Arm swing magnitude and asymmetry during gait in the early stages of Parkinson's disease

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**ABSTRACT**

The later stages of Parkinson's disease (PD) are characterized by altered gait patterns. Although decreased arm swing during gait is the most frequently reported motor dysfunction in individuals with PD, quantitative descriptions of gait in early PD have largely ignored upper extremity movements. This study was designed to perform a quantitative analysis of arm swing magnitude and asymmetry that might be useful in the assessment of early PD. Twelve individuals with early PD (in “off” state) and eight controls underwent gait analysis using an optically-based motion capture system. Participants were instructed to walk at normal and fast velocities, and then on heels (to minimize push-off). Arm swing was measured as the excursion of the wrist with respect to the pelvis. Arm swing magnitude for each arm, and inter-arm asymmetry, were compared between groups. Both groups had comparable gait velocities (\(p = 0.61\)), and there was no significant difference between the groups in the magnitude of arm swing in all walking conditions for the arm that swung more (\(p = 0.907\)) or less (\(p = 0.080\)). Strikingly, the PD group showed significantly greater arm swing asymmetry (asymmetry angle: 13.9 ± 7.9%) compared to the control group (asymmetry angle: 5.1 ± 4.0%; \(p = 0.003\)). Unlike arm swing magnitude, arm swing asymmetry unequivocally differs between people with early PD and controls. Such quantitative evaluation of arm swing, especially its asymmetry, may have utility for early and differential diagnosis, and for tracking disease progression in patients with later PD.

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condition), and (3) on their heels (an unnatural gait in which individuals maximized stride length while only letting their heels touch the ground).

1. Methods

1.1. Participants

Twelve individuals within three years of PD diagnosis and eight control participants were tested (Table 1). PD diagnosis was made by a movement disorder specialist according to published guidelines [1]. All participants in the PD group were treated with dopaminergic replacements and showed a dramatic clinical improvement. Individuals with PD were tapered off all anti-parkinsonian drugs at least 12 h prior to testing. A group consensus previously recommended that a practically defined “off” state be operationally defined as a patient’s condition after not receiving anti-parkinsonian medication for 12 h [19]. All participants were examined by a movement disorder physician (XH or JJ), and were free of muscular weakness, history of stroke, pathology or surgery to the upper extremities, or major medical illness. All individuals performed the Berg Balance scale prior to testing to estimate fall risk. A cutoff of 54 has recently been proposed to predict risk of falling in patients with PD [20]. The study protocol was reviewed and approved by the UNC Institutional Review Board (IRB # 07-2070). Written informed consent was obtained from all participants prior to participation.

1.2. Gait analysis

All participants underwent a single gait analysis session to determine the motion of the arms, trunk, pelvis and lower extremities. Body segments were tracked during gait using an eight camera, passive, three-dimensional motion analysis system (Vicon/Peak, Lake Forest, CA) sampling at 120 Hz. Heel strikes were obtained from foot switches (Motion Lab Systems, Baton Rouge, LA) synchronized with the Peak system for simultaneous collection at 1080 Hz. Retro-reflective markers were placed bilaterally on the lateral aspect of the fifth metatarsal head, medial and lateral malleoli, medial and lateral femoral condyles, greater trochanters, iliac crests, acromion processes, spinous process of C7, medial and lateral humeral condyles, and the styloid process of the ulna and radius to indicate the ends of the segments and to identify appropriate joint centers. Rigid thermoplastic shells, each with four markers firmly affixed, were attached to the posterolateral aspect of the thighs and shanks and covered with an elastic wrap to minimize movement. Marker triads were placed on the sacrum and both feet. Prior to the collection of walking trials, a static standing trial was recorded to identify appropriate joint centers. Rigid thermoplastic shells, each with four markers firmly affixed, were attached to the posterolateral aspect of the thighs and shanks and covered with an elastic wrap to minimize movement. Marker triads were placed on the sacrum and both feet. Prior to the collection of walking trials, a static standing trial was recorded to identify joint centers with respect to each segment coordinate system.

Marker position and foot switch data were recorded simultaneously while participants walked across a 25-foot walkway under three conditions: (1) normal (e.g., self-selected) walking velocity (“Normal”), (2) fastest possible walking velocity while maintaining safety and without jogging (“Fast”), and (3) walking on the heels at a self-selected velocity (“Heel-Walking”). Individuals repeated each condition five times. For Heel-Walking, participants were instructed to maximize stride length while only letting the heels touch the ground (e.g., toes up). The intention of the Heel-Walking condition was to minimize push-off, and thus accentuate arm swing to generate propulsive forces. No instructions or feedback regarding arm swing were provided for any condition.

