Università degli Studi di Napoli Federico II

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DIETI UNINA

Michela Russo

Human Movement Analysis & Artificial Intelligence for the assessment of Neurodegenerative Diseases

Tutor: Prof.ssa Maria Romano

Cycle: XXXVII Year: Third

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Candidate's information

- MSc degree in Biomedical Engineering (University of Naples, Federico II)
- DIETI Research group of Biomedical Engineering (Coord. Prof. Amato Francesco)
- PhD date 01/11/2021– 31/10/2024
- I had a university fellowship until August 16, 2024, and afterward, I obtained a PNRR fellowship under the project "A window into the mind-brain-body interplay; development of diagnostic, prognostic biomarkers and rehabilitation strategies in functional motor disorders" at AOU San Giovanni di Dio e Ruggi d'Aragona, Salerno, Italy.
- In collaboration with Department of Neurological Rehabilitation of AOU San Giovanni di Dio e Ruggi d'Aragona, Salerno, Italy.
- Visiting student at Institute of Biomedical Engineering at Karlsruhe Institute of Technology (Germany) – from 8° September to 16° December 2023, tutor Prof. Maria Francesca Spadea.

Karlsruher Institut für Technologie

Summary of study activities (1/2)

- **Ad hoc courses**

- Ultra-High Field Magnetic Resonance Imaging
- ***Statistical Data Analysis for Science and Engineering***
- ***Big Data Architecture & Analytics***
- ***Data Science for Patient Records Analysis***
- Imprenditorialità accademica
- ***Machine Learning for Science and Engineering Research***
- Muscle-based Human
- ***On the challenges and impact of Artificial Intelligence in the insure domain***
- ***Using deep learning properly***
- From Virtual histology to neural science
- Strategic orientation for stem research & writing
- ***Statistics for clinical studies and biomedical engineering*** (at Karlsruhe Institute of Technology, Germany)

- **PhD school**

Neurotechnologies to understand and restore the nervous system *– Gruppo Nazionale di Bioingegneria (GNB), Bressanone, Italy.*

Summary of study activities (2/2)

- **Conferences**

  - 22° Annual Conference of Società italiana di Analisi del Movimento in Clinica (SIAMOC); 5-8 October 2022, Bari.
  - IEEE International Conference On Metrology For Extended Reality, Artificial Intelligence And Neural Engineering (2022IEEEMetroXRAINE); 26-28 October 2022, Rome.
  - IEEE International conference on Metrology for Extended Reality, Artificial Intelligence And Neural Engineering (2023IEEEMetroXRAINE); 24-27 October 2023, Milan.
  - IEEE International conference on Metrology for Extended Reality, Artificial Intelligence And Neural Engineering (2024IEEEMetroXRAINE); 21-23 October 2024, Saint Albans, London.

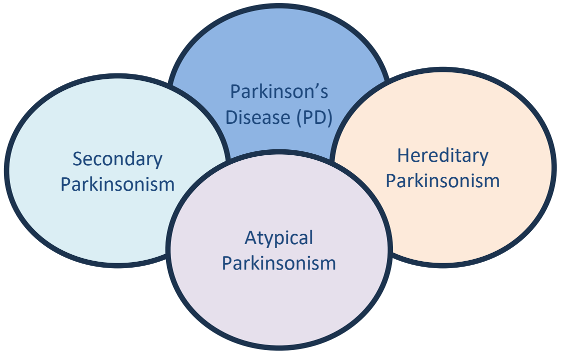
- **Organizer of a Scientific Special Session**

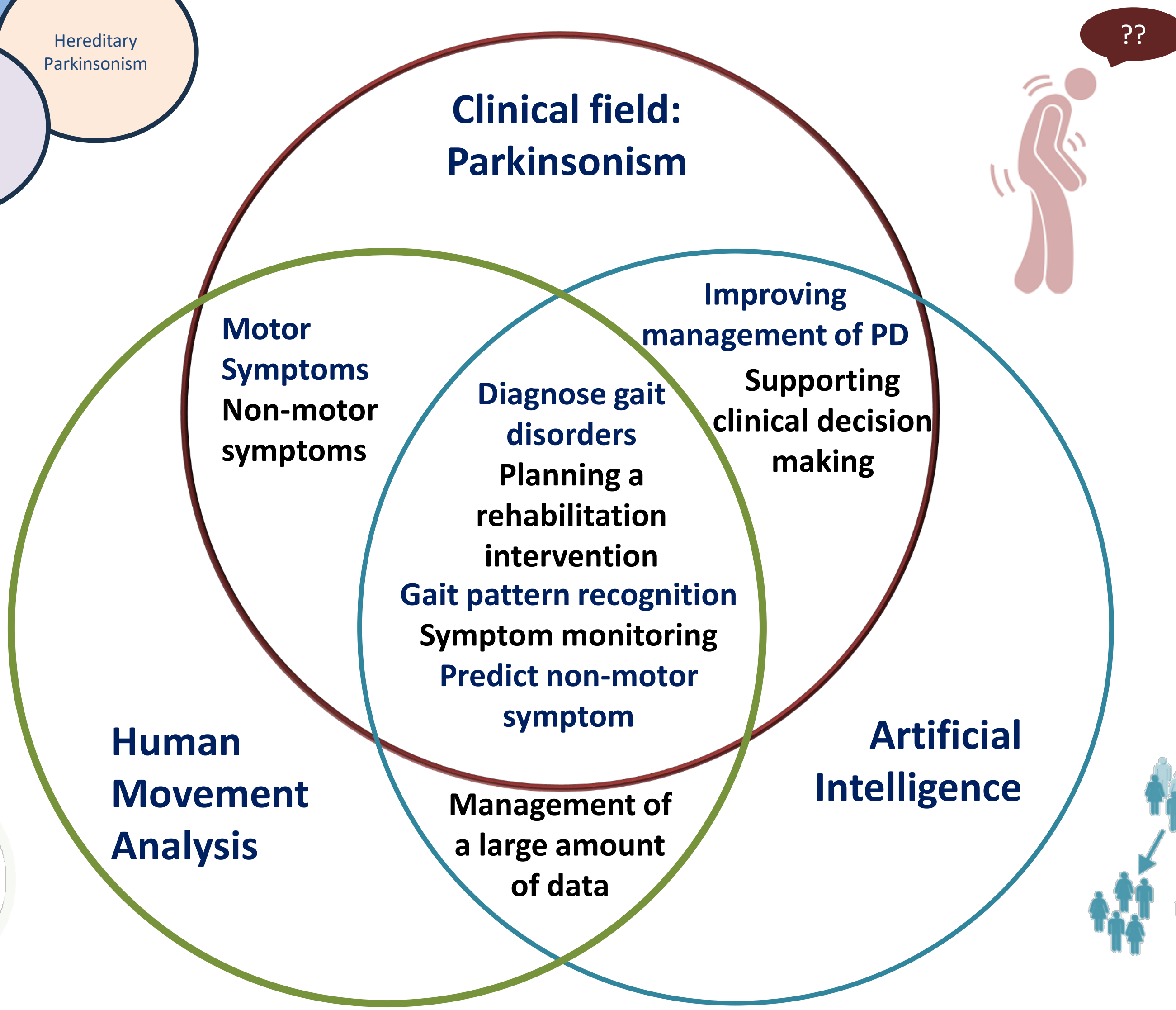
  - Simulation approaches and Artificial Intelligence for healthcare and biomedical engineering, 2023IEEEMetroXRAINE Conference.

