JMD
https://doi.org/10.14802/jmd.19043 / J Mov Disord 2020;13(1):47-56
pISSN 2005-940X / eISSN 2093-4939

ORIGINAL ARTICLE

Comparison of Spontaneous Motor Tempo during Finger Tapping, Toe Tapping and Stepping on the Spot in People with and without Parkinson's Disease

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ABSTRACT

Objective Spontaneous motor tempo (SMT), observed in walking, tapping and clapping, tends to occur around 2 Hz. Initiating and controlling movement can be difficult for people with Parkinson's (PWP), but studies have not identified whether PWP differ from controls in SMT. For community-based interventions, e.g. dancing, it would be helpful to know a baseline SMT to optimize the tempi of cued activities. Therefore, this study compared finger tapping (FT), toe tapping (TT) and stepping 'on the spot' (SS) in PWP and two groups of healthy controls [age-matched controls (AMC) and young healthy controls (YHC)], as SMT is known to change with age.

Methods Participants (PWP; $n = 30$, AMC; $n = 23$, YHC; $n = 35$) were asked to tap or step on the spot at a natural pace for two trials lasting 40 seconds. The central 30 seconds were averaged for analyses using mean inter-onset intervals (*IOI*) and coefficient of variation (*CoV*) to measure rate and variability respectively.

Results PWP had faster SMT than both control groups, depending on the movement modality: FT, $F(2, 87) = 7.92$, $p < 0.01$ (PWP faster than YHC); TT, $F(2, 87) = 4.89$, $p = 0.01$ (PWP faster than AMC); and SS, $F(2, 77) = 3.26$, $p = 0.04$ (PWP faster than AMC). PWP had higher *CoV* (more variable tapping) than AMC in FT only, $F(2, 87) = 4.10$, $p = 0.02$.

Conclusion This study provides the first direct comparison of SMT between PWP and two control groups for different types of movements. Results suggest SMT is generally faster in PWP than control groups, and more variable when measured with finger tapping compared to stepping on the spot.

Key Words Age; Finger tapping; Movement; Parkinson's disease; Spontaneous motor tempo; Stepping; Toe tapping.

Tempo refers to the rate at which something repeats with regularity over time,[1] and in music, tempo commonly corresponds to the percept of a rhythmic beat. Thus, musical tempo is often described quantitatively in terms of beats per minute

Received: May 14, 2019 **Revised:** August 8, 2019 **Accepted:** November 11, 2019
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This study was conducted at the University of Hertfordshire as part of the first author's postdoctoral research fellowship (2016–2018) and was compiled at Lucerne University of Applied Sciences and Arts in 2019.
These data were presented at the Rhythm Perception and Production Workshop in Traverse City on 17–20 June 2019.
The data used to support the findings of this study are available in excel files from the corresponding author upon request.

(bpm). Typically, humans show a preference for music that has an interbeat interval of 500–600 ms (i.e., is performed between 100–120 bpm), so it is perhaps unsurprising that the rate of preferred repetitive movements (such as walking, tapping and/or clapping) is also within this tempo range.[2] van Noorden and Moelants[3] referred to this concept in general as the 2 Hz human resonance theory (i.e., two cycles per second or 500 ms interbeat intervals). Early studies have suggested that the most common spontaneous motor tempo (SMT) was around 600 ms.[4] However, large individual differences in SMT have been observed, ranging from 300 ms to 800 ms intervals.[5] Although SMT is very reliable (correlations of measures taken across time are between 0.75–0.95), it changes over one's lifespan.[6] Studies show that children between four and seven years old have a fast SMT (300–400 ms, or 200 bpm), adults' SMT is slower (500–600 ms), and the SMT in older adults is even slower (approximately 700 ms or approximately 86 bpm).[7-9] The SMT is also affected by factors other than age, such as genetics and musical training. Twin studies suggest that although identical twins have very similar SMTs, those of nonidentical siblings vary.[4] Musical training increases the trajectory of change (i.e., slows the SMT) from childhood to adulthood.[8] However, there is little evidence to suggest that an SMT is linked to an individual's sex, handedness, body size, or heart rate.[7]

The notion of an SMT, also referred to as 'preferred', 'optimal' or 'natural' timing, is suggestive of a type of motor agency (in terms of linking feelings of control to volitional actions) that are problematic for people with Parkinson's disease (PWP).[10,11] This is because Parkinson's disease (PD) affects both the perception of time and the production of timed motor activities (including initiating and regulating movements) due to the loss of dopamine-producing neurons in the substantia nigra pars compacta.[12] The symptoms vary across individuals but can include tremor, postural instability, rigidity, akinesia and bradykinesia, resulting in functional difficulties when walking, such as freezing of gait, and/or festination (a hastening of steps difficult to stop), both of which can lead to high incidences of falling and associated complications.[13-15] Symptoms of PD also include nonmotor difficulties, such as depression, anxiety, apathy, disturbances in sleep and digestive cycles and cognitive decline.[16] Although cognitive decline is often considered a problem related to later stages of PD, it is likely that the perception of time is disturbed in earlier stages of PD.[17]

Experimental studies of timing in PD have generally relied on a finger tapping paradigm used in synchronization-continuation tasks to assess timed motor production.[12] In the task paradigm, synchronization occurs during a paced condition (i.e., tapping is guided by an external cue), whereas continuation occurs during an unpaced condition (tapping continues after the pacing cue ceases). Jones and Jahanshahi[12] compiled these synchronization-continuation studies and found mixed results in terms of finger tapping rates during the continuation condition, which may suggest differences in SMT: PWP were either faster, slower or did not differ from controls in terms of unpaced finger tapping. However, the term unpaced is somewhat of a misnomer in synchronization-continuation task paradigms, as the tempo of the motor action has essentially been primed by the cue in the synchronization condition, which immediately precedes the unpaced (continuation) condition. To ascertain whether the SMT in PWP differs from that in controls, it is essential to measure timed motor movements in the absence of any cueing. Only two studies[18,19] have included a measure of explicitly spontaneous rather than self-paced movement prior to the presentation of stimuli to PWP, and both of these studies focused on finger tapping as the sole movement modality. Yahalom and colleagues[18] reported no significant difference between PWP (n = 51) who tapped their fingers at a rate of 680 ms (88 bpm) in comparison to controls (n = 36) who tapped their fingers at a rate of 581 ms (103 bpm). Benoit and colleagues[19] also found no difference in the SMT between PWP (n = 15) and controls (n = 10) in terms of the rate [PWP: mean = 580 ms, standard error of the mean (SEM) = 78.5 ms; Controls: mean = 600 ms, SEM = 63.9 ms] and variability [measured using the coefficient of variation (CoV)] (PWP: mean CoV = 0.05, SEM = 0.08; Controls: mean CoV = 0.05, SEM = 0.04).

