Title: Evidence of compensatory joint kinetics during stair ascent and descent in Parkinson’s disease

Running Title: Altered kinetics during stair ambulation in PD

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Highlights

- PD patients have altered pattern of lower limb joint kinetics during stair walking
- Despite weaker knee extensors, PD patients use their knees more during stair walking
- Fewer degrees of freedom afforded by the knee may improve one’s sense of stability
- Improving lower limb strength may assist clinicians with ameliorating falls risk

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.

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 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 influences their movement patterns and ultimately contributes to a greater risk of recurrent falls [14, 15]. These physcial 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, 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.

Methods

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 ≥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.

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-hour following their anti-parkinsonian medication to ensure they were optimally-medicated.

Movement assessment

Participants performed stair ascents and descents at a self-selected pace on a 3-step staircase (19cm riser and 30cm 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-metres 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-metre 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 second 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.

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 identified in the first and second half of the stance phase for both stair ascent and descent. Sagittal plane hip extension, knee extension and ankle plantarflexion moment impulses were then summed to derive the support moment impulse (Newton-metres.second) [12]. The contribution of each joint to the support moment impulse was identified by expressing the joint moment impulse of each joint as a percentage of the support moment impulse (Figure 1). To highlight any differences in the joint kinetics during the transition phase from the level-ground to stair ascent/descent (Step 1) and the actual ascent/descent component of the tasks (Step 2), data for the two steps were analyses and presented separately.

Insert Figure 1 about here.

To facilitate group comparisons, stance phase duration was normalised to range from 0 to 100% and the amplitude of joint moments was normalised to each participant's body mass (Newton.metres/kilogram). Walking speed (metres/second) and cadence (steps/minute) were also calculated from the marker trajectories and force plate data. As walking speeds during stair ascent and stair descent comprise both horizontal and vertical components, distance travelled was calculated using Pythagoras' theorem and divided by time. Cadence was calculated as the elapsed time between consecutive foot contacts on the first and second step divided by 60 to yield step frequency per minute.

Statistical Analysis

Univariate analysis of variance was used to examine differences in the continuous demographic variables (e.g. age), while the Chi-square test assessed differences in the frequencies of categorical variables (e.g. gender) between the groups. To ensure the assumptions of parametric statistics were met, the Shapiro-Wilk test assessed normality, while equality of variance between groups was assessed using the Levene's test statistic. If assumptions of the parametric procedures were violated, the non-parametric Kruskal-Wallis Test was used to compare continuous demographic variables.

To take advantage of the repeated trials completed by participants, the linear mixed model (LMM) procedure was used to examine differences between groups for joint moments and support moment impulses. Furthermore, given that walking speed [25], temporal gait characteristics [26] and balance confidence [17] have the potential to influence GRFs, joint moments and/or impulses, walking speed, stance time and ABC-6 scores were entered as covariates in all of the LMMs conducted for the primary outcomes. Statistical analyses were conducted using the Statistical Package for the Social Sciences (Version 22, New York, USA) and the level of significance for all statistical tests was set at $p<0.05$.

Results

The results indicated groups did not differ with respect to age, falls history, cognition or psychological factors influencing their quality of life (SF-8). However, PD participants did record poorer balance confidence, a greater impact of physical difficulties on their quality of life (SF-8) and had significantly poorer knee extension strength (Table 1).

Insert Table 1 about here.

During stair ascent, PD participants walked significantly slower than controls (0.32±0.05 vs. 0.37±0.06 m/s; $p=0.001$) and had reduced cadence (84.19±14.04 vs. 96.38±14.14 steps/min; $p=0.023$) and longer stance times (0.98±0.17 vs. 0.84±0.11 s; $p=0.029$). Examination of the joint moments recorded on the first step during the first and second halves of stance indicated that the PD and control groups did not differ with respect to peak hip, knee or ankle moments. Furthermore, peak joint moments were typically similar between the groups on the second step; however PD participants demonstrated a reduced hip flexion moment during the second half of stance and a greater knee extension moment during the first half of stance (Table 2). The general lack of differences in lower limb joint moments on the first step ultimately resulted in similar support moment impulses being recorded for the two groups. However, analysis of the relative contribution of each joint to the support moment on the second step indicated that the knee joint contributed significantly more for PD patients, while the ankle contributed less (Table 2).

Insert Table 2 about here.

