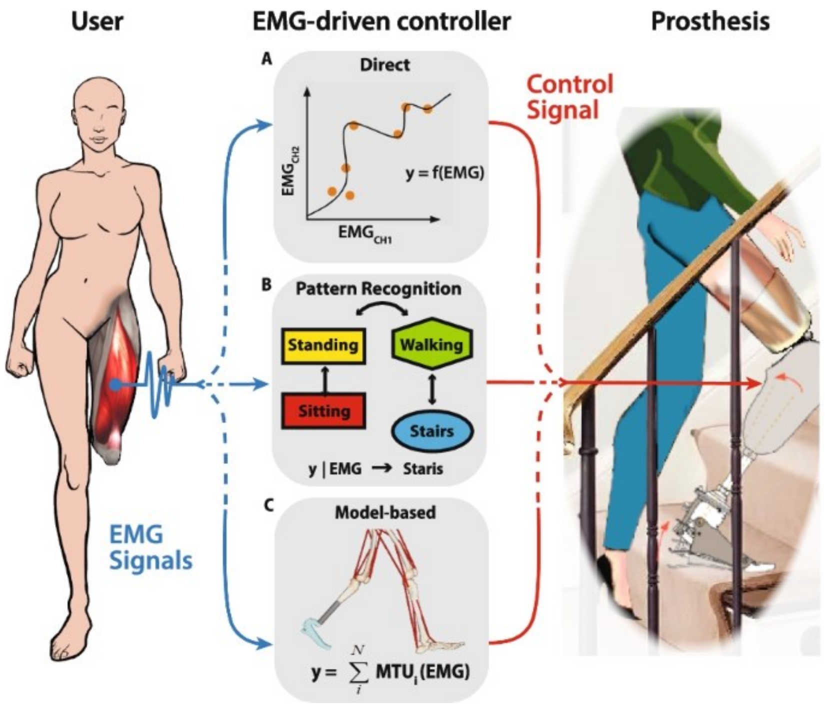
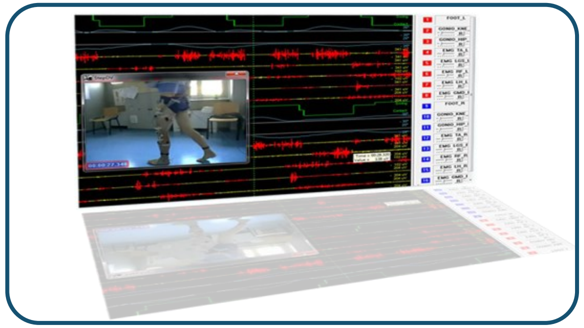
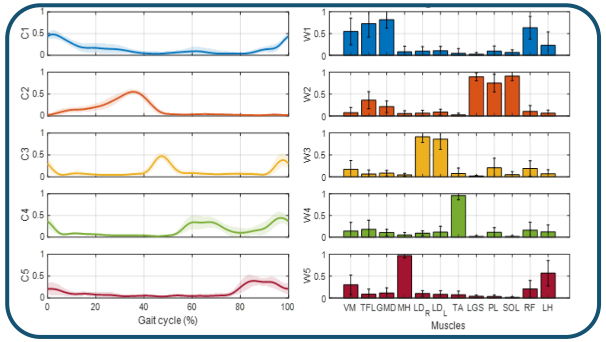


Figure extracted from:
Cimolato, A. *et al.* EMG-driven control in lower limb prostheses: a topic-based systematic review. *J NeuroEngineering Rehabil* **19**, 43 (2022). https://doi.org/10.1186/s12984-022-01019-1

Introduction





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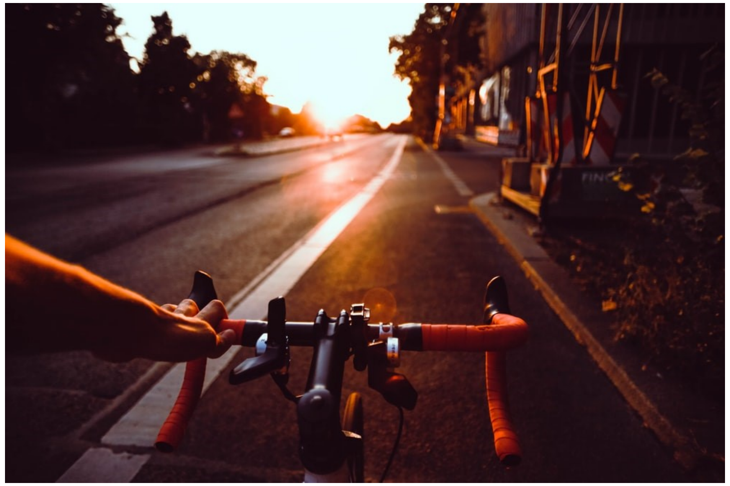
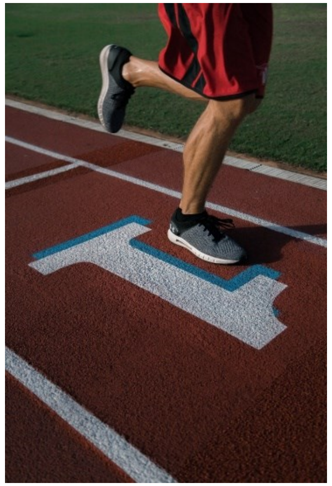
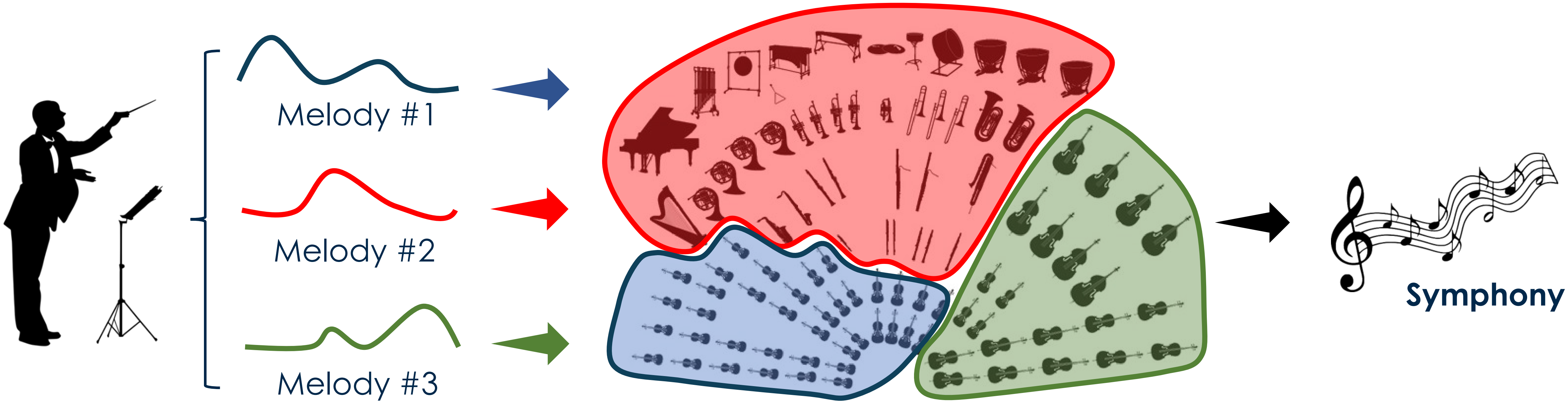
Human motor control