Although self-initiated activity can be challenging for PWP, interventions such as rhythmic auditory stimulation have shown that synchronization to external rhythmic sounds (such as metronomes or music) can improve cyclic movements, such as walking.[20] This type of therapeutic approach includes identifying a clinical aim (such as increasing step length or reducing cadence) and then training a specific motor response to the sound cue, usually at either 10% above or below the individuals' SMT.[21,22] Consequently, the tempi of the cueing stimuli should be considered relative to the type of movement because an important aim for treatments for PWP (e.g., Parkinson's UK[23]) that are developed as individualized adjunct therapies is to improve the ability to perform functional movements in everyday life. Therefore, we compared the SMTs in three types of movements, toe tapping, stepping 'on the spot' (as a proxy for dancing), and finger tapping, in PWP, age-matched controls and young healthy controls to provide information on rehabilitation interventions for researchers, clinicians and practitioners. The first two types of movements are both types of movements that are typically related to music, and finger tapping is typically used in SMT and timed movement research.

MATERIALS & METHODS

This study was approved by the Health, Sciences, Engineering & Technology ECDA (Ethics Committee with Delegated Authority; Protocol Reference aLMS/SF/UH/02547) at the University of Hertfordshire. All participants provided written informed consent prior to the beginning of the study in accordance with the recommendations of the Helsinki Declaration.

Participants

The sample was split into three groups: younger healthy controls [YHC; n = 36, 29 females, mean age 20.75 [standard deviation (SD) 3.18] years, age range 18–32 years]; age-matched (to the PWP group) controls [AMC; n = 26, 12 females, mean age 64.35 (SD 13.02) years, age range 32–78 years] and PWP [n = 30, 20 females, mean age 62.23 (SD 10.48) years, age range 34–77 years]. All participants underwent cognitive impairment assessments using the Mini Mental State Examination. The exclusion criterion was a score on this assessment of <24,[24] and no participants were excluded on this basis.

The Parkinson's group was tested during the 'ON' state of their stabilized medication. The average time since diagnosis was 67.27 months (just over 5.6 years, SD = 59.19 months). The time since diagnosis ranged from 5 months to 272 months (21 years). The Unified Parkinson's Disease Rating Scale (UPDRS)[25] was used to evaluate their current status. For the overall score of the UPDRS (max = 176), the Group mean was 25.57, and the SD = 10.15. The scores for the three factors were as follows: mentation, behavior and mood (max = 16), mean = 3.5, SD = 1.68; activities of daily living (max = 52), mean = 10.43, SD = 4.68; and motor examination (max = 108), mean = 11.63, SD = 5.64. The Schwab and England Activities of Daily Living Scale[26] score for this sample ranged between 50 and 100% (mean = 82.33%, SD = 11.94%). The Hoehn and Yahr Scale[27] mean score was 1.78 (SD = 0.83), ranging from 1–4 in this sample (0 = min, 5 = max). Current medications were also recorded. Table 1 provides data for the PWP and relates the ascribed PD subtypes according to the established guidelines[28] (further details provided in Supplementary Table 1 in the online-only Data Supplement).

Table 1. Parkinson's disease participant information

Age*	Sex	PD duration†	PD sub-type‡	UPDRS total	H&Y§	LEDD (mg)
66	F	42	UC	3	0	290
44	F	48	TD	36	3	710
48	M	48	TD	31	3	240
76	F	43	UC	34	2	-
75	F	252	PIGD	29	5	925
65	F	228	TD	39	3	550
70	F	48	TD	25	1	280
63	M	108	TD	46	3	-
71	M	60	TD	27	3	1,056
69	M	192	PIGD	25	3	1,175
65	F	36	TD	25	2	-
56	F	144	PIGD	33	2	2,356
68	F	108	UC	12	1	540
77	F	36	UC	34	2	-
59	M	180	TD	44	3	-
49	M	11	TD	29	2	80
65	F	24	UC	41	2	-
73	F	6	UC	20	2	375
59	F	69	PIGD	45	2	328
54	F	72	TD	34	2	720
58	F	20	PIGD	36	2	500
60	M	90	UC	25	1	-
34	M	43	PIGD	62	2	1,880
67	F	72	UC	32	2	663
48	F	120	UC	19	2	1,274
70	M	24	UC	43	3	-
68	F	20	UC	12	1	340
52	M	5	UC	26	2	100
63	F	30	UC	23	1	100

*age in years; †time since diagnosis in months; ‡Parkinson's disease (PD) sub-type (Stebbins et al.[28], 2013); §Hoehn and Yahr Scale (Hoehn and Yahr[27], 1967). LEDD: levodopa equivalent daily dose, UPDRS: Unified Parkinson's Disease Rating Scale (Fahn and Elton[25], 1987), F: female, M: male, UC: unclassified, TD: tremor dominant, PIGD: postural instability/gait difficulty.

Equipment

Finger and toe tapping data were collected using a stomp box [Acoustim8, Series 100, UK used by musicians (generally in acoustic music) to provide a bass drum sound. Full technical details are reported in Rose et al.,[29] 2019]. Heel strike data for stepping on the spot were gathered using BioPac (Biopac Systems Inc., Goleta, CA, USA) heel and toe strike transducers (Model RX111) attached to BioNomadix ankle sensors (Model BN-TX STRK2-T). The MP150 unit communicated with a UIM100C unit (for tapping) and two BioNomadix STRK2-R units (for stepping). A metal thimble provided auditory feedback for participants during the finger tapping condition. During the toe tapping and stepping conditions, the participants could hear the sounds of the transducers striking the stomp box or the floor.

