Trunk acceleration-derived gait indexes and symmetry metrics describe the gait abnormalities of subjects with trunk lateral postural abnormalities in subjects with Parkinson's disease

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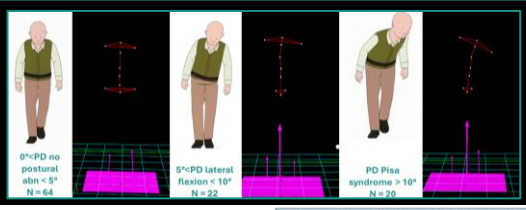
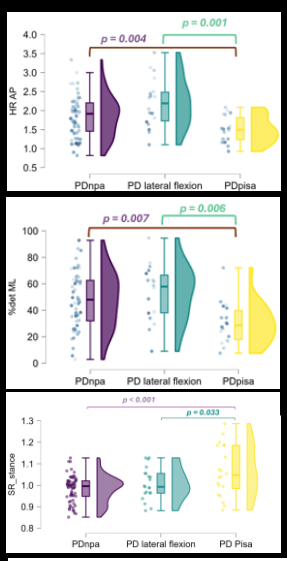
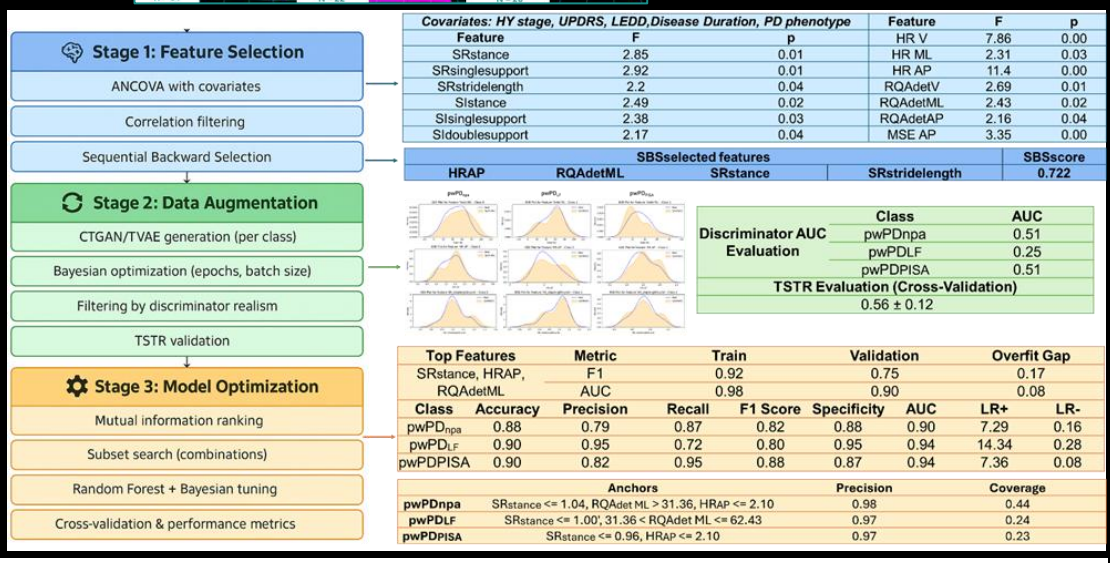
Background. Lateral postural abnormalities affect ~20% of people with Parkinson's disease (pwPD), presenting as lateral trunk flexion (≥5° to ≤10°) (pwPDLF) or Pisa syndrome (>10°) (pwPDPISA) [1], often undetected by conventional gait parameters [2].

Objectives. This study aimed to evaluate whether spatio-temporal and kinematic parameters-derived symmetry indices (SI), symmetry ratios (SR), and symmetry angles (SA) and trunk acceleration-derived gait indexes (TADI) characterize gait abnormalities in pwPD with lateral postural abnormalities.