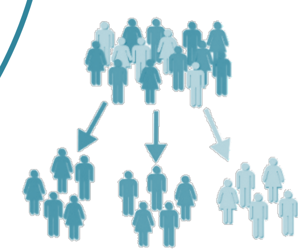
- **Award**

  - The best performance of classification on EEG datasets acquired through the Helmate headset provided by AB MEDICA, Neural Data Processing Contest, 2022IEEEMetroXRAINE Conference

Research area







Research results

Human Movement Analysis & Artificial Intelligence allow:

- ✓ *Differentiation of Motor Patterns: Distinguishing motor patterns in Parkinsonian subjects with mild cognitive disturbances, enabling differentiation from those without cognitive impairments.*

- ✓ Impact of Freezing of Gait (FOG): Analyzing the impact of FOG between Parkinsonian individuals affected by this motor symptom and those who are not, highlighting the influence of specific symptoms on movement dynamics.

- ✓ Kinematic Characterization of Camptocormia: Characterizing the kinematic patterns of a population of Parkinsonian patients with camptocormia, contributing to fall prediction and prevention strategies.

- ✓ *Postural Control: Using a 5-second sway test to effectively distinguish between typical and atypical forms of parkinsonism in the early stages of the disease.*

- ✓ *Wearable Sensor Analysis: Conducting movement analysis using wearable sensors to describe distinct patterns in patients with atypical forms of parkinsonism, performed in a more comfortable clinical setting.*

- ✓ Markerless Systems for Kinematic Analysis: Utilizing markerless systems to calculate kinematics from video recordings without the need for specialized personnel for sensor placement, facilitating assessments in outdoor environments.

Research products

[P1]	**Russo, M.**, Amboni, M., Volzone, A., Cuoco, S., Camicioli, R., Di Filippo, F., & Ricciardi, C. **Kinematic and Kinetic Gait Features Associated With Mild Cognitive Impairment in Parkinson's Disease**, *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* Volume (32), 2676-2687, 2024, DOI 10.1109/TNSRE.2024.3431234
[P2]	Franco, A*., **Russo, M*.**, Amboni, M., Ponsiglione, A. M., Di Filippo, F., Romano, M., & Ricciardi, C. *These authors contributed equally to this work **The Role of Deep Learning and Gait Analysis in Parkinson's Disease: A Systematic Review,** *MDPI Sensors, 24(18), 5957*,2024, DOI: https://doi.org/10.3390/s24185957
[P3]	Clemente, F., Amato, F., Adamo, S., **Russo, M.**, Angelone, F., Ponsiglione, A. M., & Romano, M. **Circuital modelling in muscle tissue impedance measurements**, *Heliyon*, *10*(7), 2024, DOI: https://doi.org/10.1016/j.heliyon.2024.e28723
[P4]	Abate, F., **Russo, M.**, Ricciardi, C., Tepedino, M. F., Romano, M., Erro, R., & Picillo, M. **Wearable sensors for assessing disease severity and progression in Progressive Supranuclear Palsy,** *Parkinsonism & Related Disorders,* 109, 105345, 2023, DOI: https://doi.org/10.1016/j.parkreldis.2023.105345
[P5]	**Russo, M**.; Amboni, M.; Barone, P.; Pellecchia, M.T.; Romano, M.; Ricciardi, C.; Amato, F.. **Identification of a Gait Pattern for Detecting Mild Cognitive Impairment in Parkinson's Disease** *Sensors,* DOI: **https://doi.org/10.3390/s23041985**
[P6]	**Russo, M.**, Amboni, M., Volzone, A., Ricciardelli G., Cesarelli G., Ponsiglione, A.M., Barone, P., Romano, M.,, Ricciardi C.. **Interplay between gait and neuropsychiatric symptoms in Parkinson's Disease;** Eur J Transl Myol; 2022 Jun. DOI:10.4081/ejtm.2022.10463
[P7]	Cuoco, S; **Russo, M**; Ricciardi, C; D'Arco, B; Sorrentino, C; Cappiello, A; Romano, M; Amato, Fr; Aiello, M; Erro, R; Amboni, M; Barone, P. **Fist Palm Test may identify mild cognitive impairment and freezing of gait in Parkinson's disease: A Machine Learning approach** *Movement Disorders* Status: Under review

Research products

[P8]	**Russo, M**.; Amboni, M.; Pisani, N.; Calderone D.; Barone, P.; Amato, F,; Ricciardi, C.; Romano, M. **Biomechanics parameters of gait analysis to characterize Parkinson's disease: a systematic review** Status: To be submitted
[P9]	Amboni, M.,Di Filippo, F.,De Biasi, G., **Russo, M.,** Ricciardi, C., Pisani, N.,Volzone,A., Cuoco, S., Calabrese, M., Romano, M., Barone, P., Aiello, M. **Dual-task-related Gait Patterns As Possible Marker Of Precocious And Subclinical Cognitive Alterations in Parkinson Disease** *Scientific Report* Status: Under review
[C1]	**Russo, M.,** Mestizia, M ., Amboni, M ., Di Filippo, F ., Pisani, N ., De Marca, U., Capuano, R., Di Gregorio, M ., Romano, M ., Amato, F ., Ricciardi, C **Subclinical Gait Differences in Multiple Sclerosis with mild disability: Spatiotemporal Analysis During Single and Dual Task,** *12th International Conference on E-Health and Bioengineering - EHB 2024*
[C2]	**Russo, M.,** Pisani, N., Ricciardelli, G., Volzone, A., Romano, M., Barone, P., Amboni, M., Ponsiglione, A.M., Ricciardi, C. **Quantitative Measures of Gait Kinematics in Camptocormia Parkinson's Disease,** *2024 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE)*
[C3]	Pisani, N., **Russo, M.,** Calabrese, M.C., Di Filippo, F., Cesarelli, G., Barone, P., Ricciardi, C., Amboni, M., Amato, F. **Measurements of Postural Sway to Classify Freezing of Gait in Parkinson's Disease,** *2024 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE)*
[C4]	Pisani, N., **Russo, M.**, Abate, F., Avallone, A.R., Amato, F., Barone, P., Ricciardi, C., Cesarelli, M. **Unsupervised Machine Learning Approach to Discover Subtypes of Progressive Supranuclear Palsy,** *2024 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE)* .
[C5]	**Russo, M.;** Ricciardi C.; Amboni, M.; Volzone A.; Barone, P.; Romano, M.; Amato, F. **A cluster analysis for Parkinson's Disease phenotyping with gait parameters** *2023 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE), DOI:* 10.1109/MetroXRAINE58569.2023.10405572
[C6]	**Russo, M**., Ricciardi, C., Amboni, M., Picillo, M., Ricciardelli, G., Abate, F., Romano, M. **Performing a short sway to distinguish Parkinsonisms,** *2022 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering* (MetroXRAINE) (pp. 340-345), IEEE, 2022, DOI:10.1109/MetroXRAINE54828.2022.9967668.

PhD thesis overview

Problem statement

- The key issue is the heterogeneity of Parkinsonism and lack of objective and quantitative assessment methods for evaluating gait and postural control in patients with Parkinsonism.
  - Current clinical evaluations rely heavily on subjective measures, limiting the precision in diagnosing and tracking disease progression.

Objective

- The objective of the study is to conduct a detailed analysis of human movement and posture using quantitative parameters, specifically sway, spatio-temporal, kinematic, and kinetic parameters.
  - These parameters aim to consider human movement as potential indicator to support the prediction of motor and cognitive impairments.
  - Using gait parameters as input of AI approaches to support clinical decision-making and improve the quality of life of Parkinsonian patients.

