

Comparison of Walking Protocols and Gait Assessment Systems for Machine Learning-Based Classification of Parkinson's Disease

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Supplementary Material

Table S1. Correlation of gender, age, BMI, and step velocity (speed) with gait characteristics before and after normalization.

Spearson's correlations	System	Walk Type	Data Type	Gender	Age	BMI	Step Velocity(Speed)
Mean Step Time	Axivity	Continuous	Raw	-.338 (<.001)	-.045 (.534)	.108 (.131)	-.506 (<.001)
			Normalized	.117 (.102)	.083 (.250)	-.070 (.333)	.106 (.141)
	GAITRite	Continuous	Raw	-.445 (<.001)	-.030 (.672)	.073 (.309)	-.545 (<.001)
			Normalized	.183 (.010)	.162 (.023)	-.058 (.418)	.071 (.323)
	Axivity	Intermittent	Raw	-.324 (<.001)	-.087 (.227)	.155 (.030)	-.404 (<.001)
			Normalized	.109 (.128)	-.039 (.589)	-.019 (.792)	-.029 (.687)
	GAITRite	Intermittent	Raw	-.457 (<.001)	-.035 (.624)	.079 (.270)	-.564 (<.001)
			Normalized	.208 (.003)	.147 (.040)	-.043 (.551)	.055 (.447)
Mean Stance Time	Axivity	Continuous	Raw	-.392 (<.001)	-.034 (.639)	.080 (.266)	-.457 (<.001)
			Normalized	.135 (.060)	.048 (.508)	-.041 (.571)	.075 (.297)
	GAITRite	Continuous	Raw	-.415 (<.001)	.029 (.689)	.197 (.006)	-.686 (<.001)
			Normalized	.142 (.047)	.059 (.413)	-.035 (.627)	.034 (.638)
	Axivity	Intermittent	Raw	-.360 (<.001)	-.074 (.304)	.136 (.057)	-.369 (<.001)
			Normalized	.099 (.169)	-.063 (.379)	.029 (.690)	-.039 (.585)
	GAITRite	Intermittent	Raw	-.425 (<.001)	.022 (.755)	.187 (.009)	-.706 (<.001)
			Normalized	.137 (.055)	.059 (.409)	-.017 (.810)	.022 (.758)
Mean Swing Time	Axivity	Continuous	Raw	-.232 (.001)	-.047 (.516)	.163 (.022)	-.506 (<.001)
			Normalized	.061 (.396)	-.063 (.380)	.041 (.573)	.061 (.397)
	GAITRite	Continuous	Raw	-.389 (<.001)	-.200 (.005)	-.218 (.002)	-.006 (.929)
			Normalized	.100 (.164)	-.073 (.308)	-.211 (.003)	.087 (.226)
	Axivity	Intermittent	Raw	-.277 (<.001)	-.039 (.587)	.205 (.004)	-.456 (<.001)
			Normalized	.074 (.305)	.023 (.745)	.029 (.692)	-.025 (.732)
	GAITRite	Intermittent	Raw	-.393 (<.001)	-.183 (.010)	-.190 (.008)	-.062 (.387)
			Normalized	.129 (.071)	-.059 (.415)	-.188 (.008)	.049 (.499)
Mean Step Length	Axivity	Continuous	Raw	-.167 (.019)	-.226 (.001)	-.089 (.213)	.762 (<.001)
			Normalized	.144 (.045)	.085 (.234)	-.065 (.368)	.120 (.093)
	GAITRite	Continuous	Raw	-.213 (.003)	-.275 (<.001)	-.216 (.002)	.852 (<.001)
			Normalized	.162 (.024)	.008 (.911)	-.087 (.227)	.282 (<.001)
	Axivity	Intermittent	Raw	-.127 (.076)	-.229 (.001)	-.013 (.853)	.767 (<.001)
			Normalized	.159 (.026)	-.083 (.247)	.048 (.507)	.077 (.286)
	GAITRite	Intermittent	Raw	-.217 (.002)	-.290 (<.001)	-.189 (.008)	.811 (<.001)
			Normalized	.166 (.020)	-.028 (.701)	-.057 (.424)	.225 (.002)
Step Time Variability	Axivity	Continuous	Raw	-.065 (.366)	.104 (.146)	.002 (.981)	-.174 (.014)
			Normalized	.028 (.701)	.051 (.479)	-.080 (.265)	.132 (.064)
	GAITRite	Continuous	Raw	-.079 (.272)	.160 (.025)	.136 (.057)	-.730 (<.001)
			Normalized	.013 (.854)	-.183 (.010)	-.176 (.014)	.028 (.696)
	Axivity	Intermittent	Raw	.022 (.762)	.064 (.369)	.080 (.268)	-.009 (.899)
			Normalized	-.082 (.251)	-.205 (.004)	.044 (.543)	-.098 (.172)
	GAITRite	Intermittent	Raw	-.068 (.345)	.279 (<.001)	.131 (.068)	-.649 (<.001)
			Normalized	-.009 (.906)	-.023 (.746)	-.017 (.818)	-.082 (.250)
Stance Time Variability	Axivity	Continuous	Raw	-.062 (.391)	.088 (.222)	.006 (.929)	-.193 (.007)
			Normalized	-.012 (.864)	.027 (.711)	-.089 (.214)	.156 (.029)
	GAITRite	Continuous	Raw	-.103 (.151)	.087 (.226)	.143 (.045)	-.711 (<.001)
			Normalized	-.131 (.068)	-.164 (.022)	-.117 (.101)	-.033 (.646)
	Axivity	Intermittent	Raw	.024 (.737)	.065 (.368)	.080 (.267)	-.018 (.801)
			Normalized	-.082 (.254)	-.198 (.005)	.069 (.333)	-.075 (.298)
	GAITRite	Intermittent	Raw	-.044 (.538)	.202 (.004)	.109 (.127)	-.700 (<.001)
			Normalized	.089 (.216)	.031 (.663)	-.019 (.794)	-.234 (.001)
Swing Time Variability	Axivity	Continuous	Raw	-.050 (.488)	.093 (.195)	.013 (.860)	-.236 (.001)
			Normalized	.026 (.713)	.184 (.010)	.002 (.981)	-.004 (.950)
	GAITRite	Continuous	Raw	-.142 (.047)	.220 (.002)	.097 (.178)	-.667 (<.001)
			Normalized	-.099 (.167)	-.062 (.386)	-.055 (.443)	-.098 (.172)
	Axivity	Intermittent	Raw	.022 (.762)	.067 (.352)	.116 (.107)	-.187 (.008)
			Normalized	-.126 (.078)	-.117 (.101)	.004 (.958)	-.153 (.033)
	GAITRite	Intermittent	Raw	-.201 (.005)	.377 (<.001)	.155 (.031)	-.609 (<.001)
			Normalized	.141 (.049)	.155 (.030)	.009 (.901)	.407 (<.001)
Step Length Variability	Axivity	Continuous	Raw	.096 (.180)	.026 (.713)	.035 (.624)	.127 (.076)
			Normalized	.021 (.766)	-.116 (.106)	.091 (.203)	-.116 (.107)
	GAITRite	Continuous	Raw	-.199 (.005)	.343 (<.001)	-.017 (.812)	-.376 (<.001)
			Normalized	-.213 (.003)	.034 (.638)	.108 (.132)	-.174 (.015)
	Axivity	Intermittent	Raw	.119 (.097)	.007 (.918)	.099 (.167)	.246 (.001)
			Normalized	-.002 (.980)	-.062 (.385)	.082 (.254)	-.259 (<.001)
	GAITRite	Intermittent	Raw	-.081 (.258)	.326 (<.001)	.150 (.036)	-.390 (<.001)
			Normalized				

