Instrumental Gait Analysis in Neurology

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Semiogram: from Wearable Sensors to Routine Clinical Gait Quantification

Gait Analysis Challenge

Gait analysis is crucial in neurology for managing chronic diseases and aiding rehabilitation after acute events. However, traditional assessments rely on visual evaluations by clinicians, which lack objectivity and reproducibility. Our study address this gap by evaluating the use of inertial measurement units (IMUs), a cost-effective and easily deployable technology to objectively quantify gait parameters in routine clinical settings [1].
In multiple sclerosis, gait impairment is one of the major symptoms. Its assessment contributes to disease monitoring scores, such as EDSS and MSWS.

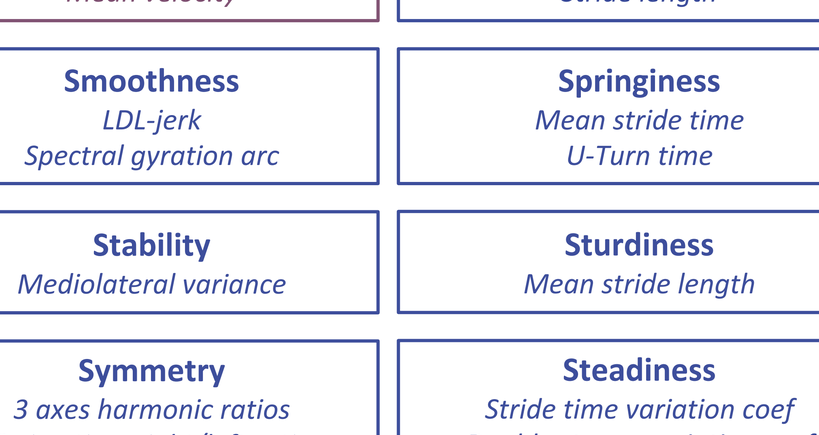
Methods

Cohorts

This study involved a cohort of 19 healthy subjects (HS) to evaluate reproducibility, and a cohort of 22 patients with progressive multiple sclerosis (MS), with a medium EDSS at 5.5 (Q1-Q3 from 3.5 to 6) to assess both reproducibility and the clinical relevance.

IMU-based gait protocol

Gait was measured in clinical routine using three IMU (accelerometer and gyrometer) placed on the lower back and dorsal part of both feet. Participants performed two 10-meter walks with a U-turn, at a self-selected comfortable speed. They were assessed three times over 6-month intervals.



Semiogram construction

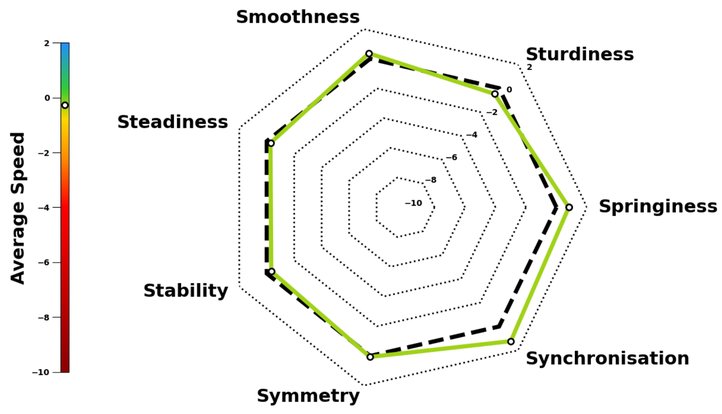
Gait parameters grouped by semiology

Seventeen mathematical and physical parameters fully detailed in [1,2] were extracted from time series and step segmentation [3]. These parameters were grouped into eight recognized semiological criteria described in the literature [4]:

Average speed *Mean velocity*	**Sturdiness** *Stride length*
Smoothness *LDL-jerk* *Spectral gyration arc*	**Springiness** *Mean stride time* *U-Turn time*
Stability *Mediolateral variance*	**Sturdiness** *Mean stride length*
Symmetry *3 axes harmonic ratios* *Swing time right/left ratio* *Craniocaudal step/stride autocorrelation ratio*	**Steadiness** *Stride time variation coef* *Double stance variation coef* *Craniocaudal step autocorrelation* *Craniocaudal stride autocorrelation*