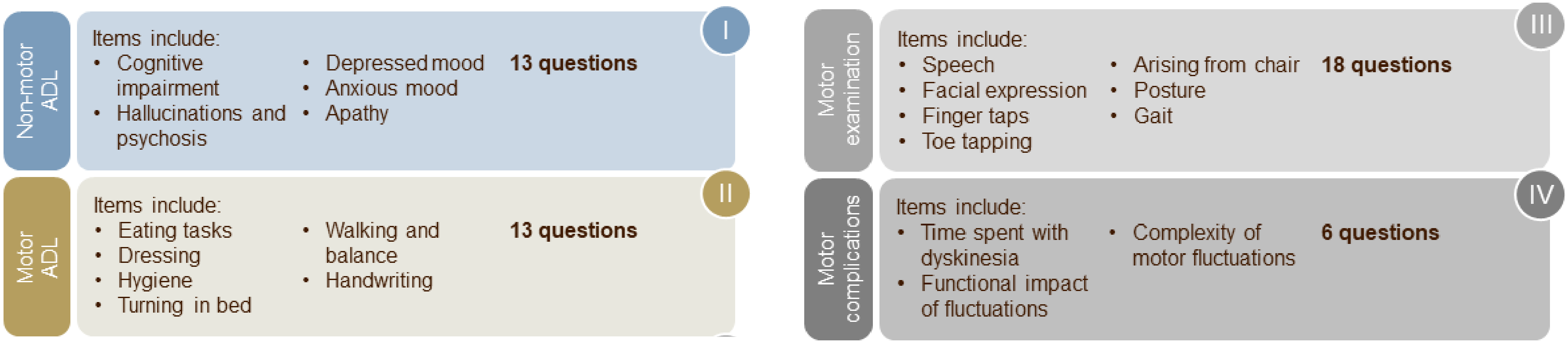
Methodology

- Different tool for human movement analysis:
  - Motion capture, wearable sensors, markerless system to collect detailed sway and gait data.
  - Investigation of indoor and outdoor clinical-setting.
- AI techniques employed to process the data:
  - Machine Learning for classification, prediction and clustering of movement patterns.

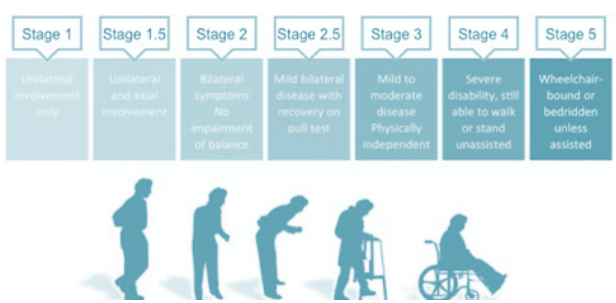
Clinical Qualitative Assessment

In the current clinical practice, the assessment of the motor symptoms of Parkinsonism is conducted using clinical rating scale, typically performed by a neurologist.

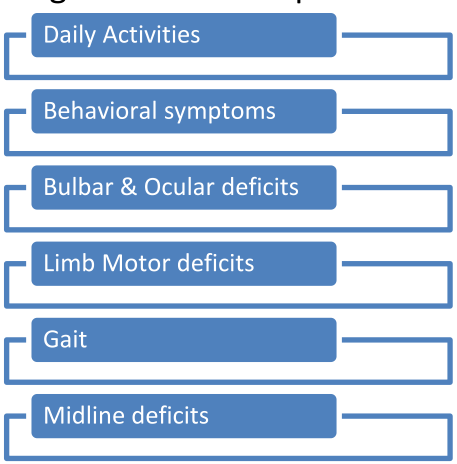
- ❑ Unified Parkinson's Disease Rating Scale (MDS-UPDRS) for defining the severity of disease



- ❑ Hoehn & Yahr (H&Y) rating scale for the progression of motor symptoms



- ❑ Progressive Supranuclear Palsy - Rating Scale (PSP-RS) for assessing deficits in PSP patients



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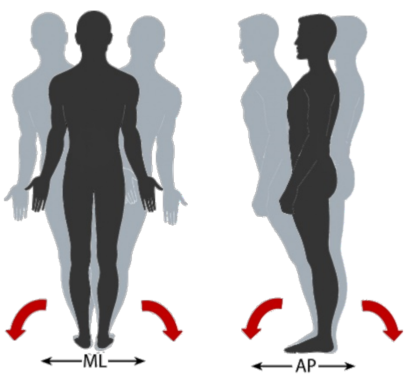
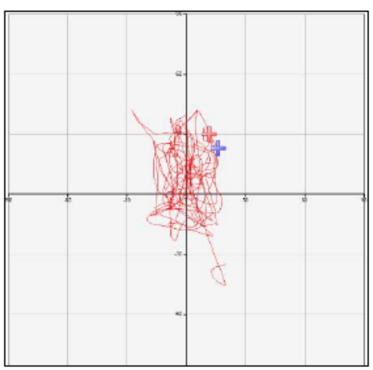
Quantitative Assessment

Human Movement Analysis is the study of human motion, which includes postural control and gait analysis. It focuses on balance and body stability in both static and dynamic conditions (**postural control**) and assesses locomotion by measuring biomechanical and kinematic parameters during walking (**gait analysis**).

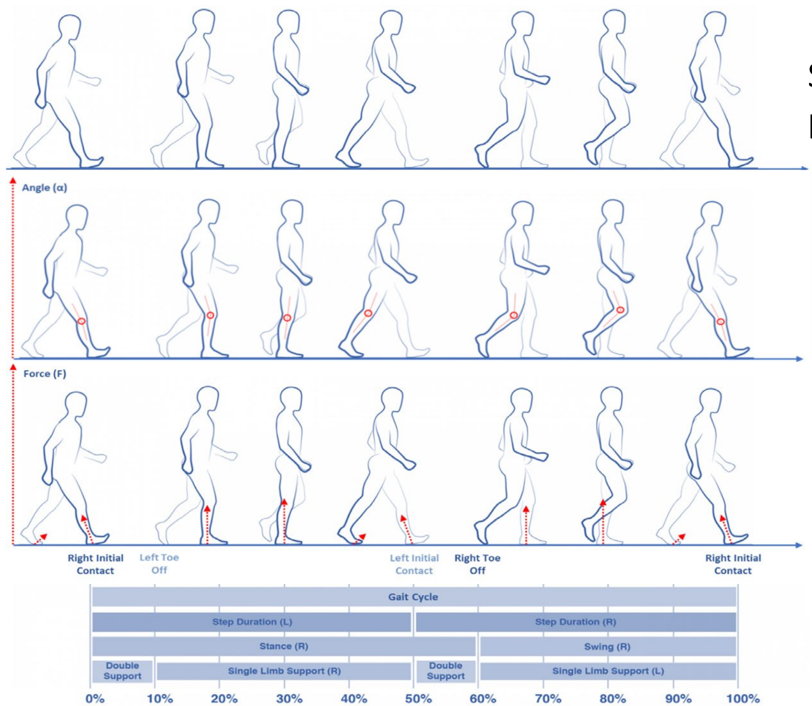
Postural Control



Sway parameters



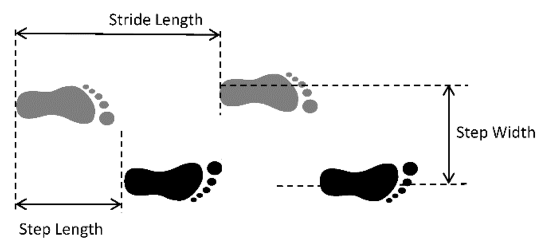
Gait Analysis



Spatial-temporal parameters

Kinematic parameters

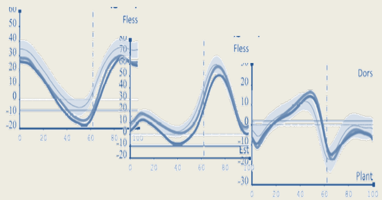
Kinetic parameters



Machine Learning

Supervised Learning

- A labelled dataset is provided
- Learning is task-driven
- Algorithm trains to improve outcome over time

