Sex differences in posture and vertical perception of gait function in patients with Parkinson's disease

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Abstract

Sex differences in the effect of posture and subjective vertical position (SPV) on gait function have not been clarified in Parkinson's disease (PD) patients. Therefore, this study aimed to determine the involvement of posture and vertical perception in the gait function of PD patients according to sex. The study included 59 adult patients with PD (31 men and 28 women) who visited the Rehabilitation Department of Neurology Clinic as outpatients. Relationships between four postural evaluations [forward trunk flexion (FTF), lateral trunk flexion (LTF), SPV], and eight gait assessments [walking time, step length, gait speed, number of steps, step time, coefficient of variation of step time (step CV), cadence, and mean gait acceleration (acceleration)] were analyzed according to sex. None of the postural evaluations showed an association with gait parameters in men. By contrast, in women, relationships were seen between walking time and SPV in the sagittal plane, stride length and FTF angle, the number of steps and FTF and LTF, and step CV and SPV in the coronal plane, indicating that posture was related to gait function. Our results could aid rehabilitative therapies to improve PD patients' gait function.

Introduction

Parkinson's disease (PD) is a neurodegenerative disorder with various motor and non-motor symptoms [1]. There are sex differences in the clinical symptoms of PD, with rigidity and rapid-eye-movement sleep behavior disorder being more prevalent in men, and dyskinesia and depressive symptoms being more prevalent in women [2]. Differences in disease severity between men and women have been reported, according to age and disease duration. Also, motor symptoms indexed by the Unified Parkinson's Disease Rating Scale (UPDRS) Part III were found to be more severe in men than in women [3].

Several studies have reported that sex differences in motor symptoms, such as gait and posture, affect the quality of life of PD patients [4–7]. Sex differences in the development of postural abnormalities have also been observed. For example, camptocormia, a severe forward-bending posture [8–10], is more prevalent in men than in women [11], whereas drop-head syndrome, characterized by a bent head-and-neck posture, is more frequent in women [12]. Thus, there are sex differences in the incidence of severe postural abnormalities in PD patients; however, no sex differences have been reported for mild or moderate abnormalities [13, 14].

The influence of posture on gait function in PD patients has also been investigated. Geroin [15] reported that PD patients with lower camptocormia had significantly lower gait speed, shorter stride length, and lower stride velocity than PD patients with upper camptocormia or no camptocormia; thus, lower camptocormia is associated with more severe gait and postural-control impairments. In contrast, gait function in PD patients with Pisa syndrome [16–18], which is a severe lateral-trunk-flexion (LTF) posture, did not differ from that of patients without Pisa syndrome or age-matched healthy controls [19]. Notably, previous studies reporting that the type of postural abnormality affected gait function [15–19] did not assess sex differences; the data of subjects of both sexes were pooled. Thus, to date, sex differences in the effect of posture on gait function in PD patients have yet to be clarified. Furthermore, it has been hypothesized that subjective vertical position (SPV) [20], which affects forward trunk flexion (FTF) and LTF in PD patients, also affects gait [21, 22]; however, the influence of SPV on gait according to sex has not been investigated.

This study examined the influence of posture and vertical perception on gait function in PD patients by sex; to our knowledge, this is the first such evaluation. Our results may facilitate the development of rehabilitation programs to improve gait in PD patients.

Results

Clinical features and anthropometrics of patients

Table 1 shows the clinical features and anthropometrics of the study participants. In total, 31 men and 28 women were included in this retrospective study. There was no significant difference in age, disease duration, the Mini-Mental State Examination (MMSE), or the modified Hoehn and Yahr (mH&Y) scale between the men and women. Men scored higher than women on the Movement Disorder Society-sponsored revision of the UPDRS (MDS-UPDRS) Parts I–III, and also had a higher mean total score (Part I, $p = 0.04$; Part II, $p = 0.006$; Part III, $p = 0.008$; total score, $p = 0.004$). In contrast, the functional reach test (FRT) ($p = 0.016$), 3-m Timed Up and Go (TUG) ($p = 0.046$), and grip strength ($p < 0.001$) were significantly lower in women than men. Height and body mass were significantly higher in men, but there was no significant sex difference in body mass index (BMI). The effect size was $d = 0.8$, and the power was $(1 - \beta) = 0.84$.

