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Forward and backward walking in Parkinson disease: A factor analysis

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ABSTRACT

Background: Forward and backward walking are both impaired in Parkinson disease (PD). In this study, an exploratory factor analysis was performed to investigate the relationship between forward and backward walking in PD.
Research question: Given the difference in levodopa response between forward and backward walking, what is the additive value of testing backwards walking in a clinical setting.
Methods: Sixty-two patients with PD (65.29 ± 7.17 yrs, UPDRS OFF = 29.68 ± 9.88, UPDRS ON = 16.40 ± 8.21) and eleven healthy age-matched controls (63.09 ± 8.09 yrs) were recruited. PD participants completed forward (F) and backward (B) walking tasks on a 6.1 m instrumented walkway (OFF and ON levodopa). Factor analysis was used to derive models for both walking tasks/medication states.
Results: In both OFF and ON, four factors were identified: Variability (OFF: F = 30.0%, B = 17.8%, ON: F = 21.6%, B = 25.0%), Rhythm (OFF: F = 14.5%, B = 17.0%, ON: F = 17.4%, B = 19.0%), Asymmetry (OFF: F = 13.7%, B = 14.3%, ON: F = 16.1%, B = 15.2%), and Pace (OFF: F = 12.2%, B = 17.0%, ON: F = 13.9%, B = 8.7%). In the ON state, a fifth factor was identified: Posture (ON: F = 3.8%, B = 7.7%).
Significance: This study demonstrates the similarity in gait domain factors in both forward and backward walking. While domains of gait are similar in both walking tasks, levodopa response is reduced in backward walking. This could be a result of the increased complexity of backward walking. This study provides a normative dataset that can be used when assessing forward and backward walking in individuals with PD.

1. Introduction

Gait dysfunction can be used to assess quality of life, risk of falling and even mortality in Parkinson disease (PD) [1–3]. Forward and backward walking impairments can be separately assessed in PD, with backward walking having greater impairment when compared with healthy controls [4–6]. Backward walking can more accurately identify elderly fallers than forward walking [7]. Given the additional information provided by backward walking, gait assessment in PD should include other walking tasks beyond forward walking [8].

Levodopa significantly modifies various aspects of forward walking in individuals with PD [8], [9]. The spatial aspects of gait (e.g. velocity and stride length) are levodopa responsive while temporal parameters of gait (e.g. cadence, swing time) are non-responsive [8]. However, the effect of levodopa on backward walking in PD is less clear. Winter et al. discussed the notion that backward walking is simply a reversal of forward walking and found reversed-image similarity in several EMG and kinetic features [10]. However, more recent studies have indicated that the neural control may differ between forward and backward walking [4,11] and the limitation of visual cues during backward walking might be challenging in a disease with increased visual dependence [12].

Hackney et al. were the first to report quantitative gait parameter changes during backward walking in individuals with PD (ON medication). Backward walking was associated with shorter stride lengths, reduced swing percentages and higher double support/stance percentages when compared with controls [4]. However, reporting the changes in individual gait parameters (e.g. gait speed or step length) does not capture the full complexity of gait mechanics. An exploratory factor analysis can be used to elucidate the relationship between various gait parameters and walking conditions. Factor analysis allows for exploration of the covariance between individual gait parameters and

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provides a broader definition of gait domains [13]. Such analysis has been applied to forward walking in the elderly, where five or six gait domains were identified (based on 16–23 gait parameters): pace, rhythm, variability, asymmetry, postural control, and phases [14–17].

Given that levodopa gait parameter response is greater in forward walking compared with backward walking, clinical examination using only forward walking may not provide the full detail of the patient's mobility. The purpose of this study was to explore the additive value of backwards walking in a clinical setting. The aim of the factor analysis was to elucidate the similarities and differences in immediate (1 h) gait response to levodopa in forward and backward walking conditions. We hypothesized that levodopa has differing effects on forward and backward walking due to the increase complexity in backward walking. The results of the study can be used in a clinical setting where forward and backward walking tasks are used to measure a patient's mobility.