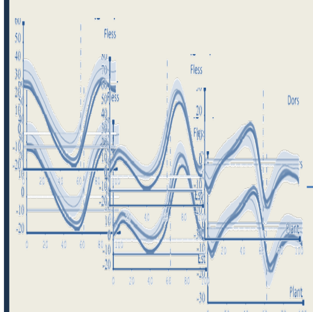


Training dataset in which known pathological features are labelled

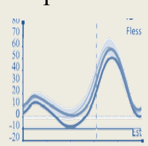
Train model to recognizing features

Evaluate model on test data

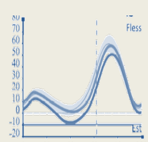
Apply model to unseen data



Output



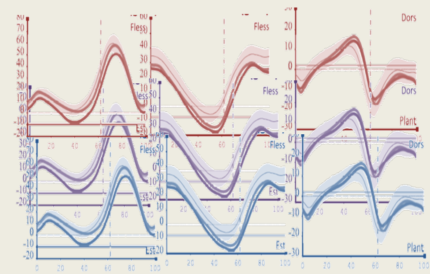
Diagnostic class 1



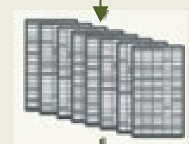
Diagnostic class 2

Unsupervised Learning

- No labelled dataset is provided and output s unknown
- Learning based on pattern identification and recognition



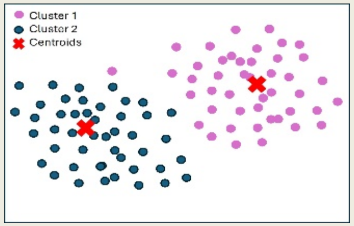
Heterogeneous patient population

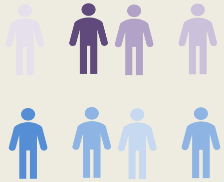


Multimodal Patient data

Unsupervised clustering on basis of gait, sway and clinical features

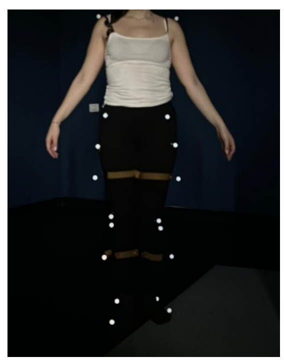
Patient subtypes





Motion Capture & Classification:
Exploring Links with Cognitive Impairment

Motion Capture – Optoeletronic System



Optoelectronic system is the Gold standard for the motion capture:

- Provides robust and precise acquisition of physical movements
- Allow to have detailed information of the subjects

Disadvantages : High cost of instrumentation

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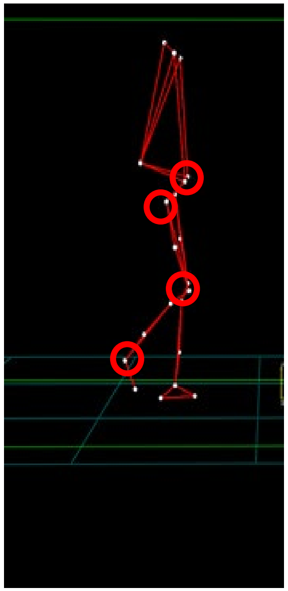
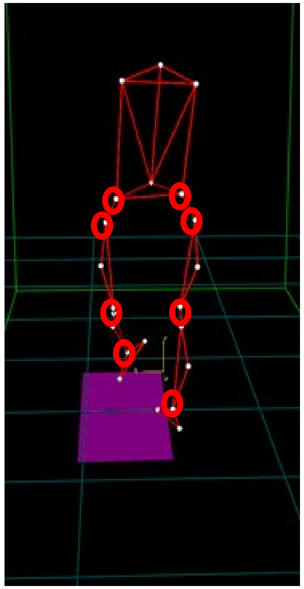
Motion Capture & Classification: Exploring Links with Cognitive Impairment



Sagittal View



Frontal View

- 90 PD patients (40 PD with Mild Cognitive Impairment (MCI) & 50 PD without MCI)
- Joints involved during the walking are:

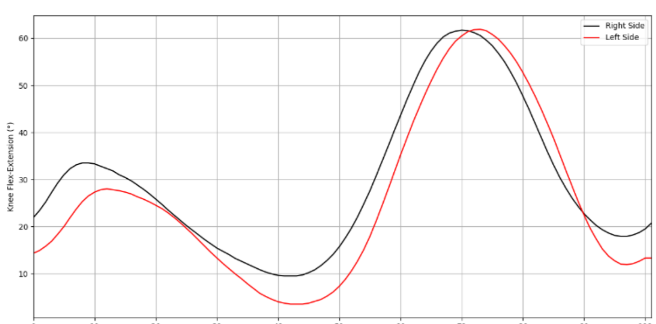
  Trunk, Pelvis, Hip, Knee, Ankle

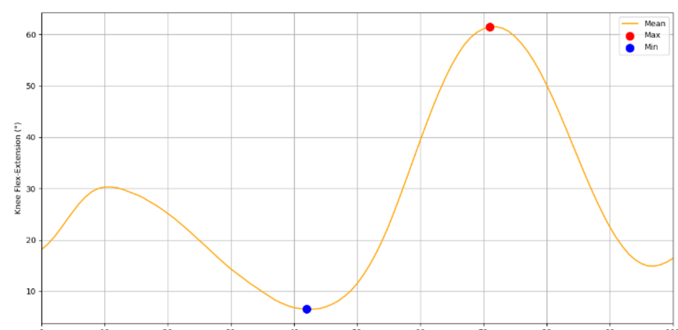
- Movements can be analysed across different anatomical planes:

  Sagittal plane: flexion and extension movements
  Frontal plane: abduction and adduction
  Transverse plane: rotation

- For each subject, the right and left signals for each movement were acquired, and the mean signal was calculated.
- Extraction of Kinematic & Kinetic Features:

  Max, Min & Range of motion (ROM)