Table 1
Clinical features and anthropometrics of the men and women with Parkinson’s disease (PD) enrolled in this study.

	Men (n = 31)	Women (n = 28)	P value
Age (years)	72.4 ± 8.4	74.3 ± 6.6	0.41
Disease duration (years)	4.0 ± 4.4	5.6 ± 7.7	0.95
MMSE (point)	26.9 ± 3.2	26.4 ± 3.1	0.44
mH&Y score	2.4 ± 0.7	2.5 ± 0.9	0.29
MDS UPDRS Part I score	7.0 ± 4.8	4.5 ± 3.6	0.04
Part II score	10.9 ± 5.3	7.0 ± 6.6	0.006
PartIII score	24.7 ± 10.5	18.0 ± 11.4	0.008
PartIV score	1.9 ± 2.8	1.9 ± 3.3	0.86
MDS UPDRS total score	44.5 ± 23.4	31.5 ± 24.9	0.004
FRT (cm)	24.3 ± 6.8	19.5 ± 5.4	0.016
TUG (sec)	10.0 ± 4.3	11.0 ± 3.6	0.046
Fall (Faller: Non-faller)	13: 18	7: 21	0.17
Grip strength (kg)	29.8 ± 8.0	17.0 ± 3.7	< 0.001
LEDD (mg / day)	553.7 ± 213.3	526.6 ± 246.7	0.71
Height (cm)	165.0 ± 6.8	149.2 ± 7.0	< 0.001
Body mass (kg)	45.4 ± 7.9	64.2 ± 12.1	< 0.001
Body mass index (kg/m^2)	20.4 ± 3.6	23.5 ± 3.5	0.99

Values are expressed as Mean ± SD except for falls. MMSE: Mini-Mental State Examination, mH&Y: Modified Hoehn & Yahr scale, MDS UPDRS: Movement Disorder Society-sponsored revision of the Unified Parkinson’s Disease Rating Scale, FRT: Functional reach test, TUG: 3m timed up and go test, LEDD: Levodopa equivalent daily dose.

Sex differences in postural evaluations and gait assessments

The postural and gait-assessment results of the patients are shown in Table 2. No difference was observed in postural evaluations between men and women. However, sex differences were evident in gait parameters, including the 10-m walking time (walking time) ($p = 0.043$), step length ($p = 0.002$), gait speed ($p = 0.032$), number of steps ($p = 0.012$) and mean of gait acceleration (acceleration) ($p = 0.043$).

Table 2
Postural and gait assessment results.

	Men (n = 31)	Women (n = 28)	P value
FTF (°)	12.4 ± 5.5	15.1 ± 10.0	0.65
LTF (°)	3.8 ± 3.6	4.3 ± 4.7	0.96
SPVs (°)	9.2 ± 5.0	11.2 ± 5.8	0.29
SPVc (°)	3.7 ± 2.8	4.9 ± 3.8	0.17
Walking time (sec)	7.8 ± 2.0	8.8 ± 2.0	0.043
Step length (cm)	64.0 ± 12.8	54.5 ± 9.6	0.002
% Step length (%)	38.7 ± 7.0	36.5 ± 6.1	0.22
Gait speed (m / min)	80.9 ± 18.2	71.5 ± 14.8	0.032
Number of steps (step)	16.3 ± 3.6	19.0 ± 4.1	0.004
Cadence (steps / min)	126.5 ± 13.2	130.8 ± 13.7	0.23
Step time (sec)	0.48 ± 0.5	0.46 ± 0.5	0.21
Step CV (%)	6.0 ± 3.9	5.4 ± 4.6	0.19
Acceleration (G)	0.38 ± 0.12	0.32 ± 0.09	0.043

Values are expressed as Mean ± SD. FTF: Forward trunk flexion, LTF: Lateral trunk flexion, SPVs: Subjective postural vertical in the sagittal plane, SPVc: Subjective postural vertical in the coronal plane, Walking time: Walking time during 10m, Step CV: Step coefficient of variation, Acceleration: Mean of gait acceleration, %Step length: (step length/ height) × 100.