			Normalized	.220 (.002)	-.346 (<.001)	-.210 (.003)	.673 (<.001)
Step Velocity Variability	Axivity	Continuous	Raw	.183 (.010)	.012 (.873)	-.003 (.967)	.312 (<.001)
			Normalized	.002 (.980)	-.152 (.034)	.118 (.099)	-.158 (.027)
	GAITRite	Continuous	Raw	-.019 (.793)	.112 (.118)	-.097 (.177)	-.075 (.299)
			Normalized	-.401 (<.001)	.133 (.064)	-.040 (.575)	-.107 (.137)
	Axivity	Intermittent	Raw	.191 (.007)	.014 (.846)	.050 (.490)	.359 (<.001)
			Normalized	-.005 (.942)	-.103 (.150)	.072 (.318)	-.179 (.012)
	GAITRite	Intermittent	Raw	.128 (.073)	.139 (.053)	.004 (.953)	-.087 (.227)
			Normalized	-.197 (.006)	.195 (.006)	.074 (.300)	-.273 (<.001)
Step Time Asymmetry	Axivity	Continuous	Raw	-.084 (.243)	-.046 (.519)	.017 (.809)	-.002 (.973)
			Normalized	.047 (.515)	-.049 (.496)	-.004 (.953)	.043 (.547)
	GAITRite	Continuous	Raw	-.105 (.142)	-.090 (.209)	.030 (.680)	-.236 (.001)
			Normalized	-.058 (.421)	-.113 (.115)	.019 (.795)	-.170 (.017)
	Axivity	Intermittent	Raw	-.063 (.384)	-.014 (.842)	.057 (.426)	.044 (.540)
			Normalized	-.581 (<.001)	-.007 (.925)	.037 (.604)	.042 (.561)
	GAITRite	Intermittent	Raw	-.195 (.006)	-.087 (.225)	.142 (.046)	-.260 (<.001)
			Normalized	-.088 (.220)	-.119 (.097)	.099 (.167)	-.162 (.023)
Stance Time Asymmetry	Axivity	Continuous	Raw	-.071 (.325)	-.038 (.595)	.057 (.428)	-.043 (.550)
			Normalized	.011 (.880)	.122 (.088)	.185 (.010)	-.205 (.004)
	GAITRite	Continuous	Raw	-.135 (.060)	-.068 (.343)	.081 (.258)	-.283 (<.001)
			Normalized	-.059 (.415)	-.149 (.038)	.015 (.835)	-.163 (.023)
	Axivity	Intermittent	Raw	-.028 (.696)	-.052 (.470)	.023 (.746)	-.044 (.537)
			Normalized	.248 (<.001)	-.082 (.255)	-.113 (.114)	.324 (<.001)
	GAITRite	Intermittent	Raw	-.188 (.008)	-.023 (.745)	.173 (.015)	-.245 (.001)
			Normalized	.257 (<.001)	-.246 (.001)	.064 (.372)	.029 (.687)
Swing Time Asymmetry	Axivity	Continuous	Raw	-.055 (.440)	-.062 (.390)	.021 (.771)	-.037 (.603)
			Normalized	-.012 (.872)	.025 (.729)	.067 (.352)	.141 (.049)
	GAITRite	Continuous	Raw	-.142 (.047)	-.070 (.330)	.110 (.125)	-.351 (<.001)
			Normalized	-.043 (.550)	-.150 (.035)	.008 (.910)	-.140 (.050)
	Axivity	Intermittent	Raw	-.026 (.716)	-.015 (.839)	.019 (.797)	-.149 (.037)
			Normalized	-.006 (.934)	.134 (.061)	-.004 (.958)	-.006 (.938)
	GAITRite	Intermittent	Raw	-.212 (.003)	.002 (.975)	.127 (.076)	-.256 (<.001)
			Normalized	.348 (<.001)	-.034 (.636)	-.143 (.045)	.336 (<.001)
Step Length Asymmetry	Axivity	Continuous	Raw	-.027 (.705)	-.120 (.094)	.006 (.938)	.000 (.995)
			Normalized	.031 (.666)	-.001 (.984)	-.047 (.514)	-.085 (.234)
	GAITRite	Continuous	Raw	-.152 (.033)	.042 (.558)	.088 (.222)	-.103 (.151)
			Normalized	.242 (.001)	-.057 (.430)	-.106 (.138)	.162 (.023)
	Axivity	Intermittent	Raw	.002 (.978)	-.124 (.085)	-.109 (.128)	.350 (<.001)
			Normalized	.038 (.596)	-.158 (.027)	-.038 (.597)	.079 (.272)
	GAITRite	Intermittent	Raw	-.253 (<.001)	.094 (.190)	.126 (.077)	-.060 (.406)
			Normalized	.467 (<.001)	-.121 (.092)	-.189 (.008)	.190 (.008)