2. Methods

2.1. Participants

Sixty-two individuals with PD and eleven healthy age-matched controls were consented and included in this study. Individuals with PD were recruited from the movement disorders clinic at London Health Sciences Center (REB #107253). Participants were included based on the following criteria: (1) have been diagnosed with idiopathic PD for at least 2 years; (2) be 45–85 years of age; (3) have been on stable doses of anti-Parkinson medication, including any levodopa preparation (stable doses indicate that no adjustments to medications have been made within the last 6 months); and (4) able to give informed consent.

2.2. Gait evaluation and walking tasks

Footfall data was captured using a 6.10 m × 1.22 m instrumented walkway with embedded pressure sensors on all this area (ZenoMetrics mat/PKMAS software, v5.07, Havertown, PA, USA). The validity of the walkway system has been previously demonstrated [18], and even used for backward walking assessment in elderly fallers [19]. Gait was measured in one study session for all participants. Individuals with PD were asked to withhold levodopa medications for 12 h prior to the study session. Forward walking was performed, at their normal pace, by walking around the track for a total of five passes (˜ 1–1.5 min.) (see Supplementary figure 1.). Backward walking, being more complex to do, was performed at their normal pace. Participants were asked to walk down the walkway, without making loops, for a total of four passes (see supplementary figure 1.). Individuals with PD completed the walking tasks in the OFF-medication state. They were then asked to take 125% of their normal levodopa medication and a 1 h wait period was given. The walking tasks were then repeated in the ON-medication state.

2.3. Gait parameters

Sixteen gait parameters were used in the factor analysis, which includes the mean, variability and asymmetry of gait parameters. Asymmetry is the gait parameter ratio between left and right sides and is related to the bilateral coordination of left-right limbs; it has been shown to improve between OFF and ON medications states [20]. Coefficient of variation (CV) is the standard deviation of the gait parameter expressed as a percentage of the mean and explores the variability over the task. Gait parameter means, standard deviation and coefficient of variance were used. The enhanced gait variability index (eGVI) is a conglomerate measure that objectively quantifies the variability measured in spatiotemporal variables [21]. Walk ratio is the ratio of step length and step cadence, it represents the relationship between the amplitude and the frequency of movement of the legs [13,22].

Table 1
Patient demographics.

	PD Participants (N = 62)	Control Participants (N = 11)	P-value
Age (Years)	65.29 ± 7.17	63.09 ± 8.09	0.400
Sex: Female, %(n)	32.31% (n = 21)	36.36% (n = 4)	
Height (cm)	172.88 ± 8.48	172.03 ± 9.02	0.818
LED (mg)	967.40 ± 431.48	–	
PD Duration (Years)	8.99 ± 4.11	–	
Levodopa Duration (Years)	7.14 ± 3.97	–	
UPDRS ON	16.40 ± 8.21	–	
UPDRS OFF	29.68 ± 9.88	–	
MoCA	25.39 ± 3.62	26.27 ± 2.15	0.411

* **LED** = levodopa equivalency dose, **UPDRS** = Unified Parkinson's Disease Rating Scale, **MoCA** = Montreal Cognitive Assessment.

2.4. Data analysis

A factor analysis was performed, keeping five factors for each walking task. Varimax rotation was performed on the eigenvectors until the 5 factors were maximized and the other factors were reduced to close to zero. Gait parameters that had a minimum loading of 0.5 were considered relevant. Factor analyses were performed in R 3.4.4 (rstudio) using the stats package factanal() function, scree plots were performed using the nFactors package (nFactors) and correlation plots were performed using the corrplot package (corrplot2017). Analysis of variance was performed on demographic data using the stats package lm() function. Significance level was set at $p < 0.05$. Gait parameters were extracted from the PKMAS software.

3. Results

Sixty-two individuals with PD (65.29 ± 7.17 yrs, female = 36.4%) and eleven healthy age-matched controls (63.09 ± 8.09 yrs, female = 32.3%) performed the walking tests; no significant difference was found in age, height or MoCA between PD and controls (see Table 1.). Individuals with PD were recruited from the Movement Disorders Clinic at London Health Sciences center, based on their disease duration (see Table 1.).

