

Quantitative assessment of repetitive lower limb movements used in the MDS-UPDRS-III scale in healthy subjects

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Background

The Movement Disorder Society Unified Parkinson's Disease Rating Scale (MDS-UPDRS) [1] is used as a standardized approach to assess motor function in Parkinson's disease (PD). This assessment is based on the examiner's subjective judgement and is therefore variable. While quantitative approaches have been evaluated for upper-limb movements, data is scarce on lower-limb movements.

The main objective of this paper is to identify and validate promising approaches for the quantitative measurement of alternating foot movements in healthy subjects from the MDS-UPDRS scale, focusing on part 3.7 (toe tapping) and 3.8 (leg agility). In a study by Rovini [2], the same foot movements were measured with inertial measurement units (IMU) and the results were compared with those of the present study. Additionally, we aim to characterize various frequency patterns and analyze how they change over time. We hypothesized that by quantitative measurements, accurate and precise assessment of the movements are possible in healthy subjects. This approach enables the identification of possible movement patterns that cannot be recognized using qualitative methods. Moreover, the measurements can provide a basis for comparison for future studies we aim to enhance our understanding of foot movement dynamics and improve diagnostic capabilities of PD-patients.

Material and Methods

All participants (n=23) performed five 20-second trials for both toe tapping and leg agility. Foot and leg movements were recorded using four IMU (Figure 1). The raw data was segmented, and various biomarkers were extracted to characterize foot-movement dynamics. The extracted biomarkers were analyzed and evaluated by dominant and non-dominant leg categories.



Figure 1: The fully-equipped participant during the study; 4 IMUs (MTw Awinda, Xsens Technologies B.V., Enschede, Netherlands) were attached to the subject using Velcro patches and straps to both ankles and both feet. The axes of the Xsens MTw Awinda are shown on one side (x-axis in red, y-axis in green, z-axis in blue) and are identical on the other side.

Each test began with the subject sitting in the neutral position on the chair (Figure 2B). For toe tapping, participants were instructed to tap the toes on the floor repetitively over 20 seconds as hard and as fast as possible (Figure 2A). For assessing leg agility, the participants were instructed to lift the foot and stamp on the floor as high and as fast as possible over a period of 20s (Figure 2C).