Procedure

The participants first provided demographic information and completed the screening tests, and the PWP completed the UPDRS. The participants were then asked to tap (with their finger, then with their toe, and finally step on the spot) at their

"most comfortable, natural rate that was neither too fast nor too slow, but felt 'just right'", as established by McAuley et al.[7] (p. 353). These data were collected in two trials lasting 30 seconds each. As the instructions focused on spontaneous repetitive movements, the participants chose whichever hand or foot they felt most comfortable to use for this specific task. Therefore, the participants were also asked which hand or foot was preferred for tapping to music to compare potential differences between the (hypothetical) tasks. These data are presented in Table 2, and data relating to the laterality of PD are presented in the Supplementary Table 1 in the online-only Data Supplement.

Table 2. Hand and foot that was used spontaneously and was preferred for tapping to music by group

Group	Used during SMT task				General preference			
	Hand	*n*	Foot	*n*	Hand†	*n*	Foot†	*n*
PWP	Right	25	Right	22	Right	17	Right	19
	Left	4	Left	5	Left	2	Left	3
	Both*	1	Both*	3	Alternating	1	Alternating	2
					Either	2	Either	4
					Prefers foot	8	Prefers hand	2
AMC	Right	24	Right	24	Right	10	Right	17
	Left	2	Left	2	Left	3	Left	3
	Both*	0	Both*	0	Alternating	1	Alternating	1
					Either	3	Either	4
					Prefers foot	9	Prefers hand	0
YHC	Right	34	Right	34	Right	24	Right	22
	Left	2	Left	2	Left	2	Left	3
	Both*	0	Both*	0	Alternating	6	Alternating	10
					Either	2	Either	1
					Prefers foot	2	Prefers hand	0

*used the right side for one trial and the left side for the other trial; †goal directed; in this instance the goal suggested was tapping to music or a metronome. SMT: spontaneous motor tempo, PWP: people with Parkinson's disease, AMC: age-matched controls, YHC: young healthy controls.

Data preparation and analyses

The inter-onset interval (*IOI*) refers to the time interval between the onsets of two successive strikes produced by a participant (i.e., finger or toe tap or a step). The mean *IOI* indicates the rate of the SMT. A second dependent variable, the *CoV*, measured the within-subject performance variability and was calculated as the *IOI* standard deviation/*IOI* mean×100).[30,31]

Equipment failure resulted in the loss of data from 25 out of a potential 368 trials (6.79%) across the 92 participants. Following distribution analyses, one outlier was removed from the FT *CoV* data (FT *CoV* = 93.42) to reach the criterion for Levene's statistic (i.e., not significant). This adjustment did not change the nature or outcome of the analyses. Effect sizes are reported as partial eta squared (interpreted as small = 0.01, medium = 0.06, and large = 0.14).[32,33] Tukey's honestly significant difference (HSD) post hoc analyses were used to explore significant findings. Analyses were conducted using SPSS Software (ver. 23 and ver. 25, IBM Corp., Armonk, NY, USA)

RESULTS

Descriptive

Table 3 presents the mean *IOI* for the SMTs for each group in each movement modality, and Table 4 presents the mean

Table 3. Mean inter-onset interval (*IOI*) for spontaneous movement tempo by group and movement modality

IOI	Group	*n*	Mean (ms)	SD (ms)	Minimum (ms)	Maximum (ms)	Bpm conversion
Finger tapping	Whole sample	90	531.77	125.12	223.09	916.31	112.83
	PWP	30	476.57	127.40	226.02	852.34	125.90
	AMC	24	515.39	78.74	223.09	636.65	116.42
	YHC	36	588.69	127.11	412.25	916.31	101.92
Toe tapping	Whole sample	88	509.03	111.30	281.14	878.63	117.87
	PWP	30	463.78	101.40	281.14	739.37	129.37
	AMC	23	553.40	86.11	436.45	878.63	108.42
	YHC	35	518.65	122.04	288.34	870.14	115.68
Stepping on the spot, right heel	Whole sample	83	519.34	69.92	326.79	749.48	115.53
	PWP	29	493.31	62.29	361.77	621.43	121.63
	AMC	22	526.07	44.87	445.71	628.56	114.05
	YHC	32	538.30	83.82	326.79	749.48	111.46
Stepping on the spot, left heel	Whole sample	82	523.69	72.16	349.25	807.90	114.57
	PWP	29	495.09	64.09	349.25	627.26	121.19
	AMC	23	530.83	50.45	423.24	629.81	113.03
	YHC	30	545.86	85.32	421.15	807.90	109.92

SD: standard deviation, Bpm: beats per minute, PWP: people with Parkinson's disease, AMC: age-matched controls, YHC: young healthy controls.

CoV for the SMTs for each group in each movement modality.

Group analyses

Analyses of variance by group was conducted for *IOI* and *CoV*, and the results are presented by movement modality. Post hoc Tukey's HSD analyses were performed to illustrate the nature of the differences (Figure 1 and 2).

Correlations

Overall, according to the two-tailed Pearson product-moment coefficients, the movement modalities were highly correlated with each other for both *IOI* and *CoV* in the whole sample (Table 5), but the correlations for TT and SS (right heel) failed to reach the significance level. However, as shown in Table 5, in contrast to the whole sample data, the PWP data showed a disruption in the relationship between effector movements (i.e., finger and toe tapping) and whole/body movement.