Participants with PD descended the stairs at slower speeds (0.28±0.12 vs. 0.35±0.15 m/s; *p=0.015*), had slower cadence (85.80±15.27 vs. 109.47±25.68 steps/min; *p=0.005*) and increased stance times (0.84±0.16 vs. 0.69±0.14 m/s; *p=0.009*) compared with controls. Unlike stair ascent, peak hip, knee and ankle joint moments typically did not differ between the groups on Step 2, although the results indicated that PD patients produced a greater knee extension moment during the second half of stance on Step 1 (Table 3). Despite the few differences observed in peak joint moments, the PD participants recorded a different pattern of joint kinetics to support the body's mass. During the transition phase of the descending task (i.e. Step 1), PD patients recorded significantly larger support moments, which were largely attributable to significantly increased hip and knee extensor impulses (Table 3). During the actual descending component of the task (i.e. Step 2), the groups did not differ with respect to the support moment impulse, but a reduced ankle contribution required greater knee joint involvement for the PD participants (Table 3).

Insert Table 3 about here.

Discussion

The first aim of this study was to investigate the lower limb joint moments of persons with PD and age-matched controls during self-paced stair ascent and descent. Given the reported disease-related declines in muscle strength, it was hypothesised that PD patients would exhibit lower joint moments than age-matched controls. Interestingly, while the results of this study typically indicated that people with PD demonstrate similar peak joint moments to age-matched controls during stair negotiation, our results suggest that patients generally produce greater knee joint moments during the actual ascending/descending component of the tasks (i.e. Step 2). During stair ascent, the increased knee extension moments were accompanied by lower hip flexion moments for the patient cohort. Considering these results in light of the poorer knee extensor strength recorded for the patient group, it could be argued that successful negotiation of stairs requires patients to exert a much greater effort than otherwise healthy older adults. This increased effort would likely contribute to poorer movement patterns and premature fatigue for people with PD, which could significantly increase their risk of tripping or overbalancing.

To fully appreciate the risk of falling during stair negotiation, it is worth considering that, during stair descent, the body experiences a rapid negative (downward) acceleration [10]. Without adequate muscle strength, people with PD would experience increased difficulty coordinating the necessary lower limb muscles to decelerate the body and lower it safely to the next step [11, 27]. Interestingly, older adults have been shown to have lower knee joint moments than younger individuals during stair walking [9]. This difference was considered to be representative of a compensatory strategy employed by the older adults to ensure that they had an adequate reserve to recover, were they to overbalance [9]. However, considering the well-established age-related decrements in muscular strength, the lower peak moments observed in the older cohort would likely have represented an equivalent or greater effort for these individuals compared with the younger adults [9, 11]. Considering these findings collectively with the poorer knee extensor strength recorded for the PD patients, the larger knee joint moments during stair ascent and descent would likely suggest that people with PD are required to work at higher proportion of their maximum capabilities when performing these tasks. As such, the negotiation of a typical flight of stairs would be likely to fatigue people with PD to a greater extent than otherwise healthy individuals and ultimately increase their risk of falling during these activities.

The second aim of this study was to ascertain whether the hip, knee and ankle joints contributed to the support moment impulse in a similar way for people with PD and controls. The results supported our hypothesis and indicated that people with PD place a greater dependence on the more proximal joints (i.e. hip and/or knee joints) and less emphasis on the distal joints (i.e. ankle joints) during stair negotiation. This finding was in agreement with a previous study that reported a significant reduction in the relative contribution of the ankle joint to the support moment impulse in people with PD during the ascent of a single step [18]. In contrast, the control participants relied more heavily on the ankle plantarflexors to contribute to the support moment impulse, which is commensurate with previous research [12, 28, 29]. Considering that the PD participants recorded significantly lower isometric strength for the knee extensors, but similar isometric strength for the ankle plantarflexors, the shifting of emphasis to the knee joint does not seem to be related to strength deficits around the ankle joint. Interestingly, the lower contribution made by the ankle joint to the support moment impulse was largely compensated for by the knee joint during stair ascent and by the hip and knee joints during stair descent. Ultimately, these compensations were adequate to either produce a support moment that was as equally large as the control participants or significantly greater, as observed during stair descent (Step 2). These results suggest that the changes in physiological function associated with PD may contribute to a greater proportion of the work being conducted by the knee extensors during stair walking.