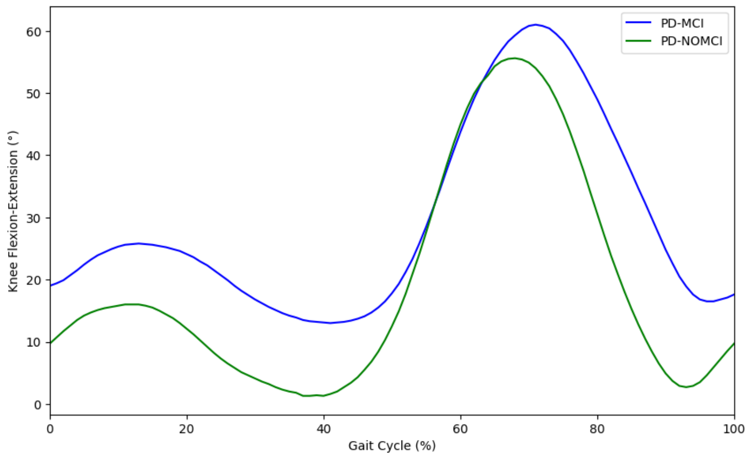


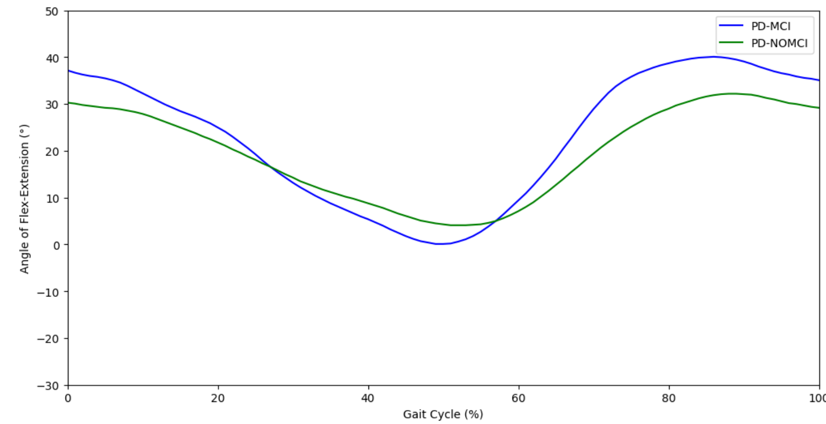


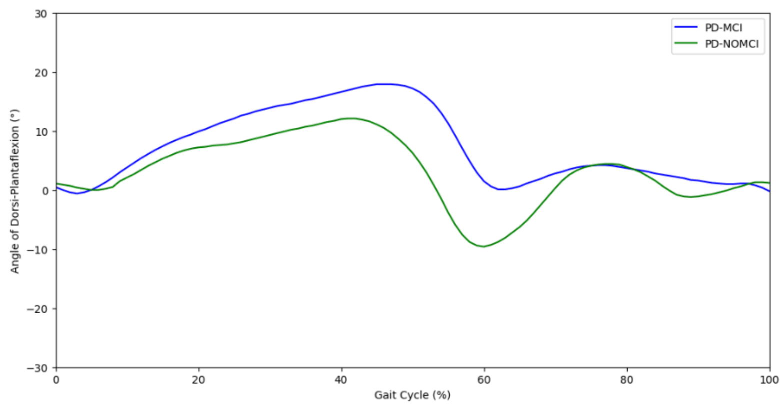
Motion Capture & Classification: Exploring Links with Cognitive Impairment

Kinematics between PD-MCI and PD-NOMCI. Mean differences in:

- Knee Flexion during mid-swing phase (about 70% of gait cycle)
- Knee Extension during stance phase (about 40% of gait cycle)
- Hip Flexion in initial contact (about 10% of gait cycle) and swing phase (about 80% of gait cycle)
- Ankle Dorsiflexion in single support phase







PD-MCI showed:

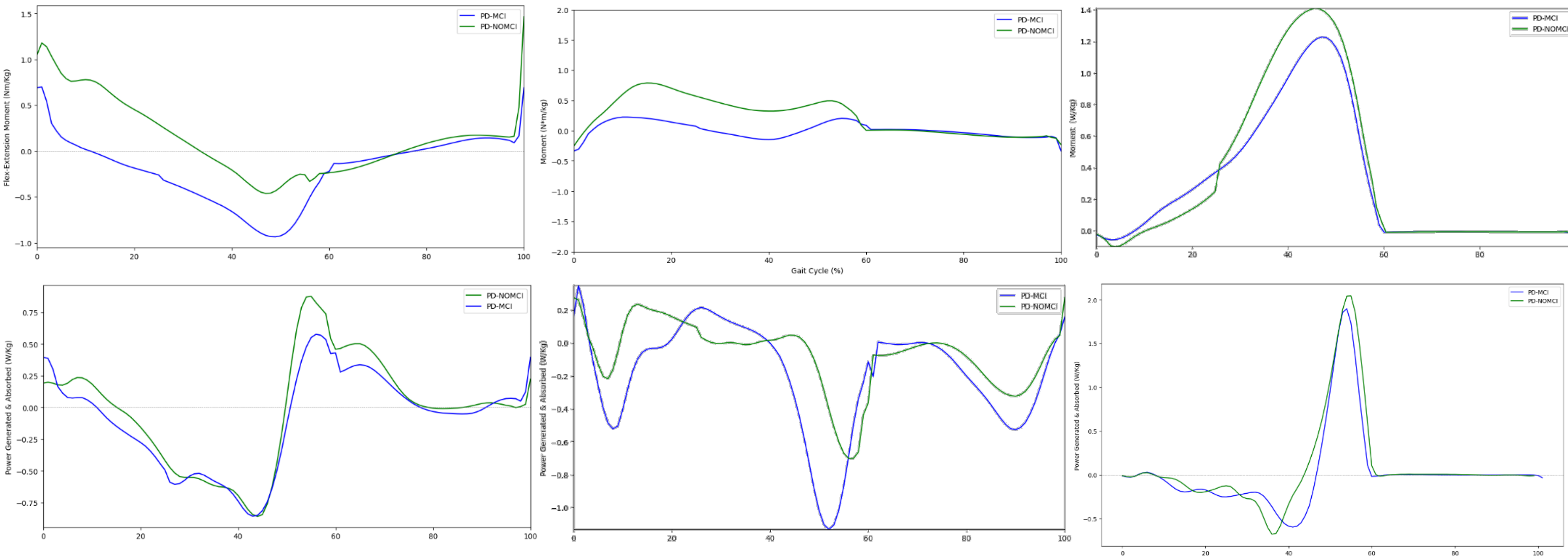
- Increased knee flexion and reduced knee extension
- Increased hip flexion
- Increased ankle dorsiflexion

These findings showed an increased sagittal flexion, suggesting that such features may represent the expression of a more malignant phenotype in which cognitive dysfunction coexists with more severe axial symptoms.

Motion Capture & Classification: Exploring Links with Cognitive Impairment

Kinetics between PD-MCI and PD-NOMCI. Mean differences in:

- Hip, knee and ankle Moment Flex-Extension
- Hip, knee and ankle Power Generated and absorbed



PD-MCI showed:

- Reduced hip flex-extension moment, power generated, and power absorbed
- Reduced knee extension moment and power absorbed
- Increased ankle moment at loading response and reduced power generated

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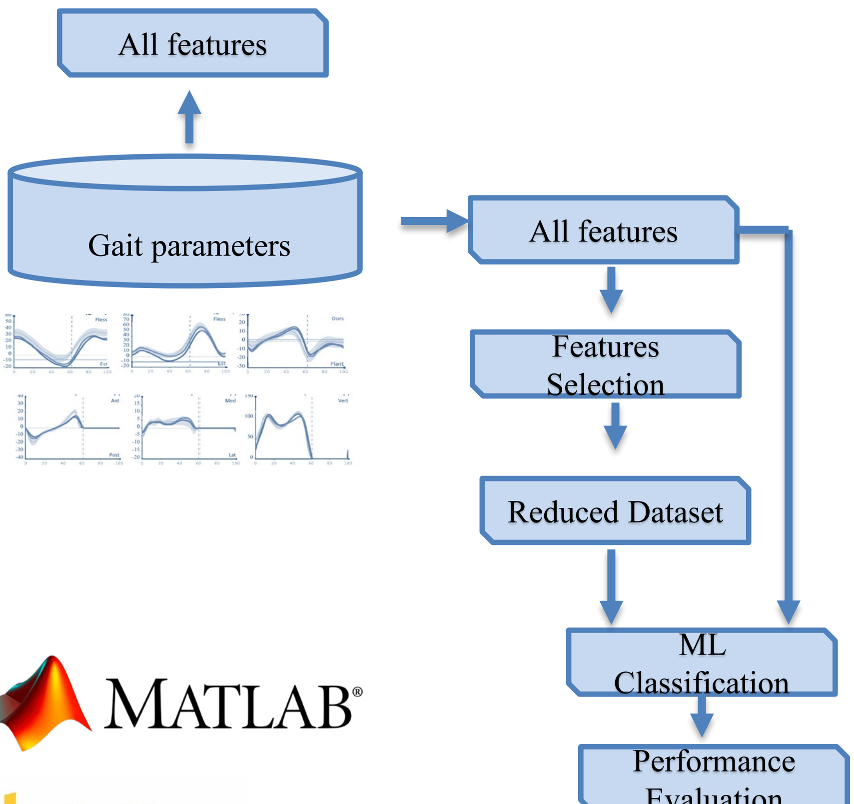
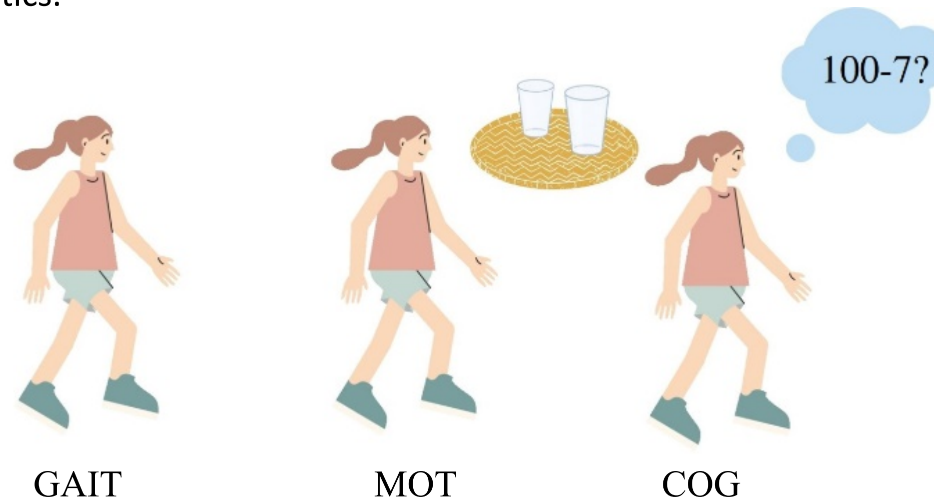
Motion Capture & Classification: Exploring Links with Cognitive Impairment

