

Title: Falls in Parkinson's disease: Evidence for altered stepping strategies on compliant surfaces

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Keywords: Falls; Gait Adaptation; Postural Control; Motion Analysis; Surface Effects

Running Title: Surface-related gait adaptations in PD fallers

Word Count 2: 2997 words (Abstract to Discussion)

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Abstract

Background: Real-world environments comprise surfaces of different textures, densities and gradients, which can threaten postural stability and increase falls risk. However, there has been limited research that has examined how walking on compliant surfaces influences gait and postural stability in older people and PD patients.

Methods: PD patients (n = 49) and age-matched controls (n = 32) were assessed using three-dimensional motion analysis during self-paced walking on both firm and foam walkways. Falls were recorded prospectively over 12 months using daily falls calendars.

Results: Walking on a foam surface influenced the temporospatial characteristics for all groups, but PD fallers adopted very different joint kinematics compared with controls. PD fallers also demonstrated reduced toe clearance and had increased mediolateral head motion (relative to walking velocity) compared with control participants.

Conclusions: Postural control deficits in PD fallers may impair their capacity to attenuate surface-related perturbations and control head motion. The risk of falling for PD patients may be increased on less stable surfaces.

Introduction

Parkinson's disease (PD) is characterised by postural instability and gait difficulties that significantly impact upon independence and quality of life[1, 2] and increase falls risk. PD patients have a nine times greater risk of recurrent falls than similarly aged healthy individuals[3]. Recent prospective research has highlighted that nearly half of PD patients experienced at least one fall over a six-month[4] (48%) and twelve-month[5] (45%) period. A similar falls rate was reported over a three-month period in a meta-analysis of six prospective studies (46%)[6]. With nearly half of these falls occurring during dynamic tasks, such as walking and turning[7], further research is needed to better understand the mechanisms underpinning gait disability in this population when walking in environments representative of real-world settings.

Parkinsonian gait is characterised by reduced walking velocity[8-11] and stride length[8-11] and less rhythmic acceleration profiles for the trunk[12] and head[13] compared with age-matched controls. PD patients who fell during a 12-month follow-up period had reduced stride length, arm swing, single support time and walking speed compared with controls and increased mediolateral head motion compared with PD non-fallers and controls following adjustment for walking speed[14]. A cross-sectional study[13] reported differences in walking velocity and stride timing variability between PD fallers and non-fallers, but the subsequent prospective study of these patients demonstrated only reduced cadence for PD fallers[5]. While these changes are widely recognised, many of these observations have been made while walking on firm and predictable surfaces. Real-world walking environments, however, comprise surfaces of different textures, densities and gradients, which require constant adjustments to the body's movement patterns to maintain stability. Compliant surfaces, such as grass, sand or carpet may reveal differences in one's capacity to use the

kinaesthetic system to accurately detect the position of the body relative to the surface[15] and adjust gait patterns. To accommodate for walking on foam surfaces, healthy younger adults exhibit increased step length, step width, step time and toe clearance[16]. However, an accelerometry-based study reported no compensatory temporospatial adjustments for healthy older adults while walking on a foam-covered walkway[17]. Given that PD fallers have poorer segmental control during controlled walking tasks[14], their risk of falling could be exacerbated under conditions that challenge postural stability. Therefore, a better understanding of surface-related adaptations to gait and postural control is essential to facilitate the development of more effective screening tools and intervention strategies to reduce the incidence of falls in PD patients.

We examined the gait adaptations made in response to walking on a foam surface by PD patients who prospectively reported falling over a twelve-month period. We hypothesised that PD fallers would show different adaptations in both temporospatial and joint kinematic characteristics compared to PD non-fallers and age-matched controls (fallers and non-fallers) and would have poorer control of the body's segments during walking.

Methodology

Study Population

Patients diagnosed with idiopathic PD based on the UK Brain Bank Criteria (n = 49) were recruited from neurology clinics and community support groups in South-East Queensland between March 2005 and December 2006. All patients were confirmed to have PD by their treating neurologist. Concurrently, age-matched controls (n = 32) were randomly recruited from the Brisbane metropolitan area via the Australian electoral role (Table 1). This sample was consistent with the population described previously[14], with the exception of two control participants whose data could not be included due to problems with data collection on the foam surface. Participants were sent a letter of invitation, before being contacted by telephone to establish their interest in participating. Participants were excluded if they were unable to ambulate independently, had a recent or recurrent history of musculoskeletal injury or surgery, or had significant visual (Bailey-Lovie high contrast visual acuity >0.30 logMAR) or cognitive impairment (Mini Mental State Exam[18] score <24). All participants gave written informed consent in accordance with the Declaration of Helsinki and the experimental protocol was approved by the Queensland University of Technology Human Research Ethics Committee. Based on studies of walking in PD[1, 9, 14], a minimum of 15 participants per group was considered to be sufficient to detect differences between groups.

Insert Table 1 about here.

Clinical Assessment

Disease severity was established using the Unified Parkinson's Disease Rating Scale[19] (UPDRS) and the Hoehn & Yahr (H&Y) score[20] (Table 1). A measure of postural instability and gait disability (PIGD) was derived from the UPDRS (sum of items 13-15, 27-

30). Freezing of gait and fear of falling were assessed using the Freezing of Gait (FOG)[21] questionnaire and the Modified Falls Efficacy Scale[22], respectively. All procedures were undertaken within 1 to 2 hours of medication to ensure that patients were optimally-medicated.

Three-Dimensional Gait Assessment

Gait was assessed during six trials while; i) walking barefooted at a self-selected pace along a firm walkway (L: 12 m x W: 2.2 m x H: 0.1 m) and ii) walking along the same walkway covered with a layer of foam (10cm thick; 0.032g/cm³ density). Twenty-eight markers were positioned in accordance with the Helen Hayes marker set[23], modified to include the upper body and head. Markers were attached on the trunk (sacrum, sternum, C7 spinous process), arms (lateral border of the acromion, olecranon process of the humerus, radial and ulnar styloids), and head (supra-auricular point, top of the head). The same experienced movement specialist attached the markers and labelled and analysed the data to minimise errors associated with inter-rater reliability.

