

Spinal Movement and Performance of a Standing Reach Task in Participants With and Without Parkinson Disease



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Background and Purpose. Evidence suggests that individuals with early and mid-stage Parkinson disease (PD) have diminished range of motion (ROM). Spinal ROM influences the ability to function. In this investigation, the authors examined available spinal ROM, segmental excursions (the ROM used) during reaching, and their relationships in community-dwelling adults with and without PD. **Subjects.** The subjects were 16 volunteers with PD (modified Hoehn and Yahr stages 1.5–3) and 32 participants without PD who were matched for age, body mass index, and sex. **Methods.** Range of motion of the extremities was measured using a goniometer, and ROM of the spine was measured using the functional axial rotation (FAR) test, a measure of unrestricted cervico-thoracic-lumbar rotation in the seated position. Motion during reaching was determined using 3-dimensional motion analysis. Group differences were determined using multivariable analysis of variance followed by analysis of variance. Contributions to total reaching distance of segmental excursions (eg, thoracic rotation, thoracic lateral flexion) were determined using forward stepwise regression. **Results.** Subjects with PD as compared with subjects without PD had less ROM (FAR of 98.2° versus 110.3°, shoulder flexion of 151.9° versus 160.1°) and less forward reaching (29.5 cm versus 34.0 cm). Lateral trunk flexion and total rotation relative to the ground contributed to reaching, with the regression model explaining 36% of the variance. **Discussion and Conclusion.** These results contribute to the growing body of evidence demonstrating that spinal ROM is impaired early in PD. [Schenkman ML, Clark K, Xie T, et al. Spinal movement and performance of a standing reach task in participants with and without Parkinson disease. *Phys Ther.* 2001;81:1400–1411.]

Key Words: *Parkinson disease, Reaching, Spinal flexibility, Spinal range of motion, Task performance.*

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Parkinson disease (PD) is an idiopathic, progressive, degenerative disorder of the central nervous system with 4 cardinal signs: slowness and poverty of movement (bradykinesia), muscle rigidity, resting tremor, and postural instability.¹ In addition, there are abnormalities in posture and disturbances in locomotion.² Impairments that occur as indirect effects of the disease also may contribute to the patient's dysfunction.³ For example, the loss of spinal range of motion (ROM), an indirect effect of rigidity and bradykinesia, can contribute, in our view, to impaired balance control and many functional difficulties experienced by patients with PD, compounding the functional limitations that occur as a result of the disease.⁴

Spinal ROM and spinal position (ie, thoracic kyphosis and lumbar lordosis) are associated with the ability of adults with no known pathology to perform some tasks, including forward reaching.⁵ Bergström et al⁶ demonstrated moderately strong correlations in 70-year-old men between restricted spinal ROM and difficulty reaching their big toe ($r=.27$, $P<.05$) or using public transportation ($r=.32$, $P<.05$). Ryan and Fried⁷ reported associations, using multivariate stepwise regression, between severity of thoracic kyphosis and time to walk 5 m ($P=.015$) and to climb a flight of stairs ($P<.001$).

Data from 2 investigations suggest that spinal ROM is less for people with PD than for community-dwelling adults without the disease.^{8,9} Spinal ROM is a predictor of

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Dr Schenkman, Mr Clark, Dr Xie, and Dr Kuchibhatla provided concept/research design, writing, and data analysis. Ms Shinberg and Ms Ray provided data collection and recruited subjects. Dr Schenkman, Ms Shinberg, and Ms Ray provided project management. Ms Shinberg provided technical direction for data collection and reduction. Dr Schenkman provided fund procurement, facilities/equipment, and institutional liaisons. Ms Ray provided consultation (including review of manuscript before submission). The authors thank the Measurement Core staff of the Claude D Pepper Older Americans Independence Center, Duke University Medical Center, for data collection efforts.

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functional reach distance, independent of disease-state (PD, no PD).⁸ A randomized controlled study comparing a group of subjects who performed exercises to improve spinal flexibility with a “no exercise” control group demonstrated that patients in early and mid-stage PD following a 10-week intervention had improved spinal ROM and improved functional reaching.¹⁰ These results are consistent with the original proposition^{3,4} that decreased spinal ROM is a sequela of PD but acts independently of the disease in contributing to diminishing the patients’ functional ability.

Relationships between spinal ROM and the kinematics of forward standing reaching have not been explored for those with PD. The distance that an individual reaches is likely to be limited by the amount of segmental ROM that occurs during reaching. Possibly, reductions in segmental motion occur in forward trunk flexion (which has the largest excursion of any segment during reaching)¹¹ and in excursions related to spinal ROM (eg, lateral trunk flexion). Furthermore, it is likely that contributions of excursions of body segments to reaching distance are independent of disease state (PD versus no PD). These suppositions are based on the reduced excursion during reaching of older people compared with younger individuals¹¹ and on the finding that the contribution of available spinal ROM to functional reaching distance is independent of disease state.⁹

The investigation we are reporting was designed to examine several of the proposed relationships. Specifically, we asked the following questions:

1. Are ROM and position of the spine different in a sample of community-dwelling adults with PD than in a sample of adults who are matched in terms of age, sex, and body mass index (BMI)?
2. Are the excursions of body segments used during forward reaching less for people with PD than for people without the disease?
3. Do available spinal ROM, the amount of thoracic kyphosis, and the amount of lumbar lordosis contribute to the amount of forward trunk flexion during forward reaching? If they contribute, is that relationship dependent on the presence of PD?
4. Do excursions of segments of the spine used during reaching contribute to forward reaching? If they contribute, is that relationship dependent on the presence of PD?