Correlations between postural evaluations and gait assessments

The correlation coefficients between postural evaluations and gait assessments in men and women are shown in Table 3. In men, there were no significant correlations between gait parameters and postural evaluations. In women, walking time and FTF ($r = 0.379$, $p = 0.047$), walking time and SPV in the sagittal plane (SPVs) ($r = 0.414$, $p = 0.028$), step length and FTF ($r = -0.483$, $p = 0.009$), gait speed and FTF ($r = -0.379$, $p = 0.049$), gait speed and SPV in the coronal plane (SPVc) ($r = -0.412$, $p = 0.029$), number of steps and FTF ($r = 0.489$, $p = 0.008$), and coefficient of variation of step time (step CV) and FTF ($r = 0.464$, $p = 0.013$), SPVs ($r = 0.444$, $p = 0.018$), and SPVc ($r = 0.405$, $p = 0.032$) were significantly correlated. The effect size was $\rho = 0.5$, and the power was $(1 - \beta) = 0.99$.

Table 3
Correlation coefficients between postural evaluations and gait assessments in men and women with PD.

	FTF		LTF		SPVs		SPVc	
Men = 31 Women = 28	Men	Women	Men	Women	Men	Women	Men	Women
Walking time (sec)	0.236	0.379*	-0.134	0.125	-0.104	0.414*	-0.106	0.135
Step length (cm)	-0.318	-0.483†	0.129	-0.271	0.039	-0.336	0.054	-0.290
Gait speed (m / min)	-0.240	-0.376*	0.135	-0.107	0.100	-0.412*	0.109	-0.128
Number of Steps (step)	0.251	0.489†	-0.202	0.270	-0.151	0.340	-0.134	0.291
Cadence (steps / min)	0.152	0.269	0.198	0.210	0.175	-0.016	0.209	0.251
Step time (sec)	-0.136	-0.278	-0.206	-0.229	-0.174	-0.001	-0.202	-0.271
Step CV (%)	0.029	0.464*	-0.248	0.340	-0.109	0.444*	-0.287	0.405*
Acceleration (G)	-0.307	-0.137	0.153	-0.179	-0.035	-0.240	0.078	-0.086

FTF: Forward trunk flexion, LTF: Lateral trunk flexion, SPVs: Subjective postural vertical in the sagittal plane, SPVc: Subjective postural vertical in the coronal plane, Walking time: Walking time during 10m, Step CV: Step coefficient of variation, Acceleration: Mean of gait acceleration, %Step length: (step length/ height) × 100. *$p < 0.05$, †$p < 0.01$.

Relationship between vertical perception and gait assessments

Multiple regression analysis was used to analyze the relationships between four postures (FTF, LTF, SPVs and SPVc) and the dependent variable (gait performance). There were no significant relationships for men. In women, SPVs was related to walking time ($R = 0.47$, $p = 0.012$; Fig. 2A), FTF to step length ($R = 0.536$, $p = 0.003$; Fig. 2C), FTF to gait speed ($R = 0.398$, $p = 0.036$; Fig. 2E), LTF to number of steps ($R = 0.550$, $p = 0.002$; Fig. 2G), and SPVc to step CV ($R = 0.534$, $p = 0.003$; Fig. 2I). The effect size was $f2 = 0.35$ and the power was $(1 - \beta) = 0.95$.

Discussion

In this retrospective study, 31 men and 28 women with PD were studied in an outpatient clinic rehabilitation department to determine the effects of standing posture (i.e., FTF and LTF) and SPV (i.e., SPVs and SPVc) on gait according to sex. Standing posture and SPV were clearly related to several gait parameters in women, whereas no relationships were observed in men. Through postural evaluations (FTF, LTF, SPVs, and SPVc), sex differences in gait parameters were demonstrated. These findings add to previously published data regarding the effects of posture and vertical perception on gait function in PD patients according to sex.

There were no sex differences in age, disease duration, MMSE, mH&Y scale, history of falls, patients' levodopa equivalent daily dose (LEDD), or postural evaluations (FTF, LTF, SPVs, and SPVc), similar to a previous study on postural abnormalities assessed by the 28 UPDRS items [13], and to a review article on posture in PD patients [14]. We also observed no sex differences in the SPV. The SPV affects the long-term course of posture in PD patients [23, 24]; our results imply that sex does not affect posture or SPV. In contrast, sex differences were observed in gait parameters (e.g., number of steps, step length, walking time, gait speed, and acceleration). Women took more steps than men, possibly because their step length is smaller. There was no sex difference in “%step length” (height ratio). These results accord with previous studies of healthy subjects [25, 26], which reported that sex differences in gait reflect differences in body-size parameters, such as height [27]. Muscle strength and balance may affect walking time, gait speed, and acceleration; grip strength, which relates to global muscle strength [28], and balance (assessed by the FRT and TUG test) are poorer in women than men. Balance function and muscle strength are independent predictors of gait function [29]. Taken together, the data indicate that physical parameters such as height, muscle strength, and balance may contribute to sex differences in gait function.