3.1. Forward and backward gait parameter changes between groups

In forward walking, the gait parameters that significantly improved between the PD groups (OFF vs. ON) were: step velocity, step velocity CV, step length, step length CV, step width SD, step time SD, step time asymmetry, stance time, stance time SD, stance time CV, GVI and walk ratio. From these parameters, the ones that were not significantly different from controls (PD ON vs. controls) were: step velocity, step velocity CV, step length, step width SD, step time SD, step time asymmetry, stance time, stance time SD, stance time CV and walk ratio. The gait features that did not change OFF to ON and remained significantly different from controls were: step length SD, step length asymmetry and swing time asymmetry. Finally, the gait parameters that were not significantly different across groups were: step velocity SD, step width, step time and swing time.

In backward walking, the gait parameters that significantly improved between the PD groups (OFF vs. ON) were: step velocity, step velocity SD, step velocity CV, step length, step length SD, stance time SD, and walk ratio. From these parameters, the ones that were not significantly different from controls (PD ON vs. controls) were: step velocity CV, step length SD, stance time SD, and walk ratio. The gait features that did not change OFF to ON and remained significantly different from controls were: step length CV, step time SD, step time asymmetry, stance time CV, swing time asymmetry and GVI. Finally, the gait parameters that were not significantly different across all

Table 2
Gait feature changes in forward and backward walking.

Gait Feature	Forward Walking			Backward Walking		
	PD OFF (N = 62)	PD ON (N = 62)	Control (N = 11)	PD OFF (N = 62)	PD ON (N = 62)	Control (N = 11)
Step Velocity (m/s)	1.003 ± 0.234	**1.204 ± 0.178*****	1.281 ± 0.171	0.630 ± 0.217	**0.809 ± 0.211*****	**1.004 ± 0.239****
Step Velocity SD (m/s)	373.644 ± 41.837	380.774 ± 34.652	382.545 ± 27.167	310.980 ± 62.453	**320.129 ± 62.312****	**346.205 ± 29.094***
Step Velocity CV (m/s)	7.103 ± 6.533	**4.545 ± 1.998****	3.999 ± 1.172	13.719 ± 4.429	**11.672 ± 3.435****	10.707 ± 3.215
Step Length (m)	0.519 ± 0.115	**0.611 ± 0.081*****	0.642 ± 0.059	0.299 ± 0.102	**0.374 ± 0.093*****	**0.481 ± 0.099*****
Step Length SD (m)	0.033 ± 0.013	0.030 ± 0.011	**0.020 ± 0.005****	0.054 ± 0.013	**0.061 ± 0.016****	0.057 ± 0.022
Step Length CV (m)	8.581 ± 8.445	**5.159 ± 2.294****	**3.124 ± 0.817****	20.053 ± 9.596	17.982 ± 8.282	**12.519 ± 4.664***
Step Length Asym (m)	0.027 ± 0.022	0.027 ± 0.020	**0.011 ± 0.010***	0.044 ± 0.033	0.052 ± 0.035	0.033 ± 0.025
Step Width (m)	0.084 ± 0.025	0.083 ± 0.028	0.092 ± 0.019	0.197 ± 0.043	0.196 ± 0.050	0.207 ± 0.055
Step Width SD (m)	0.018 ± 0.005	**0.023 ± 0.007*****	0.019 ± 0.005	0.021 ± 0.006	**0.027 ± 0.007*****	**0.032 ± 0.005***
Step Time (s)	521.090 ± 45.686	510.210 ± 44.721	505.909 ± 43.233	486.620 ± 76.581	472.013 ± 77.711	487.727 ± 48.893
Step Time SD (s)	26.298 ± 12.960	**20.500 ± 8.772****	15.000 ± 5.899	37.217 ± 15.198	34.204 ± 12.977	**24.682 ± 6.871***
Step Time Asym (s)	24.726 ± 19.950	**17.755 ± 14.919***	9.727 ± 8.147	19.417 ± 14.305	22.135 ± 17.045	**8.545 ± 6.170***
Stance Time (s)	673.177 ± 71.918	**641.548 ± 62.155****	629.818 ± 60.178	663.743 ± 99.796	628.605 ± 101.076	635.955 ± 67.460
Stance Time SD (s)	33.844 ± 31.966	**22.806 ± 9.259****	17.591 ± 6.719	54.104 ± 19.676	**46.893 ± 14.654***	39.000 ± 10.766
Stance Time CV (s)	4.626 ± 2.957	**3.569 ± 1.419***	2.749 ± 0.895	8.089 ± 2.807	7.559 ± 2.336	**6.093 ± 1.445***
Swing Time (s)	373.644 ± 41.837	380.774 ± 34.652	382.545 ± 27.167	310.980 ± 62.453	320.129 ± 62.312	346.205 ± 29.094
Swing Time Asym (s)	17.452 ± 11.654	13.458 ± 11.166	**4.818 ± 3.995***	19.102 ± 14.127	20.010 ± 12.191	**10.364 ± 8.872***
GVI	114.006 ± 15.361	**108.069 ± 12.530****	**97.549 ± 3.459****	138.938 ± 6.941	137.143 ± 7.252	**131.937 ± 7.496***
Walk Ratio	0.453 ± 0.111	**0.523 ± 0.090*****	0.541 ± 0.060	0.247 ± 0.101	**0.296 ± 0.097****	**0.391 ± 0.077****