Stage 0	No signs of disease
Stage 1	Unilateral disease
Stage 1.5	Unilateral plus axial involvement
Stage 2	Bilateral disease, without impairment of balance
Stage 2.5	Mild bilateral disease; recovery on pull test
Stage 3	Mild to moderate bilateral disease; some postural instability; capacity for living independent lives
Stage 4	Severe disability; still able to walk or stand unassisted
Stage 5	Wheelchair bound or bedridden unless aided

Figure 1.

The Modified Hoehn and Yahr stages of Parkinson disease provide staging of the disease. Signs of the disease include postural instability, rigidity, tremor, and bradykinesia. Balance is measured in response to a postural pull test. Postural instability is determined by pulling the patient backward suddenly from the shoulders. Patients with normal responses recover balance with ≤ 3 steps. Patients who “recover” on the pull test take >3 steps, but recover their balance unaided. Patients with instability would fall if not caught. Function is rated based on self-report of the patient.¹²

Method

Study Design

We used a retrospective study design, incorporating cross-sectional data previously collected at the Claude D Pepper Older Americans Independence Center at Duke University Medical Center. That database was constructed as follows. Participants included 120 adults with no known pathology aged 20 to 79 years. There were 10 men and 10 women in each decade of ages. In addition, there were 16 adults with PD in stages 1.5 to 3 of the modified Hoehn and Yahr scale¹² (Fig. 1). Participants were excluded if they had a history of pathology or surgery of the axial skeleton (eg, spinal fusion, compression fractures, laminectomy), osteoarthritis, any neurological condition (eg, stroke), hypertension that was not controlled by medication, hospitalization within the 3 months preceding the period for which we collected data, or a fracture within the previous 6 months. Those with PD who experienced fluctuating symptoms were tested during “on” periods with respect to medication (ie, during periods of effectiveness of medication). Their Hoehn and Yahr stage was confirmed by a physical therapist at the time of the laboratory test session. All participants signed an informed consent release form approved by the institutional review boards of Duke University Medical Center and Durham Veterans’ Affairs Medical Center prior to participation in the study. Data included measurements not used in the study reported here and were acquired during a single 2½-hour test session.

Measures	Kinematic Measures of Segmental Excursions Analyzed With 3-D Motion Analysis During Reaching
Spinal measures	Spinal excursions during reaching
Functional axial rotation	Lateral trunk flexion relative to the pelvis
Thoracic kyphosis	Transverse-plane thoracic rotation relative to the pelvis
Lumbar lordosis	Other segmental excursions
Extremity measures	Forward trunk flexion
Shoulder flexion	Transverse-plane lower-body relative to the support surface
Shoulder protraction	Overall excursion
	Total rotation in the transverse plane relative to the support

Figure 2.
Measures used in the study.

Subjects

The data set for this investigation included all 16 participants with PD from the original database. The mean age of the subjects with PD was 67.2 years (SD=7.3, range=52–79). Thirty-two participants without PD were chosen from the available 120 participants to form the comparison group. Prior to any data analysis, participants were chosen who most closely matched each of the 16 participants with PD. They were matched first for age, then for sex and BMI. Two participants from the comparison group were matched with each participant with PD to provide a sample size adequate for multivariate analysis. The mean age of the comparison participants was 66.3 years (SD=8.9, range=52–79).

Data Acquisition

Data were collected with measures that are often used in clinical practice and with motion analysis instrumentation. Measurements of available spinal and extremity ROM and of spinal position (ie, thoracic kyphosis, lumbar lordosis) were obtained by a physical therapist and an assistant. Measurements of spinal movements and total reaching distance were obtained by a research assistant and a bioengineer using motion analysis equipment. The measures used are summarized in Figure 2.

Order of testing. Measurements of spinal and extremity ROM, thoracic kyphosis, and lumbar lordosis were obtained first. These measurements were followed by quantification of the reaching activity using 3-dimensional (3-D) motion analysis. The total test session took about 2½ hours. Specific procedures are outlined below.

Measures of ROM, thoracic kyphosis, and lumbar lordosis.

The ROM data were collected using previously described methods.⁵ In preparation for data collection, men removed their shirts and women wore halters to allow the thorax to be visualized. Participants were barefoot and wore a pair of shorts that allowed visualization of the region of the greater trochanter.

Shoulder flexion was measured using a 30.48-cm (12-in) goniometer.¹³ Participants were positioned supine with their head in a neutral position and their shoulders in 0 degrees of abduction, adduction, and rotation. Their forearm was positioned in 0 degrees of supination and pronation with the palm of the hand facing the body. The participants were asked to lift the arm up into

flexion as far as possible. The examiner assisted the participants to achieve this position and then to return to the starting position. Shoulder flexion was measured for both arms. No differences were found for right versus left sides. Only ROM measurements obtained for the right side are reported.