Markers were tracked within the central 4 m length of the 12 m walkway (50 Hz) by a previously calibrated six-camera motion analysis system (Motus 2000; Vicon, Oxford, UK) for two complete gait cycles (1 right; 1 left). Data were reconstructed using direct linear transformation (DLT)[24] and temporospatial and angular quantities for the lower limbs were derived. These included stride length, stride frequency (cadence), step width, double support (percent of time with both feet on the ground), stride timing variability (SD of stride period)[25], walking velocity and the Gait Stability Ratio (GSR; cadence/walking velocity)[26]. Peak toe clearance was defined as the maximum vertical displacement of the toe relative to the top of the firm and foam surfaces during the swing phase. The ML and

vertical (VT) displacement of the head and pelvis were assessed to provide a measure of segmental control. Arm swing was calculated as displacement of the wrists in the sagittal plane.

Sagittal plane angular kinematics of the trunk, hip, knee and ankle joints were examined. Trunk flexion was the angle between the vector joining the sacral and C7 markers and the vertical axis of the global coordinate system. Hip flexion/extension was the angle between the vertical axis of the pelvis segment and the vector joining the hip and knee joints. Knee flexion/extension was the angle between the vectors joining the hip and knee joints and the knee and ankle joints. Ankle plantar- and dorsi-flexion was the angle between the vectors joining the knee, ankle and second metatarsal joints, where zero degrees represented the point at which the two vectors were perpendicular. These variables are altered in PD patients[9-11] and PD patients who fall[14] while walking on firm and non-threatening surfaces.

12-Month Prospective Follow-up.

Participants recorded any falls or injuries on a daily falls calendar, which they returned on a monthly basis via a reply-paid envelope over the subsequent 12-month period. Participants provided details on the timing, location and cause of any fall and any injuries. If a participant failed to return their monthly calendar, they were sent a reminder by mail and contacted via telephone. A fall was defined as “an unintentional coming to the ground or some lower level not as a result of a major intrinsic event (e.g. stroke) or overwhelming hazard”[27].

Statistical Analysis.

Analysis of variance (ANOVA) with one repeated measure (surface, 2 levels) was used to determine mean differences between; 1) PD patients and controls; and 2) fallers or non-fallers

for the temporospatial, segmental motion and joint kinematic variables. Tukey's Honestly Significant Difference (HSD) post-hoc test was used to determine statistically significant differences between faller and non-faller groups; this controls for the overall significance level when performing all pairwise comparisons in ANOVA and reduces the likelihood of a Type 1 error. Continuous demographic variables were examined using a one-way ANOVA, while the degree of association between the categorical variables was assessed with the chi-square (χ^2) test. All statistical procedures were conducted using SPSS 16 and the level of significance was set at $p < 0.05$.

Results

Falls

Thirty-two PD patients (65%) and 17 control participants (53%) reported falling at least once during the 12-month follow-up, while 21 (43%) PD and 9 (28%) control participants reported falling twice or more. Participants were divided into four groups, based on the prospective falls data; PD Fallers (n = 32); PD Non-Fallers (n = 17); Control Fallers (n = 17); and Control Non-Fallers (n = 15).

Clinical Characteristics

PD fallers had significantly longer disease duration and higher FOG scores than PD non-fallers, had an increased fear of falling compared to PD non-fallers and controls and reported more falls during the previous 12 months than PD and control non-fallers. PD fallers and non-fallers had similar average daily Levodopa intake and disease severity and neither group demonstrated freezing of gait during walking (Table 1).

Temporospatial Characteristics

Insert Figure 1 about here.

For all participants, walking on the foam surface significantly increased stride length, step width, walking velocity and toe clearance, while cadence, double support and GSR were all significantly reduced. PD fallers took shorter strides, walked more slowly, spent more time in double support, had increased stride timing variability and poorer GSRs than the control fallers and non-fallers on both surfaces (Figure 1). PD fallers had significantly reduced toe clearance compared with the control groups and a significant surface*group interaction ($F(3,77) = 3.704, p = 0.015$) demonstrated that, while the control fallers and non-fallers

significantly increased toe clearance on the foam surface, both PD groups showed no significant change (Figure 1).

Segmental Motion

While traversing the foam surface, all groups had increased VT and ML head and pelvis motion. PD fallers had significantly more ML head motion than PD non-fallers and controls following adjustment for walking velocity (Figure 2). Arm swing was significantly reduced for PD patients compared to controls, even following normalisation for walking velocity.

Insert Table 2 and Figure 2 about here.

Trunk Flexion

A significant surface*group interaction ($F(3,77) = 3.078, p = 0.032$) for trunk flexion demonstrated that, while PD fallers and non-fallers and control fallers all increased trunk flexion on the foam surface, control non-fallers did not. However, following normalisation to walking velocity, PD fallers had significantly greater trunk flexion relative to control fallers and non-fallers on both surfaces (Figure 2).

Joint Kinematics: Range of Motion

PD fallers had reduced hip and knee flexion/extension ranges compared to control groups, but following adjustment for walking velocity, only the reduced knee range of motion remained significant (Table 2). Similarly, a surface*group interaction for normalised hip ($F(3,77) = 4.348, p = 0.007$) and knee flexion/extension range ($F(3,77) = 2.838, p = 0.043$) demonstrated that, while all groups increased their hip and knee range of motion on the foam surface, these changes were greater for PD fallers (Figure 3).

Insert Figure 3 about here.