* all values are represented as mean ± SD. Comparisons were made PD-OFF vs. PD-ON and PD-ON vs. Control in both walking tasks. Bolded items are significant: * = < **0.05,** ** = < **0.01,** *** = < **0.001**.

groups were: step length asymmetry, step width, step time, stance time and swing time. Across all groups/conditions, step width, step time and swing time remained unchanged. Gait parameter changes are outlined in Table 2.

3.2. Factor analysis

In accordance with the previous work of Lord et al. and Hollman et al., the identified factors matched the previously identified domains [16,23]. In the OFF medication state, factor analysis revealed that four factors accounted for 70.4% of variance in forward walking and 66.1% of variance in backward walking. Forward walking yielded the factors: variability (30.0%), rhythm (14.5%), asymmetry (13.7%), and pace (12.2%). In backward walking, the factors that were identified were: variability (17.8%), rhythm (17.0%), pace (17.0%) and asymmetry (14.3%). These loadings are shown in Table 3. Factor 5 in both walking conditions did not load highly with the gait parameters in the last gait domain postural control.

In the ON medication state, factor analysis revealed five factors accounted for 72.8% of variance in forward walking and 75.6% of variance in backward walking. Forward walking yielded the factors: variability (21.6%), rhythm (17.4%), asymmetry (16.1%), pace (13.9%) and posture (3.8%). In backward walking, the factors that were identified were: variability (25.0%), rhythm (19.0%), asymmetry (15.2%), pace (8.7%) and posture (7.7%). These loadings are shown in Table 4.

4. Discussion

This study explored the factors of PD gait important in forward and backward walking conditions in OFF and ON levodopa states. Independent gait domains were found to be similar between the

Table 3
Gait factor analysis in the OFF medication state during forward and backward walking.