Table S2. Coefficients from the regression model by using the healthy control subjects

Regression Coefficients	Sensing System	Walk Type	Model Coefficients					Adjusted R ²	Standard Error
			β_0	β_{Gender}	β_{Age}	β_{BMI}	$\beta_{Step\ Velocity\ (Speed)}$		
Mean Step Time	Axiivity	Continuous	0.873	-0.048	-0.002	0	-0.178	0.595	0.029
		Intermittent	0.774	-0.047	-0.001	0.001	-0.134	0.368	0.042
	GAITRite	Continuous	8.72E-01	-4.90E-02	-2.00E-03	-1.00E-03	-1.41E-01	0.653	0.025
		Intermittent	0.877	-0.053	-0.002	-1.00E-03	-0.138	0.691	0.025
Mean Stance Time	Axiivity	Continuous	1.066	-0.064	-0.002	-0.001	-0.182	0.588	0.035
		Intermittent	0.955	-0.06	-0.001	0	-0.129	0.379	0.046
	GAITRite	Continuous	1.184	-6.70E-02	-0.002	0	-0.254	0.739	0.034
		Intermittent	1.181	-0.069	-0.002	0.00E+00	-2.46E-01	0.759	0.034
Mean Swing Time	Axiivity	Continuous	0.677	-0.031	-0.001	-6.40E-05	-0.175	0.454	0.032
		Intermittent	0.597	-0.031	-0.001	0.001	-0.136	0.31	0.039
	GAITRite	Continuous	5.60E-01	-0.033	-1.00E-03	-0.001	-0.026	0.393	0.023
		Intermittent	0.568	-0.036	-0.001	-1.00E-03	-0.027	0.455	0.022
Mean Step Length	Axiivity	Continuous	0.365	-0.051	-0.002	0	0.338	0.796	0.029
		Intermittent	0.293	-0.056	-0.001	0	0.372	0.783	0.034
	GAITRite	Continuous	0.474	-6.60E-02	-2.00E-03	-1.00E-03	3.29E-01	0.839	0.033
		Intermittent	0.479	-0.071	-0.002	-0.001	3.33E-01	0.84	0.034
Step Time Variability	Axiivity	Continuous	0.054	-0.002	0	0	-0.027	0.139	0.033
		Intermittent	-0.156	0.012	0.002	0.001	0.041	0.028	0.103
	GAITRite	Continuous	0.023	0.00E+00	8.75E-05	6.81E-05	-0.014	0.383	0.003
		Intermittent	0.023	0	8.93E-05	-2.44E-06	-1.20E-02	0.361	0.003
Stance Time Variability	Axiivity	Continuous	0.066	-1.00E-03	0	9.35E-05	-0.037	0.179	0.034
		Intermittent	-0.16	0.013	0.002	0.001	0.04	0.03	0.104
	GAITRite	Continuous	3.40E-02	1.00E-03	5.75E-05	8.95E-05	-0.019	0.309	0.005
		Intermittent	3.80E-02	-0.001	5.27E-05	0	-0.017	0.408	0.004
Swing Time Variability	Axiivity	Continuous	7.40E-02	-0.001	0.00E+00	-2.87E-05	-0.056	0.045	0.031
		Intermittent	-0.113	0.017	0.001	0.002	0.017	0.033	0.084
	GAITRite	Continuous	2.30E-02	0	7.72E-05	-1.97E-05	-0.011	0.333	0.003
		Intermittent	0.019	-0.001	0	-1.54E-05	-0.011	0.448	0.002
Step Length Variability	Axiivity	Continuous	-5.10E-02	6.00E-03	0.001	7.13E-05	0.056	0.035	0.033
		Intermittent	-0.18	0.006	0.001	0.001	0.121	0.088	0.057
	GAITRite	Continuous	8.00E-03	-1.00E-03	0.00E+00	6.46E-05	-7.00E-03	0.166	0.005
		Intermittent	5.88E-05	-0.001	0	0	-6.00E-03	0.181	0.005
Step Velocity Variability	Axiivity	Continuous	-0.162	2.10E-02	2.00E-03	0	1.61E-01	0.16	0.055
		Intermittent	-0.327	0.025	0.002	0.002	0.257	0.174	0.088
	GAITRite	Continuous	0.018	4.00E-03	0.00E+00	0	0	0.018	0.012
		Intermittent	0.016	0.005	0	0	0.006	0.017	0.015
Step Time Asymmetry	Axiivity	Continuous	3.40E-02	-0.006	-5.24E-05	-2.99E-05	-0.005	0.039	0.016
		Intermittent	-0.01	-0.007	0	0	0.013	0.016	0.018
	GAITRite	Continuous	0.043	-0.003	0	-5.43E-05	-0.01	0.026	0.009
		Intermittent	3.10E-02	-4.00E-03	0	5.29E-05	-0.008	0.057	0.007
Stance Time Asymmetry	Axiivity	Continuous	2.90E-02	-0.001	0.00E+00	0.00E+00	-0.023	0.05	0.018
		Intermittent	0.027	-0.003	0	0	-0.016	0.038	0.02
	GAITRite	Continuous	0.008	-0.001	5.06E-05	6.03E-05	-0.004	0.028	0.006
		Intermittent	0.001	-2.00E-03	6.99E-05	0	-0.002	0.046	0.006
Swing Time Asymmetry	Axiivity	Continuous	0.029	-1.00E-03	0.00E+00	0	-0.021	0.045	0.018
		Intermittent	0.033	0.001	0	9.68E-05	-0.028	0.051	0.016
	GAITRite	Continuous	0.014	-0.001	2.46E-05	4.92E-05	-0.007	0.051	0.006
		Intermittent	-0.002	-2.00E-03	0	0	-0.003	0.068	0.006
Step Length Asymmetry	Axiivity	Continuous	-1.20E-01	0.001	0.00E+00	0.00E+00	0.159	0.175	0.047
		Intermittent	-0.186	-6.00E-03	0.001	-0.001	0.225	0.406	0.042
	GAITRite	Continuous	-0.005	-2.00E-03	0.00E+00	0	-0.003	0.035	0.015
		Intermittent	-2.00E-03	-4.00E-03	0.00E+00	5.47E-05	-0.005	0.022	0.015

