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Evidence of compensatory joint kinetics during stair ascent and descent in Parkinson's disease

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ABSTRACT

Background: Stair ambulation is a challenging activity of daily life that requires larger joint moments than walking. Stabilisation of the body and prevention of lower limb collapse during this task depends upon adequately-sized hip, knee and ankle extensor moments. However, people with Parkinson's disease (PD) often present with strength deficits that may impair their capacity to control the lower limbs and ultimately increase their falls risk.
Objective: To investigate hip, knee and ankle joint moments during stair ascent and descent and determine the contribution of these joints to the body's support in people with PD.
Methods: Twelve PD patients and twelve age-matched controls performed stair ascent and descent trials. Data from an instrumented staircase and a three-dimensional motion analysis system were used to derive sagittal hip, knee and ankle moments. Support moment impulses were calculated by summing all extensor moment impulses and the relative contribution of each joint was calculated.
Results: Linear mixed model analyses indicated that PD patients walked slower and had a reduced cadence relative to controls. Although support moment impulses were typically not different between groups during stair ascent or descent, a reduced contribution by the ankle joint required an increased knee joint contribution for the PD patients.
Conclusions: Despite having poorer knee extensor strength, people with PD rely more heavily on these muscles during stair walking. This adaptation could possibly be driven by the somewhat restricted mobility of this joint, which may provide these individuals with an increased sense of stability during these tasks.

1. Introduction

Of those activities common to daily living, stair walking has been rated by older adults as one of the most challenging [1], as it requires an individual to keep their centre of mass within the boundaries of their base of support (provided by one or both feet) to maintain stability [2,3]. Furthermore, stair walking is a task that often requires the centre of mass and the centre of pressure to be separated [4], potentially increasing the load on the body's postural control system. The task of shifting the body's centre of mass laterally and either upwards during stair ascent or downwards during stair descent [4] requires the body's mass to be strictly controlled by muscles surrounding the hip, knee and ankle joints to produce large moments [5,6]. Compared with level-ground walking, knee joint extension moments are up to two times greater during stair ambulation [7], which ultimately indicates that one's ability to safely ambulate stairs is greatly dependent on them having adequate lower limb muscle strength [8]. Specifically during stair ascent, the ankle plantarflexors and knee joint extensors contract to shift the body's mass upwards and forwards towards the next step [9]. In contrast, stair descent features a large downward acceleration of the body [10], which requires the strong eccentric action of the leg extensor muscles to lower the body in a controlled manner [11]. During these tasks, the moments produced by the ankle plantarflexors and knee extensors contribute heavily to the forces that serve to prevent the lower limb from collapsing during weight-bearing tasks (otherwise referred to as the support moment) [12]. By definition, the support moment is calculated by summing the extensor moments for the hip, knee and ankle joints (i.e. those acting against gravity) to

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determine their collective contribution to supporting the body's weight [13].

Unfortunately, people with neurodegenerative conditions, such as Parkinson's disease (PD), often report deficits in muscle strength and endurance, which significantly influence their movement patterns and ultimately contributes to a greater risk of recurrent falls [14,15]. These physical deficits and the inherent increase in falls risk ultimately contribute to poorer balance confidence and an increased fear of falling in this population [16], which further impair their movement patterns [17]. While it seems reasonable to suggest that these physical and psychological limitations would be likely to pose greater problems for patients during more physically challenging activities of daily life, it is interesting to note that only one study has investigated differences in patient performances while ascending a single step [18]. While falls on stairs only account for 2% of the falls experienced by people with PD [19], they frequently result in more serious consequences (e.g. fracture or death) [20] and, hence, warrant specific attention. Therefore, this cross-sectional study sought to investigate differences in lower limb joint moments between persons with PD and healthy age-matched controls during the self-paced ascent and descent of multiple stairs. Furthermore, this research sought to ascertain whether the relative contribution of the hip, knee and ankle joint moments to the overall support of the body's mass during these tasks (i.e. the support moment) differed between the cohorts. As people with PD are known to have deficits in lower limb muscle strength [15], it was hypothesised that patients would exhibit significantly lower joint moments during stair negotiation. Secondly, as people with PD have been shown to have reduced ankle moments when ascending a single step [18], it was hypothesised that these individuals would adopt alternate strategies to controls that would rely less on the muscles surrounding the ankle joints.