There were strong correlations between the right and left foot stepping conditions for the whole sample (Table 5) and for PWP; the correlation in the *IOI* mean was $r(29) = 0.93$, $p < 0.01$,

Table 4. Mean coefficient of variation (*CoV*) for spontaneous movement tempo by group and movement modality

CoV	Group	*n*	Mean (ms)	SD (ms)	Minimum (ms)	Maximum (ms)
Finger tapping	Whole sample	89	32.77	15.30	13.16	93.42
	PWP	29	38.16	19.81	19.97	93.42
	AMC	24	25.71	9.36	13.16	48.75
	YHC	36	33.14	12.61	19.71	69.77
Toe tapping	Whole sample	88	33.11	10.96	14.65	70.49
	PWP	30	33.98	10.93	21.64	70.49
	AMC	23	31.19	9.07	15.44	48.64
	YHC	35	33.64	12.19	14.65	63.84
Stepping on the spot, right heel	Whole sample	83	26.45	12.04	8.87	64.43
	PWP	29	24.97	10.67	8.87	50.09
	AMC	22	23.62	9.89	9.20	42.48
	YHC	32	29.75	13.98	9.61	64.43
Stepping on the spot, left heel	Whole sample	82	27.34	17.66	9.02	112.16
	PWP	29	26.93	16.85	9.02	74.50
	AMC	23	30.42	23.07	9.54	112.16
	YHC	30	25.37	13.46	9.39	52.66

SD: standard deviation, PWP: people with Parkinson's disease, AMC: age-matched controls, YHC: young healthy controls.

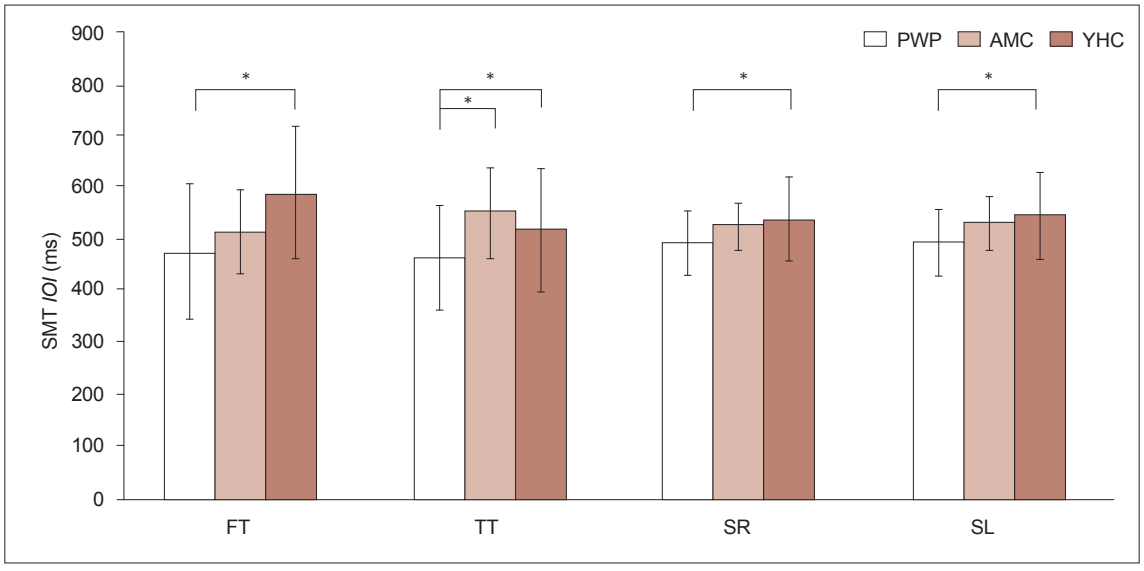

Figure 1. The group differences in spontaneous motor tempo (SMT) inter-onset intervals (*IOI*). The error bars display the standard deviation. An asterisk (*) identifies significant differences between groups ($p < 0.05$). FT: finger tapping, TT: toe tapping, SR: ss right, SL: ss left, PWP: people with Parkinson's disease, AMC: age-matched controls, YHC: young healthy controls.

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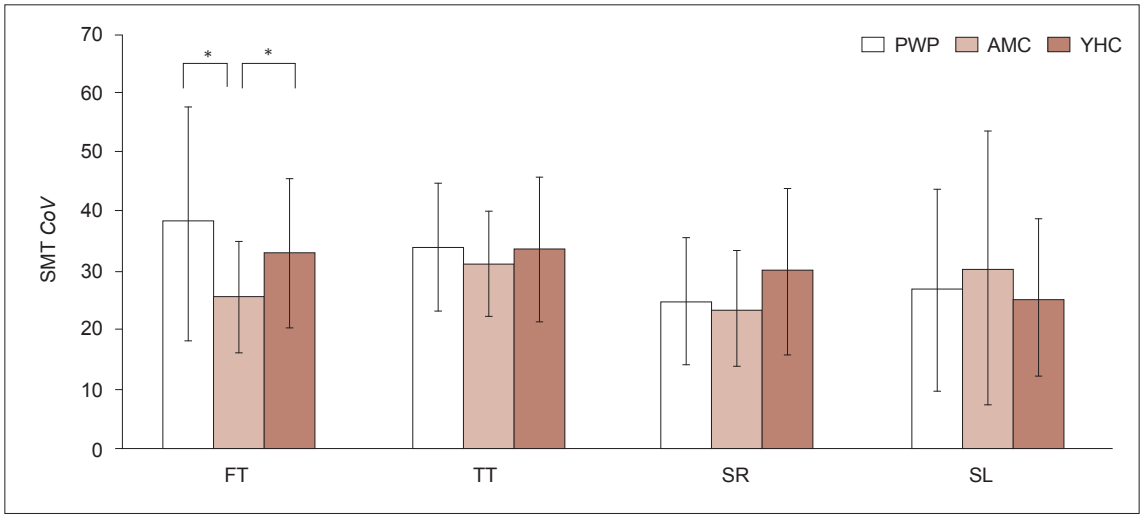

Figure 2. The group differences in spontaneous motor tempo (SMT) coefficient of variation (*CoV*). The error bars display the standard deviation. An asterisk (*) identifies significant differences between groups ($p < 0.05$). FT: finger tapping, TT: toe tapping, SR: ss right, SL: ss left, PWP: people with Parkinson's disease, AMC: age-matched controls, YHC: young healthy controls.