In our study, FTF and LTF correlated with gait parameters only in female PD patients. In multiple regression analysis using gait parameters as the dependent variables, FTF was related to step length and gait speed, and LTF was related to step length in women only. A study on healthy subjects reported that vertical axis tilt and posterior pelvic tilt in the sagittal plane affected gait speed and step length [30]. In contrast, a study of PD patients with > 5° of forward flexion, lateral flexion, and neck flexion concluded that trunk forward flexion was associated only with the degree of lateral flexion, and posture did not explain deficits in activities of daily living, motor impairment, falls or back pain [31]. Another study of PD patients with severe postural abnormalities reported similar results; gait function was not impaired even with severe LTF [19]. Data regarding the influence of posture on gait are conflicting; however, previous studies did not investigate the effects of posture and vertical perception on gait function in PD patients according to sex, which represents the unique contribution of our study. The symptoms and pathomechanisms of women with PD differ from those of men with PD, and female sex is a predictor of falling in PD [32–35]. In this study, the men and women differed in MDS-UPDRS scores, and in muscle strength and balance. The present results imply that sex differences in pathomechanisms and muscle strength may underlie the sex difference in the influence of FTF and LTF on gait function.

In female PD patients, the SPVs angle is related to walking time, while the SPVc angle is related to step CV. SPV is hypothesized to be involved in processes occurring before gait initiation [20]. The present study revealed the involvement of vertical perception in gait function in women with PD. The role of SPV in gait has not been investigated. Only Cho et al. [36] reported examining the relationship between the subjective visual vertical (SVV) and gait characteristics, in healthy young subjects. In their study, variations in stride time and stride velocity during tandem gait were significantly greater in an “SVV-increased” group than in the control. A significant correlation between stride time and SVV was observed;

however, the relationship was not assessed according to sex. In the present study, SPVc was correlated with step CV in women with PD, implying that SPV is important for gait stability in women, which is concordant with female sex being a risk factor for falls [35].

There are some limitations in the present study. This retrospective study included PD outpatients from a single clinic. The results may not be representative of the full spectrum of the disease, or of patients in other countries and regions; PD prevalence and sex differences in symptoms vary geographically. Thus, our results should be interpretated and clinically applied with caution.

In conclusion, this study is the first to demonstrate sex differences in the influence of posture on gait function in PD patients. FTF and LTF were related to gait function only in women. Also, in women with PD, SPV in the sagittal plane was related to walking time, while SPV in the coronal plane was related to step CV. Our findings could facilitate rehabilitation programs to improve gait function in PD patients.

Methods

Subjects

This retrospective study included adult patients with PD who visited the Department of Rehabilitation of Neurology Clinic as outpatients between January and September 2019. The inclusion criteria were: diagnosed according to the Movement Disorder Society clinical diagnostic criteria for Parkinson's disease [37], aged ≥ 20 years, oral medications not changed within 1 week of the evaluation, "on" state at the time of evaluation (if experiencing the "wearing-off" phenomenon), capable of understanding instructions, capable of standing upright, and able to walk without a walking aid. Patients were excluded if they were diagnosed with a PD-related disorder other than PD itself, exhibited psychiatric symptoms such as visual or other hallucinations, or showed signs of the wearing-off phenomenon during the drug-administration period. Wearing off was defined using the UPDRS Part IV and a symptom diary, as follows: unable to passively guide the patient to a vertical position due to limited range of motion, dramatic worsening of PD symptoms within 1 week before the evaluation, and/or rapid onset of postural abnormalities, i.e., onset within 1 month before the evaluation.

The study was approved by the Ethics Committee of the Open University of Japan (approval number 2020-25). Also, all methods were performed in accordance with Declarations of Helsinki. Informed consent was obtained using an opt-out form available at the clinic. The opt-out form contained information about how the participant's personal confidential data would be used for purposes beyond direct care; the form clearly stated that declining to participate in the study would not impact care. The personal data of participants were anonymized, i.e., personal identifying information were removed.