2. Methods

2.1. Study population

Two groups of 12 participants comprising; i) people with idiopathic PD; and ii) age- and gender-matched controls volunteered to participate in this study. Participants with PD were recruited from a neurology clinic in South-East Queensland, Australia and were confirmed to have PD based on the United Kingdom Brain Bank Criteria [21] by their neurologist. Controls were randomly-recruited from a pre-existing database. To be eligible, participants were required to be; i) independently living; ii) able to ambulate without assistance; iii) without dementia based on the Standardized Mini-Mental State Examination (total score $\geq$24); iv) free of clinically-diagnosed visual or musculoskeletal problems; v) free of medical conditions (other than PD) that would adversely affect their balance; and vi) receiving no non-pharmacological therapies (e.g. deep brain stimulation). An a-priori sample size calculation based on data from healthy younger and older adults [9] suggested that a minimum of 10 participants per group was required to detect differences in peak knee extension moments between groups (Effect size = 1.36, Power = 0.8, p = 0.05). The Human Research Ethics Committee at the University approved this study (approval #2014 345Q) and participants provided written informed consent.

2.2. Clinical assessment

Participants completed assessments of cognition (Standardized Mini-Mental State Examination), quality of life (Short-Form 8 questionnaire (SF-8)) and balance confidence (6-item Activities-specific Balance Confidence scale (ABC-6)). PD participants also completed the PD-specific 8-item quality of life questionnaire (PDQ-8), while disease stage and symptom severity were established by an experienced movement disorders scientist using the Movement Disorders Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS), the Hoehn and Yahr stage score· the Schwab and England Activities of Daily Living scale and the New Freezing of Gait questionnaire. Participants were assessed approximately 1-h following their anti-parkinsonian medication to ensure they were optimally-medicated.

2.3. Movement assessment

Participants performed stair ascents and descents at a self-selected pace on a 3-step staircase (19 cm riser and 30 cm tread) designed to comply with national regulations. Ground reaction forces (GRFs) were measured at 1200 Hz via two AccuGait force platforms (Advanced Mechanical Technology Inc., USA) embedded in the first and second steps. Ascent and descent trials were repeated until participants had achieved three trials with the left and right feet hitting the first step (i.e. 6 trials total). To prevent deliberate adjustment of walking patterns (otherwise known as 'targeting'), participants were blinded to this requirement and were instructed as to which foot to initiate each trial to avoid repeatedly reaching the first step with the same foot. For the ascent trials, participants started 5-m away from the staircase and, when instructed, approached the first step and ascended in a foot-over-foot pattern before walking along the 1.7-m long landing. Following an enforced rest break, participants traversed the landing, descended the staircase in a foot-over-foot pattern and returned to the starting position. For the participants' safety, handrails were present, but only trials completed without the use of the handrails were analysed due to the additional stability that they may offer.

To quantify lower limb joint moments, reflective markers were affixed over specific anatomical landmarks on the feet, knees and pelvis using double-sided tape (Tesa Tape Inc., USA) and bilaterally over the mid-thigh and mid-shank via securely-fastened rigid bodies. During the tasks, three-dimensional marker trajectories were captured at 120 Hz by a 12-camera motion analysis system that was synchronised with the GRFs using the Vicon Nexus software (v.2.1.1; Vicon, Oxford, UK). Isometric knee extensor strength was also assessed whilst participants were seated with legs hanging and their back supported. A Velcro cuff was firmly wrapped around the ankle and attached via an adjustable strap to an anchor point behind the participant. The knee angle was set at 90° prior to the trial [22] and this was confirmed with a goniometer. To assess the ankle plantarflexors, the cuff was firmly affixed around their forefoot with their knee at 90° and their foot at 90° relative to the shank. Participants completed 3 attempts (separated by a 60 s rest break to reduce potential fatigue) of each test for each limb and the maximum isometric force exerted was measured in kilograms via an inline load cell (SE Load Cell, Sun Scale Inc, Taiwan) positioned between the cuff and the anchor point.

2.4. Data analysis

Marker trajectories were processed using Vicon Nexus and both the trajectories and GRF data were low-pass filtered using a fourth-order Butterworth filter with a cut-off frequency of 6 Hz. Filtered marker trajectories were then used to calculate the three-dimensional hip, knee and ankle joint angles in Visual3D (Version 5, C-Motion, Inc., USA), in accordance with the joint coordinate system outlined by Grood and Suntay [23]. Using inverse dynamics [24], peak sagittal plane hip, knee and ankle joint moments were