The findings of this study and separate research show that people with PD have significantly reduced strength for the knee extensors [30]. Hence, one might question why people with PD place a heavier emphasis of this joint's contribution to supporting the body's mass during stair negotiation. A possible explanation for the emphasis on knee extensors may be the reduced degrees of freedom afforded by the knee joint. It is well understood that the hip and ankle joints feature large ranges of motion about each movement axis, but due to its anatomical design, the knee joint is largely restricted to movements in the sagittal plane (i.e. flexion and extension). As such, during stair walking, people with PD may preferentially rely on the knee joint to produce the necessary force to ambulate stairs, as its largely restricted motion makes it inherently more stable under normal conditions and, hence, may contribute to a greater sense of stability. With this rationale in mind, the findings of the current study can be interpreted clinically as evidence to support the maintenance and/or improvement of knee extensor strength in people with PD [31].

The findings of this research should be considered in light of a number of potential limitations. First, while isometric knee extension and ankle plantarflexion strengths were assessed and reported, hip extension strength was not assessed in this study due to the difficulties associated with accurately assessing this outcome without specialized equipment (e.g. isokinetic dynamometer). As such, it is unclear whether the greater contribution made by the hip extensors to supporting the body's mass during stair descent (Step 2) in the PD participants was compounded by strength deficits affecting these muscles. Second, previous research has shown that psychological factors, such as fear of falling, can be as debilitating to gait speed as physical limitations [17]. As such, it could be argued that the differences observed in lower limb joint kinetics may have been attributable, at least in part, to the differences observed in balance confidence between the groups, which may have led to the PD group adopting a more "cautious" gait pattern (as evidenced by the slower walking speed and reduced cadence). However, the inclusion of walking speed, stance time and balance confidence as covariates in our statistical models seems to suggest that the differences reported in this paper are not attributable to these factors, but rather represent genuine differences in the strategies used by patients to ascend and descend stairs. An appreciation of these differences should assist clinicians and physical therapists working with this patient group and may assist with developing targeted interventions that can reduce the risk of falls during stair ambulation. Future research should seek to investigate the importance of abduction and adduction moments and internal and external rotation moments in a larger cohort to provide additional insight into the gait patterns of people with PD during stair walking.

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Authors' Contributions

1. **Research project:** **A.** Conception **B.** Organization **C.** Execution
2. **Data Analysis:** **A.** Design **B.** Execution
3. **Manuscript:** **A.** First draft **B.** Review & Critique
4. **Other:** **A.** Study supervision

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References

[1] Williamson JD, Fried LP. Characterization of older adults who attribute functional decrements to "old age". Journal of the American Geriatrics Society. 1996;44:1429-34.

[2] Cole MH, Silburn PA, Wood JM, Worringham CJ, Kerr GK. Falls in Parkinson's disease: Kinematic evidence for impaired head and trunk control. Movement Disorders. 2010;25:2369-78.

[3] Riley PO, Mann RW, Hodge WA. Modelling of the biomechanics of posture and balance. Journal of Biomechanics. 1990;23:503-6.

[4] Zachazewski JE, Riley PO, Krebs DE. Biomechanical analysis of body mass transfer during stair ascent and descent of healthy subjects. Journal of Rehabilitation Research & Development. 1993;30:412-22.

[5] Costigan PA, Deluzio KJ, Wyss UP. Knee and hip kinetics during normal stair climbing. Gait & Posture. 2002;16:31-7.

[6] Protopapadaki A, Drechsler WI, Cramp MC, Coutts FJ, Scott OM. Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. Clinical Biomechanics. 2007;22:203-10.

[7] Nadeau S, McFadyen BJ, Malouin F. Frontal and sagittal plane analyses of the stair climbing task in healthy adults aged over 40 years: what are the challenges compared to level walking? Clinical Biomechanics. 2003;18:950-9.

[8] Karamanidis K, Arampatzis A. Altered control strategy between leading and trailing leg increases knee adduction moment in the elderly while descending stairs. Journal of Biomechanics 2011;44:706-11.

[9] Reeves ND, Spanjaard M, Mohagheghi AA, Baltzopoulos V, Maganaris CN. Older adults employ alternative strategies to operate within their maximum capabilities when ascending stairs. Journal of Electromyography and Kinesiology. 2009;19:e57-68.