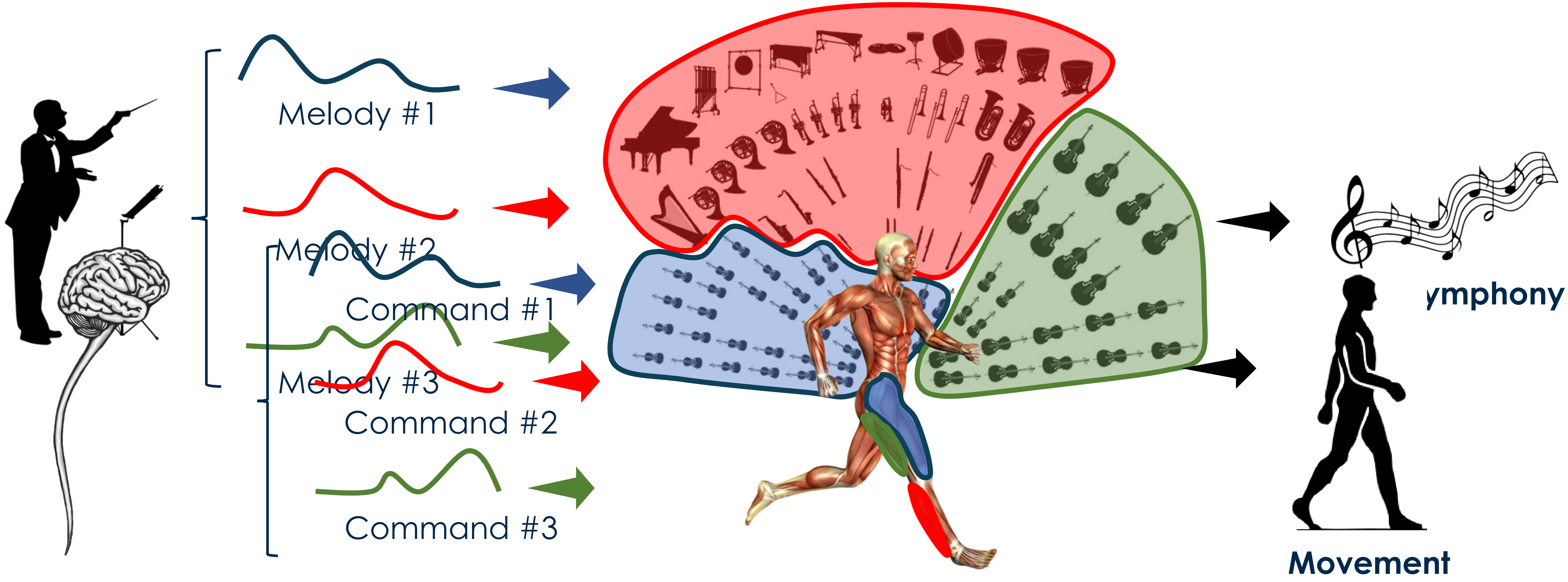


Modularity of motor control

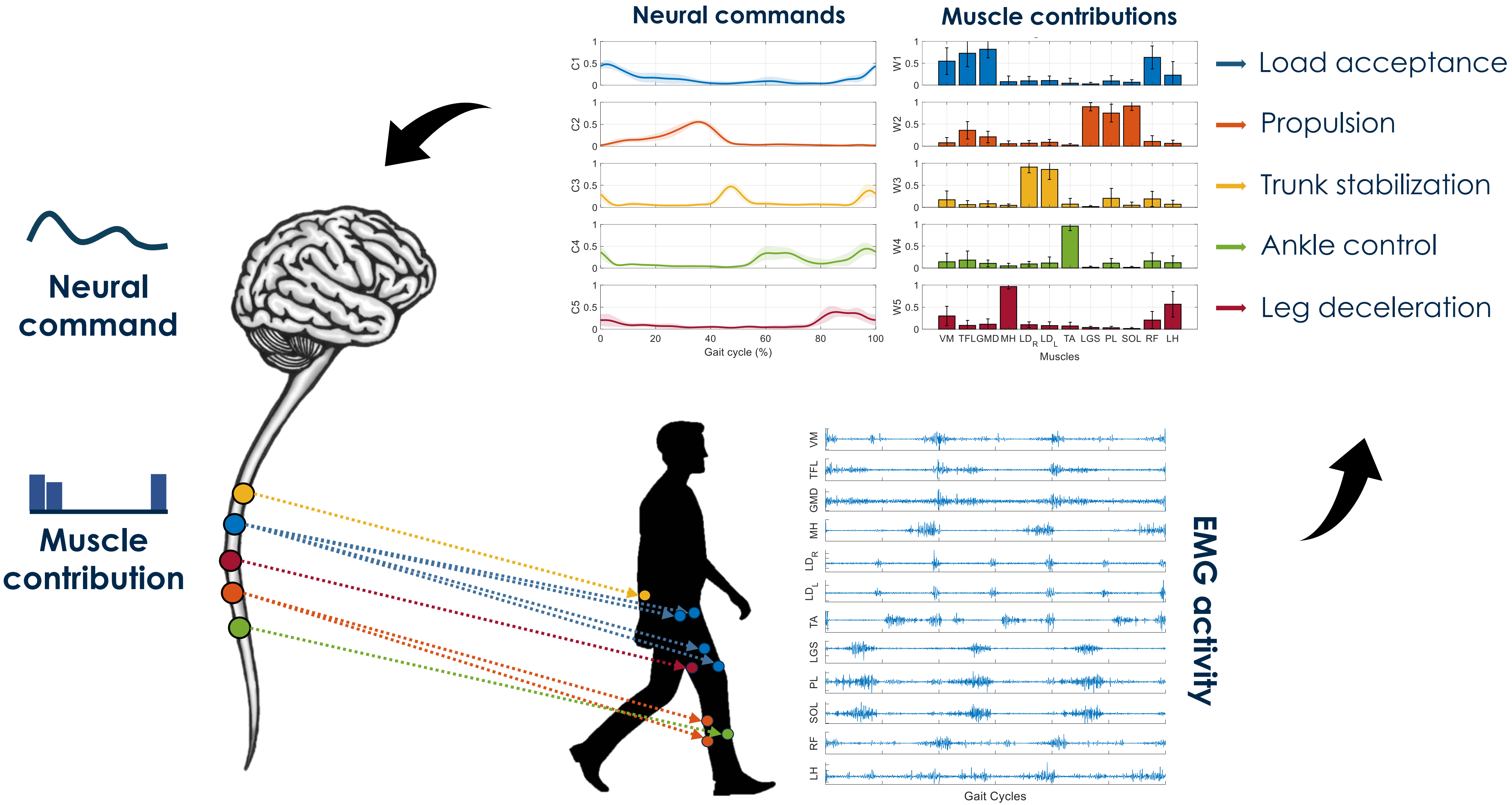
Analogy with symphonic orchestra



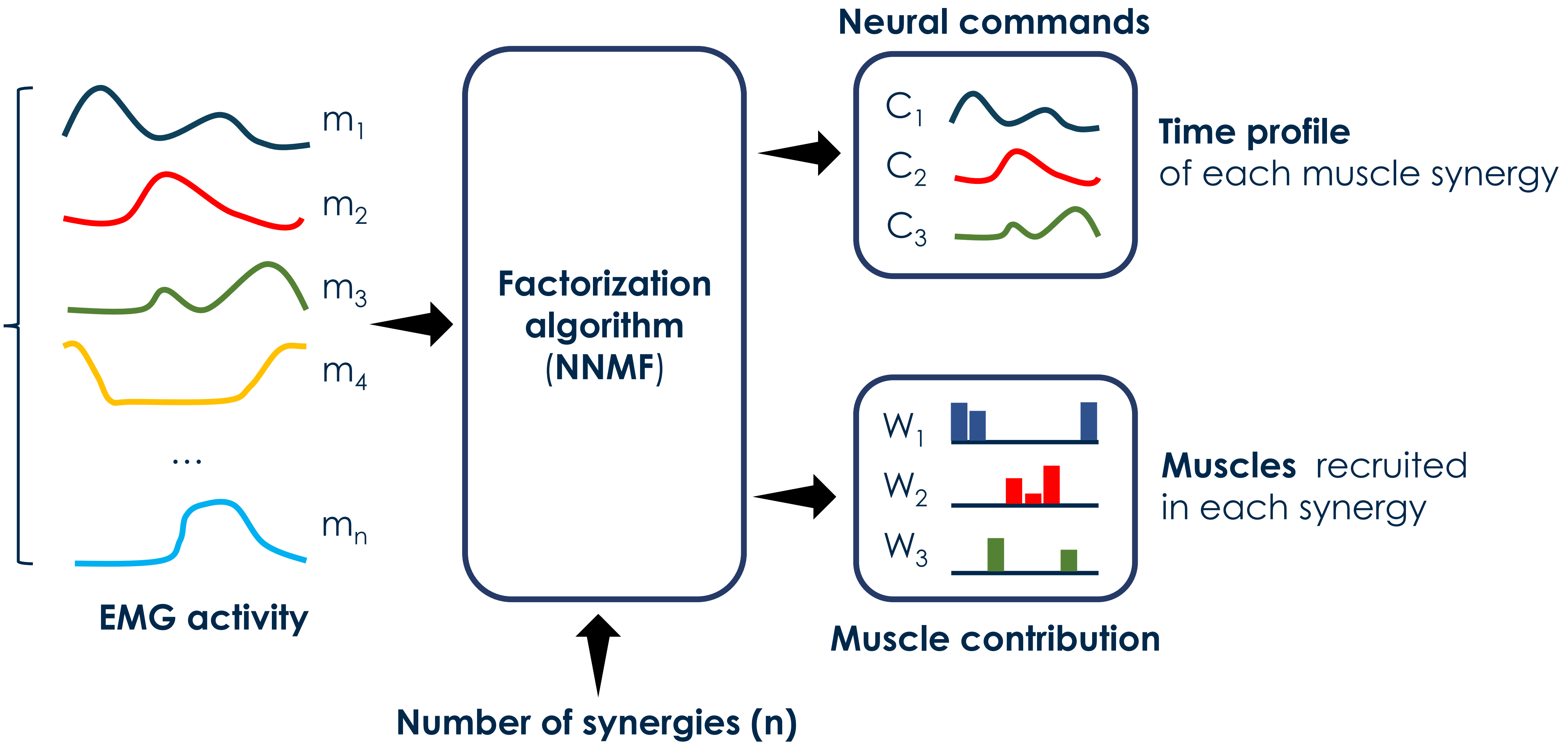
Modularity of motor control



Muscle synergies theory



Muscle synergy extraction



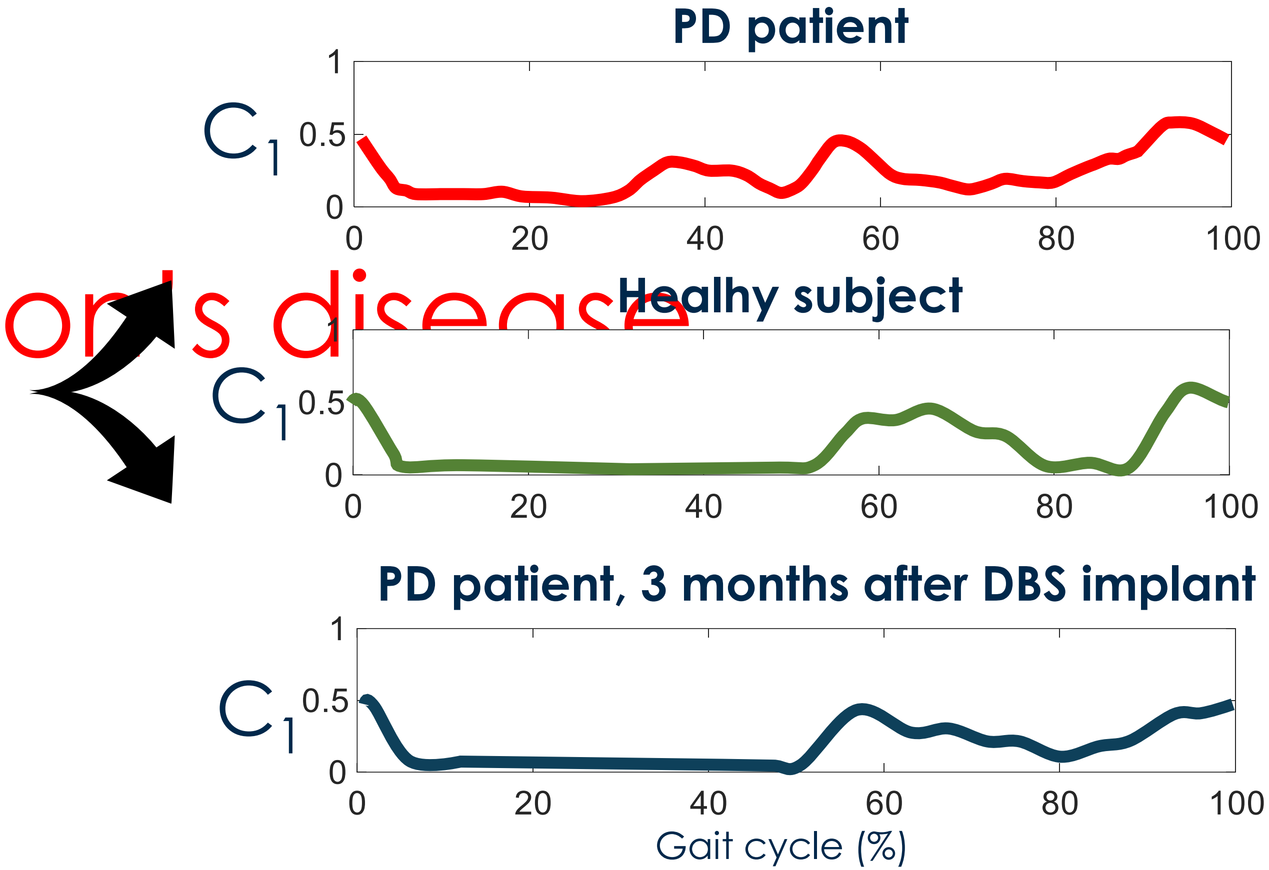
M. Ghislieri et al. "Muscle Synergies Extracted Using Principal Activations: Improvement of Robustness and Interpretability" in *IEEE Transactions on Neural Systems and Rehabilitation Engineering* (2020). Doi: 10.1109/TNSRE.2020.2965179.

Muscle synergies in clinics

Neuropathies
Dystrophy
Hydrocephalus
Hemiplegia
Alzheimer
Multiple sclerosis
Dyskinesia
Parkinson's disease
Ataxia
Chronic ankle instability
Stroke
Lumbar pain
Cerebral palsy
Essential tremor
Parkinsonism
Dystonia
Epilepsy