Table 5. Pearson correlation results for the whole sample and for the Parkinson's disease group for the inter-onset intervals (*IOI*) and coefficients of variation (*CoV*) between movement modalities

Movement modalities	SMT *IOI*	SMT *CoV*
Whole sample		
Finger tapping—toe tapping	$r(86) = 0.71$, $p < 0.01$	$r(84) = 0.61$, $p < 0.01$
Finger tapping—stepping on the spot (right heel)	$r(82) = 0.31$, $p < 0.01$	$r(80) = 0.24$, $p = 0.03$
Finger tapping—stepping on the spot (left heel)	$r(81) = 0.463$, $p < 0.01$	$r(79) = 0.30$, $p < 0.01$
Toe tapping—stepping on the spot (right heel)	$r(80) = 0.22$, $p = 0.05$	$r(80) = 0.22$, $p = 0.05$
Toe tapping—stepping on the spot (left heel)	$r(78) = 0.38$, $p < 0.01$	$r(78) = 0.33$, $p < 0.01$
Stepping on the spot (right heel–left heel)	$r(77) = 0.96$, $p < 0.01$	$r(77) = 0.33$, $p < 0.01$
Finger tapping—stepping on the spot*	$r(76) = 0.36$, $p < 0.01$	$r(74) = 0.34$, $p < 0.01$
Toe tapping—stepping on the spot*	$r(74) = 0.24$, $p = 0.04$	$r(74) = 0.29$, $p = 0.01$
Parkinson's disease group		
Finger tapping—toe tapping	$r(30) = 0.77$, $p < 0.01$	$r(28) = 0.64$, $p < 0.01$
Finger tapping—stepping on the spot (right heel)	ns ($p = 0.11$)	ns ($p = 0.09$)
Finger tapping—stepping on the spot (left heel)	$r(29) = 0.48$, $p < 0.01$	$r(27) = 0.68$, $p < 0.01$
Toe tapping—stepping on the spot (right heel)	ns ($p = 0.55$)	ns ($p = 0.12$)
Toe tapping—stepping on the spot (left heel)	ns ($p = 0.13$)	ns ($p = 0.083$)
Stepping on the spot (right heel–left heel)	$r(29) = 0.93$, $p < 0.01$	$r(29) = 0.69$, $p < 0.01$
Finger tapping—stepping on the spot*	$r(29) = 0.40$, $p = 0.03$	$r(27) = 0.58$, $p < 0.01$
Toe tapping—stepping on the spot*	ns ($p = 0.28$)	ns ($p = 0.07$)

*mean of the left and right heel strike events. ns: not significant. SMT: spontaneous motor tempo.

and that for *CoV* was $r(29) = 0.69$, $p < 0.01$. Thus, the two SMT rates for stepping on the spot for right heel and left heel were averaged to make a new dependent variable Stepping *IOI* and Stepping *CoV* for further analyses.

Finger tapping

Significant differences between groups were revealed for FT *IOI* $F(2, 87) = 7.92$, $p < 0.01$, $\eta_p^2 = 0.15$. The PWP had faster finger tapping than the YHC [p <0.01, mean difference ± 112.21 ms, standard error (SE) = 28.78 ms]. However, the PWP and AMC did not differ ($p = 0.45$). Although the AMC tended to be faster than the YHC, this difference between control groups was not significant ($p = 0.05$).

Significant differences between groups were also revealed for FT *CoV* $F(2, 87) = 4.10$, $p = 0.02$, $\eta_p^2 = 0.09$. The PWP were more variable than the AMC ($p = 0.01$, mean difference ± 10.47, SE = 3.75) but not more variable than the YHC ($p = 0.37$). The YHC were also more variable than the AMC ($p = 0.04$, mean difference ±

7.42, SE = 3.55).

Toe tapping

Significant differences between groups were revealed for TT *IOI* $F(2, 87) = 4.89$, $p = 0.01$, $\eta_p^2 = 0.10$. The PWP were faster than the AMC ($p < 0.01$, mean difference ± 89.67, SE = 29.57 ms) and YHC ($p = 0.04$, mean difference ± 54.87, SE = 26.55 ms). The AMC and YHC did not differ ($p = 0.23$). No significant differences in the *CoV* were revealed between groups for TT ($p = 0.62$).

Stepping on the spot, right heel

A significant difference between groups was revealed for SS right heel *IOI* $F(2, 80) = 3.49$, $p = 0.04$, $\eta_p^2 = 0.08$. The PWP were faster than the YHC ($p = 0.03$, mean difference ± 44.99 ms, SE = 17.41 ms) but were not different from the AMC ($p = 0.21$). The YHC and AMC did not differ ($p = 0.79$). No significant differences in the *CoV* were revealed between groups for stepping on the spot (right heel) ($p = 0.13$).

Stepping on the spot, left heel

A significant difference between groups was revealed for SS left heel *IOI* $F(2, 81) = 4.10$, $p = 0.02$, $\eta_p^2 = 0.09$. The PWP were faster than the YHC ($p < 0.01$, mean difference ± 50.77 ms, SE = 18.11 ms) but were not different from the AMC ($p = 0.07$). The YHC and AMC did not differ ($p = 0.44$). No significant differences in the *CoV* were revealed between groups for stepping on the spot (left heel) ($p = 0.59$).

Stepping

The mean of the data for both feet were used to generate two dependent variables: Stepping *IOI* and stepping *CoV*. A significant difference between groups was revealed for stepping *IOI* $F(2, 77) = 3.26$, $p = 0.04$, $\eta_p^2 = 0.08$. The PWP were faster than the YHC ($p < 0.05$, mean difference ± 43.50 ms, SE = 17.26 ms), but were not different from the AMC ($p = 0.30$). The YHC and AMC did not differ ($p = 0.65$). No significant differences in the *CoV* were revealed between groups for stepping ($p = 0.91$).

Additional exploratory analyses

As analyses revealed significant differences between the PWP and controls, additional analyses were performed to understand which (if any) specific aspects of PD might predict SMT performance. A series of linear regressions were conducted on all the SMT dependent variables using the UPDRS total scores and the subscale scores (I, II, III, and IV) as predictor variables. Although significant results are reported below, once alpha p was adjusted for multiple comparisons, these findings did not remain significant. Therefore, these findings are provided for clinical interest only.