Postural evaluation

The postural evaluation was performed in a standing posture and SPV, i.e., the posture that the patient subjectively perceived as vertical. The landmarks for the postural evaluation were the spinous processes of the seventh cervical (C7) and fifth lumbar (L5) vertebrae. Reflective markers (Nobbyteck VNS-BL-MC-190) were attached to these sites for three-dimensional motion analysis. Images were captured at rest using a digital camera (Panasonic DMC-LZ10); software was used to calculate the angle between the vertical axis and an arbitrary second axis. Image-analysis software (Image J; https://imagej.nih.gov/ij/index.html) was used to measure the relevant angles [6].

Standing posture at rest

Each patient's FTF and LTF were measured to assess standing posture. The patient's position on opening his/her eyes immediately after standing was evaluated three times, and the mean value was taken as the patient's standing position. A digital camera aimed at the level of the iliac crest was used to measure LTF in the coronal plane and FTF in the sagittal plane. Photographs were taken at rest, and included both C7 and L5. The standard axis was taken as the vertical line crossing L5 and descending to the floor. The axis of forward flexion was defined as the line connecting C7 to L5 along the sagittal plane; the axis of lateral flexion was defined as a line connecting C7 and L5 along the coronal plane [6].

SPV evaluation

Each patient's SPV was evaluated in the sagittal plane (SPVs) and coronal plane (SPVc). The SPVs was defined as the angle between the axis of forward flexion and the vertical line when the patient perceived that they were in a vertical position (Figure 1A) [21]. The SPVs was measured by first establishing the starting position, which entailed the patient closing their eyes in a standing position and then being passively guided to a forward-flexion angle of 45°. Next, the patient was passively moved in the extension direction reported in perceived vertical position. This sequence was performed three times; the mean value was taken as the SPVs.

The SPVc was measured by first establishing the starting position, which entailed the patient closing their eyes while standing and then being passively guided into the position of maximum LTF. The investigator then guided the patient toward the vertical axis. The patient notified the investigator when they perceived their trunk to be vertical. Images were taken at rest in this position at the height of Jacoby's line, and along the posterior midline. This sequence was performed three times each on the left and right, for a total of six measurements. The mean value of these measurements was taken as the SPVc (Figure 1B) [38].

Gait assessments

For gait assessment, a portable gait analyzer (MC-1100; LSI Medience Corporation, Tokyo, Japan) with a built-in accelerometer was attached to the patient's L5 during the 10-m walking test at maximum speed to obtain spatiotemporal parameters. The walking time, step length, gait speed, number of steps, step time, step CV, cadence, and acceleration were evaluated. Step length was calculated as % step length = (step length / height) × 100.

Collection of clinical information

Clinical information including age, sex, height, weight, BMI, disease duration, PD severity, and outcomes of neuropsychological examinations was collected. PD severity was evaluated using mH&Y scale [39] and the MDS-UPDRS [40]. The MMSE [41] was used for cognitive evaluation. The FRT [42] and TUG test [43] were used to assess balance. Patients' LEDD was also obtained [44].

Statistical analyses

The Shapiro–Wilk test was used to examine normality. A two-tailed *t*-test, the Mann–Whitney U test, and the chi-square test were used to compare the variables between groups. Spearman's rank correlation coefficient was employed to assess the associations between gait parameters and postural evaluations. Multiple regression analysis was conducted using a stepwise regression model; each gait parameter was included as a dependent variable to explore further the associations of posture and gait parameters. The independent variables were the FTF, LTF, SPVs, and SPVc postures.

Effect sizes were analyzed using G*Power software [45]; all other statistical analyses were performed using SPSS for Windows software (Version 27.0; IBM Corp, Armonk, NY, USA). P-values < 0.05 were considered statistically significant.

Declarations

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Author contributions

1) Research project: A. Conception; KM, NS

B. Organization; KM, TK, NS

C. Execution; KM

2) Statistical Analysis: A. Design; KM, NS

B. Execution; KM

C. Review and Critique; NS

3) Manuscript: A. Writing of the first draft; KM

B. Review and Critique; KM, TK, NS

Kyohei Mikami: KM

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Data availability statement

All the relevant data are presented in the manuscript. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors have no conflicts of interest directly relevant to the content of this article.