Joint Kinematics: Stance Limb

At peak toe-clearance, PD fallers had increased knee flexion in the stance limb compared with control fallers and non-fallers. Additionally, significant surface*group interactions were observed for normalised (for walking velocity) hip ($F(3,77) = 2.674, p = 0.050$) and knee ($F(3,77) = 3.191, p = 0.028$) flexion/extension angles for the stance leg at peak toe clearance of the contra-lateral limb (Figure 4). These relationships demonstrated that control participants had significantly reduced knee flexion (i.e. straighter knee) in the stance limb at peak toe clearance on the foam surface (Table 2). In contrast, PD patients maintained a similar degree of knee flexion on the firm and foam surfaces, but had reduced hip extension (i.e. straighter hip) on the foam surface.

Insert Figure 4 about here.

Joint Kinematics: Swing Limb

Similar to the stance limb, PD fallers had increased knee flexion angle in the swing limb compared with control fallers and non-fallers. Significant surface*group interactions for normalised knee flexion/extension ($F(3,77) = 4.928, p = 0.003$) and ankle plantar/dorsiflexion ($F(3,77) = 3.018, p = 0.035$) at peak toe clearance (Figure 4) illustrated that, while control participants maintained a consistent knee flexion angle at peak toe clearance on both surfaces, PD patients significantly increased knee flexion and ankle plantar-flexion on the foam surface.

Discussion

This study is the first to examine surface-related adaptations of gait and segmental control in PD patients who prospectively reported falling. PD fallers had different walking patterns to age-matched controls and adapted differently to walking on a foam surface. There were marked differences in the patterns of lower limb kinematics which resulted in reduced amplitudes of toe clearance during stepping. PD fallers also demonstrated increased disease duration and freezing of gait compared with PD non-fallers and a greater fear of falling compared with PD non-fallers and controls. Fear of falling has been associated with poorer gait performance[28] and, while it may have emanated from the greater number of previous falls experienced by these participants, it could also reflect a greater awareness of deficits in walking stability.

In agreement with previous research, there were clear differences in temporospatial gait parameters for PD patients with respect to age-matched controls[1, 9-11] and for PD fallers relative to non-fallers and controls[14] on both firm and foam surfaces. PD fallers demonstrated increased stride timing variability compared with controls and while this was in agreement with two cross-sectional studies, it was in contrast to two prospective studies[5, 14]. However, unlike previous research, the current study examined gait on a compliant walking surface, which may have exposed motor control deficits and accentuated stride timing variability in PD fallers.

When walking on the foam surface all groups increased stride length, step width and walking speed. This was commensurate with findings for younger participants walking on a foam surface[16], but not those for older adults[17]. These changes may represent two types of strategic adaptation to the foam surface. Firstly, increases in stride length and walking

velocity reduce the number of times that each foot contacts the challenging surface[29] thereby limiting the number of opportunities for the body to be destabilised. While plausible, this explanation is unlikely to apply to real-world situations where compliant surfaces can extend over larger areas. An alternate explanation could be that the increased step width and stride length increased the base of support thereby providing greater stability for controlling the body throughout the gait cycle[16].

Although all groups demonstrated similar changes in stride length, step width and walking velocity on the foam surface, PD fallers recorded reduced toe clearance on the firm surface and unlike the age-matched controls (fallers and non-fallers), did not increase toe clearance on the softer surface.

Alterations in body and limb control provide insight into the origin of these differences. PD fallers walked with increased trunk flexion (relative to walking velocity), which, without any other compensation, would position the COM further ahead of the base of support and challenge postural stability. However, PD fallers increased knee flexion in the stance limb, which should lower the COM and shift it posteriorly; this would distribute the mass over the base of support and improve the stability of the body[16]. The lower COM position that resulted from having a more flexed knee during stance required PD fallers to increase knee flexion in the swing leg at peak toe clearance to ensure that they adequately cleared the walking surface. However, PD patients had increased ankle plantar-flexion during the swing phase which effectively positioned the toe closer to the floor. In contrast, the age-matched controls compensated by lifting their feet higher while walking on the compliant terrain, which limits the risk of tripping[16]. PD fallers may, therefore, be at a higher risk of tripping

compared with age-matched controls, particularly on compliant or uneven surfaces, where the height of the walking surface is constantly changing.

PD fallers demonstrated increased normalised ML head motion compared with PD non-fallers and control groups and, while not statistically significant (surface*group interaction; $p = 0.098$), there was evidence that this was exacerbated on the foam surface. This may be indicative of a postural control deficit in PD fallers, which impaired their capacity to attenuate surface-related perturbations and control head motion. Increased head motion may impair the ability to use visual and vestibular cues to regulate upright posture during walking[30].

These findings should be considered in light of several delimitations. Firstly, although similar to previous studies[1, 9, 14], a larger sample may provide further insight into surface-related gait adaptations of PD patients. Secondly, the PD patients assessed for this research were largely early stage patients ($H\&Y \leq 2$) and falls are a significant problem even in this early stage[4]. These postural control impairments may be exacerbated in later stage PD patients who have an increased risk of falling. Finally, while it is unlikely that an individual will be required to walk continuously on a foam surface in the real-world setting, it provides an easily controlled experimental surface that is analogous with real-world surfaces, such as grass, sand and carpet.

PD patients demonstrate different adaptive strategies while walking on less stable surfaces and, combined with poorer head control, likely expose these individuals to a greater risk of falling. These findings highlight the importance of examining gait and dynamic postural control under situations that are more applicable to the real-world setting. Future research

should examine the predictive power of gait-related measures with the aim of developing better screening tools and interventions to identify and assist patients with a higher propensity for falling.

Acknowledgements.

This research was supported by research grants from Queensland University of Technology and NHMRC Injury Prevention Partnership grant: Prevention of Older Peoples Injuries. The authors thank Melissa Newton, Matthew Roodevelt, Oren Tirosh and Jocelyn Stewart for assistance in data collection and processing. Furthermore, the authors are grateful to those Parkinson's patients and control participants who gave so generously of their time and helped to make this research possible.