[10] Buckley JG, Cooper G, Maganaris CN, Reeves ND. Is stair descent in the elderly associated with periods of high centre of mass downward accelerations? Experimental Gerontology. 2013;48:283-9.

[11] Reeves ND, Spanjaard M, Mohagheghi AA, Baltzopoulos V, Maganaris CN. The demands of stair descent relative to maximum capacities in elderly and young adults. Journal of Electromyography and Kinesiology. 2008;18:218-27.

[12] Novak AC, Brouwer B. Sagittal and frontal lower limb joint moments during stair ascent and descent in young and older adults. Gait & Posture. 2011;33:54-60.

[13] Winter DA. Overall principle of lower limb support during stance phase of gait. Journal of Biomechanics. 1980;13:923-7.

[14] Bloem BR, van Vugt JP, Beckley DJ. Postural instability and falls in Parkinson's disease. Advances in neurology. 2001;87:209-23.

[15] Kerr GK, Worringham CJ, Cole MH, Lacherez PF, Wood JM, Silburn PA. Predictors of future falls in Parkinson disease. Neurology. 2010;75:116-24.

[16] Cole MH, Rippey J, Naughton GA, Silburn PA. Use of a Short-Form Balance Confidence Scale to Predict Future Recurrent Falls in People With Parkinson Disease. Archives of physical medicine and rehabilitation. 2016;97:152-6.

[17] Brodie MA, Wang K, Delbaere K, Persiani M, Lovell NH, Redmond SJ, et al. New Methods to Monitor Stair Ascents Using a Wearable Pendant Device Reveal How Behavior, Fear, and Frailty Influence Falls in Octogenarians. IEEE transactions on bio-medical engineering. 2015;62:2595-601.

[18] Skinner JW, Lee HK, Roemmich RT, Amano S, Hass CJ. Execution of Activities of Daily Living in Persons with Parkinson Disease. Med Sci Sports Exerc. 2015;47:1906-12.

[19] Ashburn A, Stack E, Ballinger C, Fazakarley L, Fitton C. The circumstances of falls among people with Parkinson's disease and the use of Falls Diaries to facilitate reporting. Disability and rehabilitation. 2008;30:1205-12.

[20] Manning DP. Deaths and injuries caused by slipping, tripping and falling. Ergonomics. 1983;26:3-9.

[21] Hughes AJ, Daniel SE, Kilford L, Lees AJ. Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases. Journal of Neurology, Neurosurgery & Psychiatry. 1992;55:181-4.

[22] Lord SR, Menz HB, Tiedemann A. A physiological profile approach to falls risk assessment and prevention. Physical therapy. 2003;83:237-52.

[23] Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. Journal of Biomechanical Engineering. 1983;105:136-44.

[24] Winter DA. Biomechanics and motor control of human gait: normal, elderly and pathological1991.

[25] Nilsson J, Thorstensson A. Ground reaction forces at different speeds of human walking and running. Acta physiologica Scandinavica. 1989;136:217-27.

[26] Martin PE, Marsh AP. Step length and frequency effects on ground reaction forces during walking. J Biomech. 1992;25:1237-9.

[27] Pandy MG, Andriacchi TP. Muscle and joint function in human locomotion. Annual Review of Biomedical Engineering. 2010;12:401-33.

[28] Marchese R, Bove M, Abbruzzese G. Effect of cognitive and motor tasks on postural stability in Parkinson's disease: a posturographic study. Movement Disorders. 2003;18:652-8.

[29] Mitchell SL, Collins JJ, De Luca CJ, Burrows A, Lipsitz LA. Open-loop and closed-loop postural control mechanisms in Parkinson's disease: increased mediolateral activity during quiet standing. Neurosci Lett. 1995;197:133-6.

[30] Durmus B, Baysal O, Altinayar S, Altay Z, Ersoy Y, Ozcan C. Lower extremity isokinetic muscle strength in patients with Parkinson's disease. J Clin Neurosci. 2010;17:893-6.

[31] Nocera JR, Buckley T, Waddell D, Okun MS, Hass CJ. Knee extensor strength, dynamic stability, and functional ambulation: are they related in Parkinson's disease? Archives of physical medicine and rehabilitation. 2010;91:589-95.

Figure Legends

Figure 1: Graphical representation of the contributions of the hip, knee and ankle joint moments to the support moment (Nm.kg), with impulse (Nm.s) for each of the graph shown by the shaded areas for a patient with Parkinson’s disease during stair ascent.