The UPDRS II (activities of daily living) predicted variability in finger tapping (FT *CoV*) - $F(1, 26) = 7.77$, $p = 0.01$, $R^2 = 0.23$. The model predicts that for every 1.76 increase in the score on the UPDRS II, the FT SMT *CoV* (i.e., variability) will increase by 18.03 ms. The score on the UPDRS II explained 23% of the variance in finger tapping. Higher scores (i.e., more difficulties in activities of daily living) were associated with more variability in finger tapping. Similarly, the UPDRS II score predicted toe tapping variability (TT *CoV*): UPDRS II $F(1, 28) = 4.56$, $p = 0.04$, $R^2 = 0.14$ (therefore explaining 14% of the variance in toe tapping). This model suggests that for every 0.89 increase in the score on the UPDRS II, the TT SMT *CoV* (i.e., variability) will increase by 24.69 ms.

These findings led to the evaluation of whether the hand or foot used in the SMT task, in comparison to the hand or foot affected by PD, impacted the results. Although no significant effect was found in relation to the hand used in the PWP, the effect of PD on the foot used was significant. By comparing the foot used with the side affected by PD, a foot match issue was confirmed in relation to the SMT rates for toe tapping: $F(1, 26) = 5.60$, $p = 0.02$, accounting for 18.7% of the variance ($R^2 = 0.19$). The foot used significantly predicted the SMT variability (*CoV*) for toe tapping: $F(1, 28) = 12.23$, $p < 0.01$, $R^2 = 0.30$. In this group, 22 PWP used their right foot (mean *CoV*, 31.47, SD = 8.15, range 21.6–44.57), five used their left foot (mean *CoV*, 32.71, SD = 7.64, range 24.27–41.58) and three used one foot for each of the two trials (mean *CoV*, 54.52, SD = 14.32, range 42.84–70.49). This result suggests that for PWP whose feet were affected by PD, using either side did not overcome the problem of tapping consistency. In contrast, PWP were able to compensate with their hands, for which there was no apparent significant effect.

These analyses were also conducted using PD duration and severity (according to the Hoehn and Yahr stages, and the Schwab and England percentiles), but these factors as independent variables did not predict SMT rate or stability. Furthermore, as performed in a previous study,[18] the PWP participants were grouped according to PD subtypes[28] (Table 1). As Yahalom et al.[18] found a difference in SMT between the unclassified (UC) and freeze predominant subtypes, it was important to compare the tremor dominant (TD, $n = 10$), postural instability/gait difficulty (PIGD, $n = 6$), and UC ($n = 14$) subtypes in these data. However, no PD subtype differences were revealed, and none of the PD subtypes predicted SMT performance in this sample of PWP.

Due to the differences in the number of males and females in the groups, analyses by sex were also conducted. For the whole sample, a significant difference between males and females was revealed for the stepping on the spot only, mean *IOI* $F(1, 75) = 5.112$, $p = 0.027$, $\eta_p^2 = 0.064$. The males (mean = 539.09 ms, SD = 73.38 ms) stepped on the spot more slowly than the fe-

males (mean = 504.49 ms, SD = 58.54 ms). There was no interaction with Group ($p > 0.17$), and no significant differences according to sex for any of the SMT dependent variables were revealed within the PWP group only.

DISCUSSION

This study compares SMTs in different types of movement in people with and without PD. Age-matched and younger controls were included to provide information on rehabilitation interventions for researchers, clinicians and practitioners. There are two main findings. First, the SMT rates in the PWP were faster than those in both control groups during toe tapping but were faster than that in the younger control group only during finger tapping and stepping on the spot. The PWP were also more variable than both control groups for finger tapping, but no group differences in variability were observed for toe tapping and stepping on the spot, for which the least amount of variance was observed. Second, although the whole group analyses suggested that the three types of movements (finger and toe tapping and stepping on the spot) were correlated with the SMT rates, this result did not hold for the PWP. These findings are now discussed in relation to those reported in previous studies and the literature relating to timed motor behaviors in individuals with PD.

Finger tapping is commonly used in timing studies and therefore can be directly compared. In the present study, the difference between the PWP and the younger control group amounted to a difference of 24 bpm for finger tapping (with the PWP performing the task faster than the YHC group), and this finding had a large effect size. As the PWP did not differ significantly from the AMC in the SMT rate, the most parsimonious interpretation of the finding would be that the younger controls were slower than the PWP and AMC. A similar finding was reported previously in a large-scale finger tapping study, whereby McAuley et al.[7] noted what they described as a "potential blip in SMTs" (p. 354) in the 18- to 38-year-old group of individuals included in their study. However, two studies[18,19] have previously reported slower SMTs for PWP when finger tapping, although different methods were used. Yahalom et al.[18] collected SMT data for 16 seconds using the least affected limb for the PD participants to limit the effects of motor deficits on the timing tasks. Furthermore, for 75% of these 51 participants with PD, their least affected hand corresponded to their nondominant hand. Benoit et al.[19] collected SMTs for both hands for 60 seconds each and seemingly reported the mean of these data (though this is not explicitly stated). There are therefore two important points to consider: 1) the use of the hand (and in our study, foot) and 2) the faster SMT rate reported in this study compared with previous studies.

To address the first of these points, as previously mentioned, there are several ways to measure spontaneous movements, and there are difficulties associated with all of them, at least in the context of PD research. For example, finger tapping is used in event-based or predictive timing studies because it is thought to enable the parsing of variance caused by motor 'noise' and to identify an individual's motor intent, whereas the continuous movement of stepping has been associated with emergent timing.[34-37] However, finger tapping is not naturally associated with spontaneous movements. Therefore, toe tapping was included in this study as a comparable effector type movement associated with spontaneous responses to music. Similarly, gait is often used as a measure of spontaneous (bipedal) timing, but it is not directly comparable to tapping due to the forward motion associated with gait. Therefore, we included stepping on the spot as a whole-body spontaneous motion specifically because it has been shown to be associated with emergent rather than predictive timing due to the continuous nature of the movement.