Muscle synergies in clinics

Locomotor control in PD patients



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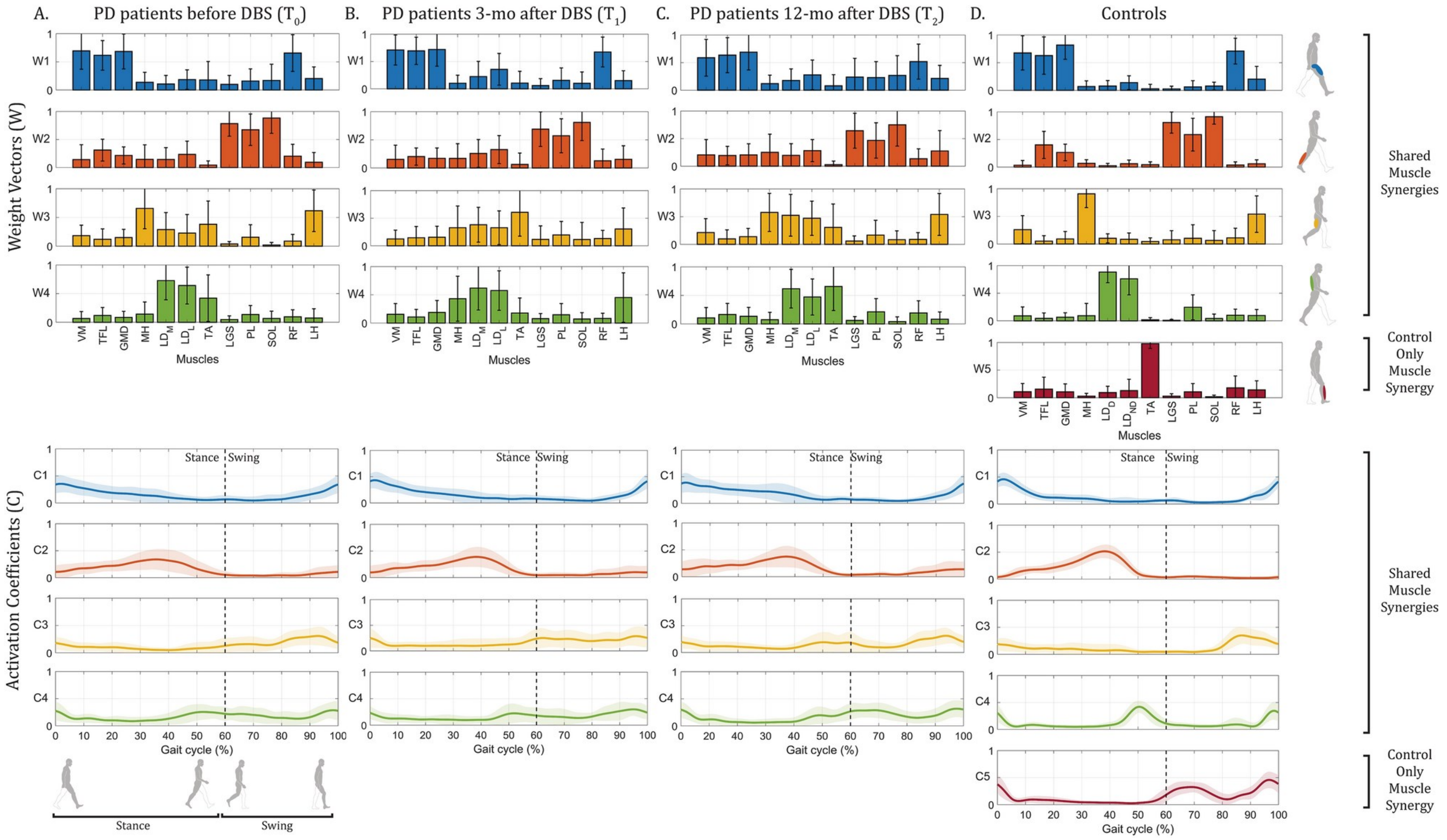
Muscle synergies in clinics

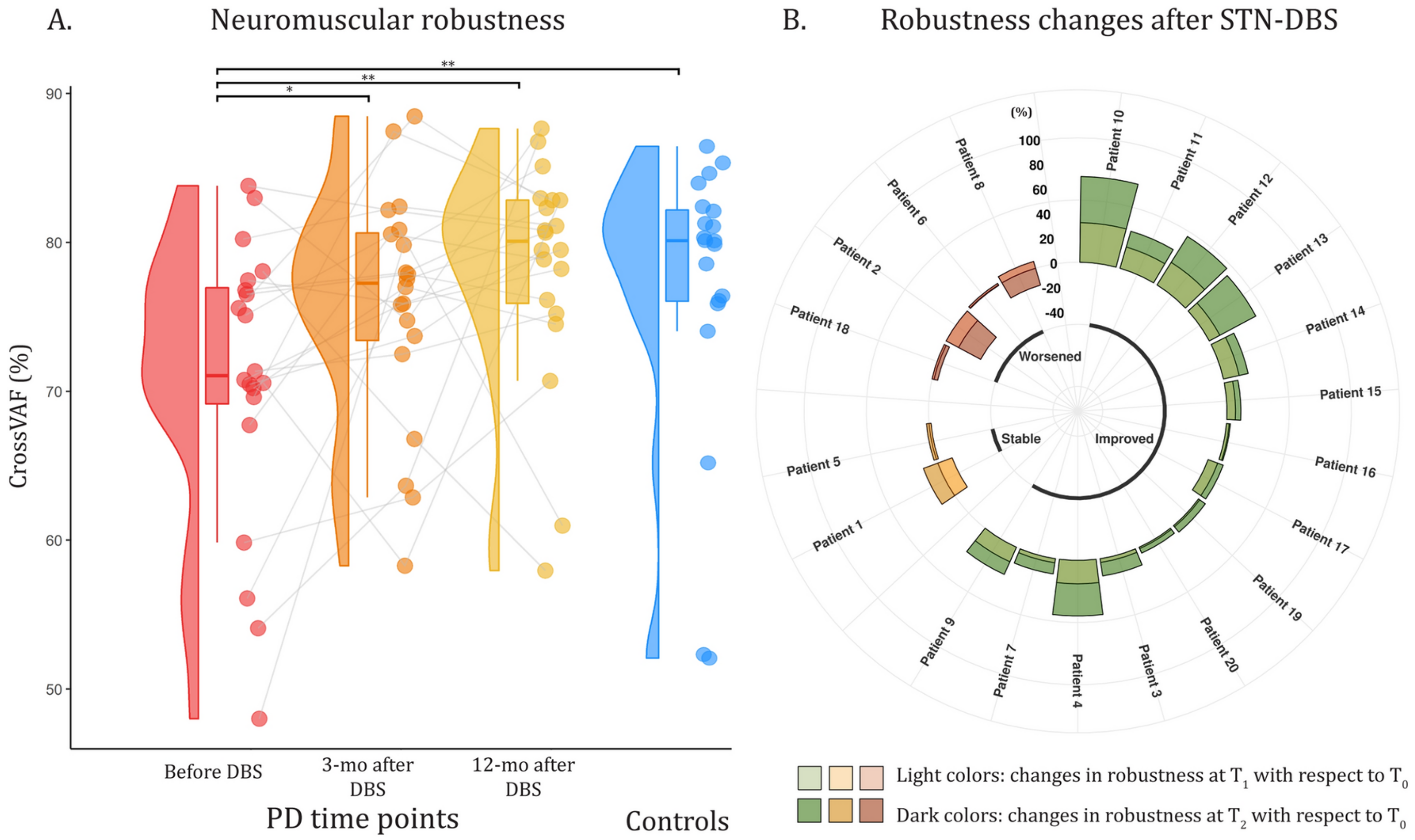
Effects of bilateral Deep Brain Stimulation



M., Ghislieri et al. "Muscle synergies in Parkinson's disease before and after the deep brain stimulation of the bilateral subthalamic nucleus" in Sci Rep (2023). Doi: 10.1038/s41598-023-34151-6.