Shoulder protraction was measured using a modification of the functional reach test.¹⁴ Participants were seated in a ladder-back chair just far enough away from a wall so that the arms could dangle freely at the sides (Fig. 3). To simplify data collection, only the dominant arm was measured. The dominant arm was positioned closest to the wall. Participants sat with their buttocks at the back of the chair with the spine in as close to neutral alignment as possible. A yardstick was affixed to the wall at the height of the acromion and parallel to the floor. Stabilization of the participants was attempted using Velcro straps* to decrease the motion of the thorax during shoulder protraction. One strap was positioned across the pelvis, angled in a posteroinferior direction, and secured beneath the chair. A second strap was placed horizontally across the middle to upper ribs and fastened behind the chair. A third strap was placed under the dominant arm, across the sternum, and over the front of the nondominant shoulder and was fastened behind the chair. The participants raised the dominant arm straight up, and the research assistant checked to ensure that clothing was not restricting movement.

Participants were told to make a fist and raise the dominant arm to shoulder height. The research assistant

* Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

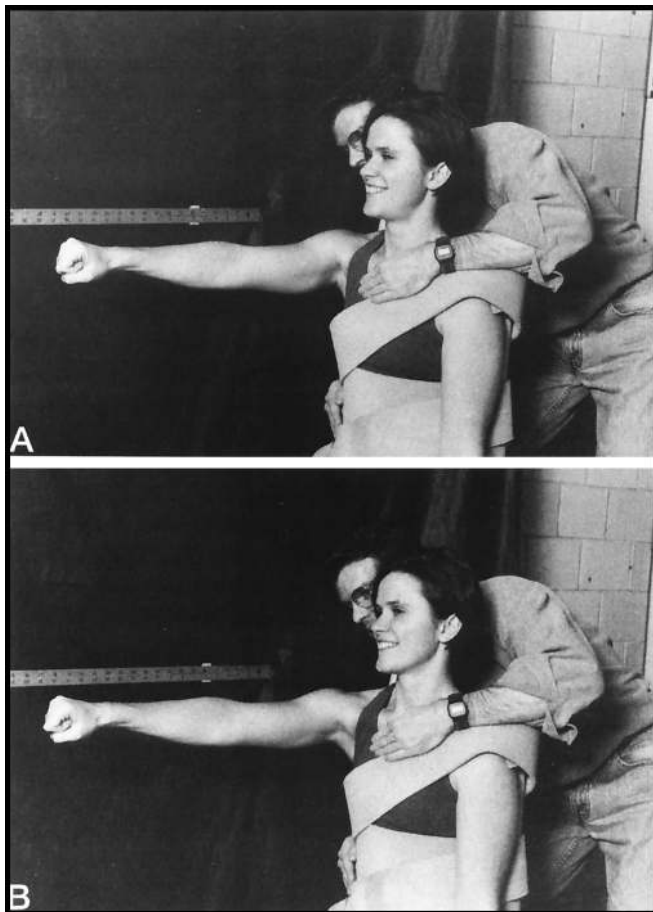


Figure 3.

Measurement of shoulder protraction. (A) The subject is seated in neutral alignment with the arm raised to 90 degrees of shoulder flexion. The subject makes a fist, and a rater determines the starting position of the metacarpals with respect to the yardstick affixed to the wall. (B) The subject reaches as far forward as possible without moving the thorax. One investigator stabilizes the subject's thorax and determines the end position of the metacarpals. A second rater determines the position of the metacarpal heads with respect to the yardstick. (Reprinted with permission of the Orthopaedic and Sports Physical Therapy sections of the American Physical Therapy Association from Schenkman ML, Laub KC, Kuchibhatla M, et al. Measures of shoulder protraction and thoracolumbar rotation. *J Orthop Sports Phys Ther.* 1997;25:329–235.

adjusted the start position to neutral shoulder alignment (without protraction or retraction with respect to elevation) and spine alignment (ie, thorax with respect to pelvis, acromion with respect to greater trochanter), and an assistant recorded the starting position of the third metacarpophalangeal (MCP) joint relative to the yardstick. The participants then were told to reach as far forward as possible without moving the thorax. Additional stabilization was attempted by gentle pressure from the examiner on the sternum to ensure that only shoulder girdle motion occurred. The assistant recorded the ending position of the third MCP joint. The participants then returned to a relaxed position. Test-retest reliability (intraclass correlation coefficient [ICC (1,1)] for shoulder protraction was .85 for participants with PD

(n=16) and .95 for older adults with functional limitations who did not have PD (n=11).¹⁴