In this study, the participants chose whichever hand or foot they felt most comfortable using for the task, but we also gathered information regarding which hand they would use if they were completing a goal-orientated task (in this case, we suggested tapping to music, in comparison to a SMT, which is simply tapping at one's most comfortable speed) and which hand and foot were most affected by PD. We analyzed these data and found that for PWP, although there was a hand match issue (that is, the first choice was compromised by PD) in 2/3rds of the participants, it did not seem to affect performance regarding the rate of tapping; it only seemed to affect the variance. However, with toe tapping, although the same ratio was recorded in terms of the match issue, the use of the foot did significantly affect performance. Although no group differences in the variance were observed for toe tapping, it was noticeable that all groups performed with more variance in toe tapping than in finger tapping for this task. Furthermore, the least amount of variance was apparent for stepping on the spot. This finding suggests that in general, stepping was the easiest task, that the PWP found finger tapping the hardest task to sustain, and that toe tapping was the most difficult task. Why then, would PWP perform this task in particular faster than both control groups?

There are two possible explanations suggested by the literature: hastening and kinesia paradoxica. Hastening is a phenomenon whereby tapping is executed at a higher rate than required (in comparison to a target tempo), and it is reported to occur in older people and people with PD, for whom it may be related to freezing and/or festination.[18] As research has suggested that differing clinical phenotypes in PD may be related to risk factors for motor symptoms (i.e., TD or PIGD), we classi-

fied the PWP in this study into these subtypes[28] to ascertain whether such differences in presentation manifested in a SMT for the movements observed. No associations between the PD subtypes and SMT variables were established, but this result may be because the sample was not sufficiently large to detect differences. Future studies, preferably longitudinal studies, that include measures for both hands, both feet, stepping on the spot and gait, as well as sex matching groups, should be conducted to determine how SMT might change over time. Although sex differences have not been reported in SMT studies per se, gait studies have suggested that the differences reported herein for the whole sample for stepping may be related to whole-body kinematics, such as hip movement and arm swing.[38] This comprehensive approach to future research will also help elucidate whether the posited slowing of the internal clock theory is linked to cognitive decline in PWP.[7,17] The second possible explanation is kinesia paradoxica, which is the idea that a motor response is partially dependent on a person's emotional state, and this may or may not be associated with bradykinesia in PD.[39] Although kinesia paradoxica is also usually associated with external triggers, heightened emotional arousal can affect performance in spontaneous motor tasks. Hypothetically, this theory can be tested using a measure of momentary affective states. However, this theory is highly speculative, and although we know of no study that has considered this theory, it is another possible avenue for future SMT research.

Finally, by comparing the correlations between SMT for the three different movement types, for the whole group and for PWP only, this study presents evidence of a disconnect between effector movements (finger and toe tapping) and the whole-body movement of stepping on the spot. These data also provided evidence that PWP (and YHC) were significantly more variable than age-matched controls (AMC) in finger tapping. This finding had a medium to large effect size, and it was most noticeable that no differences between groups were observed in the other movement modalities for this measure of variability. Medication is known to impact timing performance,[12] and future studies should consider testing PWP during both the ON and OFF medication regimes. However, from this study, the results suggest that different types of movement should be considered for different applications. For example, finger tapping may provide evidence of PD impairment for research, but stepping on the spot appears to be a relatively preserved form of spontaneous movement for PWP. This result may be because emergent timing is thought to be relatively unaffected due to the compensatory support from the cerebellum, whereas predictive timing (as associated with finger tapping) relies on the basal ganglia.[34-37] As reduced performance in bimanual tasks compared to unimanual tapping tasks has been observed,[40] this result strengthens the suggestions that it is the nature of stepping on the spot in particular that may be useful for therapeutic application. This activity can be performed safely (by holding the back of a chair, for example) in the patient's own home to increase activity levels and fitness, and further research has also shown that this type of movement is particularly good for sensorimotor synchronization to music (rather than metronomes).[29] If practitioners and clinicians can assess the patients' SMT for this movement, they can match the timing to preferred music (therefore bpm measures are included in Tables 3 and 4) to optimize therapeutic goals and increase the enjoyment of the activity.

However, the potential claims of this study are limited because the order in which the SMT data was collected was not counterbalanced, the groups were not sex matched, and the PWP were not tested in both the ON and OFF states of medication. Overall, the main finding is that practitioners and clinicians should not assume that their age and/or PD slows patients' spontaneous movement tempo for all types of motor actions. There are large individual differences in SMT,[21] so it is important to establish an individual's baseline SMT to personalize treatment to achieve therapeutic goals.

Supplementary Materials

The online-only Data Supplement is available with this article at https://doi.org/10.14802/jmd.19043.

Conflicts of Interest

This study was not funded, but the research was supported by the authors' institutions, including the University of Hertfordshire (UK), Lucerne University of Applied Sciences and Arts (Switzerland), McMaster University (Canada), and Western University (Canada). This study was conducted at the University of Hertfordshire as part of the first author's postdoctoral research fellowship (2016-2018), during which a research visit to Canada resulted in the collaboration. The study was compiled at Lucerne University of Applied Sciences and Arts in 2019 as part of the first authors' new role as a Senior Research Associate. The authors declare no conflicts of interest.

Acknowledgments

The authors acknowledge Professor Yvonne Delevoye-Turrell and Dr. Laurent Ott from SCALab at University of Lille, France for extracting the data.

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Supplementary Table 1. Extended version of the Parkinson's disease participant information