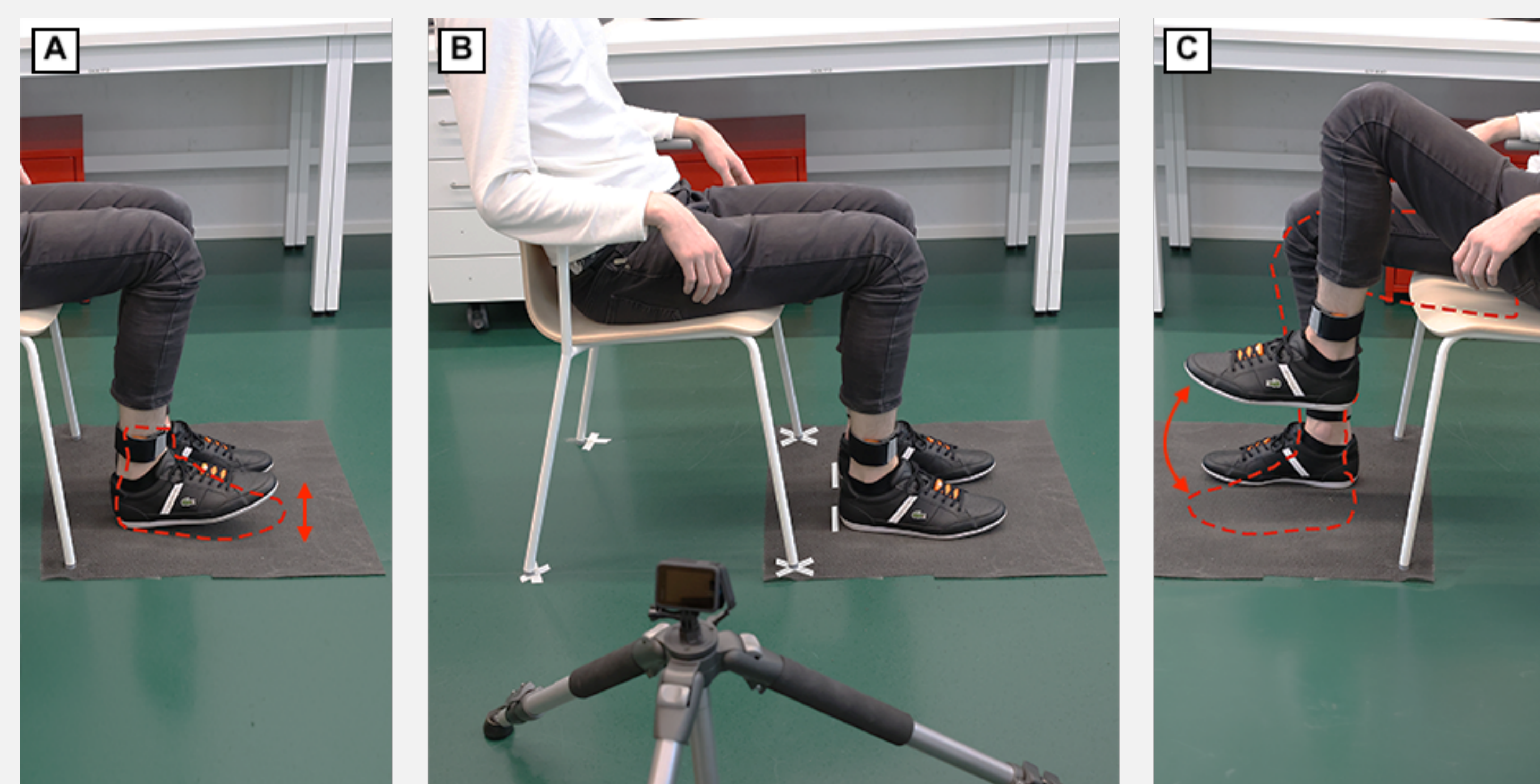


Figure 2: The participant was prepared for the examination in the designated neutral position (B). The positions of the chair legs and the ends of the participant's shoes were marked with tape on both the floor and the non-slip mat to ensure consistent positioning throughout the procedure. The participant performed toe tapping (A) and leg agility (C).

Results

The correlation between frequency and angle displayed non-linearity for toe tapping, with a clear decrease in angle above 2 Hz for a 20s exercise duration (Figure 3A) and no clear decrease in the first 10s (Figure 3B). Moreover, time samples are recorded at a frequency of 2 Hz over the entire angular range for the entire duration of the exercise.

