applied sciences

MDPI

Supplementary Material

Bidirectional Prediction of Gait Kinetics and Sagittal Joint Angles During Walking: A Participant-Independent Multi-Study Evaluation

Participant-independent prediction errors, paired comparisons and secondary evaluations. Task 1: angles and mass to kinetics. Task 2: GRF to angles.

Table S1. Participant-independent errors for every procedure and output channel. RMSE and MAE weight participants equally. NRMSE divides errors by each outer-training channel SD; overall selection averages channels equally. R pools coordinates within the stated channel only. The baseline predicts training-average waveforms, evaluated on the same held-out participants.

Task	Procedure	Signal	Unit	RMSE	MAE	NRMSE	R
1	SVR-RBF	Vertical GRF	BW	0.060	0.040	0.129	0.992
1	SVR-RBF	Anterior-posterior GRF	BW	0.018	0.011	0.215	0.979
1	SVR-RBF	Ankle moment	N m/kg	0.212	0.126	0.333	0.941
1	SVR-RBF	Knee moment	N m/kg	0.228	0.130	0.622	0.781
1	SVR-RBF	Hip moment	N m/kg	0.260	0.156	0.604	0.815
1	random forest	Vertical GRF	BW	0.061	0.038	0.133	0.991
1	random forest	Anterior-posterior GRF	BW	0.019	0.012	0.230	0.974
1	random forest	Ankle moment	N m/kg	0.223	0.124	0.349	0.936
1	random forest	Knee moment	N m/kg	0.243	0.139	0.659	0.749
1	random forest	Hip moment	N m/kg	0.258	0.158	0.605	0.820
1	MLP-ANN	Vertical GRF	BW	0.092	0.071	0.199	0.980
1	MLP-ANN	Anterior-posterior GRF	BW	0.022	0.013	0.255	0.970
1	MLP-ANN	Ankle moment	N m/kg	0.274	0.162	0.430	0.903
1	MLP-ANN	Knee moment	N m/kg	0.257	0.145	0.703	0.730
1	MLP-ANN	Hip moment	N m/kg	0.289	0.176	0.677	0.770
1	Inner-selected procedure	Vertical GRF	BW	0.060	0.040	0.129	0.992
1	Inner-selected procedure	Anterior-posterior GRF	BW	0.018	0.011	0.215	0.979
1	Inner-selected procedure	Ankle moment	N m/kg	0.212	0.126	0.333	0.941
1	Inner-selected procedure	Knee moment	N m/kg	0.228	0.130	0.622	0.781
1	Inner-selected procedure	Hip moment	N m/kg	0.260	0.156	0.604	0.815
1	Mean-waveform baseline	Vertical GRF	BW	0.080	0.051	0.173	0.985
1	Mean-waveform baseline	Anterior-posterior GRF	BW	0.025	0.016	0.297	0.959
1	Mean-waveform baseline	Ankle moment	N m/kg	0.283	0.165	0.447	0.895
1	Mean-waveform baseline	Knee moment	N m/kg	0.320	0.193	0.866	0.500
1	Mean-waveform baseline	Hip moment	N m/kg	0.361	0.233	0.840	0.581
2	SVR-RBF	Ankle angle	deg	6.797	5.173	0.510	0.842
2	SVR-RBF	Knee angle	deg	9.400	6.614	0.419	0.904
2	SVR-RBF	Hip angle	deg	9.759	6.964	0.534	0.859

Task	Procedure	Signal	Unit	RMSE	MAE	NRMSE	R
2	random forest	Ankle angle	deg	6.836	5.004	0.509	0.824
2	random forest	Knee angle	deg	9.033	6.363	0.402	0.900
2	random forest	Hip angle	deg	8.690	6.279	0.475	0.861
2	MLP-ANN	Ankle angle	deg	12.037	6.202	0.927	0.596
2	MLP-ANN	Knee angle	deg	25.262	8.333	1.143	0.575
2	MLP-ANN	Hip angle	deg	16.407	8.226	0.898	0.617
2	Inner-selected procedure	Ankle angle	deg	7.015	5.191	0.523	0.823
2	Inner-selected procedure	Knee angle	deg	9.763	6.735	0.434	0.896
2	Inner-selected procedure	Hip angle	deg	9.741	6.751	0.530	0.856
2	Mean-waveform baseline	Ankle angle	deg	9.824	7.509	0.748	0.573
2	Mean-waveform baseline	Knee angle	deg	10.255	7.503	0.460	0.869
2	Mean-waveform baseline	Hip angle	deg	13.447	11.083	0.738	0.702

Table S2. Individual representative-waveform RMSE distributions under participant-independent validation. Task 1 includes 340 observations from 32 participants; Task 2 includes 361 from 39. Quartiles and the 95th percentile summarize observation-level heterogeneity; repeated conditions are not independent participants. These are errors for participant-condition/trial average waveforms, not raw-stride errors.

