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Gait Assessment – Methods Document

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Summary

Gait disturbances play a major role in the motor manifestation of PD. Traditional assessments aimed at measuring motor deficits, including the UPDRS, do not identify subtle differences in individuals at risk for PD, while quantitative measures have shown promise in this. Therefore, more sensitive tests of motor function are needed to increase the likelihood of identifying pre-diagnosis motor changes. Quantitative measures of gait and mobility should provide a means for assessing pre-diagnosis changes and measures of disease progression.

The Gait study was proposed in order to obtain quantitative, objective motor measures that could inform on pre-clinical symptoms, progression markers, and dynamic changes of function throughout disease and potential modifiers and mediators of motor symptoms. This project was proposed as a sub-study within the PPMI genetic cohort project to add information, which could enhance the current PPMI protocol and dataset.

Method

The gait system used includes three lightweight wireless wearable sensors containing three axial accelerometers, gyroscopes and magnetometers (Opal, APDM Ltd.). The system measures acceleration of movement in three orthogonal axes as a function of time. The recording unit is small, lightweight and housed in a custom-made Velcro-belt. The sensors are worn on both wrists and on the lower back of the participants during all gait measurements to quantify temporal measures. The system is robust and data collected has been validated on large cohorts.
The designed protocol includes an assessment performed during annual visits of subjects in the genetic cohort group. Assessment includes six tests:

- Sway 30 sec eyes open – center of mass displacement during usual condition.
- Sway 30 seconds eyes closed- center of mass displacement during challenging condition.
- Timed Up and Go (TUG) 1- assessment of mobility, transfers and turns.
- TUG 2- repeated task.
- Usual walk- 1 minute- preferred walking speed

- Dual task walk-1 minute- walk while simultaneously serially subtracting 3's from a predefined 3-digit number (e.g., 476) for 1 minute.

Gait features extracted from the test

Motor features extracted from the raw accelerometer and gyroscope signals are presented in the tables below. Features reflect spatial temporal measures of consistency, rhythmicity and smoothness (Jerk) for each of the tasks performed during the test. These features are obtained for both the usual and challenging conditions to be compared between tasks and over time.

Sway	Timed Up and Go (TUG)	Walking	Arm swing	Axial
velocity (mm/s)	TUG duration (s)	Walk Speed (m/sec)	Amplitude_Right_arm (deg)	Trunk Rotation Asymmetry (%)
Sway path (mm)	Number of steps	Cadence (steps/min)	Amplitude_Left_arm (deg)	Average Amplitude trunk (deg)
centroidal frequency (Hz)	Average step duration during straight walking (s)	Average stride time (sec)	Variability _Right_arm (%)	
Jerk ($m^2/s^{5)}$	Average step duration during turns (s)	Stride CV (%)	Variability _Left_arm (%)	
	Step regularity [g^2]	Step Regularity	Symmetry Right/Left	
	Step Symmetry	Step Symmetry	Jerk Right ($deg/^3$)	
		Jerk ($deg/^3$)	Jerk Left ($deg/^3$)	
			Asymmetry_index	

Data Processing and data transfer

Data from the gait assessments in each site is saved onto a designated computer at the site and later transferred to a central database at TASMC for processing. Once received, TASMC's engineer, explores the data for quality and integrity and processes the data to extract the features from the raw accelerometer and gyroscope signals using validated algorithms. Data is then checked again to ensure quality and accuracy.

The team at TASMC worked with CTCC to create a data legend and an infrastructure for the transfer of data to the PPMI website (LONI) as open access data (see table below). All subjects retain their PPMI unique identification number, thus the gait data could be combined with other information collected in PPMI. Data obtained in the gait study is transferred regularly, every month, in a cumulative manner to ensure integrity and reduce possible errors.

Measure	**Descriptive**	**Calculation method**
	Walk	
SP_U SP_DT	Speed base walking and Dual task walking (m/sec)	Calculated from the 10m walking time. Same procedure for usual walking and dual task walking
RA_AMP_U RA_AMP_DT	Right arm amplitude base and Dual task walking (deg)	Average Amplitude of the Right arm presented in degrees. Calculated from the right wrist accelerometers as the range from peak anterior movement to posterior movement (rotational movement included into calculation based on Euler angles)
LA_AMP_U LA_AMP_DT	Left arm amplitude base and Dual task walking (deg)	Average Amplitude of the Left arm degree (same as above for the left)
RA_STD_U RA_STD_DT	Right arm variability (standard deviation) in base walking and Right arm standard deviation in Dual task walking (%)	Standard deviation of the average amplitude of the Right arms presented in degrees. Calculated from the right wrist accelerometers as the range from peak anterior movement to posterior movement (rotational movement included into calculation based on Euler angles)
LA_STD_U LA_STD_DT	Left arm standard deviation in base walking Left arm standard deviation in Dual task walking (%)	Standard deviation of the Left arm degree (same as above)
SYM_U SYM_DT	Between arm symmetry base walking Between arm symmetry Dual task walking (%)	$Sym = 1 - \frac{Average\ Amplitude\ Right}{Average\ Amplitude\ Left}$
R_JERK_U R_JERK_DT	Jerk from right arm in base walking Jerk from right arm in Dual task walking (deg/sec^3)	Jerk is the rate of change of acceleration, is a measure of smoothness calculated from the derivative right arm acceleration with respect to time.
L_JERK_U L_JERK_DT	Jerk from Left arm in base walking Jerk from Left arm in Dual task walking (deg/sec^3)	Jerk is a measure of smoothness calculate from the angel of the left arm (same as above)
ASA_U ASA_DT	ASA between arms in base walking ASA between arms in Dual task walking (%)	The ASA represent asymmetry in arm swing magnitude between arms.