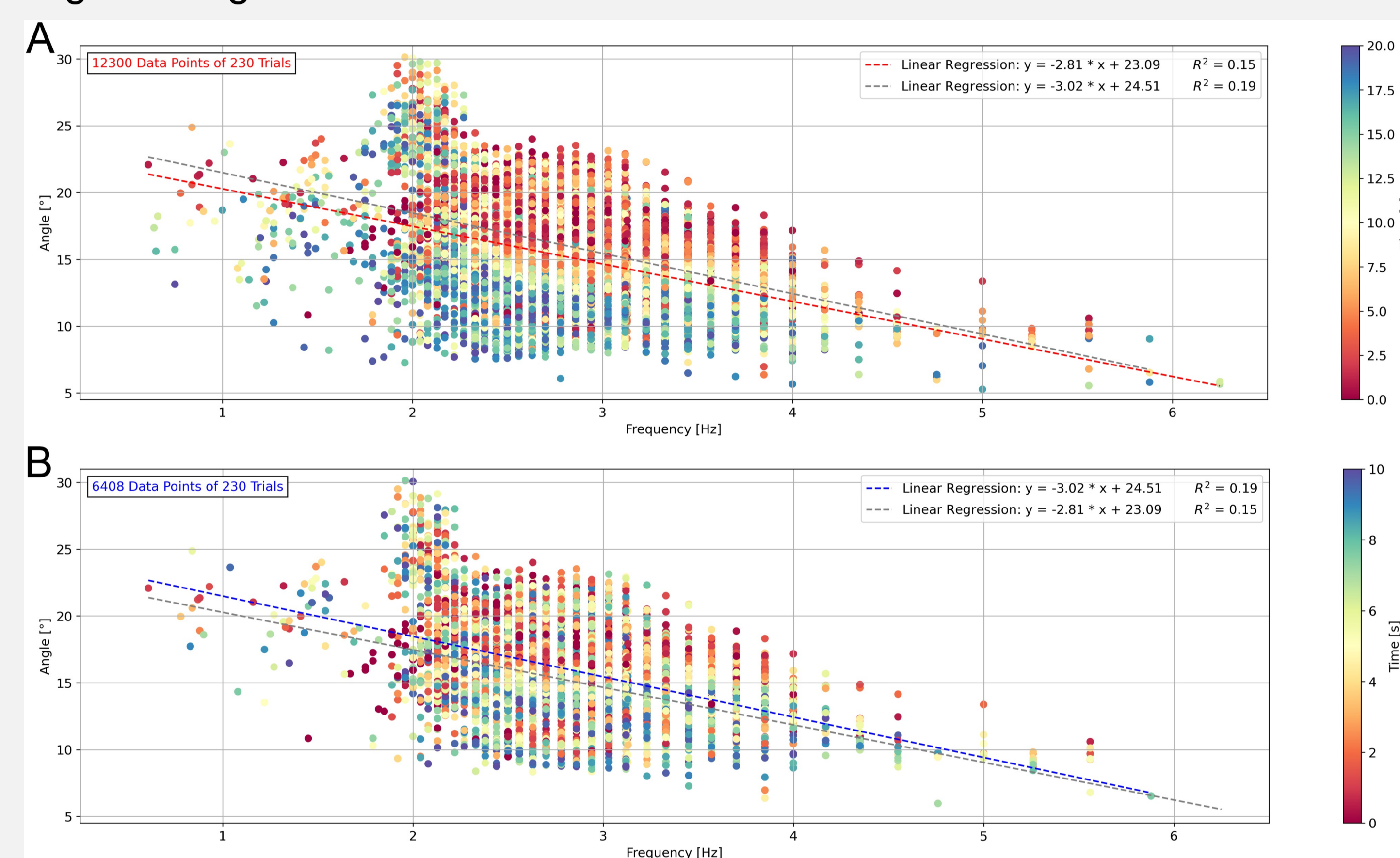


Figure 3: Frequency/angle correlation during toe tapping for all subjects for the 20-second test duration (A) and for the first 10 seconds (B). Each tap has a frequency and an angle and is represented as a point. The colors of the points depend on the time in the exercise (A: 0-20s / B: 0-10s). The linear trend line for all data points is shown as a red dashed line. The linear trend line for the data points in the first 10 seconds is shown as a blue dashed line.

A paired Wilcoxon test showed no significant differences in toe tapping and leg agility based on leg dominance. The median frequency and angle for toe tapping were 2.78 Hz and 15.1°. The median frequency for leg agility was 2.63 Hz. The percentage deviations of the interquartile range (IQR) from the median for each parameter are less than 30% for this study (except for DLJ). Overall, the deviations are significantly smaller, with the parameter values in our study showing significantly lower IQR and variability parameters compared to Rovini [2]. In general, the parameter values for Rovini were significantly higher in most cases (Table 1).