1.3. Data management and processing

Data analysis software (Peak Motus) was used to identify the locations of the markers in the lab coordinate system, and to low-pass filter these marker trajectories at 6 Hz. The markers defined a kinematic model for tracking the three-dimensional motion of the arms, trunk, pelvis, and lower limb segments. All segment coordinate systems were defined with the positive X-axis to the right, positive Y-axis facing anteriorly, and positive Z-axis pointing superiorly. Visual3D software (C-Motion, Germantown, MD) estimated segment properties from measured anthropometric values [21]. All segments were modeled as a frustra of cylinders.

Our primary interest was in quantifying arm swing: we defined this operationally as the distance traveled by the wrist during an entire stride (e.g., path depicted by thick black lines), with respect to the origin of the pelvis (shown at 0,0 in the figures).

Fig. 1. Representative example of arm swing for an individual from PD group for an entire stride during (A) Normal, (B) Fast, and (C) Heel-Walking conditions. Arm swing magnitude was calculated as the total distance that the wrist travelled during an entire stride (e.g., path depicted by thick black lines), with respect to the origin of the pelvis (shown at 0,0 in the figures).

Table 1

Participant’s demographic information.

<table>
<thead>
<tr>
<th></th>
<th>PD group</th>
<th>Control group</th>
<th><em>p</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>68 ± 8 years</td>
<td>61 ± 12 years</td>
<td>0.148</td>
</tr>
<tr>
<td>Gender</td>
<td>9 males/3 females</td>
<td>5 males/3 females</td>
<td>0.642</td>
</tr>
<tr>
<td>More affected side</td>
<td>10 right/2 left</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Berg balance Scale</td>
<td>54 ± 2</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Handedness</td>
<td>11 right/1 left</td>
<td>8 right/0 left</td>
<td>0.999</td>
</tr>
<tr>
<td>Months of PD diagnosis</td>
<td>24 ± 10 months</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>H&amp;Y score at “off”</td>
<td>1.29 ± 0.40</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Motor UPDRS scores at “off”</td>
<td>11.25 ± 5.55</td>
<td>N/A</td>
<td></td>
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</tbody>
</table>
Conversely, arm swing was affected significantly by walking condition \((\text{ArmSwing}_\text{more}: F(2,36) = 88.271; p < 0.001; \text{ArmSwing}_\text{less}: F(2,36) = 53.150; p < 0.001)\). Fast walking produced significantly greater arm swing of both arms than Normal walking \((p < 0.001)\), whereas Heel-Walking generated greater arm swing than both the Normal \((p < 0.001)\) and Fast \((p < 0.001)\) walking conditions.

The PD group exhibited significantly greater ASA compared to the control group (Fig. 2) across all walking conditions \((F(1,18) = 11.890; p = 0.003)\). Post hoc testing revealed that ASA measures were significantly greater in the PD group for the Normal \((p < 0.001)\) and Fast \((p = 0.015)\) conditions, but not for Heel-Walking \((p = 0.062)\).

No significant main effect of walking condition was observed for ASA \((F(2,36) = 0.059; p = 0.943)\), and there was no significant interaction effect \((\text{group} \times \text{condition}: F(2,36) = 2.493; p = 0.097)\). We established a threshold of excessive asymmetry during Normal walking based on the values from the control group (threshold = 7.4%). Based on this threshold, 10 of 12 (83%) participants in the PD group and 0 of 8 (0%) of the control group had excessive ASA during normal walking \((p < 0.001)\).

The magnitude of trunk rotation (Table 2) was not significantly different between the PD and control groups \((F(1,18) = 0.386; p = 0.542)\). A main effect for condition \((F(2,36) = 50.320; p < 0.001)\) was noted, such that Fast walking produced significantly greater trunk rotation than Normal walking \((p < 0.001)\), and Heel-Walking generated greater trunk rotation than both the Normal \((p < 0.001)\) and Fast \((p < 0.001)\) walking conditions. Our purpose for measuring trunk rotation was to ensure that ASA values were not simply a reflection of asymmetrical trunk rotation. Importantly, we observed that TRA (Table 2) was not significantly different between the PD and control groups \((F(1,18) = 3.371; p = 0.083)\). A significant main effect of condition was observed for TRA \((F(2,36) = 3.564; p = 0.039)\). Post hoc tests indicated that TRA was greater during Heel-Walking compared to the Normal speed condition \((p = 0.040)\).

The STA (Table 2) was not significantly different between groups \((F(1,18) = 1.325; p = 0.265)\). Furthermore, STA was not significantly affected by walking condition \((\text{ArmSwing}_\text{more}: F(2,36) = 88.271; p < 0.001; \text{ArmSwing}_\text{less}: F(2,36) = 53.150; p < 0.001)\).