Combined spinal motion was assessed using the functional axial rotation (FAR) test.¹⁵ *Functional axial rotation* was defined as a combined, total triplanar motion of the spine, including motion of the cervical, thoracic, and lumbar segments. Although referred to as “functional axial rotation,” this measure has not been shown to be a predictor of function. Each participant was seated in a backless chair with the pelvis stabilized by Velcro straps (Fig. 4). A hoop with symbols (numbers and letters) was suspended at eye level by 2 tripods, one in front of the participant and the other behind. The symbols corresponded to 5-degree increments, with 0 degrees aligned with the midline of the participant's face and 180 degrees aligned with the seventh cervical vertebra. Marks at 90 and 270 degrees were aligned with the participant's greater trochanters. The participant donned the headpiece of the Cervical Range of Motion device (CROM),^{16,†} with the forward head arm of the unit used as a pointer oriented toward the hoop. The examiner told the participant to turn as far as possible in one direction (right or left), letting his or her arms dangle at the sides. The participant then turned as far as possible in the other direction. The degree of rotation (FAR) was calculated from the symbol with which the pointer was aligned. Mean FAR was calculated using the average of the left and right side values. Interrater reliability (ICC [2,1]) was .97 for 17 subjects who had no known impairments (mean age=48.8 years, SD=21.6, range=20–74) for the right and left sides. Test-retest reliability (ICC [1,1]) was .95 and .90 for the right and left sides, respectively, of these subjects.¹⁵ Test-retest reliability (ICC [1,1]) was .89 for 15 subjects with PD (mean age=74.5 years, SD=5.7, range=64–84).¹⁷

Measurements of thoracic kyphosis and lumbar lordosis were obtained using a Debrunner kyphometer¹⁸ while participants stood. Midpoints between T2-3, T11-12, and S1-2 were palpated and marked. Participants were told to assume an erect posture with feet positioned hip width apart and arms resting at the sides. Degrees were read directly from the scale with the blocks of the kyphometer spanning T2-3 and T11-12 for thoracic kyphosis and T11-12 and S1-S2 for lumbar lordosis. Excellent reliability has been reported for measurements of lordosis and kyphosis in subjects without known disorders.¹⁸ Test-retest reliability has been established for measurements of thoracic kyphosis (ICC [1,1]=.93) and lumbar lordosis (ICC [1,1]=.87) in 15 subjects with PD (mean age=74.5 years, SD=5.7, range=64–84).¹⁷

† Performance Attainment Associates, 3550 LaBore Rd, Ste 8, St Paul, MN 55110-5126.

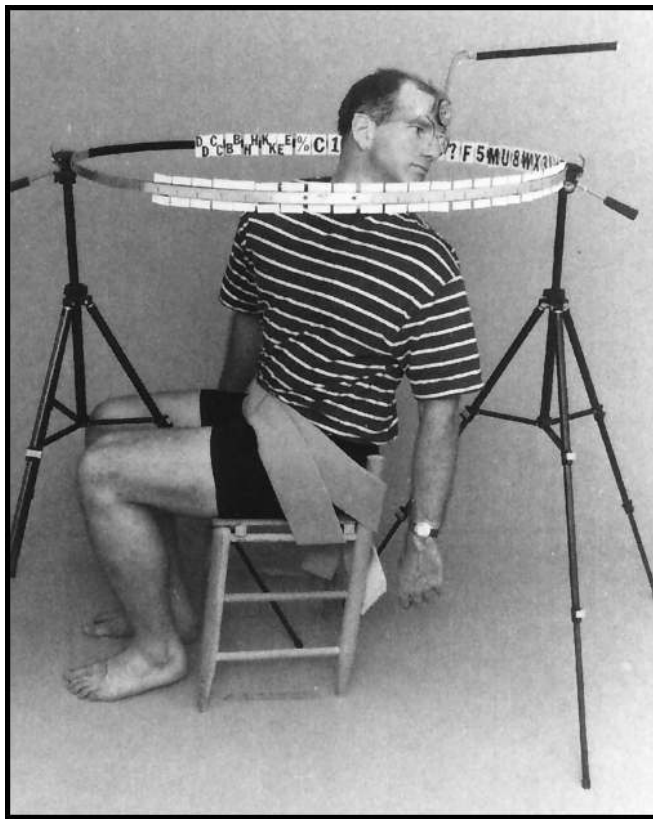


Figure 4. Measurement of functional axial rotation. The seated subject turns as far to the posterior as possible without lifting the buttocks from the chair seat. Excursion is determined by alignment of the pointer affixed to the head with the symbols marked on the hoop. Reprinted with permission of the American Physical Therapy Association from Schenkman ML, Hughes MA, Bowden MG, Studenski SA. A clinical tool for measuring functional axial rotation. *Phys Ther.* 1995;75:151-156.

Kinematic data acquisition. Kinematic data were collected with the Peak 5 video motion measurement system.[‡] Two Panasonic D5100 video cameras,[§] one Panasonic CL350 video camera,[§] and an Everex 386-25 personal computer^{||} were used to acquire and process videotape data. Data were filtered using a fourth-order, zero-lag digital Butterworth filter with a 5-Hz low-pass cutoff frequency.

Three-dimensional motion analysis was used to measure transverse-plane trunk and lower-body rotations and frontal-plane lateral trunk flexion during reaching. Two cameras and corresponding floodlights were placed in a fixed position behind the force platform at a 51-degree angle to each other. The intersection of the optical axes was directed toward the participants' back, with the center of the visual field located along the middle of the spine.

[‡] Peak Performance Technologies Inc, 7388 S Revere Pkwy, #601, Englewood, CO 80112.

[§] Panasonic USA, 1 Panasonic Way, Secaucus, NJ 07094.

^{||} Everex Systems Inc, 5020 Brandin Ct, Fremont, CA 94538.