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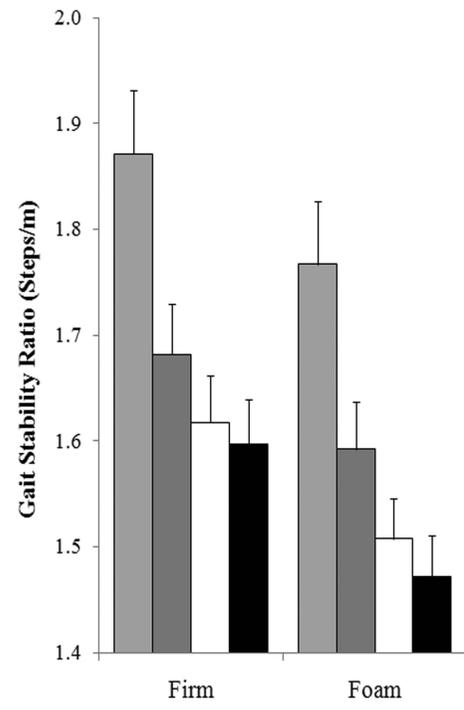
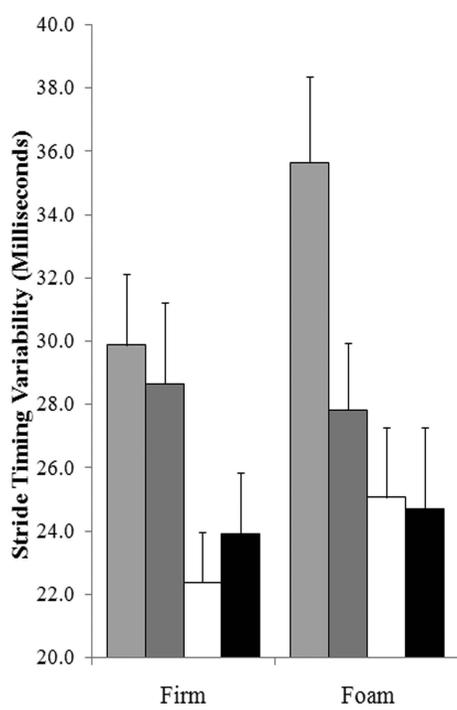
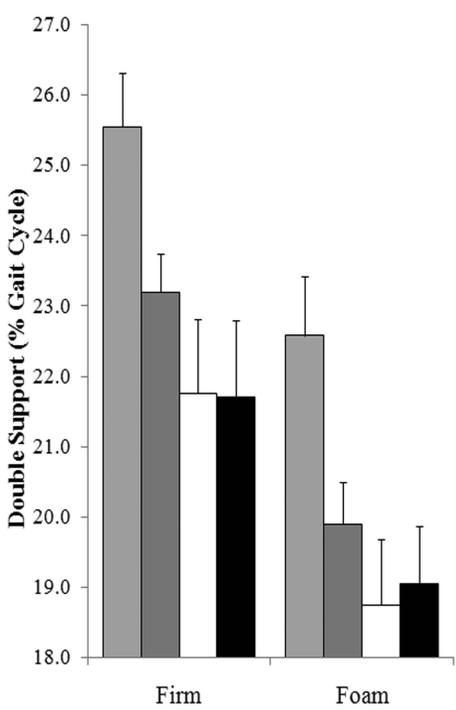
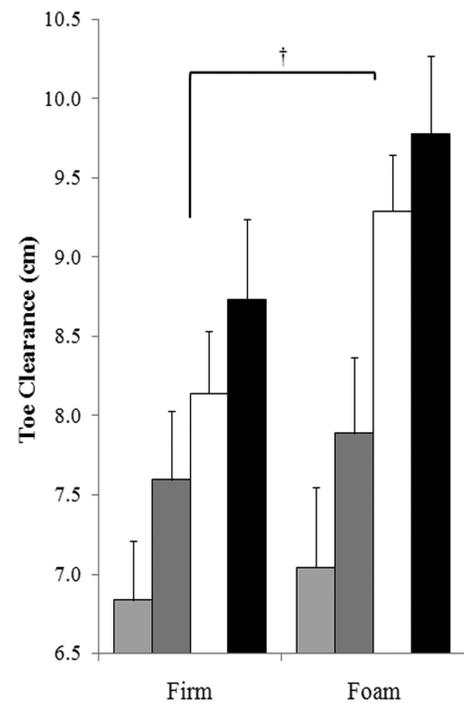
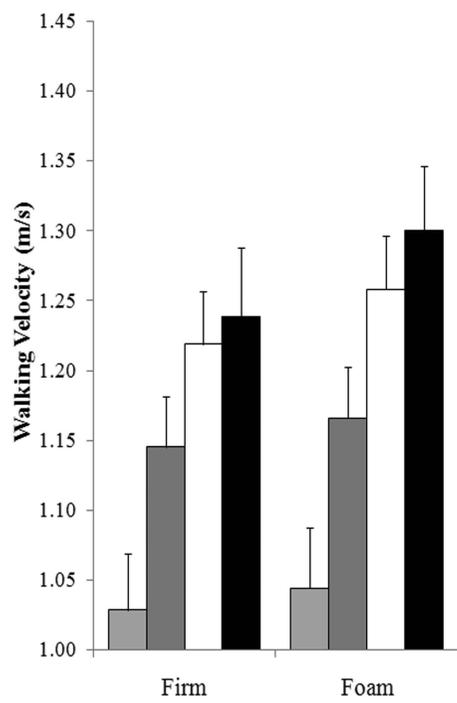
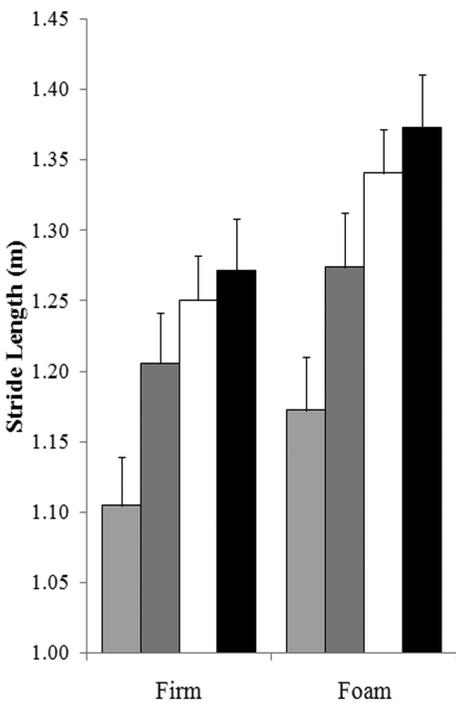
Figure Captions

