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Altered joint kinetic strategies of healthy older adults and individuals with Parkinson's disease to walk at faster speeds

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ABSTRACT

Individuals with Parkinson's disease (PD) exhibit poorer walking performance compared to healthy, age-matched adults. Lower extremity joint kinetics may provide insight into this performance deficit but are currently lacking in the PD literature, especially across multiple speeds. The primary purpose of this study was to compare joint kinetics between individuals with PD and healthy older adults at both comfortable and maximal walking speeds. Secondarily, we quantified relationships between joint kinetics and walking speeds within each group. Biomechanical gait analyses were conducted for 13 individuals with PD and 12 age-matched controls during comfortable (CWS) and maximal (MWS) speed walking. Relative contributions to total positive work from the hip, knee, and ankle were compared across groups and speeds. Within each group, relationships between relative joint work and CWS and MWS were also quantified. Significant group by speed interactions indicated that healthy older adults increased hip and decreased ankle relative work at MWS compared to CWS whereas relative work at all joints in PD group remained stable across speeds. In the older group, positive relationships were observed between relative hip work and MWS. In the PD group, negative relationships were observed between relative hip work and CWS and MWS. Healthy older adults disproportionately increased mechanical contributions from the hip at MWS compared to CWS. Individuals with PD did not exhibit similar disproportionate scaling of joint kinetics across speed conditions. Inability to appropriately scale joint kinetics in PD may represent an inflexible neuromuscular system in PD, which may limit walking performance in this population.

1. Introduction

Parkinson's Disease (PD) is a neurodegenerative disorder that results in hypokinetic movement patterns, which can lead to reduced walking performance compared to healthy age-matched controls (Morris et al., 2005; Sofuwa et al., 2005). Despite performance improvements with pharmacological intervention, some deficits persist, such as reduced balance and slow walking speed, which can reduce overall quality of life (Ferrarin et al., 2005; Marras et al., 2008). Mechanisms underlying reduced walking performance are therefore important to elucidate. Lower extremity joint-level kinetics (i.e., moments and powers) during gait reflect joint-level control and may shed more light on such mechanisms. For example, faster walking speeds can be achieved by altering stride length, cadence, or both and these spatiotemporal alterations influence the mechanical demand of walking (Donelan et al., 2002; Umberger and Martin, 2007). Increased mechanical demand at faster speeds is met by increased power generation from the three primary lower extremity joints (hip, knee, ankle) (Winter, 1983) and an inability to appropriately scale joint-level power generation can limit walking speed (Jonkers et al., 2009).

Comfortable walking speed is a sensitive measure of disability and gait dysfunction in older adults (Abellan van Kan et al., 2009). However, safe community ambulation also requires the capacity to increase walking speed (e.g., increasing speed to cross a street). Maintenance of maximal walking speeds with advanced age relies on the ability of healthy, older adults to adopt appropriate biomechanical strategies for increasing speed. Increased hip relative to ankle joint kinetics (e.g., positive work) is a hallmark biomechanical feature of gait in older compared with younger adults (Buddhadev and Martin, 2016; DeVita and Hortobagyi, 2000; Hortobagyi et al., 2016; Silder et al., 2008) and it appears that older adults increase the magnitude of this gait characteristic

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(i.e., rely further on positive mechanical work from the hip and less from the ankle joint) to reach faster walking speeds (Kuhman et al., 2018). Thus, the mechanical strategy utilized by older adults to increase walking speed can be characterized by a disproportionate increase in performance of positive work at the hip compared to the ankle. Scarcity of joint-level kinetic comparisons between healthy aging and PD, especially across multiple walking speeds, make it difficult to determine whether individuals with PD utilize a similar mechanical strategy to alter speed. Such comparisons will enhance our understanding of gait mechanics in PD and may help explain reduced walking performance in this population. Ultimately, such data may provide useful information for targeted and individualized interventions aimed at improving walking performance and overall quality of life in PD.

The primary purpose of this study was to compare positive work performed at each of the lower extremity joints between individuals with PD and healthy older adults at both comfortable and maximal walking speeds. First, we hypothesized that comfortable and maximal speeds would be slower in PD compared to healthy older adults. Second, we hypothesized that differences in joint work would be found between PD and older adults at both speeds (i.e., a main effect of group). Third, we hypothesized that both groups would adopt a similar mechanical strategy, characterized by increased positive work at the hip joint, to walk at maximal compared to comfortable speeds (i.e., a main effect of condition). As a secondary purpose, we quantified relationships between joint work and walking speeds within each group separately. This secondary, exploratory analysis was conducted to examine the potential influence of joint work variation on variation in walking performance within each group. This study represents an initial step toward understanding lower extremity joint kinetics and their potential impact on walking performance in individuals with PD.