Methods We included 106 pwPD categorized into 3 postural classes via optoelectronic measurement of the angle between C7 and sacrum on the frontal plane during static upright standing position [1]: 64 without postural abnormalities (pwPDnpa), 22 pwPDLF, and 20 pwPDPISA. Gait data were collected using a lumbar-mounted mIMU over a 30-meter walk. Forty-two age and gait speed-matched healthy subjects (HS). We extracted SR, SI, SA, and harmonic ratios (HR), log-dimensionless jerk, recurrence quantification metrics (RQAdet, RQArec), multiscale sample entropy, and Lyapunov exponents in the three acceleration directions [3]. ANCOVA adjusted for clinical covariates identified features differentiating pwPD classes and HS. Feature selection refinement used correlation filtering and Sequential Backward Selection (SBS). Synthetic data were generated using Bayesian-tuned CTGAN and TVAE to achieve a target of 100 samples per class and validated with Train-on-Synthetic-Test-on-Real (TSTR). Random Forest classifiers were trained and evaluated with 5-fold cross-validation. Performance metrics included macro-averages and overfitting gap analysis. Model explainability was enhanced with AnchorTabular (ALIBI framework)







Covariates: HY stage, UPDRS, LEDD,Disease Duration, PD phenotype

Feature	F	p
SRstance	2.85	0.01
SRsinglesupport	2.92	0.01
SRstridelength	2.2	0.04
SIstance	2.49	0.02
SIsinglesupport	2.38	0.03
SIdoublesupport	2.17	0.04

Feature	F	p
HR V	7.86	0.00
HR ML	2.31	0.03
HR AP	11.4	0.00
RQAdetV	2.69	0.01
RQAdetML	2.43	0.02
RQAdetAP	2.16	0.04
MSE AP	3.35	0.00

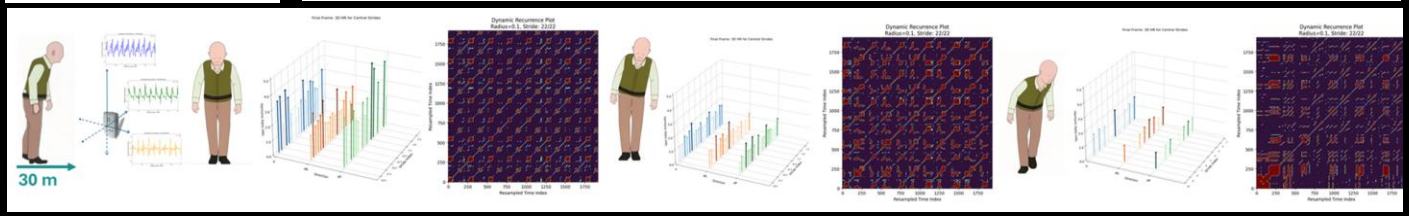
SBSselected features				SBSscore
HRAP	RQAdetML	SRstance	SRstridelength	0.722

	Class	AUC
Discriminator AUC Evaluation	pwPDnpa	0.51
	pwPDLF	0.25
	pwPDPISA	0.51
TSTR Evaluation (Cross-Validation)		0.56 ± 0.12

Top Features	Metric	Train	Validation	Overfit Gap
SRstance, HRAP, RQAdetML	F1	0.92	0.75	0.17
	AUC	0.98	0.90	0.08

Class	Accuracy	Precision	Recall	F1 Score	Specificity	AUC	LR+	LR-
$pwPD_{npa}$	0.88	0.79	0.87	0.82	0.88	0.90	7.29	0.16
$pwPD_{LF}$	0.90	0.95	0.72	0.80	0.95	0.94	14.34	0.28
pwPDPISA	0.90	0.82	0.95	0.88	0.87	0.94	7.36	0.08

Anchors		Precision	Coverage
pwPDnpa	SRstance <= 1.04, RQAdet ML > 31.36, HRAP <= 2.10	0.98	0.44
pwPDLF	SRstance <= 1.00, 31.36 < RQAdet ML <= 62.43	0.97	0.24
$pwPD_{PISA}$	SRstance <= 0.96, HRAP <= 2.10	0.97	0.23



Results. Thirteen gait features showed class-wise associations. The optimal selected subset (SRstance, RQAdetML, HRAP, SRstridelength) yielded a balanced accuracy of 0.72. Synthetic data realism was supported (AUCs<0.50; TSTR accuracy= 0.56±0.11), particularly improving minority class representation. The best classifier (HRAP + SRstance + RQAdetML) achieved validation (F1 = 0.75, AUC = 0.90), with minimal overall overfitting (gap = 0.25). Class-wise precision and recall exceeded 0.78 and 0.71, respectively (Fig.1).

Discussion. HR_{AP}, SR_{stance}, and RQA_{detML} characterize pwPD gait dysfunction across lateral trunk postural abnormalities. Synthetic augmentation strengthened classification under class imbalance, validating the clinical relevance of inertial gait metrics for characterizing pwPD with postural abnormalities.

REFERENCES

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