Parameter	Non-Dominant Leg		Dominant Leg		Left Leg (Rovini et al., 2020)		Right Leg (Rovini et al., 2020)	
	HC Median (IQR)	Dev. (%)	HC Median (IQR)	Dev. (%)	HC Median (IQR)	Dev. (%)	HC Median (IQR)	Dev. (%)
TT_Taps	28.0 (5.0)	17.86	28.0 (6.0)	21.43	28.0 (11.2)	38.94	29.0 (9.0)	81.08
TT_Freq [Hz]	2.78 (0.83)	19.06	2.78 (0.62)	22.30	3.29 (1.17)	38.56	2.89 (0.92)	81.88
TT_Freq_Var [%]	28.06 (18.42)	47.82	25.71 (14.88)	58.95	41.3 (25.4)	61.80	48.5 (28.6)	48.86
TT_Angle [°]	15.82 (4.07)	25.73	16.20 (4.13)	25.49	10.4 (5.3)	80.96	7.7 (5.8)	78.82
TT_Angle_Var [%]	20.98 (9.92)	45.76	21.84 (9.74)	44.50	60.8 (25.1)	58.21	70.1 (27.4)	59.09
TT_DLJ	7061.88 (12855.0)	182.02	6782.8 (11697.9)	202.29	-	-	-	-
TT_LLJ	8.86 (1.67)	18.85	8.66 (1.79)	20.67	-	-	-	-
TT_LLJ_Var [%]	35.22 (18.76)	52.10	35.2 (21.83)	61.18	-	-	-	-
TT_IAV	26.0 (5.0)	19.23	26.0 (6.0)	23.08	108.6 (4.2)	3.87	99.0 (17.7)	17.88
LA_Taps	2.68 (0.48)	18.25	2.63 (0.53)	20.15	3.86 (0.69)	17.88	3.59 (0.83)	23.12
LA_Freq [Hz]	12.23 (5.14)	42.02	11.41 (6.18)	54.16	-	-	-	-
LA_Acc [m/s ²]	122.7 (32.7)	26.65	124.82 (34.07)	27.30	-	-	-	-
LA_Acc_Var [%]	44.88 (19.74)	37.52	45.96 (12.78)	28.17	-	-	-	-
LA_IAV	6.12 (1.87)	28.65	6.2 (1.86)	21.94	140.5 (26.4)	18.79	104.5 (11.8)	11.29
LA_IAV_Var [%]	84.81 (18.07)	37.55	82.23 (11.94)	35.93	81.9 (23.4)	39.86	6.1 (16.6)	263.93
LA_Average Power	-	-	-	-	-	-	-	-
LA_Peak Power	-	-	-	-	111.1 (80.1)	72.10	127.8 (92.5)	72.88
							12.2 (28.4)	215.15
								13.3 (28.6)
								177.44

Table 1: Median, interquartile range (IQR) and associated percentage deviation of parameters for toe tapping and leg agility. Data were recorded for both healthy subjects (HS) and Parkinson's patients (PD) and are categorized by dominant and non-dominant leg for this study and left and right leg for the work of Rovini et al. [2]. Empty fields represent parameters that are only contained in one study.

Discussion

The significant fatigue of the angle parameter during toe tapping over 20 seconds supports limiting future measurements of this MDS-UPDRS 3 item to 10 seconds duration. With the angle of excursion being stable over time at a frequency of 2 Hz in healthy subjects, we propose the use of a metronome in future studies to optimize the consistency of data points. Relatively constant parameters were measured for leg agility, but these should be measured more accurately in the future by introducing standardized shoes to ensure even better comparability of results. The differences between the two projects can be attributed to different age groups, a different measurement setup and a slightly different movement execution in each case, which needs to be improved and clearly defined in further studies. With an even more precise characterization of the dynamics of foot movement, promising observations and evaluations in PD can be expected.

Literature

- [1] Goetz, Christopher G. (2008). The MDS-sponsored Revision of the Unified Parkinson's Disease Rating Scale.
- [2] Rovini et al. (2020). A Wearable System to Objectify Assessment of Motor Tasks for Supporting Parkinson's Disease Diagnosis. doi:10.3390/s20092630