Figure 1: Mean (+1 SEM) stride length, walking velocity, toe clearance, double-support time, stride timing variability and gait stability ratio for the four groups on the firm and foam surfaces. **N.B.** † denotes a significant surface*group interaction ($p < 0.05$).

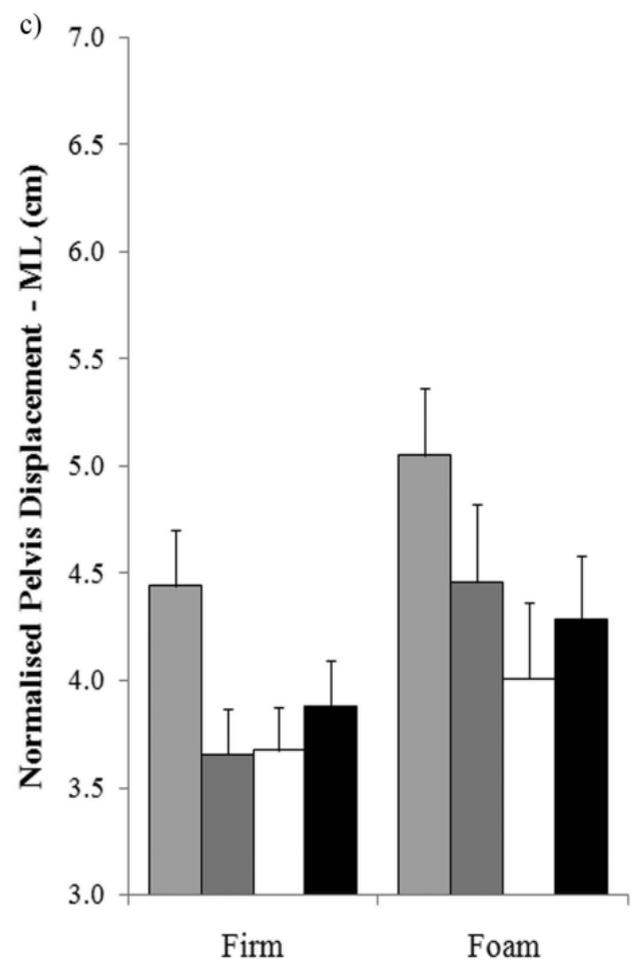
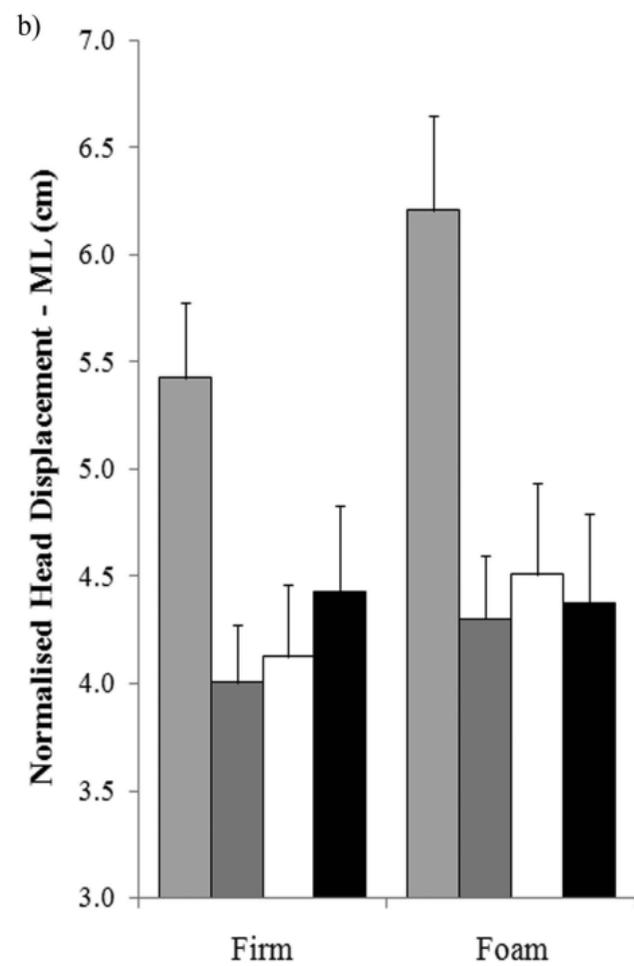
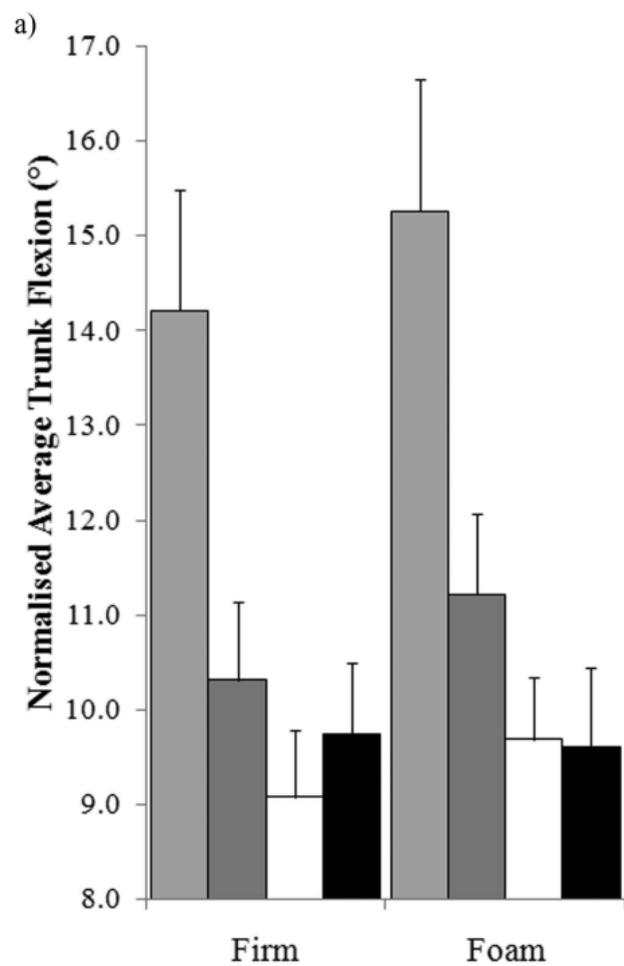
Figure 2: Mean (+1 SEM) values for a) normalised trunk flexion angle and normalised mediolateral displacement of the; b) head and; c) pelvis for the PD and control fallers and non-fallers on the firm and foam surfaces.