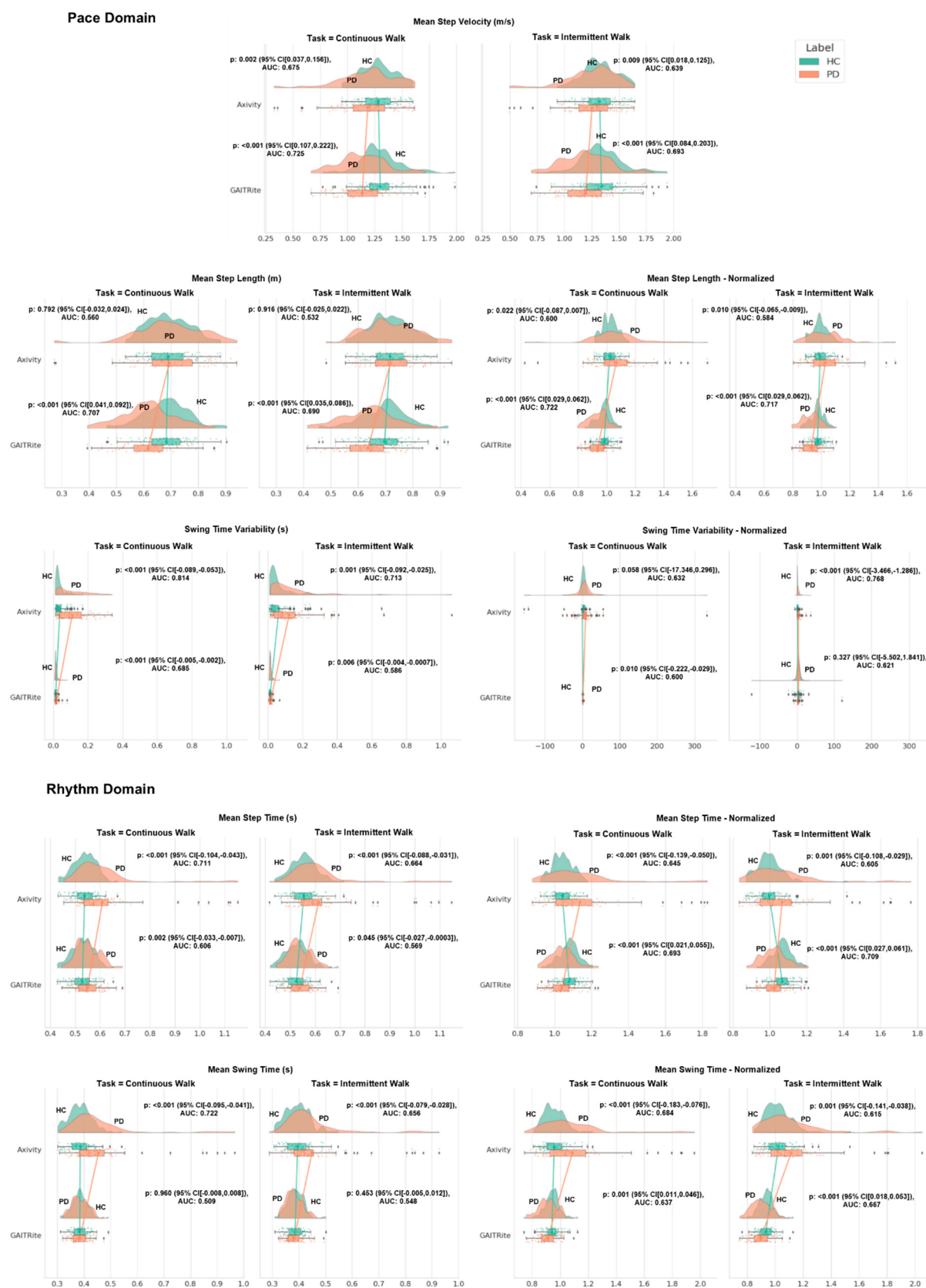
Table S3. Importance of gait characteristics in the classification of PD before and after gait characteristics normalization