For 3-D imaging, the examiner placed reflective markers 5.08 to 7.62 cm (2-3 in) on each side of thoracic (T), lumbar (L), or sacral (S) interspaces as follows: T2-3, T12-L1, and L5-S1. Each pair of markers constituted a horizontal line segment from which rotation and lateral flexion were to be determined.

Two-dimensional (2-D) motion analysis was used to measure sagittal-plane forward trunk flexion and maximum reaching distance. All data were collected during the same trial with the 3 cameras synchronized for simultaneous recording of data for 2-D and 3-D data analysis. The single camera and floodlight were aligned perpendicular to the forward reaching direction to record sagittal-plane movement.

For 2-D imaging of the reaching side, the examiner placed reflective markers at the lateral forearm midway between the elbow and wrist, the middle of the thorax in the frontal plane, the lateral aspect of the iliac crest in the frontal plane, the greater trochanter, and along the lateral aspect of the middle third of the femur (see Fig. 5 for marker placement). For a few variables and a few subjects, the markers were obscured during reaching.

Three-dimensional data from the cameras placed posteriorly were used to calculate maximum excursion achieved during reaching for the following variables: (1) thoracic rotation relative to the pelvis (thoracic rotation), (2) lateral trunk flexion relative to the pelvis (lateral trunk flexion), and (3) total rotation in the transverse plane relative to the ground (total rotation). *Thoracic rotation* was measured in the transverse plane and was defined as the maximum internal angle between the T2-3 horizontal line segment and the T12-L1 segment at end position minus start position. *Lateral trunk flexion* was measured in the frontal plane and was defined as the maximum internal angle between the T2-3 horizontal line segment and the L5-S1 segment. *Total rotation* was measured in the transverse plane and was defined as the sum of the transverse-plane thoracic rotation and lower-body rotation (calculated by the maximum internal angle between the T2-3 horizontal line segment and the ground at end position minus start position).

Two-dimensional data from the single camera, aligned perpendicular to the forward reaching direction, was used to determine *forward trunk flexion* in the sagittal plane, defined as the complement of the minimal internal angle created by the intersection of a segment formed by the mid-thoracic and iliac crest markers and a second segment formed by the greater trochanter and midline markers of the femur. The *reaching distance while standing* was measured by use of the lateral mid-forearm