Muscle synergies in clinics

Effects of bilateral Deep Brain Stimulation



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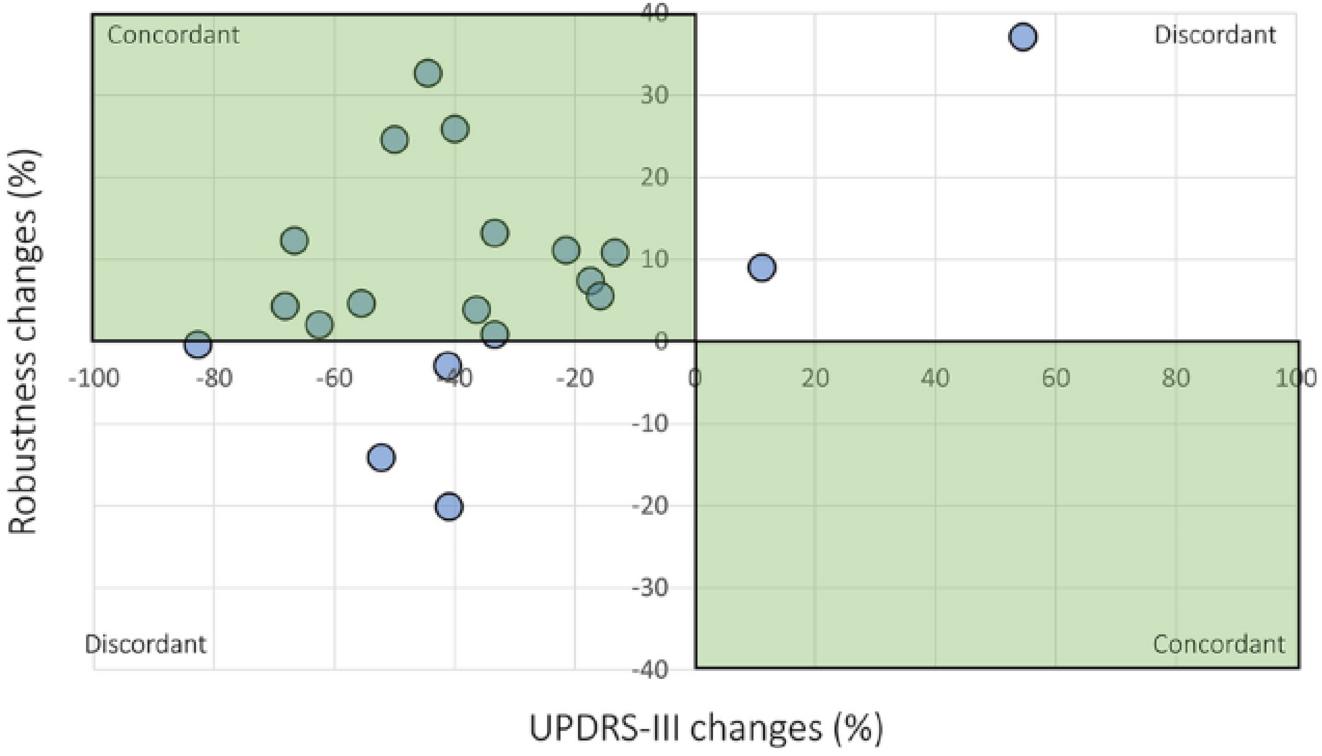
Muscle synergies in clinics

Effects of bilateral Deep Brain Stimulation

Concordance with clinical score

The relative robustness changes at 12 months after DBS with respect to baseline are represented (T_2–T_0).

The **quadrants showing concordance** are highlighted in green.



M., Ghislieri et al. "Muscle synergies in Parkinson's disease before and after the deep brain stimulation of the bilateral subthalamic nucleus" in Sci Rep (2023). Doi: 10.1038/s41598-023-34151-6.

Muscle synergies in clinics

Effects of bilateral Deep Brain Stimulation

- Results revealed a significant **improvement in the neuromuscular robustness** in the locomotion of PD patients, already at 3 months (T_1) and even more clearly at 12 months (T_2) after DBS, compared to PD patients before DBS (T_0).
- From the clinical point of view, an enhanced robustness, that can be read as a **higher intra-subject locomotion regularity**, can be hypothesized to have an impact in **decreasing the fall risk of PD patients**.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Muscle synergies in Parkinson's disease before and after the deep brain stimulation of the bilateral subthalamic nucleus

Marco Ghislieri, Michele Lanotte, Marco Knaflitz, Laura Rizzi & Valentina Agostini

Scientific Reports **13**, Article number: 6997 (2023) | Cite this article

M., Ghislieri et al. "Muscle synergies in Parkinson's disease before and after the deep brain stimulation of the bilateral subthalamic nucleus" in Sci Rep (2023). Doi: 10.1038/s41598-023-34151-6.

Effect of bilateral Deep Brain Stimulation

Is the study of motor control necessary in clinics?

Foot-switch signals alone can provide sufficient information?

Muscle synergies in clinics

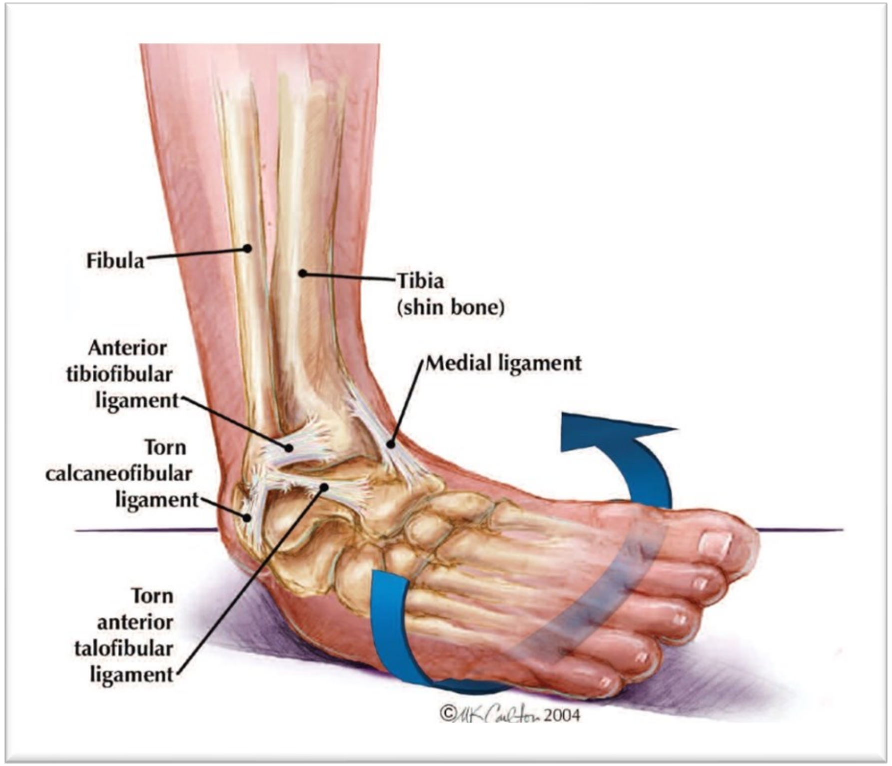
Chronic Ankle Instability (CAI)

POLITO BIOMEDLAB

SERVIZIO SANITARIO REGIONALE
EMILIA - ROMAGNA
Istituto Ortopedico Rizzoli di Bologna
Istituto di Ricovero e Cura a Carattere Scientifico

Lateral ankle sprain, characterized by **hyper-supination and hyper-inversion of the foot**, is one of the most common **musculoskeletal injuries that can happen during sport or activity of the daily living**. Individuals involved in the first episode of ankle sprain frequently undergo further injuries, developing **CAI**.

CAI is a condition characterized by **recurrent ankle sprain episodes** or **perception of ankle giving-way**, accompanied by a reduced ROM and self-reported function, weakness, and pain, that can persist for more than 1 year after the first ankle sprain episode. The persistence of ankle instability may also lead, in the long term, to joint degenerative pathologies, such as osteoarthritis.



Ankle sprain

Labanca L. et al. "Muscle activations during functional tasks in individuals with chronic ankle instability: a systematic review of electromyographical studies" in Gait & Posture (2021). Doi:10.1016/j.gaitpost.2021.09.182.

Muscle synergies in clinics

Genesis of Chronic Ankle Instability (CAI)

- **MECHANICAL**: the first episode of lateral ankle sprain causes **damage to the structures of the lateral foot-ankle complex** including ligaments, nerves, tendons, and muscles, which in turn leads to a **mechanical increase of the ankle joint laxity**.
- **NEURAL**: several neural factors have been identified in individuals suffering from CAI. **Spinal and supraspinal alterations** which persist over time cause **maladaptation in the control of movement**. During the performance of balance challenging tasks, individuals suffering from CAI also show a proximal muscle excitation strategy.

Labanca L. et al. "Muscle activations during functional tasks in individuals with chronic ankle instability: a systematic review of electromyographical studies" in Gait & Posture (2021). Doi:10.1016/j.gaitpost.2021.09.182.