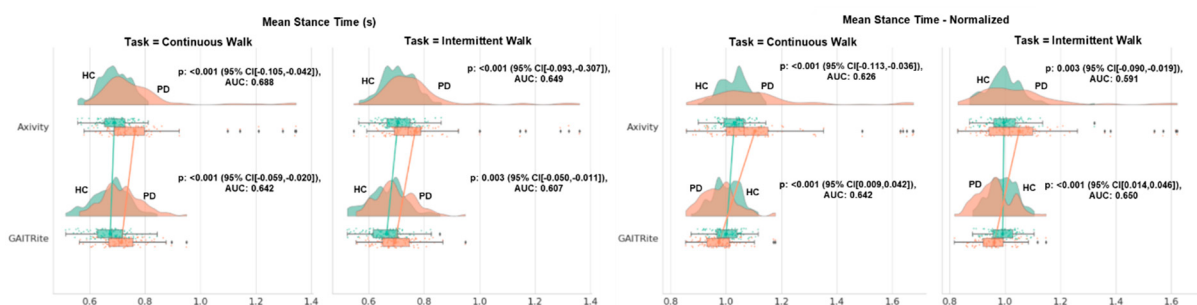
Sensing System – Walk	Raw Gait Characteristics		Normalized gait characteristics	
	Characteristics name	Importance	Characteristics name	Importance
Axivity – Continuous	Step Time Variability	7.84	Step Velocity Variability	1.10
	Stance Time Variability	6.76	Mean Swing Time	0.72
	Swing Time Variability	5.62	Mean Step Length	0.49
	Step Velocity Variability	3.80	Stance Time Variability	0.20
	Step Length Asymmetry	3.06	Step Length Variability	0.12
GAITRite – Continuous	Mean Step Velocity	0.81	Mean Step Length	3.80
	Mean Step Length	0.40	Mean Step Time	2.72
	Mean Step Time	0.12	Stance Time Asymmetry	1.21
	Mean Stance Time	0.03	Mean Stance Time	1.10
	Mean Swing Time	0.03	Swing Time Asymmetry	0.72
Axivity – Intermittent	Step length Asymmetry	3.61	Mean Step Length	0.22
	Stance Time Variability	3.24	Mean Stance Time	0.20
	Step Time Variability	2.89	mean Swing Time	0.15
	Swing Time Variability	1.69	Swing Time Variability	0.14
	Step Time Asymmetry	1.21	Mean Step Time	0.07
GAITRite – Intermittent	Mean Step Velocity	1.32	Mean Step Time	0.23
	Mean Step Length	0.45	Step Velocity Variability	0.22
	Step Velocity Variability	0.09	Step Length Variability	0.15
	Mean Step Time	0.03	Swing Time Variability	0.14
	Step Length Asymmetry	0.03	Mean Step Length	0.09