Figure 3: Average (+1 SEM) normalised sagittal joint range of motion for the hip, knee and ankle joints for the four groups walking on the firm and foam surfaces. **N.B.** † denotes a significant surface*group interaction ($p < 0.05$).

Figure 4: Average (+1 SEM) normalised hip, knee and ankle joint angles at peak toe clearance for the stance limb (Figures 3a to 3c) and swing (Figures 3d to 3f) limbs for the four groups walking on the firm and foam surfaces. **N.B.** † denotes a significant surface*group interaction ($p < 0.05$) and negative joint angles represent hip and knee extension or ankle plantar-flexion.

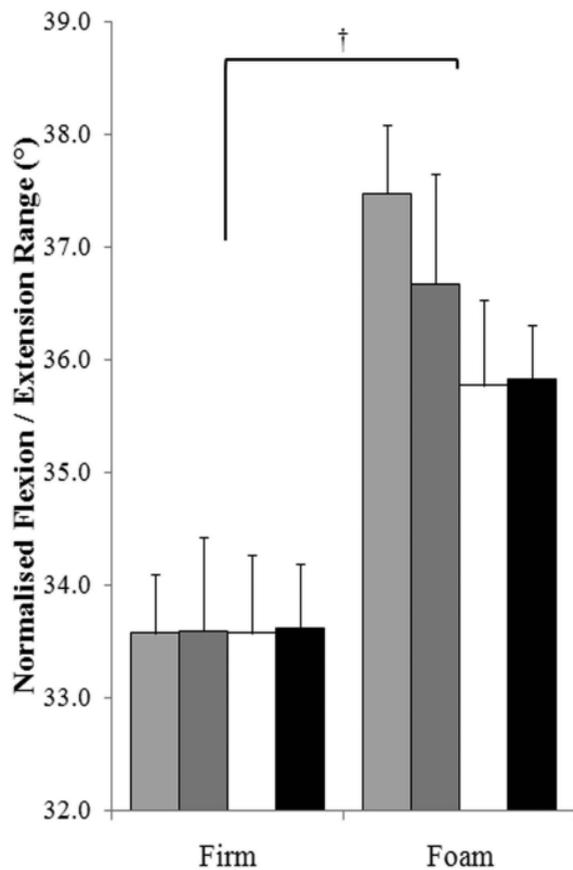


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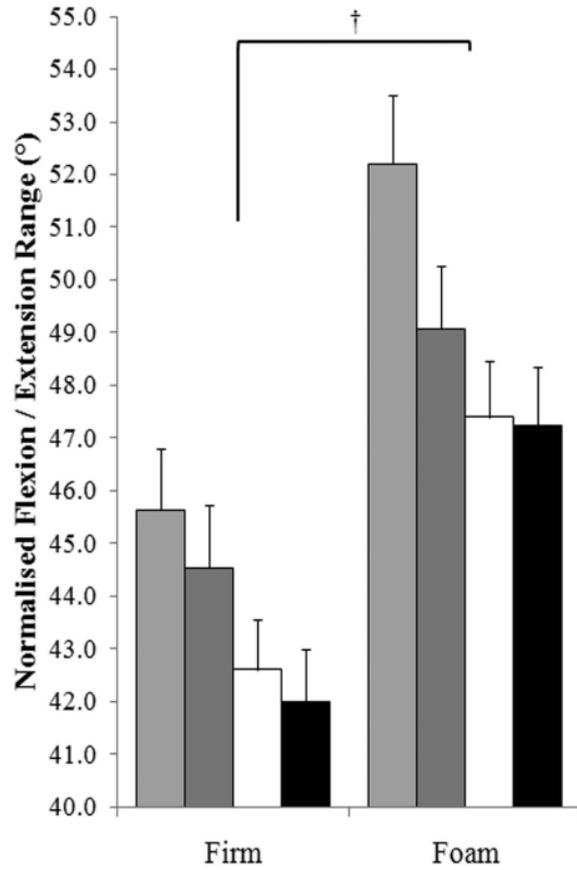