Muscle synergies in clinics

How to assess Chronic Ankle Instability (CAI)

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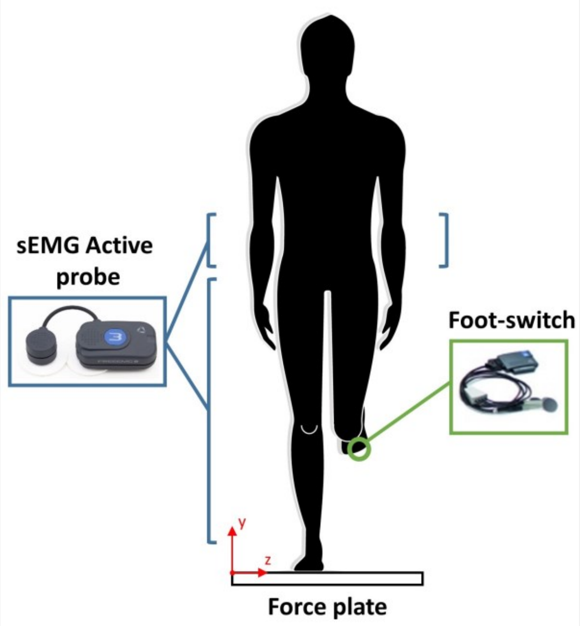
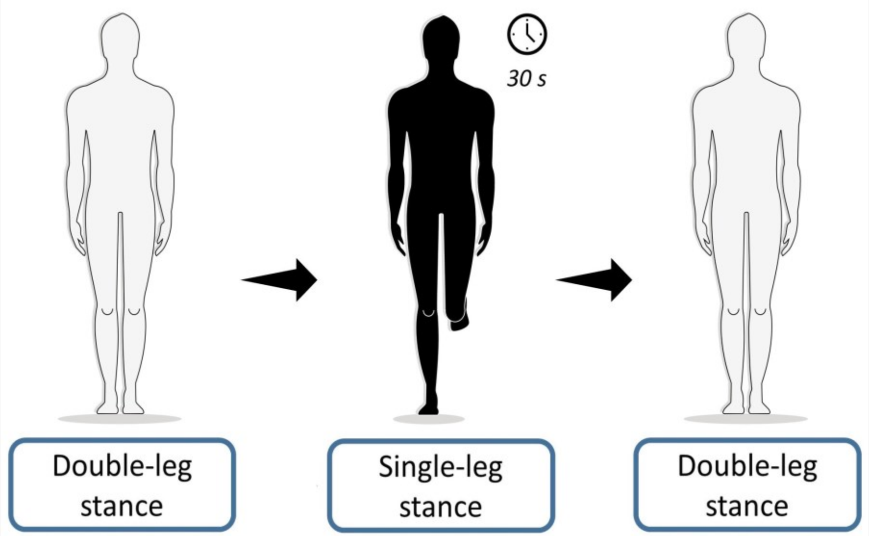
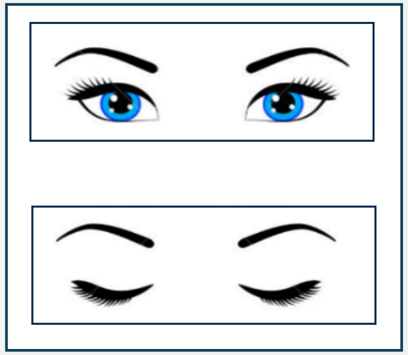
PROTOCOL





× 2 randomized conditions:



Ghislieri M. et al. "Muscle Synergy Assessment During Single-Leg Stance" in *IEEE Transactions on Neural Systems and Rehabilitation Engineering* (2020). Doi:10.1109/TNSRE.2020.3030847.

Ghislieri M. et al. "Balance and Muscle Synergies During a Single-Limb Stance Task in Individuals With Chronic Ankle Instability" in *IEEE Transactions on Neural Systems and Rehabilitation Engineering* (2023). Doi:10.1109/TNSRE.2023.3328933.

Muscle synergies in clinics

How to assess Chronic Ankle Instability (CAI)

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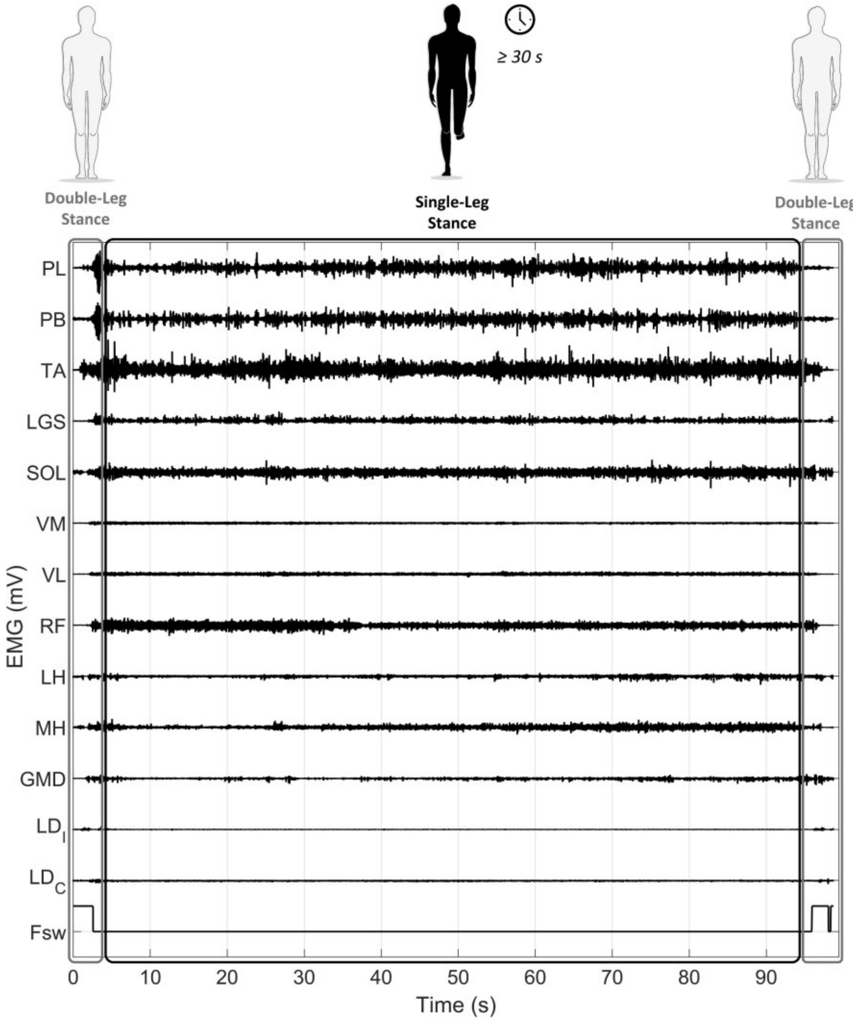
- **Population**: 20 CAI patients and 20 controls.
- **Experimental protocol**: each individual tried to maintain SLS balance, for at least 30 s, while standing on a force platform with their injured (CAI) or dominant (control) lower limb.
- **Acquisition system**: **sEMG signals** were acquired from **13 lower-limb and trunk muscles**. A **foot-switch signal** was acquired from the limb that it is raised from floor during the balance task.