Kinematics and kinetics were evaluated during a single walking task, as well as during motor and cognitive dual tasks, to assess the influence of dual-task conditions.

The kinematics and kinetics data were provided separately as input to ML classifiers. Then, feature selection was performed to identify the best subset of kinematic and kinetic characteristics.





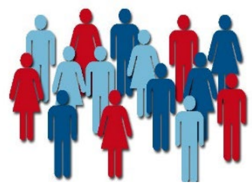
Findings suggest that kinematic patterns distinguishing PD-MCI mainly loaded on GAIT task, while ML classification based on kinetic parameters loaded on COG task variables.

Tree-based Classifiers showed the best results.

Unsupervised Machine Learning for phenotyping with Gait Parameters

Unsupervised Machine Learning for phenotyping with Gait Parameters

K-means techniques using a combination of spatiotemporal gait parameters to investigate the interaction between motor and non-motor aspects of PD, aiming to identify different henotypes and specific treatment strategies.



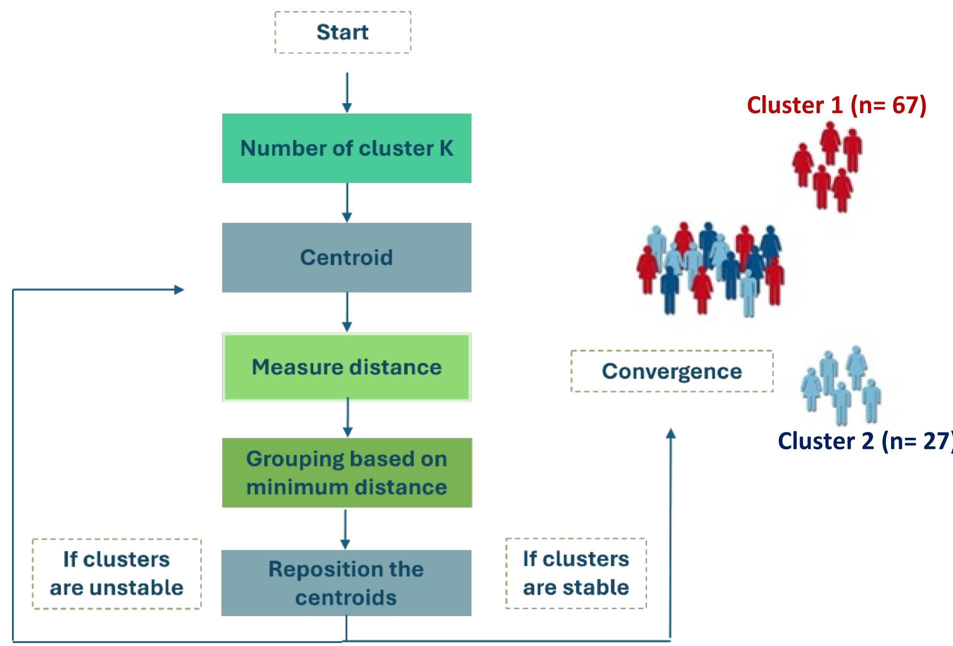
94 Subjects affected by PD

PD patients were in the stage ON of the levodopa daily dose

Task :
Single free walking at self-selected speed for 10m and for 4 times.

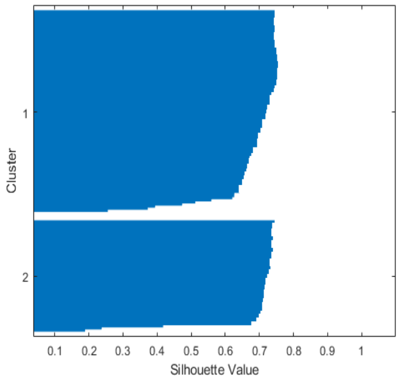
Data Elaboration:

- ❑ Average among 4 walks to increase data reliability
- ❑ Average between right and left limb gait signal
- ❑ Gait Features :
  16 spatial-temporal parameters

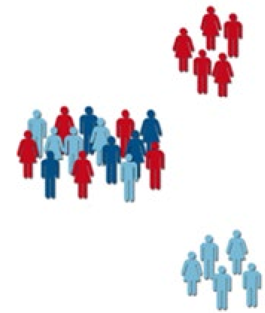


MATLAB®

Unsupervised Machine Learning for phenotyping with Gait Parameters

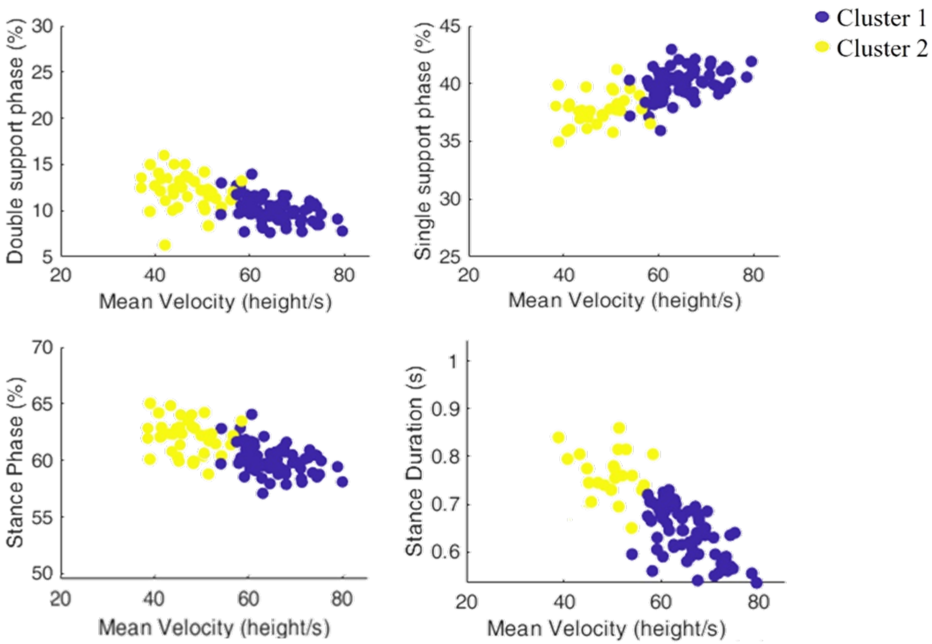


Silhouette coefficient number of clusters		
K=2	*K*=3	*K*=4
0,713	0,477	0,457



Cluster 1 (n= 67)