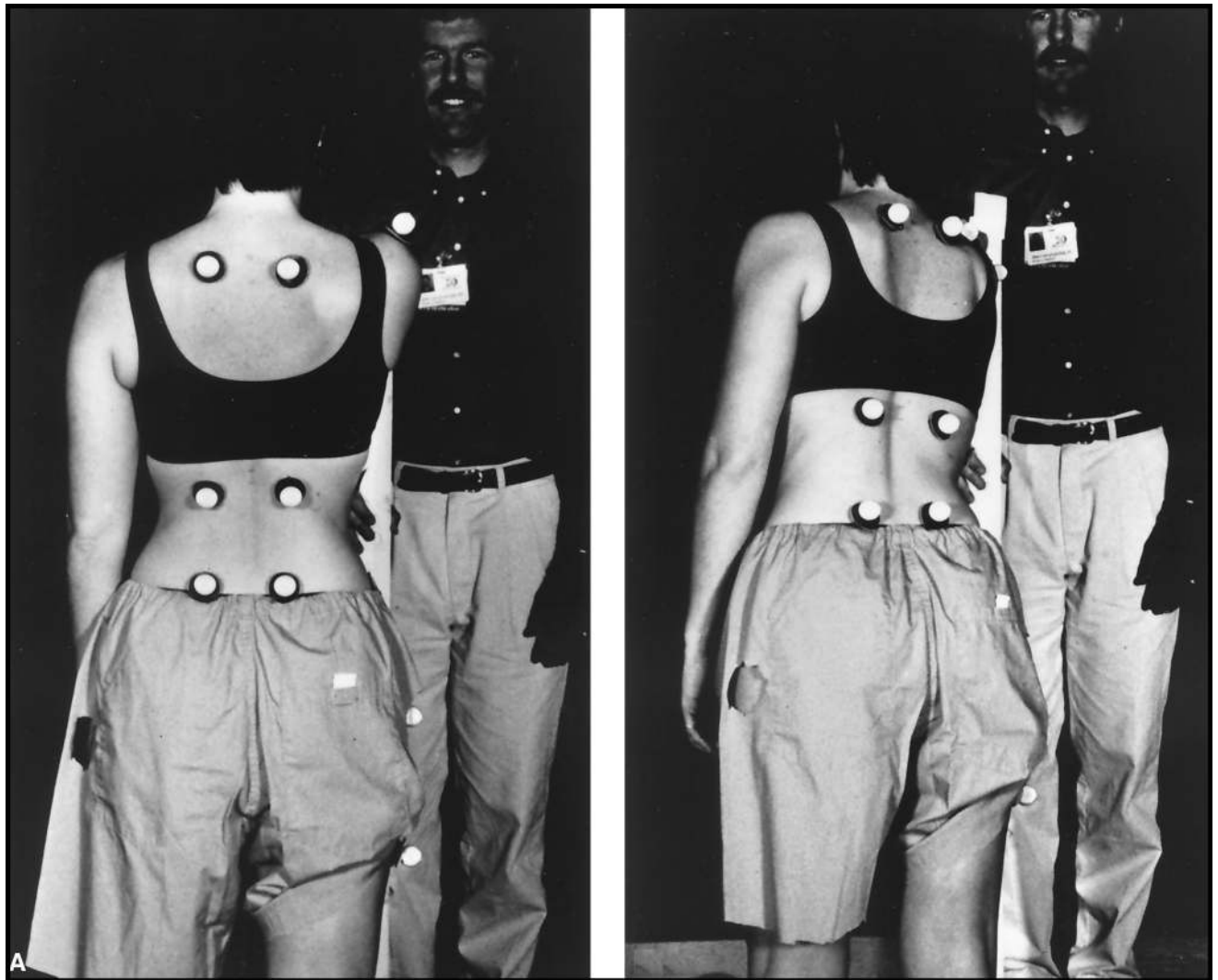


Figure 5.

Marker placement for kinematic quantification of segmental excursions during forward standing reach. (A) Posterior view of spinal markers: (left) initial position, (right) position during reaching. (B) Lateral view of the side markers: (left) initial position, (right) position during reaching. Reprinted with permission of Elsevier Science from Cavanaugh JT, Shinberg M, Shipp KM, et al. Kinematic characterization of standing reach: comparison of younger vs older subjects. *Clin Biomech.* 1999;14:271–279.

marker and was defined as the difference between the final and start positions.

For data collection, the participants stood on the force platform with feet placed at a self-selected width apart, toes oriented in a forward direction, and weight on both feet. The participants' footprints were traced to increase the likelihood of similar positioning for each trial. To determine which arm was to be used for reaching, each participant was asked to identify the arm that he or she preferred to use during daily activities. The examiner held an object several feet ahead of the participants in the sagittal plane and at the level of the acromion. The participants then were instructed to make a fist with the dominant hand, raise the arm, and point directly at the object, thus creating a starting position of 90 degrees of shoulder flexion. The examiner then instructed the

participants to reach as far forward as possible toward the object without taking a step and then return to an upright position while maintaining the shoulder at 90 degrees and with the elbow straight. Participants performed the task at a self-selected speed.

Excursions of body segments were determined next from the videotape of the participants during forward reaching, as was total reaching distance. One practice trial was followed by 2 test trials.

Data Analysis

Descriptive statistics (means, standard deviations, and percentages) were used to characterize the 2 groups. Range of motion, spinal position, and segmental excursions during reaching were compared for the 2 groups. First, group comparisons were carried out using multi-



Figure 5.
Continued.

variate analysis of variance (MANOVA) to examine differences in related variables (eg, shoulder flexion, protraction). Where differences were significant, further testing was carried out using analysis of variance (ANOVA).

Range of motion and spinal position were examined using stepwise multiple regression analysis to determine their contributions to trunk flexion during reaching. The predictor variables were entered in the following order: thoracic kyphosis, lumbar lordosis, shoulder flexion, shoulder protraction, FAR, and reaching distance. Excursions that occurred during reaching also were examined using stepwise multiple regression analysis to determine their contributions to total reaching distance. The predictor variables were entered in the following order: thoracic rotation, lateral trunk flexion, forward trunk flexion, and total rotation relative to the ground. The level of significance for all statistical tests was $P < .05$.

Results

Table 1 includes data from the 16 participants with PD and the 32 comparison participants. The average age of

Table 1.
Characteristics of the Sample

Variable	Participants With Parkinson Disease (n=16)	Comparison Participants (n=32)
Percentage female	37.5	40.6
Age (y)		
\bar{X}	67.2	66.3
SD	7.3	8.9
Height (cm)		
\bar{X}	170.9	170.2
SD	7.4	8.9
Range	158.8–185.4	155–193
Weight (kg)		
\bar{X}	68.7	71.6
SD	8.8	12.7
Range	46.3–82.6	47.2–107.0
Body mass index		
\bar{X}	23.4	24.4
SD	2.8	2.8

Table 2.Comparison of Range of Motion and Configuration of the 2 Groups^a

Variable	Participants With Parkinson Disease (n=16)			Comparison Participants			MANOVA	ANOVA
	\bar{X}	SD	Range	\bar{X}	SD	Range		
Flexibility							.010	
Shoulder flexion (°)	151.9	14.2	115–165	160.1	10.8	141–180		.052
Shoulder protraction (cm)	3.0	1.0	1.0–4.7	3.6	0.07	2.0–5.2		.030
Functional axial rotation (°)	98.2	13.2	78.8–125.0	110.3	12.7	82.5–138.8		.005
Posture							.272	
Thoracic kyphosis (°)	44.5	9.2	23–58	40.3	9.8	20–67		NA
Lumbar lordosis (°)	28.6	12.8	13–51	29.7	10.9	9–53		NA

^a MANOVA=multivariate analysis of variance, ANOVA=analysis of variance, NA=not applicable because the MANOVA was not significant.**Table 3.**Comparison of Kinematic Variables for the 2 Groups^a