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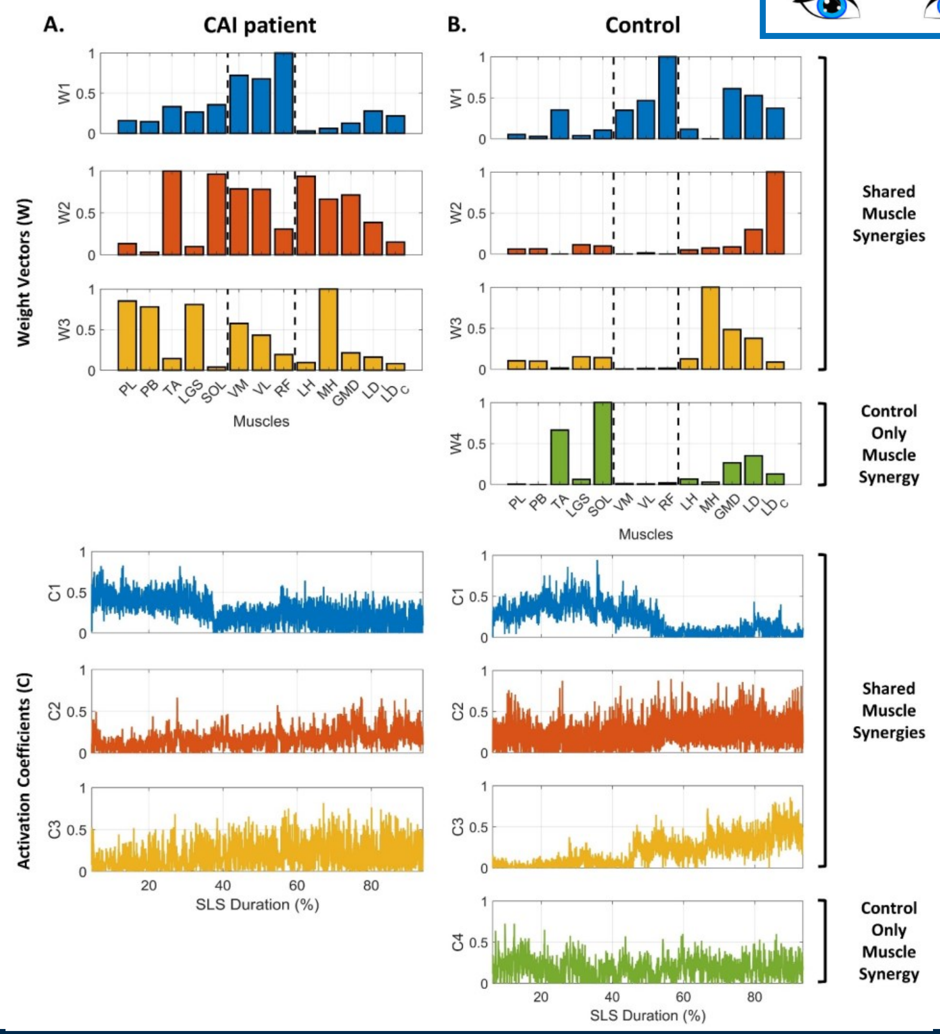
Muscle synergies extracted from a CAI patient and healthy control

The CAI patient expresses:

- A **smaller number of synergies** (3 instead of 4), with respect to the control subject
- A **higher degree of muscle co-activation** in each of the shared muscle synergies (both in terms of the number of muscles involved in each synergy and their weight).



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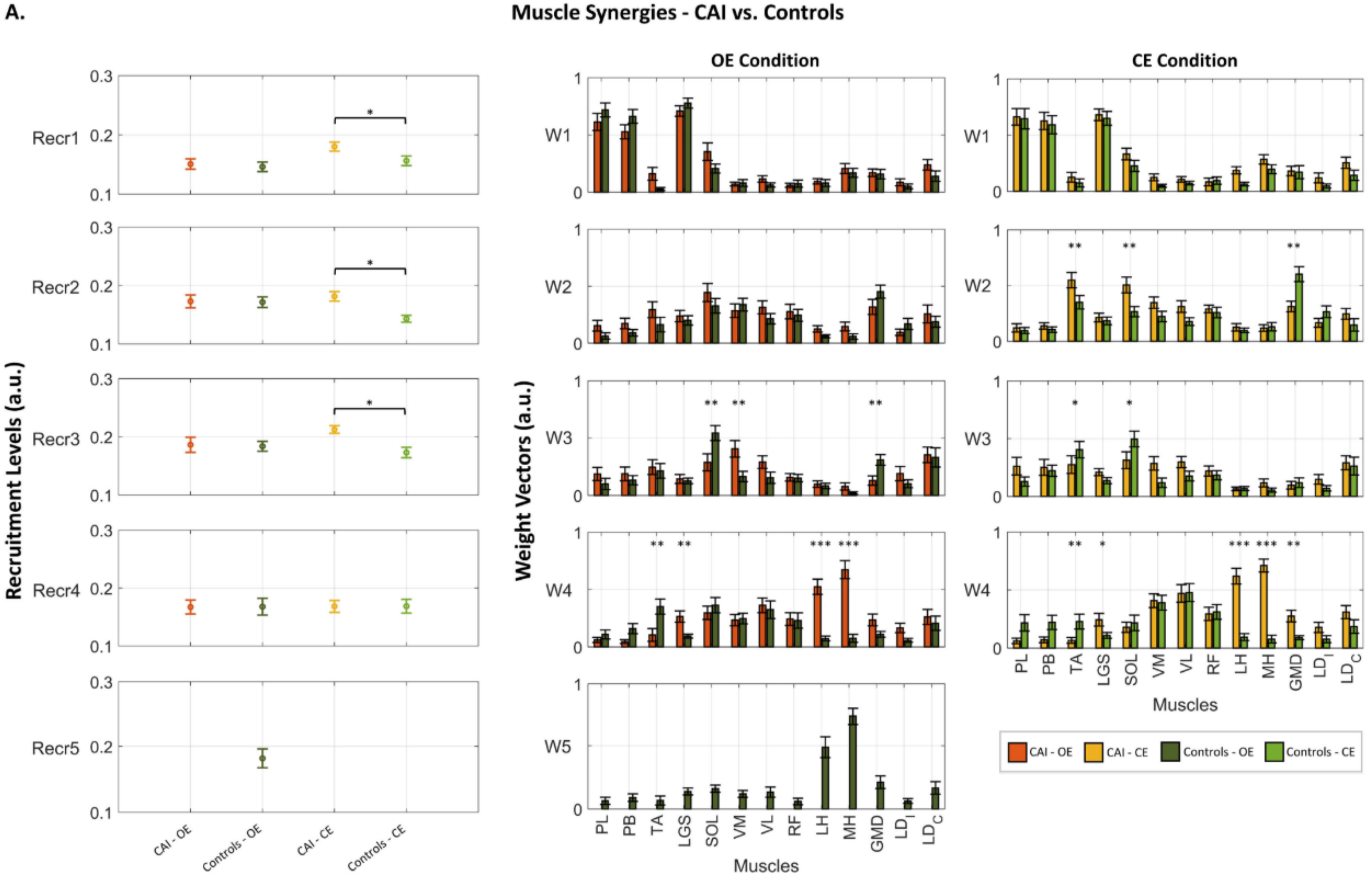