	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5	
	FW	BW	FW	BW	FW	BW	FW	BW	FW	BW
Step Time CV (s)	**0.753**	**0.919**	-0.078	-0.141	0.297	-0.185	-0.317	0.236	0.426	0.117
Stance Time CV (s)	**0.905**	**0.859**	0.052	-0.110	0.151	-0.056	-0.054	0.223	0.183	0.045
Swing Time CV (s)	**0.869**	**0.671**	0.037	-0.133	0.305	-0.448	-0.225	0.302	0.172	0.249
eGVI	**0.854**	**0.626**	0.148	0.016	0.186	**-0.549**	-0.257	0.110	0.037	0.342
Step Time (s)	0.063	-0.096	**0.991**	**0.988**	0.036	-0.010	0.046	0.073	0.017	-0.039
Stance Time (s)	0.390	0.050	**0.881**	**0.956**	-0.025	-0.200	-0.136	0.133	0.088	0.048
Swing Time (s)	-0.425	-0.312	**0.725**	**0.845**	0.137	0.305	0.302	-0.042	-0.174	-0.164
Step Velocity (m/s)	**-0.640**	-0.259	-0.329	-0.183	-0.151	**0.863**	**0.670**	-0.204	0.043	-0.301
Step Length (m)	**-0.655**	-0.363	0.046	0.267	-0.129	**0.806**	**0.737**	-0.133	0.024	-0.321
Step Width SD (m)	-0.021	-0.048	0.131	0.200	0.109	**0.599**	**0.609**	0.089	-0.140	0.075
Step Velocity SD (m/s)	0.479	0.019	-0.106	-0.260	0.124	0.452	0.289	-0.117	-0.201	0.067
Step Width (m)	0.130	0.093	-0.004	0.029	0.046	-0.157	-0.219	0.073	0.136	-0.043
Swing Time Asym (s)	0.083	0.156	0.030	0.061	**0.974**	-0.098	0.013	**0.975**	0.087	0.049
Stance Time Asym (s)	0.206	0.178	0.036	0.118	**0.906**	-0.065	0.105	**0.894**	0.075	0.081
Step Time Asym (s)	0.251	0.348	-0.012	0.013	0.449	-0.163	-0.347	**0.570**	**0.746**	0.063
Step Length CV (m)	**0.821**	0.309	0.121	-0.045	-0.043	-0.424	-0.321	0.179	0.161	**0.825**
Step Length Asym (m)	0.127	0.050	0.031	-0.050	0.177	0.117	-0.114	0.023	0.079	**0.720**
Percent Variance	**30.0%**	**17.8%**	**14.5%**	**17.0%**	**13.7%**	**17.0%**	**12.2%**	**14.3%**	**5.7%**	**9.7%**
Factor Label	Variability	Variability	Rhythm	Rhythm	Asymmetry	Pace	Pace	Asymmetry	--	--

* Bolded correlation weights are significant contributors to the respective factor. Asym = asymmetry.

Table 4
Gait factor analysis in the ON medication state during forward and backward walking.

	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5	
	FW	BW	FW	BW	FW	BW	FW	BW	FW	BW
Swing Time CV (s)	**0.689**	**0.934**	-0.146	-0.108	0.472	0.237	-0.337	-0.078	0.201	0.017
eGVI	**0.836**	**0.900**	0.033	0.042	0.155	0.053	-0.347	-0.099	0.169	0.232
Step Time CV (s)	**0.677**	**0.815**	-0.172	-0.150	0.431	0.373	-0.240	-0.028	0.132	0.098
Stance Time CV (s)	**0.789**	**0.738**	-0.011	-0.229	0.279	0.303	-0.187	0.050	0.077	0.117
Step Length CV (m)	**0.606**	**0.644**	-0.058	-0.087	0.106	-0.114	-0.442	-0.209	0.352	**0.681**
Step Velocity SD (m/s)	**0.775**	0.253	-0.012	-0.448	0.108	-0.009	0.047	0.219	0.027	0.054
Step Time (s)	-0.060	-0.034	**0.976**	**0.989**	-0.071	0.121	-0.076	0.026	0.175	-0.000
Stance Time (s)	-0.075	0.126	**0.896**	**0.959**	-0.092	0.073	-0.232	-0.047	0.155	0.047
Swing Time (s)	-0.015	-0.276	**0.950**	**0.865**	-0.024	0.114	0.247	0.206	-0.176	-0.095
Swing Time Asym (s)	0.173	0.208	-0.012	0.051	**0.981**	**0.949**	0.040	0.012	0.017	-0.060
Stance Time Asym (s)	0.206	0.148	0.056	0.047	**0.841**	**0.937**	0.128	0.034	0.045	0.050
Step Time Asym (s)	0.228	0.171	-0.018	0.201	**0.667**	**0.673**	-0.108	-0.080	0.085	0.087
Step Length (m)	-0.321	**-0.591**	0.198	0.166	-0.070	0.015	**0.911**	**0.746**	0.066	-0.249
Step Velocity (m/s)	-0.274	**-0.550**	-0.376	-0.447	-0.004	-0.041	**0.880**	**0.631**	-0.062	-0.278
Step Width SD (m)	0.338	0.064	0.194	-0.004	0.157	-0.028	0.295	**0.596**	0.358	0.073
Step Length Asym (m)	0.153	0.108	0.134	-0.048	0.131	0.067	-0.017	0.013	**0.514**	**0.752**
Step Width (m)	0.034	0.176	-0.072	0.109	0.167	0.074	-0.043	0.110	0.071	0.149
Percent Variance	21.6%	25.0%	17.4%	19.0%	16.1%	15.2%	13.9%	8.7%	3.8%	7.7%
Factor Label	Variability	Variability	Rhythm	Rhythm	Asymmetry	Asymmetry	Pace	Pace	Posture	Posture