Table Legends

Table 1: Demographics, falls history, fear of falling, cognition, quality of life, medication use and disease-specific scores for the Parkinson's disease and control participants. Data represent mean (+1 SD), absolute numbers (percentage sample)^{Ŧ} or medians (range)$^{¥}$.

Table 2: Peak sagittal plane joint moments (Newton.metres/kilogram) during the first (1) and second (2) half of the stance phase of the stair ascent task and the support moment impulse (Newton-metres.second) with the relative percentage contribution of the hip, knee and ankle joints presented. Data represent the estimated marginal means (and standard errors) from the linear mixed model analyses conducted with walking speed (0.34 m/s), stance time (0.91 s) and the Activities-specific Balance Confidence scale (79.76) entered as covariates.

Table 3: Peak sagittal plane joint moments (Newton.metres/kilogram) during the first (1) and second (2) half of the stance phase of the stair descent task and the support moment impulse (Newton-metres.seconds) with the relative percentage contribution of the hip, knee and ankle joints presented. Data represent the estimated marginal means (and standard errors) from the linear mixed model analyses conducted with walking speed (0.32 m/s), stance time (0.76 s) and the Activities-specific Balance Confidence scale (81.12) entered as covariates.

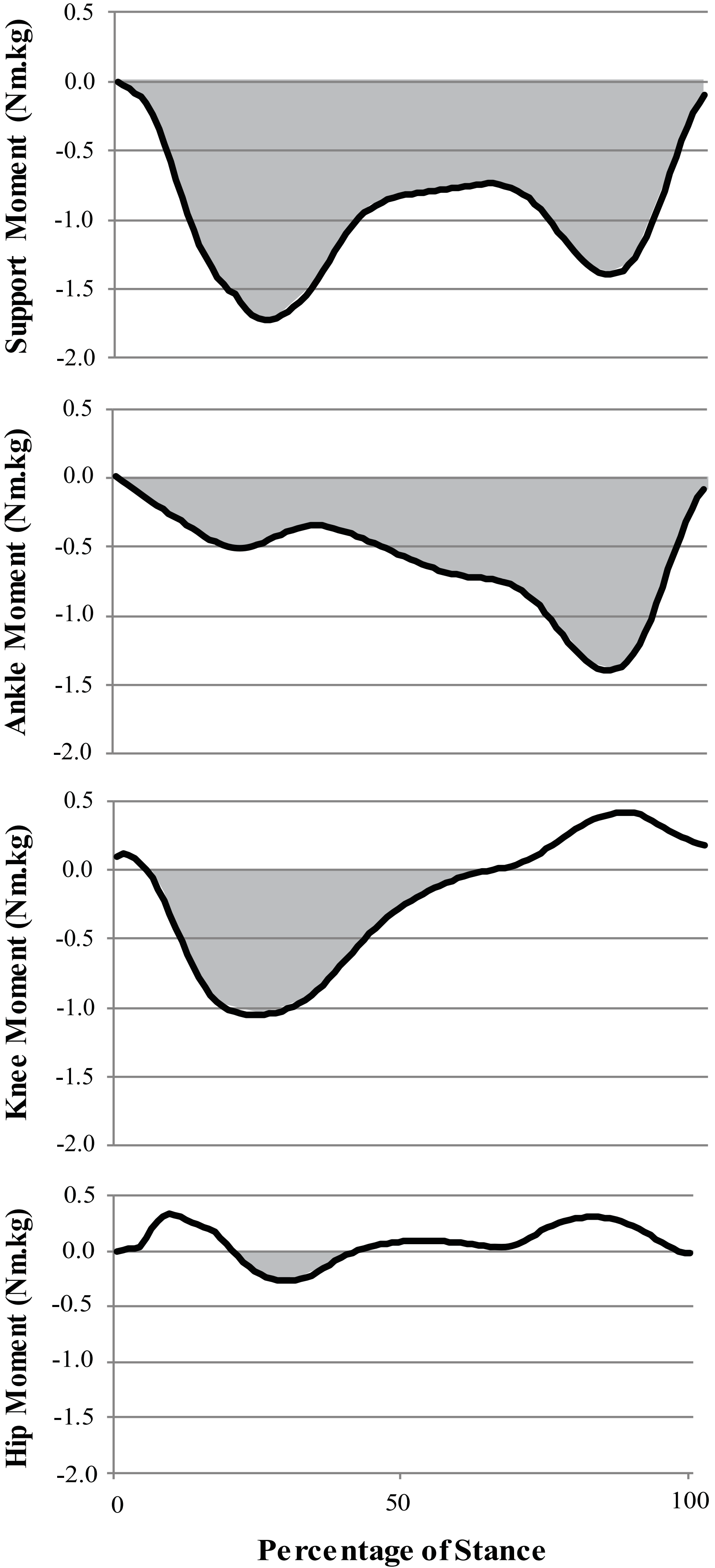
Support Moment (Nm.kg)
Ankle Moment (Nm.kg)
Knee Moment (Nm.kg)
Hip Moment (Nm.kg)
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
50
100
Percentage of Stance