Table S4. Random forest (RF) classification performance after gait normalization

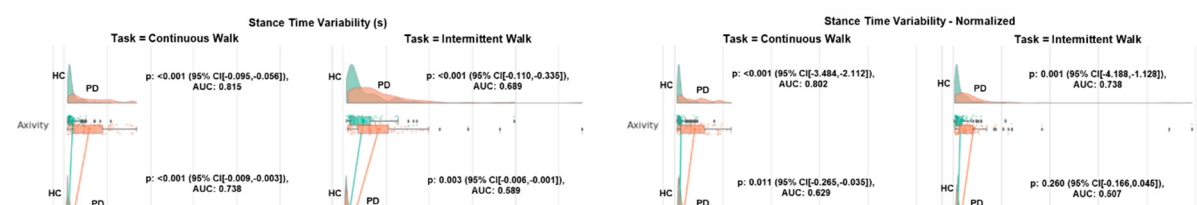
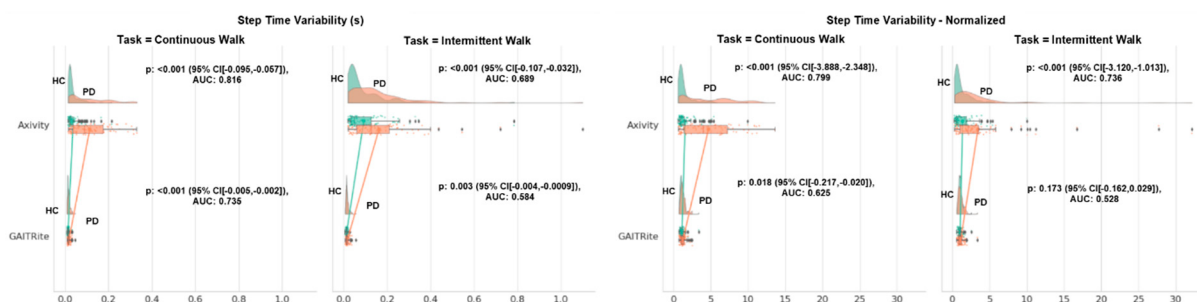
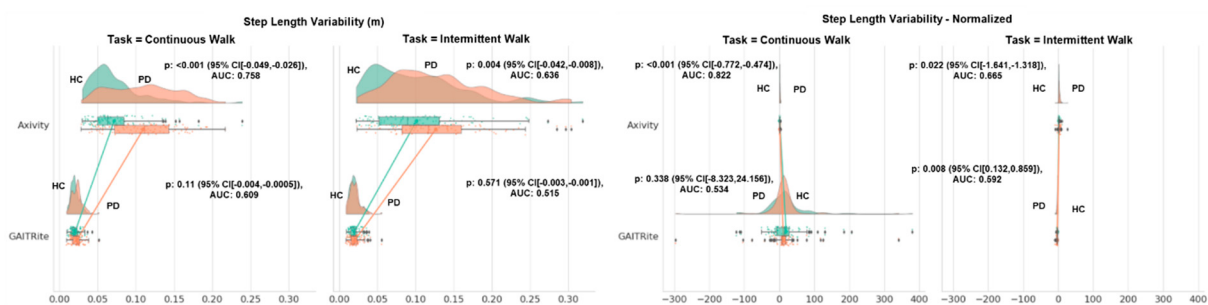
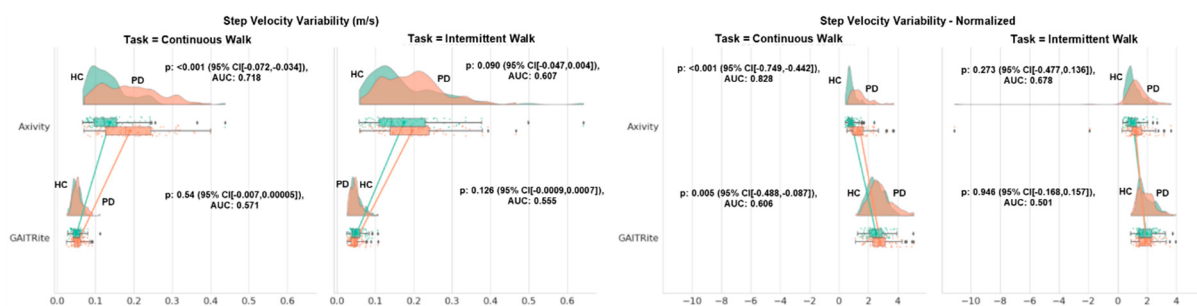
Sensing Systems	Walking Protocols	
	Continuous Walk	Intermittent Walk
Axivity (AX3)	83.45 ± 8.38	78.45 ± 9.97
GAITRite	69.14 ± 11.27	69.13 ± 11.62

Figure S1. Distribution of the gait characteristics from 5 domains of conceptual gait model with statistical analysis





Variability Domain



Asymmetry Domain



Postural Control Domain

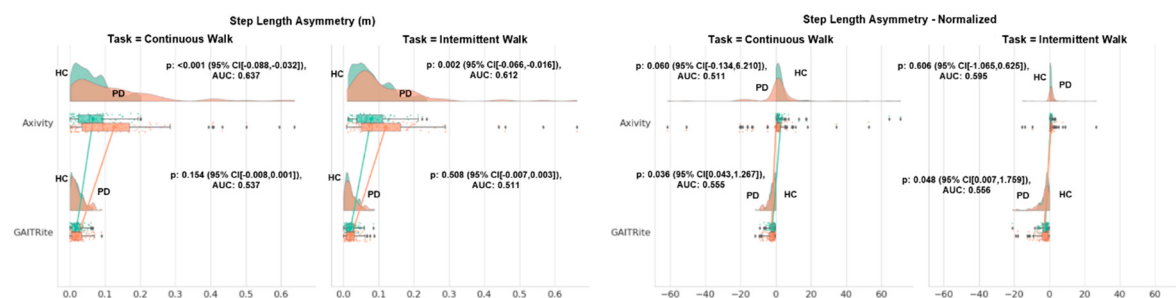


Figure S2. Correlations among gait characteristics before and after normalization