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Figures

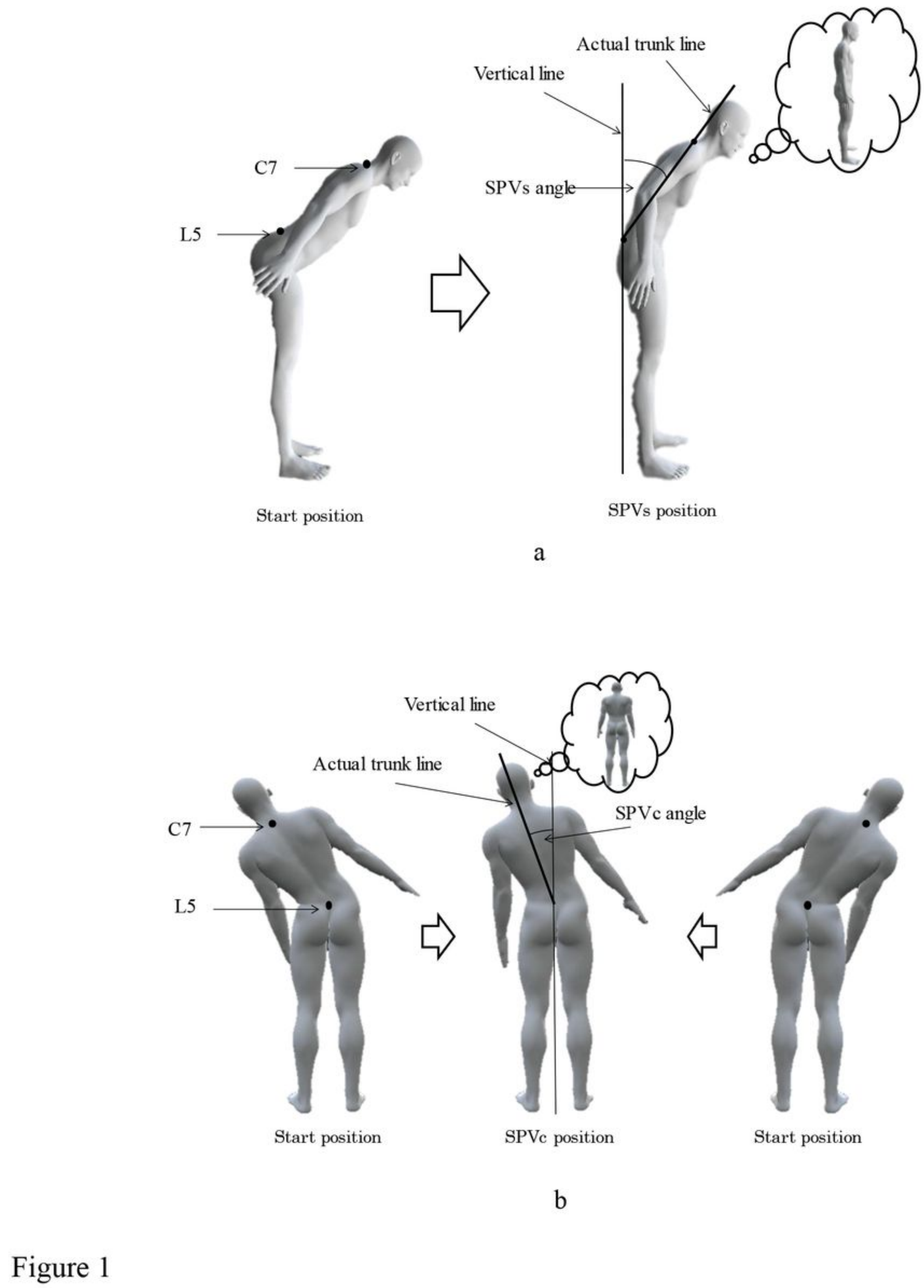

Figure 1

A: Evaluation of subjective postural vertical in the sagittal plane (SPVs). B: Evaluation of subjective postural vertical in the coronal plane (SPVc). C7: seventh cervical vertebra, L5: fifth lumbar vertebra, Vertical line: vertical line to the floor through L5, Actual trunk line: a line connecting C7 and L5 [21 22].