Table 1.

	Controls (n = 12)	**PD (n = 12)**	**Test**	**p-value**
Demographics				
Age (years)	62.9 (8.0)	67.1 (8.2)	1	*0.215*
Height (m)	1.7 (0.1)	1.7 (0.1)	1	*0.489*
Mass (kg)	79.7 (13.3)	73.8 (14.9)	2	*0.564*
Body Mass Index (kg/m^2)	27.3 (3.0)	26.1 (3.8)	2	*0.684*
Falls and Fear of Falling				
Previous falls Ŧ	3 (25.0%)	3 (25.0%)	3	*1.000*
ABC-6	92.6 (5.5)	66.0 (28.1)	1	***0.004***
Cognition and Quality of Life				
SMMSE	29.8 (0.4)	29.2 (1.0)	2	*0.062*
SF-8 Physical component	56.6 (4.2)	48.2 (5.4)	2	***0.001***
SF-8 Mental component	56.6 (3.9)	54.3 (4.3)	2	*0.104*
PDQ-8	-	21.6 (15.9)	-	-
Neurological exam				
Disease duration (years)	-	4.3 (2.0)	-	-
MDS-UPDRS III	-	26.6 (11.9)	-	-
No PD medications Ŧ	-	1 (8.3%)	-	-
Levodopa dose (mg/day)	-	695.3 (362.8)	-	-
Dopamine agonists Ŧ	-	2 (16.7%)	-	-
COMT inhibitors Ŧ	-	6 (50.0%)	-	-
MAO inhibitors Ŧ	-	4 (33.3%)	-	-
Benzodiazepines Ŧ	-	0 (0.0%)	-	-
Freezing of Gait (N-FOG)	-	8.6 (11.3)	-	-
Hoehn & Yahr ¥	-	1.5 (1.0-3.0)	-	-
Schwab & England ADL scale	-	83.3 (8.6)	-	-
Strength				
Ankle plantarflexion (kg)	18.1 (3.1)	13.2 (5.5)		0.231
Knee extension (kg)	32.7 (2.7)	22.3 (3.6)		***0.031***

ABC-6: 6-item Activities-specific Balance Confidence scale; **SMMSE:** Standardized Mini-Mental State Examination; **SF-8:** Short-Form 8; **N-FOG**: New Freezing of Gait questionnaire; **PDQ-8:** 8-item Parkinson's Disease Questionnaire; **MDS-UPDRS III:** Motor subscale of the Unified Parkinson's Disease Rating Scale; **COMT Inhibitors:** Catechol-O-Methyl Transferase Inhibitors; **MAO Inhibitors:** Monoamine Oxidase Inhibitors; **Test 1:** One-Way ANOVA; **Test 2:** Kruskal-Wallace Test; **Test 3:** Chi-square.

Table 2.