Variable	Participants With Parkinson Disease			Comparison Participants			MANOVA	ANOVA
	\bar{X}	SD	Range	\bar{X}	SD	Range		
Reaching distance (cm)	29.5	6.9	19.6–40.9	34.0	4.3	25.2–46.7		.024
Segmental excursions							.075	
Forward trunk flexion (°)	35.9	13.4*	15.4–55.0	45.4	10.8*	27.1–68.6	NA	
Thoracic rotation (°)	7.9	3.0	3.1–14.6	8.6	4.2	2.0–20.8	NA	
Lateral trunk flexion (°)	8.3	5.0*	1.4–22.1	12.6	6.0*	0.4–25.4	NA	
Total rotation (°)	17.6	7.1	3.1–36.9	23.5	9.5	9.5–49.5	NA	

^a MANOVA=multivariate analysis of variance, ANOVA=analysis of variance, NA=not applicable because the MANOVA was not significant. Asterisk indicates one or more markers were obscured so that data were not available from all subjects for this variable. For all analyses presented, data were available for a minimum of 15 participants with PD and 30 comparison participants.

the participants was 66.3 years; 40% were female, and 60% were male. The modified Hoehn and Yahr stage of the participants with PD (Fig. 1) was as follows: 1 participant was in stage 1.5, 2 participants were in stage 2, 7 participants were in stage 2.5, and 6 participants were in stage 3.

The first question was whether range of motion and spinal position were different between the participants with PD and the comparison subjects. Functional axial rotation was different ($P=.005$) (Tab. 2), with a mean difference of greater than 10 degrees between the groups. Group differences also were found by MANOVA for shoulder motions ($P=.010$). Further testing with ANOVA revealed a difference in shoulder protraction of 0.6 cm ($P=.030$). No differences were found for shoulder flexion, thoracic kyphosis, or lumbar lordosis.

The second question was whether segmental excursions measured from the videotape analysis of forward reaching were different between the 2 groups (Tab. 3). Overall reaching distance was less (3.5 cm) for the participants with PD ($P=.024$).

The third question was whether spinal ROM and position contributed to forward trunk flexion, the major segmental excursion, during reaching. To answer this question, we used stepwise multiple regression analysis with a model that included 1 outcome variable (forward trunk flexion) and 6 predictor variables (thoracic kyphosis, lumbar lordosis, shoulder flexion, shoulder protraction, FAR, reach distance). The variables were not significant in the model (data not shown), nor did the addition of group (PD, no PD) alter the results of this analysis.

To answer the fourth question, contributions of segmental excursions to total reaching distance were examined. We again used stepwise multiple regression with a model that included 1 outcome variable (reaching distance) and 4 predictor variables. The first predictor variable was not significant. With the addition of the next variable, lateral trunk flexion, the model explained 28.3% of the variance ($P=.0004$). Addition of forward trunk flexion did not alter the adjusted R^2 value. However, the addition of the last variable (total rotation) to the final model was significant ($P=.0003$, adjusted $R^2=.36$) and

Table 4.

Regression Analysis of Contributions of Spinal Segmental Motions to Reaching Distance

Adjusted $R^2=.360$, $P=.0003$		
Segmental Motion	Parameter Estimate	P>F
Thoracic rotation	.104	.2111
Lateral trunk flexion	.121	.030
Forward trunk flexion	.040	.110
Total rotation	.080	.025

explained an additional 7% of the variance in reaching distance (Tab. 4).

In this final model, lateral trunk flexion and total rotation were significant (Tab. 4). The addition of group (PD, no PD) did not contribute to the model. In the final model, the estimate for lateral trunk flexion of 0.12 indicates that for every 1 degree of lateral trunk flexion, there is an expected 0.3-cm (0.12-in) increase in reaching distance. The range of lateral trunk flexion values for the total sample was almost 25 degrees (from 0.4° to 25°), potentially accounting for 7.62 cm (3 in) of the reaching distance (25×0.12). Similarly, the estimate for total rotation was 0.08, with a range for total body rotation within the sample of 40 degrees. Thus, total body rotation potentially accounted for 32 cm (1.2 in) of the reaching distance ($40 \times .08$).

Discussion

The results of our investigation indicate that changes in ROM begin relatively early in PD. The participants with PD were matched with a comparison group for sex, age, and BMI. Even though the participants with PD were relatively early in the disease process, their appendicular motion (shoulder protraction) and axial motion (FAR) were less than in the comparison participants. Because the 2 participant groups were closely matched, these results provide evidence that appears to confirm findings from previous studies in which the participants were not matched.^{8,9}

The results regarding contributions to forward trunk flexion during reaching were somewhat surprising to us. Because forward trunk flexion is the predominant segmental excursion during reaching,¹¹ we thought it possible that spinal ROM and/or spinal posture could provide contribute to forward trunk flexion. There was no contribution of any of the variables tested.

For total reaching distance, the regression model explained 36% of the variance. Significant contributors were total body rotation relative to the support surface and lateral trunk flexion. These contributions were independent of whether the participant had PD. Parameter estimates demonstrated that these contributions

were not small. For example, lateral trunk flexion potentially accounted for approximately 25% of the total reaching distance. Similarly, total rotation potentially accounted for about 10% of the total reaching distance (3 cm/30 cm total). We had anticipated that forward trunk flexion (the greatest segmental excursion during reach) would be the major contributor to reaching distance. This variable did not even contribute to reaching distance. One likely explanation is that the participants moved the trunk/pelvis forward over the stance extremities, but simultaneously moved into relative planar flexion, thereby reducing the overall forward excursion relative to the support surface. Thus, the forward trunk flexion excursion could be great, but the relative excursion of the center of mass is relatively limited, possibly explaining why forward trunk flexion does not contribute to reaching distance. This is conjecture on our part and will require further investigation.