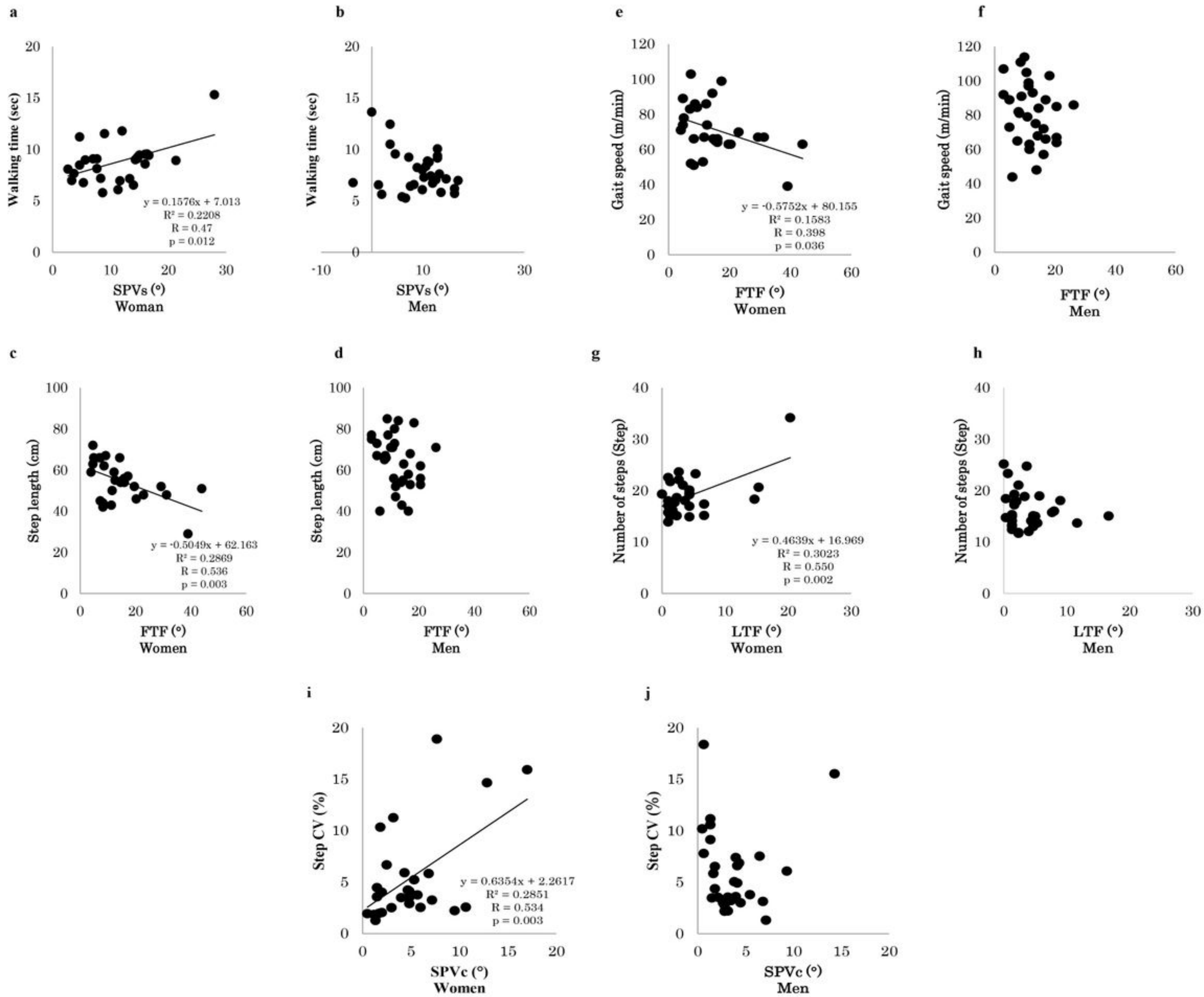

Figure 2

Figure 2

Relationship between postural and gait assessments. A Scatter plot showing the regression line and regression equation.

A Scatter plot, the corresponding regression line, and regression equation were shown. CV, coefficient of variation: SPVs, Subjective postural vertical in the sagittal plane: SPVc, Subjective postural vertical in the coronal plane, Walking time: Walking time during 10m, Step CV: coefficient of variation of step time.