* Bolded correlation weights are significant contributors to the respective factor. Asym = asymmetry.

walking conditions, with greater forward walking variability in the OFF medication state. However, when ON medication, the variability is greater in backwards walking, which has been found previously [24].

4.1. Gait parameters

This study demonstrated that levodopa improves PD gait parameters in both forward and backward walking conditions. In response to levodopa, step velocity, step length, step width SD and walk ratio were not significantly different from controls in forward walking but remained significantly different in backward walking. This may suggest that individuals with PD have larger deficits in backward walking compared to forward walking. Another explanation could be that backward walking is a more complex walking task. McNeely et al. (2012) hypothesized that levodopa would only improve normal walking and not improve backward walking as it is a more complex walking task (McNeely2012a). They found a significant effect of levodopa on step velocity between forward and backward walking tasks. In healthy older adults, decreased backward walking step velocity has been linked to increased risk of falling [19].

Interestingly, stance time was the only temporal gait parameter that significantly improved in the presence of levodopa between both walking tasks. Step time and swing time were not significantly different from controls in forward and backward walking. Lack of improvement in the temporal domain of PD gait has been summarized in literature [25].

4.2. OFF levodopa: factor analysis

The variability factor was comprised of gait parameter CV values and was the factor that explained most of the variance in the data. Lord et al. found that, in healthy older individuals, variability was the fourth factor and explained 14.5% of the variance in forward walking. Furthermore, they found that spatial variability loaded onto the variability factor while temporal variability loaded onto the pace factor. The present study found that, in individuals with PD, temporal variability loaded onto the variability factor in both forward and backward walking. This finding suggests that timing of the gait parameter, rather than distance, seems to explain more of the variance in PD OFF levodopa gait.

The rhythm factor was the second highest contributor in the analysis, being comprised of temporal gait parameters in both walking conditions. This finding matched Lord et al. who reported all temporal gait parameters loaded onto the rhythm factor, which was also found to be the second factor. In another study, the rhythm factor was associated with memory decline, which indicates the potential usefulness of this factor for early detection of memory deficits [26].

Pace was the third factor in backward walking and the fourth factor in forward walking. In both walking conditions, the gait parameters that loaded onto the pace factor is contrary to previous work that found a strong negative loading of step velocity and step length to the pace factor [14], [16]. Furthermore, in previous studies the pace factor explained the most variance in the data in the ON medication state. This difference may be due to the patients being OFF levodopa (step velocity and step length would be reduced). Pace explained 12.2% of the variance in forward walking and 17.0% in backward walking. This difference could be associated with the response of levodopa on the gait features that loaded onto pace. Levodopa returned step velocity and step length to control levels in forward walking but not in backward walking, a finding that has been reported in a previous study [27]. Step velocity and step length were only improved ON levodopa during forward walking and explained a greater amount of variance in the model during backwards walking. Given these findings, step velocity and step length may become impaired earlier in the disease state during backwards walking, which may indicate early risk of falling [7].

An asymmetry factor was the third factor in forward walking and the fourth factor in backward walking. The percent contribution in both walking conditions was similar to previous work which found asymmetry to be the third factor, explaining 15.5% of the variance in forward walking of healthy older individuals [16]. In the present study, and in previous work [16], temporal gait parameter asymmetries were found to load onto this factor and not spatial gait parameters.