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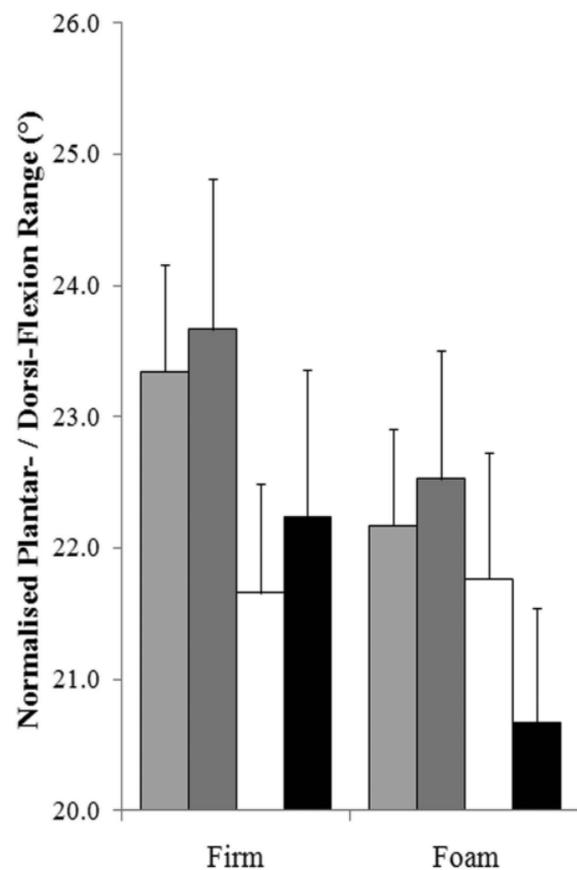
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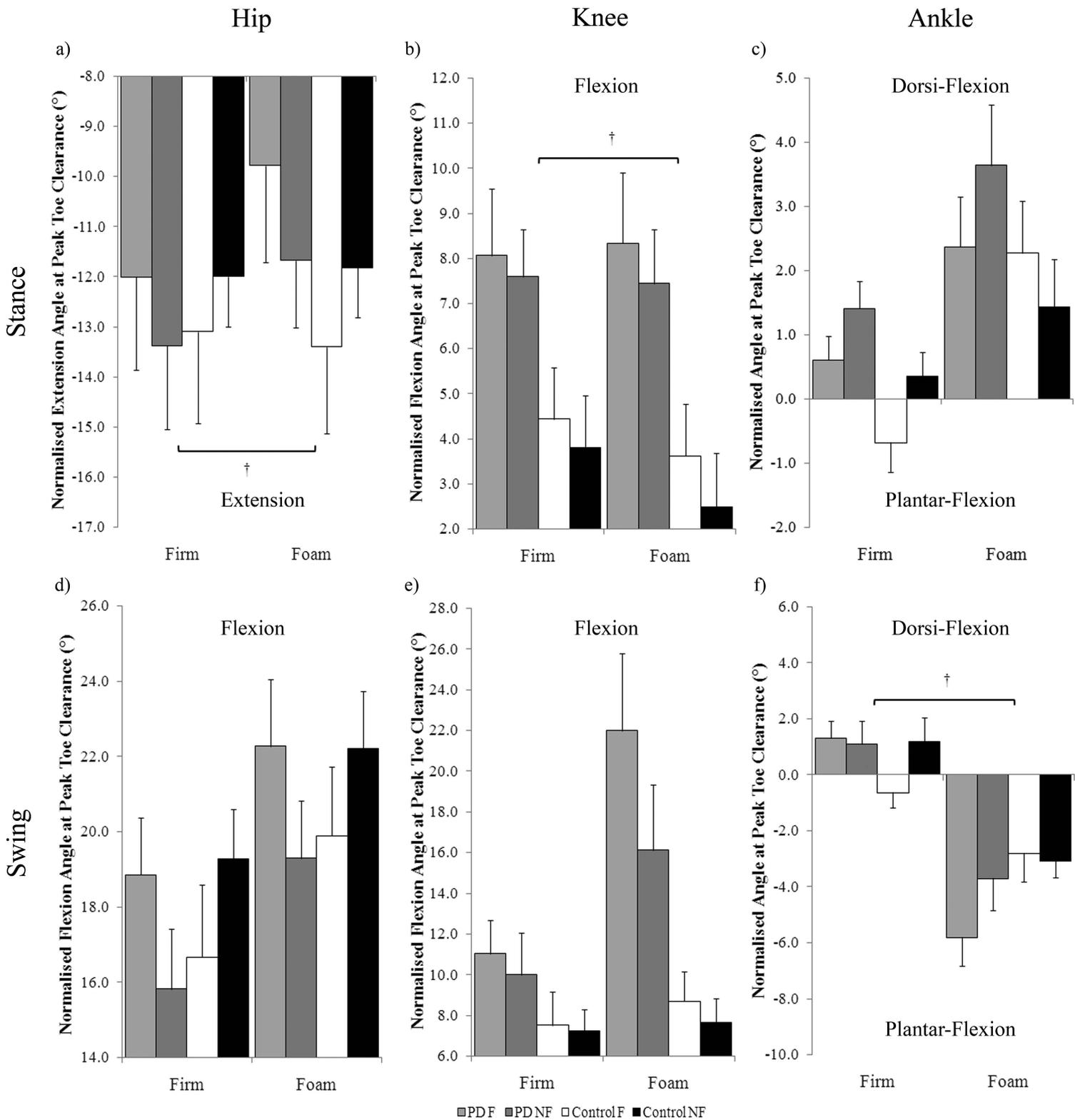


Table 1: Demographics and disease-specific scores for the Parkinson's disease and Control participants and the faller and non-faller subgroups. Data represent the mean (and standard error of the mean (SEM)) values or absolute numbers and percentages.