The results of our investigation indicate that overall ROM (both spinal and extremity), but not spinal position, is reduced early in PD. The results also indicate that lateral trunk flexion during reaching contributes to reaching distance, whether or not an individual has PD. These findings are consistent with the proposition that the functional limitations of people with PD stem from a combination of the primary impairments associated with the disease and the loss of ROM that occurs indirectly from or as a sequela to PD.³ Furthermore, results from our previous work¹⁰ demonstrate that both spinal ROM and functional reach distance can increase with physical intervention directed at improvements of spinal ROM through a program¹⁹ emphasizing relaxation during movement. Taken together, these results suggest that physical intervention should be initiated early in PD (ie, stages 1 and 2 of the Hoehn and Yahr scale) to improve or retain spinal ROM of patients with PD and to enhance use of that ROM during functional tasks.

We had expected that the participants with PD might have greater thoracic kyphosis and more limited lumbar lordosis than the comparison participants. Our study, however, did not demonstrate such differences. Indeed, our findings are consistent with Morris' suggestion²⁰ that excessive kyphosis and limited lordosis occur later in PD. Because of the relationship between spinal position and performance of tasks observed by other investigators,⁷ future studies are needed to determine what subset of patients have spinal deformities of the extent that such impairments contribute to functional decline in the later stage of PD. Despite this lack of difference in thoracic kyphosis and lumbar lordosis early in the development of PD, our findings indicate that early differences do exist in available spinal ROM and in ROM of spinal segments during reaching.

Participants with PD demonstrated a shorter reaching distance than participants in the comparison group, consistent with our previous work using the functional reach test.⁸ Previous results demonstrated that older people generally have smaller spinal excursions (eg, lateral trunk flexion, spinal rotation) during reaching than do younger individuals.¹¹ Results of this investigation demonstrate that people with PD have even more limited ROM than do older individuals without PD.

Some variables did not show between-group differences. The small sample size may have contributed to the lack of differences. Additionally, the participants with PD were relatively early in the disease (10 of the 16 participants were in Hoehn and Yahr stage 2.5 or lower). Greater differences in these variables might be seen in individuals in later stages of the disease.

A few limitations of the study should be acknowledged. A number of physiological variables were not investigated. We designed our study to examine spinal and extremity ROM and position. Other variables, including general physiological constraints (eg, impaired sensation, decreased muscle force production) and impairments associated with PD (eg, bradykinesia, difficulties with motor planning and organization, impaired postural control mechanisms), presumably account for some of the variance in reaching distance and should be examined in future studies.

Because only 3 cameras were available for this study, we were unable to measure forward trunk flexion with 3-D motion analysis. A minimum of 4 cameras would be required to measure all subject movements in 3 dimensions. We decided that camera placement would be optimized for frontal- and transverse-plane movements of the trunk. Use of a single camera to measure forward trunk flexion and maximum reaching distance may have induced error due to trunk rotation, but we believe that the magnitude of this error was small compared with the full ROM in the sagittal plane. Although this was a compromise, we contend that it was the best solution given the limitations of the recording system and that it should not have affected the results to any meaningful degree.

For several variables, markers occasionally were obscured by the participants' upper extremities, resulting in missing values for some variables and for some participants. This is a common occurrence in 3-D motion analysis. Fortunately, for all of the variables, data were available for at least 15 of the 16 participants with PD and for at least 30 of the 32 comparison participants. The missing values are unlikely to have reduced the statistical power by very much.

Due to the small sample size and because this was a preliminary study, we did not separately analyze data for the participants with PD and the comparison participants. Future studies with larger samples will be necessary to determine whether there are differences between people with and without PD with respect to segmental ROM and the order of segmental motions during the reaching activity. Nevertheless, despite our small sample size, our results indicate the importance of lateral trunk flexion for reaching. The results of this investigation also indicate that this contribution is independent of the presence of PD and is consistent with our earlier findings⁸ that FAR is a significant contributor to overall reaching distance, independent of the presence of PD.

Conclusion

The results of our study demonstrate that ROM is less for people in early stages of PD compared with a comparison group matched for age, sex, and BMI. The results also indicate the importance of lateral trunk flexion excursion during forward standing reach. Together with other data in the literature, our findings are consistent with the notion that musculoskeletal alterations associated with PD are precipitated by the disease but that their influence on the kinematics of reaching is independent of the presence of PD.

We believe that a larger, more definitive study now is warranted, examining the contributions of a number of physiological variables on the kinematics of standing forward reach. Future studies also should examine how improvements relate to available ROM, segmental excursions during reaching, and overall functional ability. Finally, investigations are needed to examine how improvements in specific segmental excursions during reaching (eg, lateral trunk flexion) relate to improved reaching distance and to improved function for people with PD.

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