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		$$ASA = \left\lvert \frac{45^0 - \arctan\left(\frac{Greater\ hand\ Amplitude}{Smaller\ hand\ Amplitude}\right) * 100\%}{90} \right\rvert$$ The ASA is designed to represent asymmetry in arm swing magnitude between each arm. A value of 0.00 would indicate that both arms are moving exactly the same magnitude.
ASYM _IND_U ASYM _IND_DT	Asymmetry index calculated from arms in base and dual task walking (%)	$$Asymmetry\ Index = \left\lvert \frac{Av_{Amplitude_L} - AV\_Amplitude_R}{Av_{Amplitude_L} + AV\_Amplitude_R} \right\rvert * 100\%$$
TRA_U TRA_DT	Trunk Rotation asymmetry index in base walking and dual task (%)	Calculated from the acceleration signal from the lower back sensor, we quantified trunk rotation to the left and to the right as the transverse plane angular rotation of the thorax. The magnitude of trunk rotation was quantified as the total side-to-side rotation of the thorax during a stride cycle. We then calculated the trunk rotation asymmetry (TRA) as follows: $$TRA = \left\lvert \frac{45^0 - \arctan\left(\frac{Trunk_{more}\ magnitude}{Trunk_{less} magnitude}\right) * 100\%}{90} \right\rvert$$
T_AMP_U T_AMP_DT	Average trunk amplitude of rotational movement in base and Dual task walking (deg)	Average Amplitude of rotational movement around the vertical axis of the trunk in degrees. Calculated from the Euler angles from the lower back sensor.
CAD_U CAD_DT	Cadence in base and Dual task walking (step/min)	Number of gait cycles taken within one minute of walking. Calculated from the acceleration signal from the lower back sensor
STR_T_U STR_T_DT	Average stride time in base and dual task walking (sec)	Stride time average during straight-line walking (turns excluded). Calculated from the vertical acceleration signal from the lower back sensor.
STR_CV_U STR_CV_DT	Stride variability (coefficient of variation-CV) in base and Dual task walking (%)	Average Stride CV from straight-line walking (turns excluded). Calculated from the vertical acceleration signal from the lower back sensor.
STEP_REG_U STEP_REG_DT	Step Regularity in base and Dual task walking (g^2)	Derived from the autocorrelation signal of the vertical acceleration from the lower back

		sensor. Steps of both legs are averaged to provide one measure. Perfect regularity (i.e., no variability) result in correlation coefficients of 1.
STEP_SYM_U STEP_SYM_DT	Step Symmetry in base and dual task walking	Step symmetry were derived from frequency analysis of vertical acceleration signals using autocorrelation.
JERK_T_U JERK_T_DT	Jerk of the acceleration movement of the legs during base and dual task walking (m/sec^3)	Jerk calculated as the time- derivative of trunk acceleration, to quantify smoothness.
	Sway	
SW_VEL_OP SW_VEL_CL	Sway velocity (m/sec) in Eyes open and Eyes closed conditions (30 sec each)	Mean velocity is obtained through the derivative of the displacement the anterior-posterior (AP) and medial- lateral (ML) acceleration of the sensor on the lower back
SW_PATH_OP SW_PATH_CL	Sway path (m/sec^2) in Eyes open and Eyes closed conditions (30 sec each)	Total length of CoP (Center of pressure)) trajectory , calculated from the anterior-posterior (AP) and medial- lateral (ML) acceleration of the sensor on the lower back
SW_FREQ_OP SW_PATH_CL	Centroidal frequency (HZ) in Eyes open and Eyes closed conditions (30 sec each)	The frequency at which the spectral mass is concentrated. Calculated from the anteriorposterior (AP) acceleration using Fast Fourier Transformation (FFT).
SW_JERK_OP SW_JERK_CL	Jerk sway (m/sec^3) in Eyes open and Eyes closed conditions (30 sec each)	A measure of Sway smoothness. Calculated as the time-derivative of the anterior-posterior (AP) and medial- lateral (ML) acceleration from the sensor on the lower back.
	TUG	
TUG1_DUR TUG2_DUR	TUG 1 and 2 duration (sec)	The time from start of sit-to-stand (the minimum AP acceleration peak before the signal started to rise from steady state), until end of stand-to-sit (the minimum acceleration peak when the AP acceleration reached steady state).
TUG1_STEP_NUM TUG2_STEP_NUM	TUG 1 and 2 number of step (#number)	Number of steps throughout the duration of the task including turns.
TUG1_STRAIGHT_DUR TUG2_STRAIGHT_DUR	TUG 1 and 2 Average step duration during straight walking (sec)	Average time initial gait step (detected from back sensor vertical acceleration) until 1st turn (detected from back sensor gyroscope –yaw) + duration from end of 1st turn until beginning of turn to sit.

TUG1_TURNS_DUR TUG2_TURNS_DUR	TUG 1 and 2 Average step duration during turns (sec)	Turning measures were derived from the yaw axis of the back gyroscope. The start and end points of each turn were determined as the points in the yaw signal in which it crossed 0.1 of the maximum yaw peak amplitude of the turn. Average step duration for these segments is calculated from the vertical acceleration signal.
TUG1_STEP_REG TUG2_STEP_REG	TUG 1 and 2 Step regularity (g^2)	Step regularity was derived from the autocorrelation signal of the vertical acceleration.
TUG1_STEP_SYM TUG2_STEP_SYM	TUG 1 and 2 step symmetry	$step\ symmetry = \frac{step\ regularity}{stride\ regularity}$

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