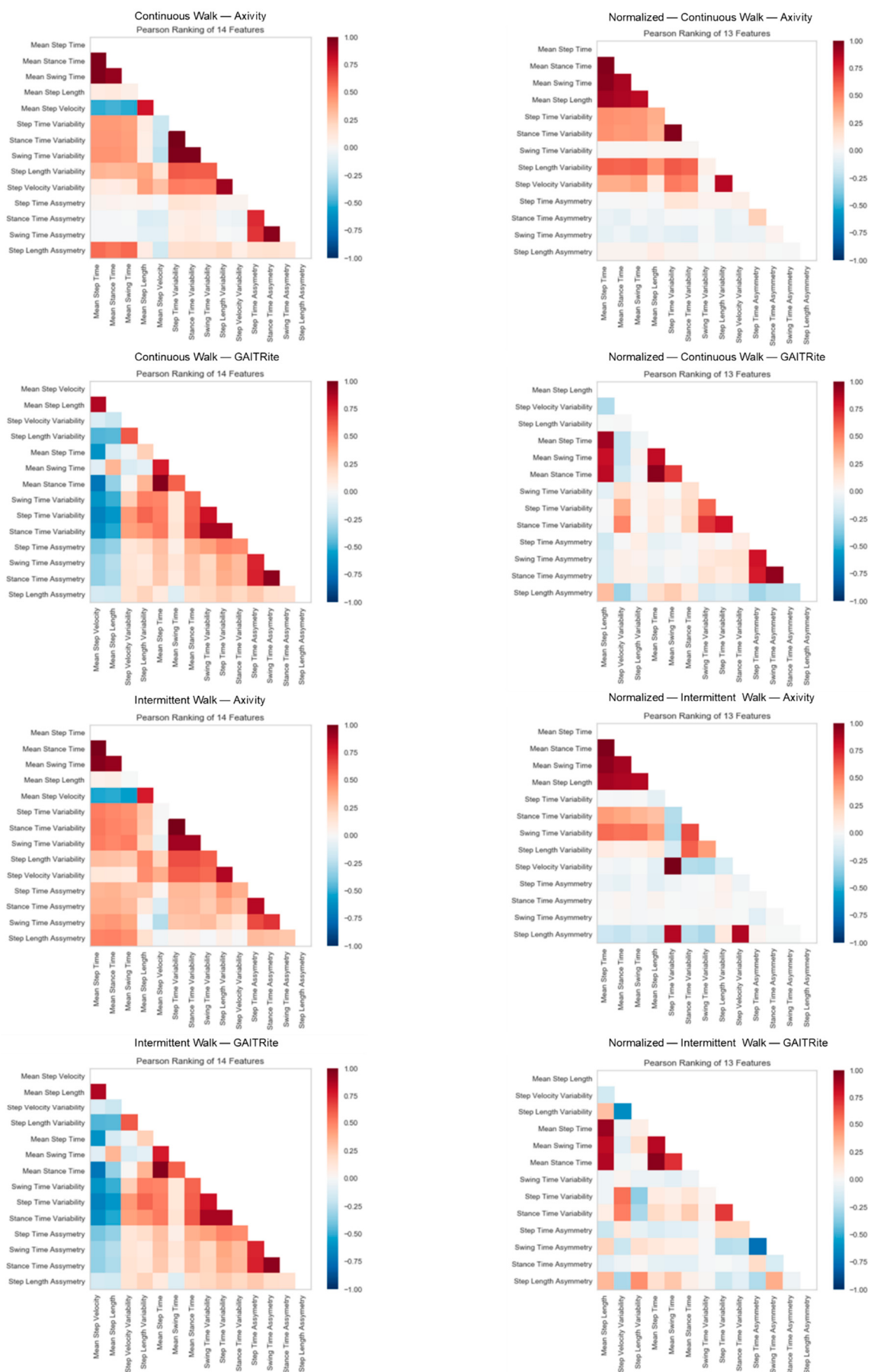


Figure S3. Contribution of the gait characteristics in the classification modelling in Support vector machine