Anon ID	Age*	Sex	Duration†	PD sub-type‡	UPDRS total	H&Y§	S&E%‖	PD affected hand	Hand used	PD affected foot	Foot used	Hand Pref¶	Foot Pref¶	Self-reported PD daily medication	LEDD (mg)	Other conditions
46	66	F	42	UC	3	1	100	Right	Left	Neither	Right	Either	Either	Sinemat 12.5/50 mg, Ropinerole 12 mg	290	Blood pressure, Osteoporosis
47	44	F	48	TD	36	3	90	Both	Right	Both	Right	Prefers foot	Right	Co-careldopa MR 50/200 mg, Ropinerole 8 mg, Co-careldopa 25/100 mg × 4	710	
48	48	M	48	TD	31	3	90	Both	Right	Both	Right	Right	Right	Rotigotine neupro patches 8 mg	240	
49	76	F	43	UC	34	2	50	Left	Right	Left	Right	Right	Right	Not disclosed	-	
50	75	F	252	PIGD	29	5	60	Left	Right	Both	Right	Either	Right	Sinemat plus 25/100 mg, Entacapone SR 500 mg, Ropinerole 8 mg	925	
51	65	F	228	TD	39	3	70	Both	Left	Both	Left	Left	Left	Amantadine 100 mg × 2, Co-careldopa 25/100 mg × 3 and Co-careldopa 12.5/50 mg at night	550	
52	70	F	48	TD	25	1	100	Right	Right	Right	Right	Right	Right	Requip SR ropinerole 14 mg	280	50 mg Thyroxine 50 mg × 1, Omeprezole 40 mg × 1 and 300 mg Gabapentin as required
53	63	M	108	TD	46	3	70	Both	Right	Both	Right	Prefers foot	Right	Madopar 600 mg, Entacapone, Rasagiline	-	Latanoprost
54	71	M	60	TD	27	3	80	Both	Right	Both	Left	Right	Right	Madopar 12.5/50 mg × 1, Ropinerole 12 mg × 1, Sinemat plus 25/100 mg × 4, Half sinemat 25/100 mg × 1, Entacapone 200 mg × 1	1,056	Finasteride 5 mg × 1, Aspirin 75 mg × 1, Simvastatin 40 mg × 1, Mirtazapine 15 mg × 1, Mirabegron 25 mg × 1, Tamsulosin 400 mcg × 1
55	69	M	192	PIGD	25	3	70	Both	Right	Both	Right	Right	Right	Sinemet plus × 9, Amantadin 100 mg × 1, Ropinerole 5 mg × 1, Caramet CR 25/100 mg × 1	1,175	
56	65	F	36	TD	25	2	90	Left	Right	Left	Right	Right	Right	Sinemat × 3	-	Anastrozol
57	56	F	144	PIGD	33	2	90	Right	Right	Right	Right	Right	Right	Ropinerol SR 8 mg × 1, Sinemet plus × 6, Entacopone 200 mg × 6	2,356	Paracetamol and B12
58	68	F	108	UC	12	1	100	Right	Right	-	Left	Prefers foot	Right	Requip XL 12 mg × 1, Sinemat 25/100 mg × 3	540	
59	77	F	36	UC	34	2	80	Both	Right	Left	Right	Right	Either	Selegiline × 8	-	Tamoxifen, Omeprazole, Bisoprolol quinine
60	59	M	180	TD	44	3	90	Both	Right	Bilateral	Right	Right	Right	Rasagiline 10 mg × 1, Amantadine × 2, Cipralex × 1, Co-careldopa 50 mg × 4, Pramipexole × 2	-	
61	49	M	11	TD	29	2	80	Left	Right	Left	Left	Alt. Hands	Alt. Feet	Ropinerole XL 4 mg	80	Losartan Bendroflumethiazide, Propranolol 40 mg
62	65	F	24	UC	41	2	80	Right	Right	Right	Right	Prefers foot	Either	Mirtazapine 15 mg	-	Mirtazapine 15 mg
63	73	F	6	UC	20	2	80	Left	Left	Left	Right	Left	Either	Madopar 375 mg	375	Cortiment steroid
64	59	F	69	PIGD	45	2	80	Right	Both	Right	Both	Prefers foot	Alt. Feet	Selegiline 10 mg × 1, Sinemat 12.5/50 mg × 3, Pramipexole 0.78 mg × 1	328	Omeprazole
65	54	F	72	TD	34	2	90	Left	Right	Left	Right	Right	Right	Ropinerole CR 16 mg, Sinemet plus 25/100 mg × 4	720	Tamoxifen, Levothyroxine
66	58	F	20	PIGD	36	2	80	Left	Right	Left	Right	Right	Right	Sinemat plus × 4, Rasagiline 1 mg × 1	500	
67	60	M	90	UC	25	1	90	Left	Right	Left	Right	Right	Right	Ropinerole 8 mg, Rasagiline × 4	-	Omeperzole
68	34	M	43	PIGD	62	2	80	Right	Right	Right	Both	Prefers foot	Right	Rasagiline 1 mg × 1 daily (pm), Repinex XL 8 mg × 1 daily + 2 mg × 3 daily (pm), Sinemat 25/250 mg × 6 daily (7 am, 10 am, 1 pm, 4 pm, 7 pm and 10 pm)	1,880	
69	67	F	72	UC	32	2	80	Right	Left	Right	Left	Right	Right	Half Sinemet × 5, Rasagiline 1 mg × 1 daily, Madopar 62.5 mg × 1	663	Felodopine
70	48	F	120	UC	19	2	80	Left	Right	Left	Right	Right	Left	Amantadin 1 mg × 2, Stanek 125 mg × 4, Rasagiline 1 mg × 1, Ropinerole 8 mg × 2, Sinemat SR 50/250 mg (at night)	1,274	Salbutamol and Beclometasone Inhalers + 12.5 mg sleeping tablet
71	70	M	24	UC	43	3	70	Both	Right	Both	Right	Right	Prefers hand	Not disclosed	-	
72	75	F	43	UC	27	2	80	Left	Right	Left	Right	Right	Prefers hand	Selegiline ×1, Co-careldopa 25/100 mg × 3	360	Medication for Osteoporosis
73	68	F	20	UC	12	1	100	Right	Right	Right	Right	Prefers foot	Right	Ropinerole SR 12 mg × 1, Co-careldopa 25/100 mg	340	
74	52	M	5	UC	26	2	80	Right	Right	Right	Both	Prefers foot	Left	Rasagiline 1 mg × 1	100	Tamsulosin
75	63	F	30	UC	23	1	80	Left	Right	Left	Right	Right	Right	Selegiline 10 mg	100	Amias

*age in years, †time since diagnosis in months, ‡Parkinson's disease (PD) subtype according to Stebbins et al.[28], 2013); §Hoehn and Yahr Scale (Hoehn and Yahr[27], 1967), ‖Schwab and England Activities of Daily Living Scale (Fahn and Elton[25], 1987), ¶hand/foot preferred when tapping to music, LEDD: levodopa equivalent daily dose, UPDRS: Unified Parkinson's Disease Rating Scale, F: female, M: male, UC: unclassified, TD: tremor dominant, PIGD: postural instability/gait difficulty, MR: modified release, SR: sustained release, CR: controlled release, XL: extra long (release), Alt.: alternate.