Cluster 2 (n= 27)



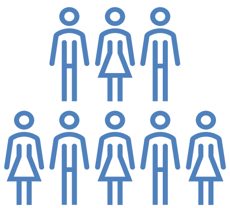
Clinical and demographic characteristics of PD patients belonging to Cluster 1 and Cluster 2

	Cluster 1 (N=66)	Cluster 2 (N=26)	p-value
BMI	26,80 ± 3,76	28,66 ±1 3,81	**0,027**
AGE	63,66 ± 9,01	64,90 ± 8,83	0,580
LEDD	552,71 ± 717,33	682,05 ± 480,93	**0,004**
DISEASE DURATION	4,56 ± 2,62	4,77 ± 2,34	0,174
H&Y	1,81 ± 0,38	1,97 ± 0,28	**0,016**
MDS-UPDRS - I	Behaviour and Mood		**0,012**
MDS-UPDRS - II	Activity of daily living		**0,004**
MDS-UPDRS - III	Motor Examination		**0,026**
MDS-UPDRS - IV	1,77± 2,95	1,25 ± 2,51	0,714
MDS-UPDRS-TOT	37,58 ± 14,95	49,12 ± 18,27	**0,001**

Significance level was set to p-value < 0.05

Postural Control & Classification for typical and atypical Parkinsonisms

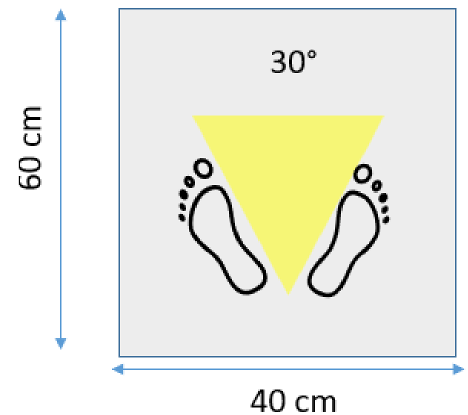
Using a standing single task of 5-6 seconds, in both typical and atypical Parkinsonisms, to demonstrate that a shorter sway time may help distinguish between different forms of Parkinsonism at the early stage of disease.

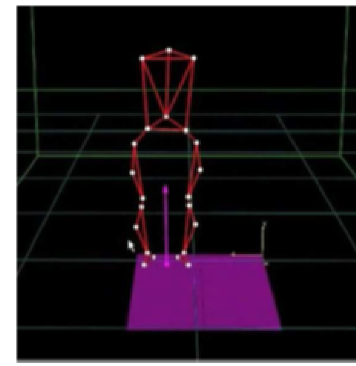


30 patients

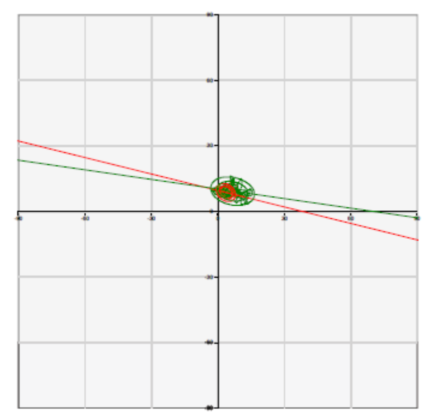
15 Denovo PD

15 PSP (Progressive Sopranuclear Palsy)





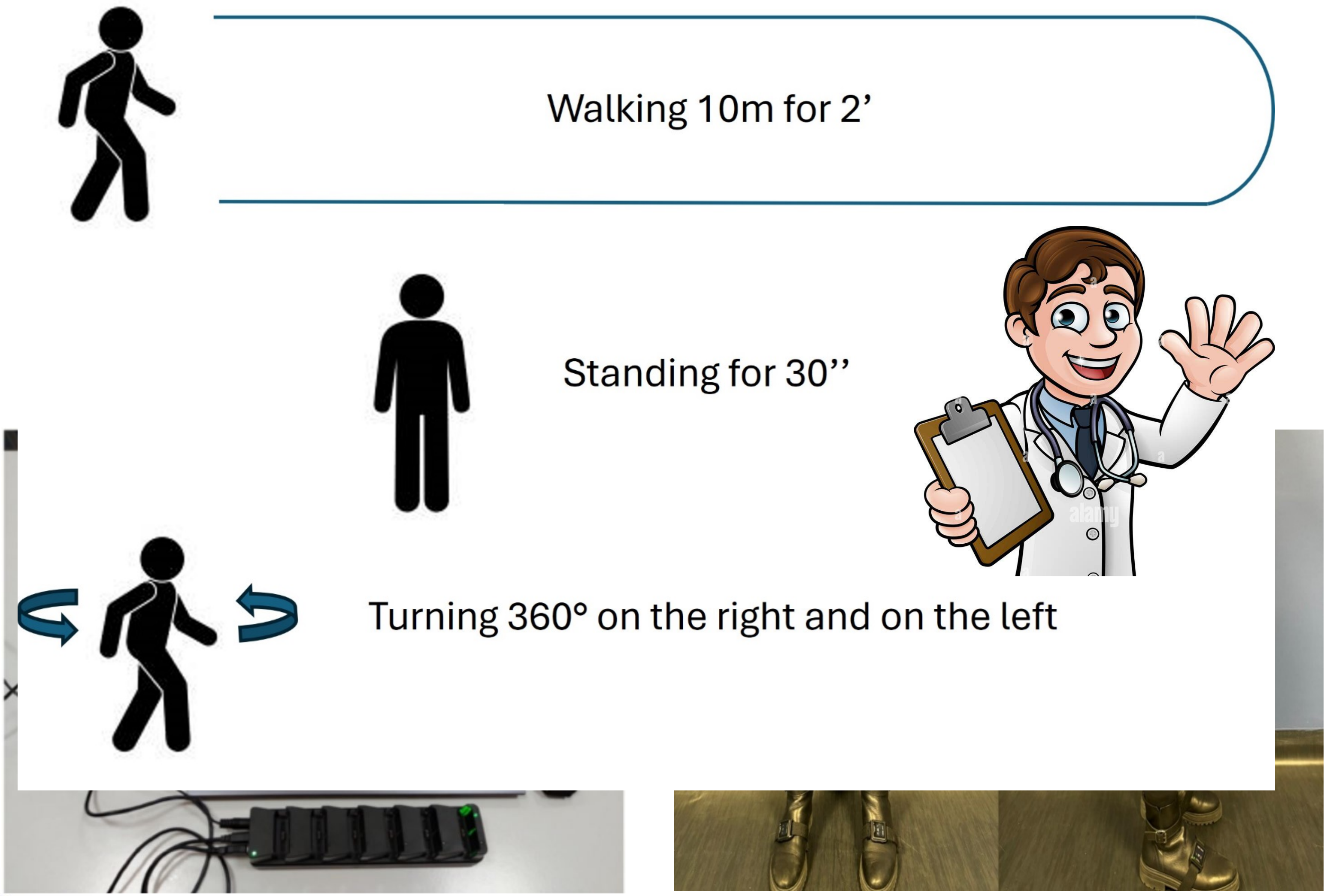
Sta



PSP patients showed greater motor impairments in mediolateral displacement.

Tree-based Classifiers showed the best results.