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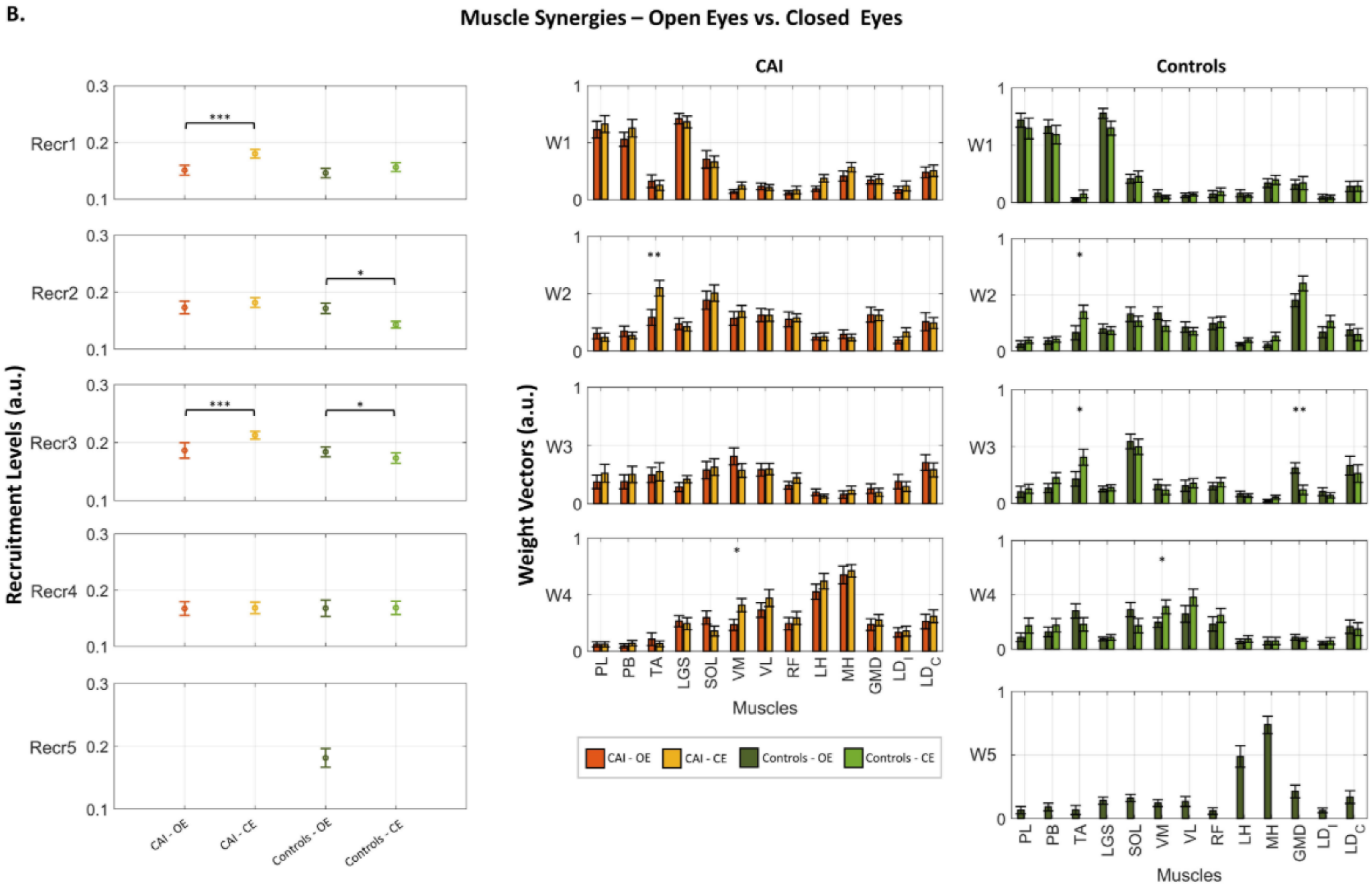

Single-Leg Stance Duration

Chronic Ankle Instability (CAI)

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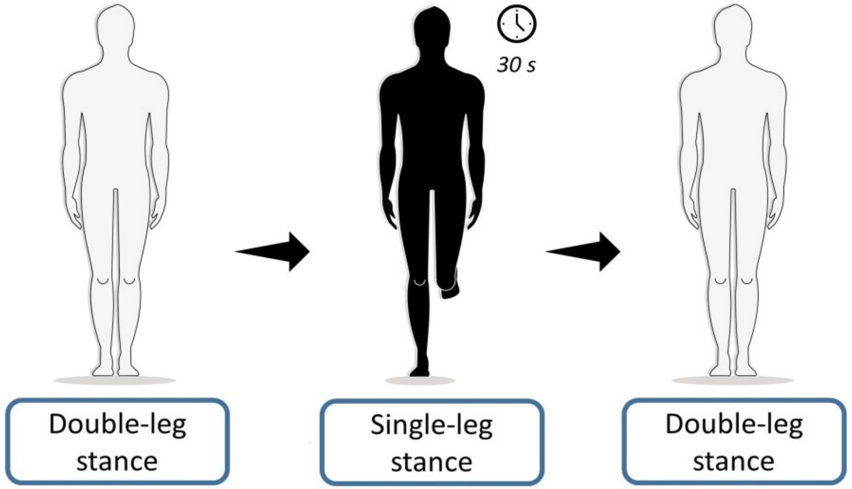
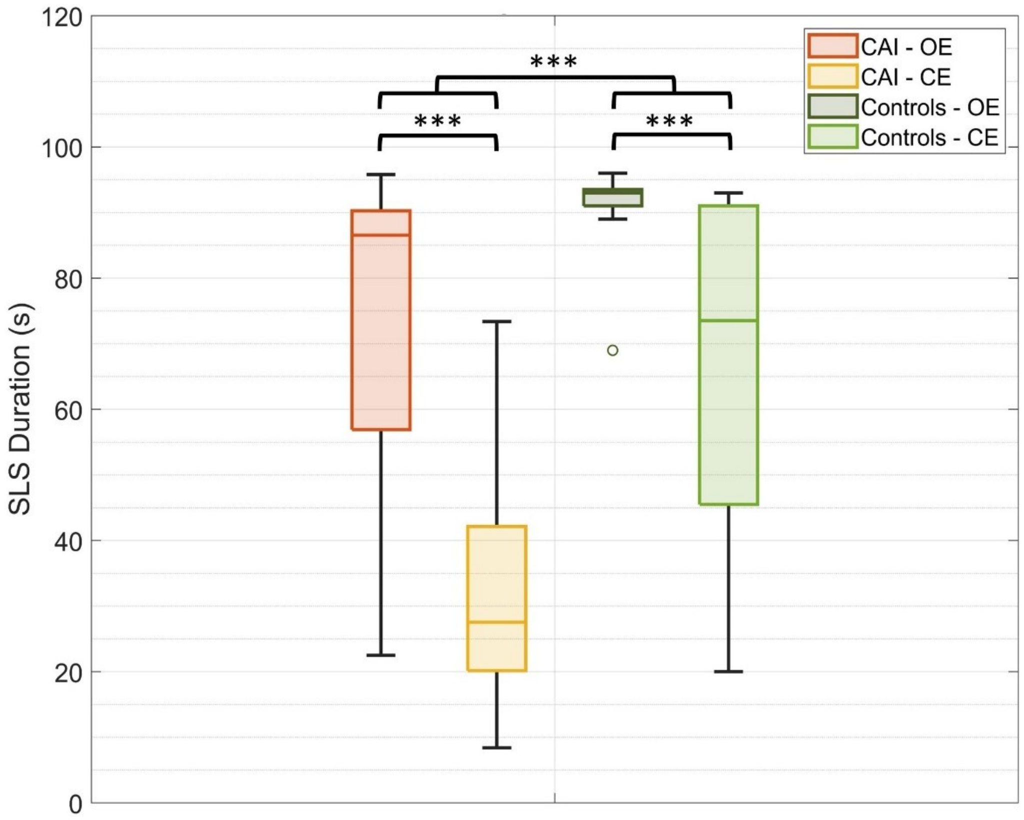


We used foot-switch measurements, but a simple stopwatch can be used…



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Single-Leg Stance Duration

Chronic Ankle Instability (CAI)

Is the study of motor control necessary in clinics?

Traditional balance measurements alone can provide sufficient information?

Conclusions

- Digital biomarkers obtainable in a simple and direct way from instrumental gait analysis (e.g. atypical cycles), or posture (e.g. duration of the monopodalic support) are powerful tools and very sensitive to appreciate even the smallest functional alterations, and are easy to use in clinical practice.
- The study of muscle synergies is a useful investigation tool to obtain digital biomarkers closely related to the patient's neuromotor control, where a thorough assessment of the neural component is required. (Ex: Evaluation of the effect of deep brain stimulation on the motor control of Parkinson's disease patients, and study of motor control in chronic ankle instability).

¡Muchas gracias por vuestra atención!

¿Preguntas?

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