**2. Results**

Gait velocities were comparable between groups for all conditions \((F(1,18) = 0.01; p = 0.922)\), although gait velocities were significantly different among walking conditions \((F(2,36) = 76.68; p < 0.001)\) (Table 2). Specifically, both the PD and control groups had a higher gait velocity during the Fast condition compared to the Normal or Heel-Walking conditions \((p < 0.001)\). No difference was seen between the Normal and Heel-Walking conditions \((p = 0.156)\).

Across walking conditions, \(\text{ArmSwing}_\text{more} (F(1,18) = 0.014; p = 0.907)\) and \(\text{ArmSwing}_\text{less} (F(1,18) = 3.447; p = 0.080)\) were not significantly different between the PD and control groups (Table 2). Conversely, arm swing was affected significantly by walking condition.
significantly different among walking conditions ($F(2,36) = 1.682; p = 0.200$), and there was no significant interaction effect (group $\times$ condition: $F(2,36) = 0.304; p = 0.740$).

3. Discussion

We believe that the current study is the first comprehensive study of arm swing in patients with early PD, and suggests that asymmetry, but not the magnitude of arm swing, may be an early sign of the disease. This suggests that a quantitative description of arm swing, especially its asymmetry, should be evaluated in future studies because of the potential implication for early and differential diagnosis, and for predicting and tracking PD progression.

It was somewhat unexpected that no significant differences in arm swing magnitude were found between PD and control groups because decreased arm swing has been described as an early sign of PD [23]. There are several possible factors influencing our finding, including the fact that all participants with PD were in the early stage of their disease, may still have been influenced by residual drug effects that had not “washed out”, and/or performed better because they were aware that they were being observed.

Most notably, the data show an unequivocal distinction in arm swing asymmetry between individuals with early PD and controls during Normal walking. The asymmetric process of nigrostriatal dopaminergic denervation and motor asymmetry occurring in PD has been well described [11,12]. The clinically judged presence of motor asymmetry (tremor, rigidity, and bradykinesia) has been used to help increase the accuracy of PD diagnosis [13]. The current data now provide quantitative measurements for one aspect of this motor asymmetry.

Although others have reported the presence of swing time asymmetry in the lower extremities of individuals with de novo PD [16] the current data showed asymmetry only in arm, not leg, swing in individuals with early PD. This discrepancy may be due to differences in the methodology which was employed. First, we used a novel asymmetry angle purported to correct for artificially inflated values of previous asymmetry measures [22]. Moreover, all individuals in our PD group were treated with anti-parkinsonian medication, whereas prior studies used drug naive patients. Although we attempted to wash out drug effects overnight (12 h), there will be residual medication benefit that could have masked the STA. Nevertheless, the current data suggest that arm swing asymmetry may either preclude, or be more robust than, lower extremity asymmetry in marking the early stages of PD.

Similar to prior reports, we demonstrated that arm swing magnitude is associated with gait velocity in patients with PD [7] and controls [10,24,25]. Thus, findings that there is decreased arm swing in individuals in the later stages of PD may be associated with the diminished gait velocity commonly observed with PD [4,7]. It is interesting to note that whereas arm swing magnitude was significantly modified by both walking velocity (Normal or Fast) and pattern (natural or unnatural), arm swing asymmetry was relatively resistant to the changes in walking conditions. We therefore propose that arm swing asymmetry may serve as a more reliable parameter than arm swing magnitude in studying PD.

Because reductions in trunk rotation during gait are well known to be present in individuals with PD [4,24], it is possible that the arm swing measurements could have been confounded by alterations in trunk rotation between groups. The fact that trunk rotation asymmetry was not different between the groups in our study suggests that the arm swing asymmetry measurement was able to account for any discrepancies in trunk rotation.

There has been a great deal of effort to detect PD in preclinical states using a variety of non-motor symptoms (such as olfaction, autonomic dysfunction and sleep disorders) [23,26,27]. Although such non-motor symptoms may be sensitive for the early detection of PD, they remain non-specific [27]. Arm swing belongs to the domain of motor function, and the dramatic differences in arm swing asymmetry between early PD and control groups suggests that arm swing asymmetry may have unique use in the early and differential diagnosis of PD, and indeed, in monitoring its progression.

Acknowledgements

This work was supported in part by the National Institutes of Health [R01NS06722 and K23AG21491 to XH, and UL1RR025747 from the Clinical and Translational Science Award program of the Division of Research Resources]; and the UNC Center for Human Movement Sciences. We thank Richard Mailman for his insightful feedback about the manuscript.

Conflict of interest statement

The results of this study have led to the filing of a U.S. provisional patent application by Penn State University on behalf of the inventors. This creates a potential conflict-of-interest for Dr. Huang and other inventors to be listed if that technology is ever commercialized. The opinions in this manuscript represent solely those of the authors alone, and not of their university employers.

References