2. Methods

2.1. Participants

Thirty individuals (10 females) were initially enrolled in this study; 15 had idiopathic PD and 15 were age and sex-matched, non-PD controls (referred to throughout as "controls"). Data presented here represent a secondary analysis of cross-sectional data collected to assess differences in mobility and muscle physiology (Hammond et al. in review). Individuals with PD and controls shared the following inclusion criteria: 45–85 years of age and able to ambulate at least 6-meters independently. Additional inclusion criteria for PD participants were: Hoehn and Yahr stages 2–3 and medication-stable for at least four weeks prior to enrollment. Exclusion criteria for all participants included regular participation in resistance exercise training in the last six months, participation in drug studies or the use of investigational drugs within 30 days prior to enrollment, acute illness or active infection, confounding medical, neurological, or musculoskeletal conditions, or any contraindication to exercise testing. PD participants were generally ambulatory but displayed some amount of PD-related motor impairment. This study was approved by the Institutional Review Board of the University of Alabama at Birmingham. All participants provided written informed consent.

2.2. Experimental setup

PD participants were tested while optimally medicated. Overground walking speeds were measured using electronic timing gaits (FarmTek Inc., Wylie, TX, USA) placed 6-meters apart. Kinematic and ground reaction force (GRF) data were collected simultaneously using eight infrared cameras (Vicon Motion Systems, Denver, CO, USA; 100 Hz) and a split-belt force-instrumented treadmill (Motekforce Link, Amsterdam, The Netherlands; 1000 Hz), respectively. Vicon Nexus, Visual 3D (C-Motion Inc., Rockville, MD, USA), and laboratory software written in MATLAB (MathWorks Inc., Natick, MA, USA) were used to collect, process, and analyze biomechanical data.

2.3. Testing protocol

Participants first completed questionnaires assessing functional performance, including: Modified Baecke Questionnaire for Older Adults (MBQOA) (Voorrips et al., 1991), Activity-specific Balance Confidence (ABC) Scale (Powell and Myers, 1995), Fatigue Severity Scale (FSS) (Herlofson and Larsen, 2002). To further describe disease state, PD participants completed the 39-item Parkinson's Disease Quality of Life Scale (PDQ-39) (Jenkinson et al., 1997), and were assessed by a certified evaluator using Section III (motor) of the Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS) (Goetz et al., 2008) and Hoehn and Yahr staging (Hoehn and Yahr, 1998).

Participants performed three over-ground walking trials at both comfortable (CWS) and safe-maximal speeds (MWS) with instructions to walk at "a speed that is comfortable for you" and "the fastest speed at which you feel safe," respectively. The three-trial averages for both conditions were then matched on the treadmill for gait analysis. A total of 28 passive reflective markers were used to define and track movement of the trunk, pelvis, and the thigh, shank, and foot of both legs during treadmill walking trials. The pelvis was defined and tracked by markers placed on the left/right anterior and posterior superior iliac spines. Thigh segments were defined by left/right greater trochanters and the medial/lateral femoral epicondyles and tracked using the greater trochanter, lateral femoral epicondyle, and a marker placed on the anterior aspect of the thigh. Shank segments were defined by medial/lateral femoral epicondyles and medial/lateral malleoli and tracked using lateral femoral epicondyle, lateral malleolus, and a marker placed on the anterior aspect of the shank. Feet segments were defined by medial/lateral malleoli and first/fifth metatarsophalangeal (MP) joints and tracked using markers on the first/fifth MP joints and a single marker placed on the heel. The trunk was defined by left/right acromion and left/right iliac crest markers and tracked using markers placed on the acromion processes, the manubrium, and the 7th cervical vertebra. Participants were placed in a fall harness that provided no bodyweight support and was used only to ensure participant safety, which does not appear to alter gait kinematics (Pavol et al., 1999). After acclimating to the treadmill, participants walked at their CWS and then MWS while biomechanical data were collected continuously for ~60-seconds (in each condition).

2.4. Data analysis

Due to technical difficulties, primarily an inability of some participants to maintain one foot on each treadmill belt, kinetic data could not be processed for three controls and two PD participants. This was primarily an issue for participants when walking at their MWS. Step width decreases with walking speed (Orendurff et al., 2004; Stimpson et al., 2017), making it more difficult to maintain one foot on each belt on a step-by-step basis during MWS. We did not offer explicit instructions to maintain one foot on each belt, as doing so may have caused participants to walk with an unnatural gait pattern (e.g., increased step width). For the remaining participants, joint kinetics were analyzed for the left hip, knee, and ankle. Kinematic and GRF data were filtered using fourth order low-pass Butterworth filters with cutoff frequencies of 6 Hz and 12 Hz, respectively. Joint moments and powers were estimated in

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