Task	Procedure	Signal	Unit	Median	Q25–Q75	P95
1	SVR-RBF	Vertical GRF	BW	0.050	0.038–0.067	0.094
1	SVR-RBF	Anterior-posterior GRF	BW	0.014	0.011–0.019	0.031
1	SVR-RBF	Ankle moment	N m/kg	0.128	0.087–0.208	0.546
1	SVR-RBF	Knee moment	N m/kg	0.114	0.083–0.212	0.567
1	SVR-RBF	Hip moment	N m/kg	0.132	0.101–0.225	0.699
1	random forest	Vertical GRF	BW	0.051	0.038–0.068	0.099
1	random forest	Anterior-posterior GRF	BW	0.016	0.012–0.022	0.031
1	random forest	Ankle moment	N m/kg	0.134	0.091–0.195	0.544
1	random forest	Knee moment	N m/kg	0.134	0.089–0.232	0.605
1	random forest	Hip moment	N m/kg	0.152	0.102–0.234	0.747
1	MLP-ANN	Vertical GRF	BW	0.073	0.054–0.101	0.155
1	MLP-ANN	Anterior-posterior GRF	BW	0.017	0.012–0.024	0.036
1	MLP-ANN	Ankle moment	N m/kg	0.157	0.120–0.220	0.705
1	MLP-ANN	Knee moment	N m/kg	0.135	0.095–0.208	0.727
1	MLP-ANN	Hip moment	N m/kg	0.160	0.120–0.248	0.801
1	Inner-selected procedure	Vertical GRF	BW	0.050	0.038–0.067	0.094
1	Inner-selected procedure	Anterior-posterior GRF	BW	0.014	0.011–0.019	0.031
1	Inner-selected procedure	Ankle moment	N m/kg	0.128	0.087–0.208	0.546
1	Inner-selected procedure	Knee moment	N m/kg	0.114	0.083–0.212	0.567
1	Inner-selected procedure	Hip moment	N m/kg	0.132	0.101–0.225	0.699

Task	Procedure	Signal	Unit	Median	Q25–Q75	P95
1	Mean-waveform baseline	Vertical GRF	BW	0.072	0.053–0.090	0.124
1	Mean-waveform baseline	Anterior-posterior GRF	BW	0.021	0.015–0.028	0.039
1	Mean-waveform baseline	Ankle moment	N m/kg	0.198	0.151–0.257	0.725
1	Mean-waveform baseline	Knee moment	N m/kg	0.195	0.147–0.278	0.757
1	Mean-waveform baseline	Hip moment	N m/kg	0.254	0.193–0.357	0.951
2	SVR-RBF	Ankle angle	deg	4.898	3.214–7.958	14.543
2	SVR-RBF	Knee angle	deg	5.793	4.188–9.231	21.698
2	SVR-RBF	Hip angle	deg	5.273	3.321–9.109	19.254
2	random forest	Ankle angle	deg	5.003	3.661–7.856	15.248
2	random forest	Knee angle	deg	6.225	4.174–8.911	21.769
2	random forest	Hip angle	deg	5.467	3.537–8.888	21.380
2	MLP-ANN	Ankle angle	deg	6.227	3.930–9.264	16.445
2	MLP-ANN	Knee angle	deg	6.472	4.624–10.380	27.637
2	MLP-ANN	Hip angle	deg	6.325	3.940–10.582	26.491
2	Inner-selected procedure	Ankle angle	deg	4.902	3.516–7.768	15.248
2	Inner-selected procedure	Knee angle	deg	5.700	3.879–9.264	23.610
2	Inner-selected procedure	Hip angle	deg	5.241	3.234–8.464	22.587
2	Mean-waveform baseline	Ankle angle	deg	8.269	4.644–13.695	20.967
2	Mean-waveform baseline	Knee angle	deg	8.076	5.610–11.058	26.541
2	Mean-waveform baseline	Hip angle	deg	9.165	6.048–12.520	29.710

Table S3. Paired differences in participant-independent mean channel NRMSE (A minus B). Negative differences favor A. Intervals use 2,000 paired, study-stratified participant resamples, retaining all observations of each sampled participant. They are conditional on the saved fits/folds, descriptive and unadjusted for multiple comparisons; they do not establish universal algorithm superiority.

Task	Procedure A	Procedure B	Difference	95% interval
1	SVR-RBF	random forest	-0.015	-0.041–0.018
1	SVR-RBF	MLP-ANN	-0.072	-0.115–-0.017
1	SVR-RBF	Inner-selected procedure	0.000	0.000–0.000
1	SVR-RBF	Mean-waveform baseline	-0.144	-0.180–-0.098
1	random forest	MLP-ANN	-0.057	-0.089–-0.020
1	random forest	Inner-selected procedure	0.015	-0.018–0.041
1	random forest	Mean-waveform baseline	-0.129	-0.156–-0.099
1	MLP-ANN	Inner-selected procedure	0.072	0.017–0.115
1	MLP-ANN	Mean-waveform baseline	-0.072	-0.113–-0.034
1	Inner-selected procedure	Mean-waveform baseline	-0.144	-0.180–-0.098
2	SVR-RBF	random forest	0.025	-0.043–0.100
2	SVR-RBF	MLP-ANN	-0.501	-1.082–-0.034
2	SVR-RBF	Inner-selected procedure	-0.008	-0.056–0.028
2	SVR-RBF	Mean-waveform baseline	-0.161	-0.239–-0.072
2	random forest	MLP-ANN	-0.527	-1.091–-0.034

Task	Procedure A	Procedure B	Difference	95% interval
2	random forest	Inner-selected procedure	-0.033	-0.094–0.011
2	random forest	Mean-waveform baseline	-0.186	-0.275–-0.082
2	MLP-ANN	Inner-selected procedure	0.494	0.000–1.082
2	MLP-ANN	Mean-waveform baseline	0.340	-0.153–0.934
2	Inner-selected procedure	Mean-waveform baseline	-0.153	-0.255–-0.036

Table S4. Secondary evaluations. Participant holdouts exclude the stated test participants from training. Known-participant observation holdouts deliberately share participants across training and test sets and measure within-participant condition prediction. Each evaluation repeats the full inner tuning procedure.

Task	Evaluation	Test participants	Test observations	Inner-selected family	NRMSE
Task 1	One participant per source	3	32	SVR-RBF	0.321
Task 1	Known-participant observations	32	62	SVR-RBF	0.198
Task 2	One participant per source	4	35	random forest	0.335
Task 2	Known-participant observations	39	69	random forest	0.307