	Stair Ascent					
	Step 1			Step 2		
	Controls	Parkinson's disease	*p-value*	Controls	Parkinson's disease	*p-value*
Joint Moments (Nm/kg)						
Hip Joint						
Flexion Peak 1	0.41 ± 0.04	0.32 ± 0.04	*0.15*	0.92 ± 0.05	0.76 ± 0.05	*0.06*
Flexion Peak 2	0.31 ± 0.05	0.24 ± 0.05	*0.36*	1.07 ± 0.06	0.90 ± 0.05	***0.05***
Knee Joint						
Extension Peak	-0.98 ± 0.06	-1.00 ± 0.06	*0.83*	-0.29 ± 0.04	-0.43 ± 0.04	***0.02***
Flexion Peak	0.29 ± 0.03	0.23 ± 0.03	*0.28*	0.97 ± 0.08	0.80 ± 0.08	*0.16*
Ankle Joint						
Plantarflexion Peak 1	-0.59 ± 0.06	-0.57 ± 0.06	*0.80*	-1.30 ± 0.06	-1.17 ± 0.06	*0.16*
Plantarflexion Peak 2	-1.41 ± 0.10	-1.30 ± 0.10	*0.47*	-2.31 ± 0.08	-2.12 ± 0.08	*0.14*
Impulses (Nm.s)						
Support Moment	-0.97 ± 0.06	-0.97 ± 0.06	*0.98*	-1.24 ± 0.06	-1.21 ± 0.06	*0.81*
Hip Joint						
Extensor Impulse	-0.10 ± 0.03	-0.08 ± 0.03	*0.75*	-0.00 ± 0.00	-0.00 ± 0.00	*0.99*
Support Contribution (%)	10.10 ± 3.04	8.99 ± 3.04	*0.81*	0.08 ± 0.06	0.20 ± 0.06	*0.19*
Knee Joint						
Extensor Impulse	-0.27 ± 0.03	-0.32 ± 0.03	*0.32*	-0.05 ± 0.01	-0.10 ± 0.01	***0.01***
Support Contribution (%)	25.99 ± 2.58	35.66 ± 2.53	***0.02***	2.50 ± 3.18	12.54 ± 3.15	***0.05***
Ankle Joint						
Ankle Joint moment	-0.60 ± 0.05	-0.57 ± 0.05	*0.63*	-1.19 ± 0.06	-1.11 ± 0.06	*0.45*
Support Contribution (%)	64.13 ± 4.40	55.29 ± 4.36	*0.21*	97.39 ± 3.16	87.31 ± 3.12	***0.05***

Table 3.

	Stair Descent					
	Step 1			Step 2		
	Controls	Parkinson's disease	*p-value*	Controls	Parkinson's disease	*p-value*
Joint Moments (Nm/kg)						
Hip Joint						
Extension Peak 1	-1.38 ± 0.15	-1.64 ± 0.15	*0.26*	-0.66 ±0.12	-0.85 ± 0.12	*0.33*
Extension Peak 2	-0.70 ± 0.10	-1.09 ± 0.10	***0.02***	-0.54 ± 0.09	-0.60 ± 0.10	*0.68*
Knee Joint						
Extension Peak 1	-1.44 ± 0.13	-1.66 ± 0.13	*0.27*	-0.74 ± 0.11	-0.86 ± 0.12	*0.52*
Extension Peak 2	-1.03 ± 0.12	-1.48 ± 0.13	***0.03***	-0.60 ± 0.05	-0.74 ± 0.05	*0.07*
Ankle Joint						
Plantarflexion Peak 1	-0.23 ± 0.03	-0.20 ± 0.03	*0.54*	-0.49 ± 0.28	-0.61 ± 0.29	*0.79*
Plantarflexion Peak 2	-0.62 ± 0.04	-0.64 ± 0.05	*0.76*	-1.17 ± 0.05	-1.11 ± 0.05	*0.47*
Impulses (Nm.s)						
Support Moment	-1.42 ± 0.13	-1.91 ± 0.14	***0.03***	-1.05 ± 0.08	-1.19 ± 0.08	*0.26*
Hip Joint						
Extensor Impulse	-0.54 ± 0.07	-0.79 ± 0.07	***0.02***	-0.24 ± 0.05	-0.30 ± 0.05	*0.37*
Support Contribution (%)	38.21 ± 1.14	40.26 ± 1.19	*0.26*	19.36 ± 1.66	21.90 ± 1.74	*0.34*
Knee Joint						
Extensor Impulse	-0.68 ± 0.07	-0.93 ± 0.07	***0.03***	-0.27 ± 0.04	-0.40 ± 0.04	***0.04***
Support Contribution (%)	47.36 ± 1.14	48.64 ± 1.19	*0.48*	23.70 ± 2.29	31.24 ± 2.39	***0.05***
Ankle Joint						
Ankle Joint moment	-0.19 ± 0.01	-0.18 ± 0.02	*0.42*	-0.55 ± 0.02	-0.49 ± 0.02	*0.08*
Support Contribution (%)	14. 49 ± 1.20	11.00 ± 1.24	*0.07*	57.07 ± 3.08	46.73 ± 3.21	***0.04***