The fifth factor was not well defined by gait parameters, so it was not considered. In this study, step width variability loaded onto the pace factor. Hollman et al. found that step width variability loaded onto a fifth factor they termed base of support. This contradictory result indicates that factor domains may overlap in the OFF medication state, resulting in a lack of a well-defined fifth factor.

4.3. ON levodopa: factor analysis

As in the OFF medication state, variability was the factor that

explained the most variance in both walking conditions ON medication. However, the variance in gait performance explained by the variability factor increased in backward walking and decreased in forward walking when comparing OFF to ON levodopa. Interestingly, both temporal and spatial gait parameter variabilities loaded onto the variability factor. This was also found by Hollman et al. who reported both temporal and spatial gait parameter variabilities loaded onto the variability factor in forward walking of healthy older individuals. Considering the eGVI there was a significant improvement from OFF to ON medication in forward walking but not in backward walking (Table 2.). This finding matches Hackey et al., who reported increased gait variability in backward walking when individuals with PD were in the ON state [4].

The rhythm factor, ON medication state, matched the OFF medication state with regards to factor number and loaded gait parameters. The percent of variance explained by rhythm increased in both walking conditions from the OFF medication state. It was found that step time and swing time remained not significantly different across groups, while stance time was only significantly different after levodopa administration in forward walking. The lack of levodopa response of temporal gait parameters may explain the similarities found in the factor analysis between OFF and ON medication states.

The asymmetry factor was the third factor in both walking conditions; with similar percent of variance explained. Lord et al. found asymmetry was the third factor and explained 15.1% of total variance in the data. This previous finding matched the results from the current analysis, which found percent of variance explained in forward walking was 16.1% and in backward walking was 15.2%.

The pace factor was the fourth factor in the analysis and variance explained was higher in forward walking than in backward walking. A notable difference was that step width variability loaded onto pace in backward walking but not in forward walking. As previously discussed, Hollman et al. found that step width variability loaded onto base of support in forward walking. This may indicate that, in backward walking, participants had a harder time maintaining their balance and had an increased requirement for a base of support.

The posture factor was found to be the fifth factor in both walking conditions, the asymmetry of step length was the gait parameter that loaded onto this domain. This factor loading was similar to Lord et al. who found step length asymmetry and step width loaded onto a fifth factor they termed postural control. The difference from the current results is that step width did not load onto any factor in the analysis.

4.4. Strengths and limitations

The strengths of the current study include the large PD population and the number of walking passes completed by each patient. The study had a few limitations worth noting. First, this was a cross-sectional study, thus, age and disease related changes could not be studied directly. However, when recruiting patients, PD disease duration was considered to obtain a more representative study cohort. Another limitation is that the forward walking was completed using loops while backward walking was completed in a straight line. The extended walking path in forward walking may have fatigued the patient more than backward walking. Third, cognitive capacity was not considered in the analysis. Previous studies have reported an increased cognitive load during backward walking [27–29], a relationship that, if added in this study, may tease out further relationships between the walking task and levodopa response.

5. Clinical significance and conclusion

This study provides a large normative dataset for levodopa response in PD patients during forward and backward walking, adding substantially to the existing literature. If using forward and backward walking in a clinical setting, the gait domains provide the clinician with an idea of which gait parameters to monitor in both walking conditions. This study provides a normative PD gait parameter factor analysis for both forward and backward walking, which can be used for assessing and interpreting gait impairment. A factor analysis identified similar gait domains, ON and OFF levodopa, between forward and backward walking. However, it was found that fewer gait parameters improved in response to levodopa during backward walking. Temporal gait parameters were not responsive to levodopa in forward and backward walking. These results support differing neural control networks for forward and backward walking, suggesting that backward walking may provide additive information about mobility and should be used in a clinical setting.

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Roles

Greydon Gilmore: Project Administration, Conceptualization, Methodology, Software, Formal Analysis, Writing – Original Draft.

Arnaud Gouelle: Formal Analysis, Data curation, Writing- Original draft preparation, Visualization.

Michell Adamson: Visualization, Investigation, Writing- Original draft preparation.

Marcus Peiterman: Investigation, Data Curation.

Mandar Jog: Writing- Reviewing and Editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.08.005.

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