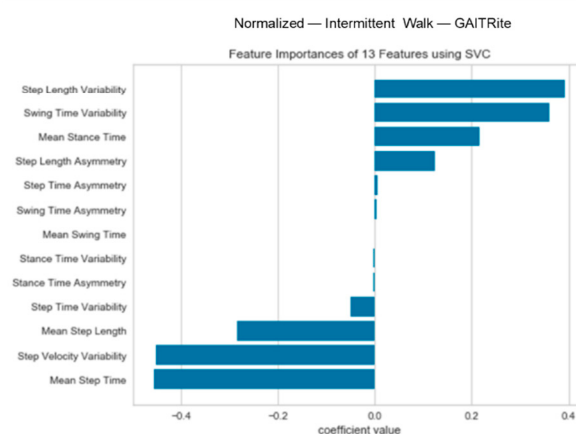
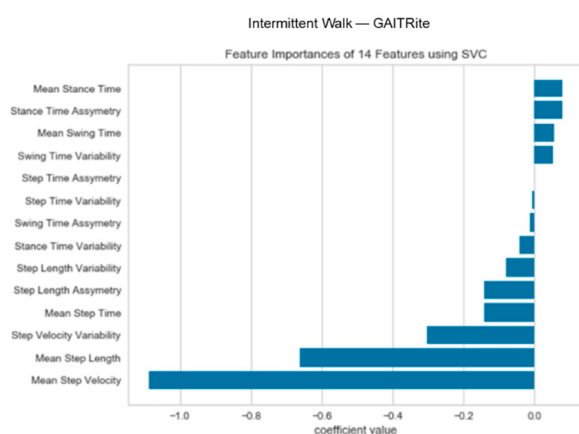
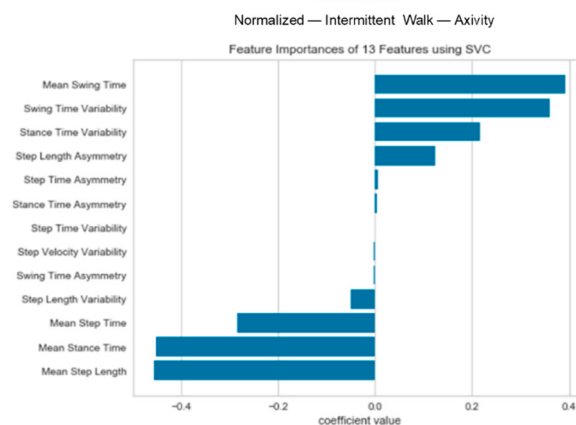
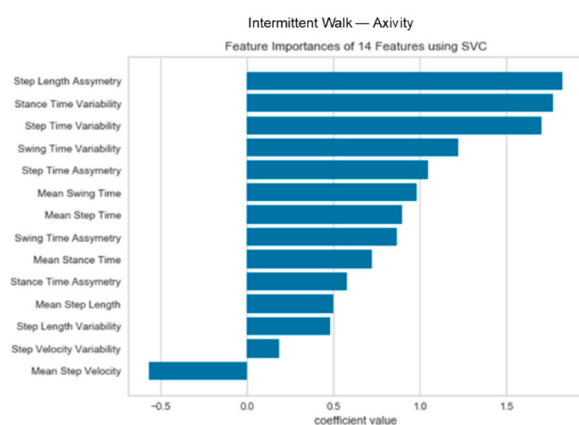
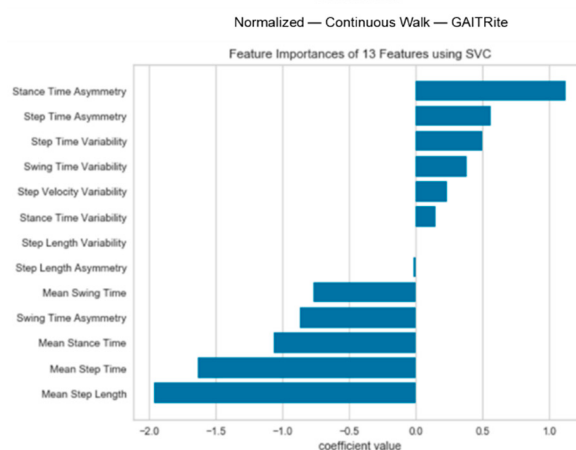
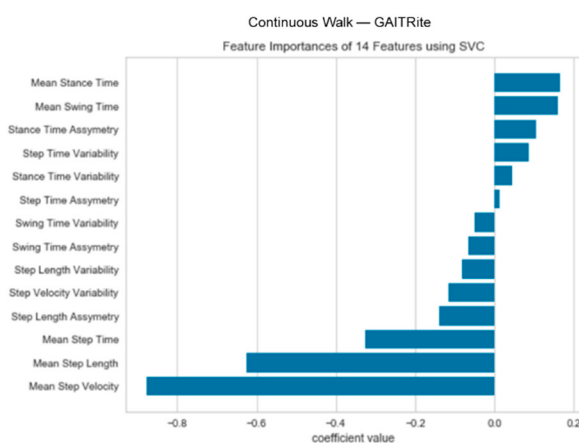
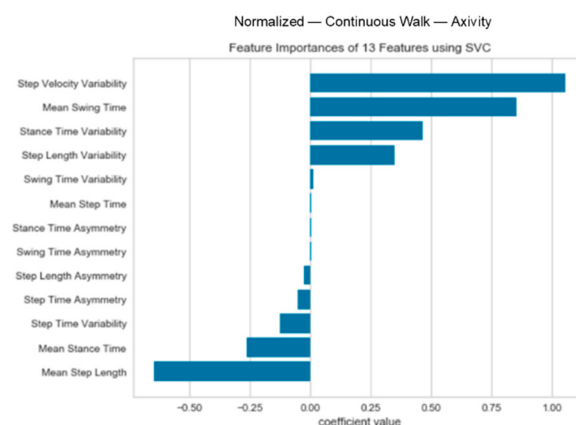
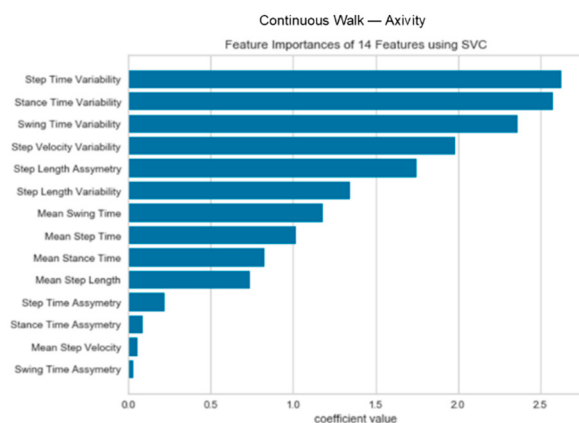


Figure S4. SVM performance before gait characteristics normalization