Results

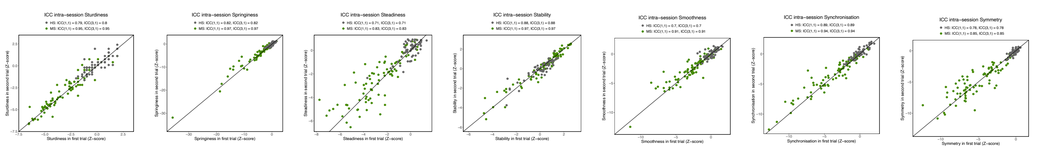
1 – A simple and reproducible tool

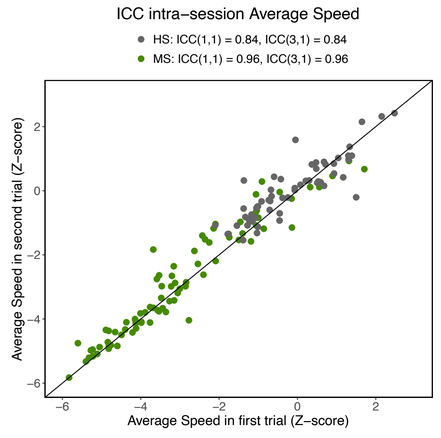


Semiogram for a healthy subject

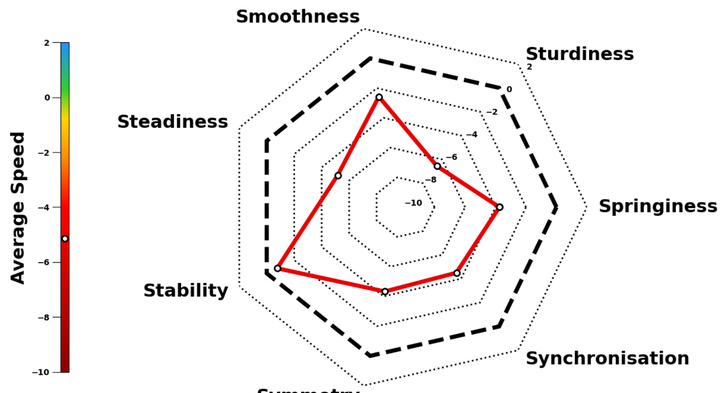
The semiogram visual aspect is based on comparing parameter values to expected values for the general population (Z-scores). Z-scores are aggregated and plotted along axes for quick interpretation, while speed, a global parameter, determines the final figure's color.

Reliability was confirmed with intraclass correlation coefficients (ICCs) ranging from 0.7 to 0.9. An illustration about Average Speed is given :



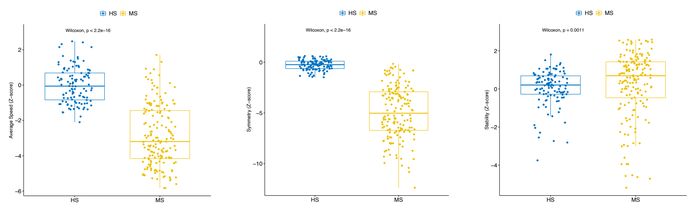


2 – A clinically relevant tool tested on multiple sclerosis



Semiogram for a patient with multiple sclerosis (EDSS 5)

Clinical consistency was first assessed by the ability of the semiogram criteria to differentiate between MS and HS cohorts (3 examples below).

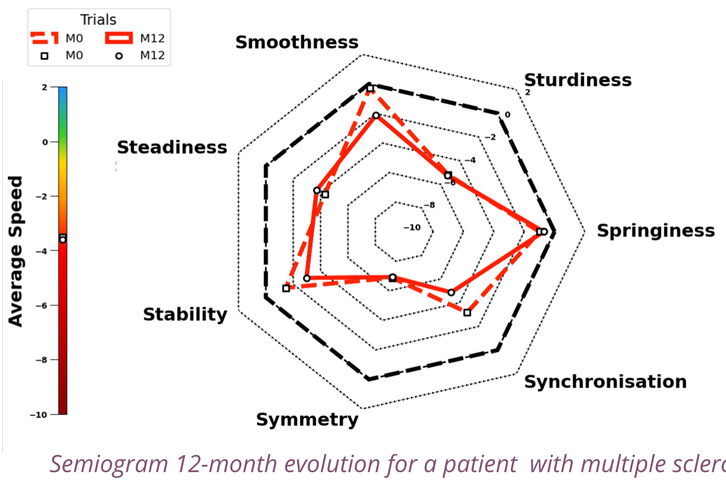


Clinical coherence was further validated by comparing semiogram values with two clinical disease monitoring scales: MSWS and EDSS. For EDSS, the functional sub scores with the strongest correlations were the pyramidal and cerebellar ones.

	MSWS		EDSS	
	r	*p-value*	r	*p-value*
Speed	−0.18	**0.024**	−0.74	**≤0.001**
Springiness	−0.20	**0.012**	−0.50	**≤0.001**
Smoothness	−0.24	**0.003**	−0.63	**≤0.001**
Steadiness	−0.18	**0.026**	−0.59	**≤0.001**
Sturdiness	−0.15	0.062	−0.70	**≤0.001**
Stability	0.00	0.987	0.33	**≤0.001**
Symmetry	0.03	0.727	−0.44	**≤0.001**
Synchro	−0.05	0.543	−0.63	**≤0.001**

Significant correlations appear in bold type.

3 – A tool designed for longitudinal monitoring



Semiogram 12-month evolution for a patient with multiple sclerosis (M0: EDSS=6 ; M12: EDSS=6.5) Between the two assessments, treatment and rehabilitation remain unchanged, but the patient reports increased fatigue and greater sensitivity to heat.

Comparing two gait trials several months apart remain a challenge for the clinician's eye. Subtle changes in gait may not be immediately detected during the visit.

The **quantified component** of the semiogram, with the values of the criteria, allows for precise tracking of gait evolution over time.

Evolution and Perspectives

- Describing and analysing the physiological evolution of gait by building a large database of parameters in healthy subjects
- Developing a global indicator of gait evolution, usable as a clinical research criterion
- Deploying the semiogram in routine neurological practice to gather clinician feedback and adapt it to their needs

References

[1] Voisard C., de l'Escalopier E. et al. (2024), Innovative Multidimensional Gait Evaluation using IMU in Multiple Sclerosis: introducing the Semiogram, Frontiers in Neurology.
[2] Voisard C. et al (2024), Semiogram: a Visual Tool for Gait Quantification in Routine Neurological Follow-Up, Image Processing Online.
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[4] Vienne, A. et al. (2017), Inertial sensors to assess gait quality in patients with neurological disorders: A systematic review. Frontiers in Psychology.