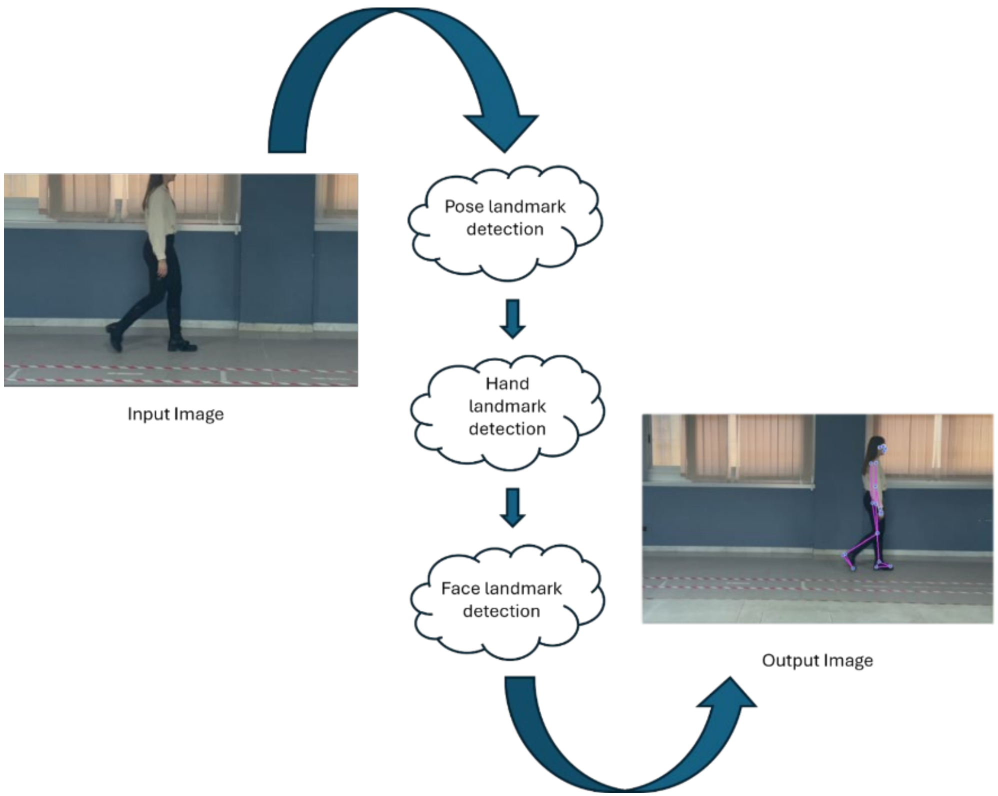
Wearable Sensors



Opal - APDM

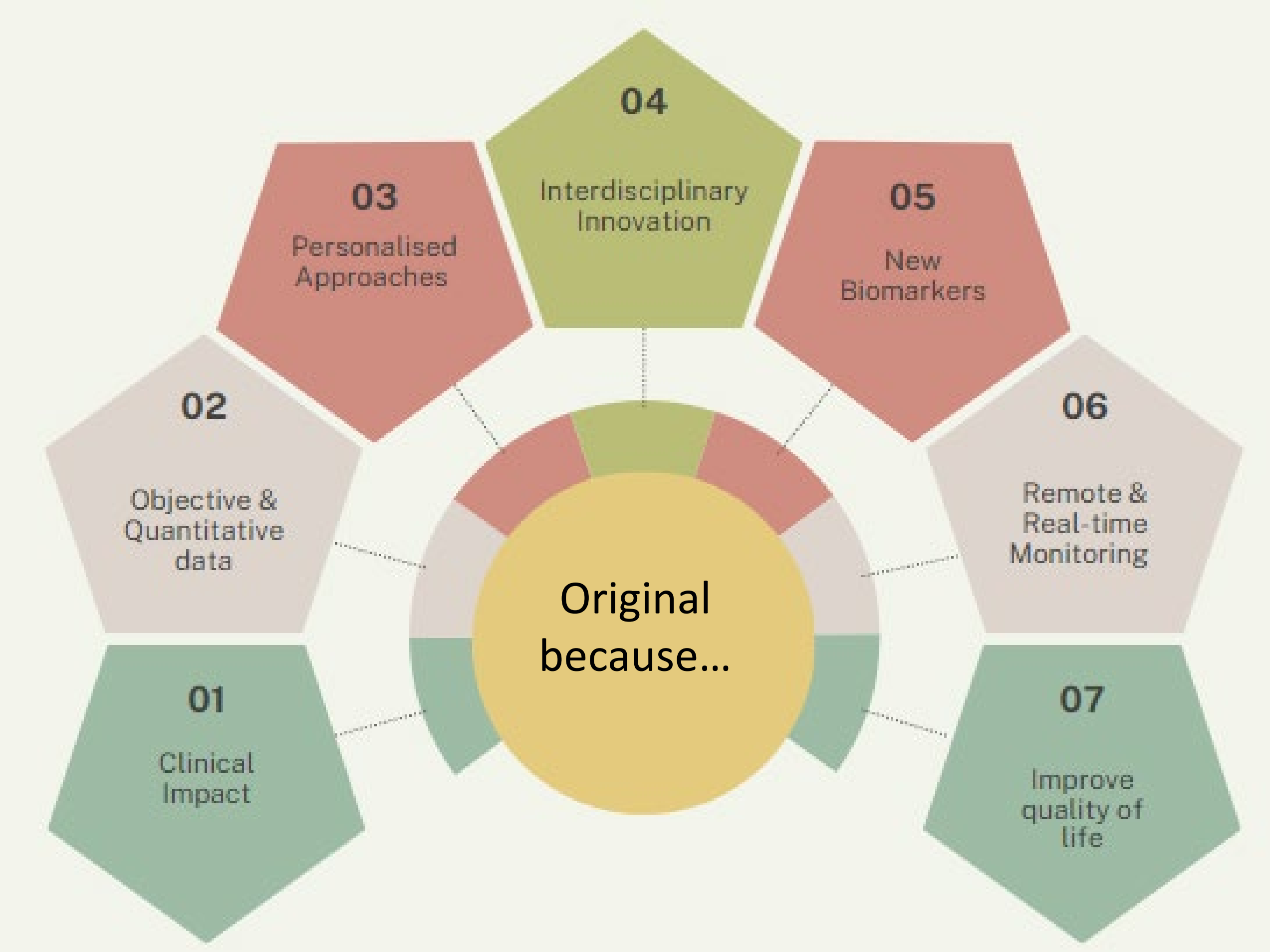
Development of a low-cost Human Motion Analysis System Based on Smartphone Video

Agreement study between MediaPipe & wearable sensor



Kinematic Parameters	Level of Agreement
Right Knee Flexion (°)	Agreement
Right Knee Extension (°)	Very close agreement
Right Knee ROM (°)	Agreement
Left Knee Flexion (°)	Agreement
Left Knee Extension (°)	Very close agreement
Left Knee ROM (°)	Agreement
Right Ankle Dorsiflexion (°)	No Agreement
Right Ankle Plantarflexion (°)	Very close agreement
Right Ankle ROM (°)	No Agreement
Left Ankle Dorsiflexion (°)	No Agreement
Left Ankle Plantarflexion (°)	Very close agreement
Left Ankle ROM (°)	No Agreement

PhD thesis


04
Interdisciplinary
Innovation
03
Personalised
Approaches
05
New
Biomarkers
02
Objective &
Quantitative
data
06
Remote &
Real-time
Monitoring
Original
because…
01
Clinical
Impact
07
Improve
quality of
life

Outlook:

- This thesis has developed methods to effectively address challenges in obtaining quantitative and detailed parameters related to motor function in Parkinsonism patients. The results indicate that motion analysis, while primarily used in research, can significantly enhance clinical decision-making processes.

- By offering objective, data-driven insights into a patient's motor function, motion analysis provides clinicians with a valuable tool for assessing disease progression and evaluating treatment efficacy.

- Continuing the research is essential with the potential to refine methodologies.

- Integrating multimodal data, including clinical, neuropsychological, and imaging information, could provide a more comprehensive view of disease progression, leading to personalized care and improved patient outcomes.

Thanks for the attention!