		Parkinson's Disease			Controls			
		All PD (n = 49)	PD Faller (n = 32)	PD Non-Faller (n = 17)	All Controls (n = 32)	Control Faller (n = 17)	Control Non-Faller (n = 15)	
		Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Sig.
Demographics								
	Age (years)	66.4 (1.2)	66.2 (1.4)	66.9 (2.1)	68.4 (1.5)	70.2 (2.3)	66.3 (1.6)	ns
	Gender (male)	33 (67.3%)	20 (62.5%)	13 (76.5%)	19 (59.4%)	10 (58.8%)	9 (60.0%)	ns
	Height (cm)	167.1 (1.1)	167.3 (1.4)	166.6 (1.7)	168.9 (1.5)	167.5 (2)	170.4 (2.3)	ns
	Mass (kg)	73.8 (1.9)	76.1 (2.5)	69.4 (2.8)	78.5 (2.9)	76.0 (4.0)	81.4 (4.1)	ns
	BMI (kg/m ²)	26.4 (0.6)	27.1 (0.8)	24.9 (0.8)	27.4 (0.7)	26.9 (1.1)	27.9 (0.9)	ns
Falls History and Fear of Falls								
	Modified Falls Efficacy Scale	8.7 (0.3)	8.3 (0.4)	9.7 (0.1)	9.7 (0.1)	9.7 (0.2)	9.7 (0.2)	a, b, c, d
	Previous Falls	2.9 (2.0)	4.3 (3.1)	0.3 (0.1)	0.3 (0.1)	0.5 (0.2)	0.1 (0.1)	a, b, d
Visual and Cognitive Functioning								
	High Contrast Visual Acuity (LogMAR)	0.00 (0.01)	0.01 (0.02)	-0.02 (0.02)	0.00 (0.01)	0.02 (0.02)	-0.01 (0.01)	ns
	Mini-Mental State Exam	27.4 (0.3)	27.1 (0.4)	27.8 (0.5)	27.9 (0.4)	27.7 (0.6)	28.1 (0.6)	ns
Neurological Exam								
	Disease Duration (years)	5.4 (0.5)	6.2 (0.7)	3.9 (0.6)				b
	Levodopa dose (mg/day)	657.6 (75.7)	688.8 (109.2)	598.8 (75.8)				ns
	Freezing of Gait	4.0 (0.6)	4.2 (0.7)	2.1 (0.6)				b
	Hoehn & Yahr	1.8 (0.1)	1.8 (0.1)	1.6 (0.2)				ns
	UPDRS Total	31.8 (2.3)	34.5 (2.7)	26.6 (3.7)				ns
	PIGD	3.9 (0.5)	4.4 (0.6)	3.0 (0.6)				ns

- ns.** No significant differences between the groups ($p > 0.05$)
- a.** PD significantly different to Controls ($p < 0.05$)
- b.** PD Fallers significantly different to PD Non-Fallers ($p < 0.05$)
- c.** PD Fallers significantly different to Control Fallers ($p < 0.05$)
- d.** PD Fallers significantly different to Control Non-Fallers ($p < 0.05$)

Table 2: Segmental coordination and sagittal joint kinematics for the Parkinson's disease and Control fallers and non-fallers while walking on the firm and foam surfaces. Data represent the mean (and standard error of the mean (SEM)) values.

	Firm Surface				Foam Surface				Sig.
	PD Faller (n = 32)	PD Non-Faller (n = 17)	Control Faller (n = 17)	Control Non-Faller (n = 15)	PD Faller (n = 32)	PD Non-Faller (n = 17)	Control Faller (n = 17)	Control Non-Faller (n = 15)	
	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	
Segmental Motion (cm)									
Avg Arm Swing	21.55 (2.33)	25.39 (2.16)	28.54 (1.66)	33.10 (3.17)	23.12 (2.64)	24.54 (2.29)	28.86 (1.75)	36.42 (3.73)	a, d
Norm Arm Swing	20.22 (1.66)	21.94 (1.71)	23.81 (1.54)	27.51 (2.39)	21.61 (2.03)	20.78 (1.76)	23.22 (1.47)	27.80 (2.18)	a
Norm Head Motion - VT	2.86 (0.12)	2.80 (0.11)	2.85 (0.12)	2.88 (0.22)	3.13 (0.13)	3.21 (0.17)	3.31 (0.18)	3.25 (0.25)	§
Norm Head Motion - ML	5.43 (0.35)	4.01 (0.27)	4.13 (0.34)	4.43 (0.44)	6.21 (0.44)	4.30 (0.29)	4.51 (0.43)	4.37 (0.45)	§, a, b, c, d
Norm Pelvis Motion - VT	2.87 (0.11)	2.81 (0.10)	2.82 (0.12)	2.82 (0.21)	3.35 (0.11)	3.34 (0.14)	3.42 (0.18)	3.37 (0.24)	§
Norm Pelvis Motion - ML	4.44 (0.26)	3.65 (0.22)	3.67 (0.21)	3.92 (0.23)	5.05 (0.32)	4.46 (0.37)	4.01 (0.35)	4.29 (0.32)	§, a
Joint Kinematics (°)									
Trunk Flexion Angle	13.55 (0.81)	11.56 (0.83)	10.77 (0.61)	11.73 (0.79)	14.60 (0.86)	12.85 (0.90)	11.95 (0.63)	12.08 (0.87)	†, §, a
Norm Trunk Flexion Angle	14.21 (1.27)	10.31 (0.83)	9.08 (0.70)	9.74 (0.76)	15.26 (1.39)	11.22 (0.85)	9.69 (0.66)	9.61 (0.84)	§, a, c, d
Norm Hip Flx/Ext Range	33.57 (0.53)	33.59 (0.83)	33.57 (0.69)	33.62 (0.56)	37.47 (0.61)	36.67 (0.97)	35.77 (0.76)	35.82 (0.48)	†, §
Norm Knee Flx/Ext Range	45.64 (1.17)	44.53 (1.20)	42.61 (0.96)	42.00 (1.00)	52.21 (1.29)	49.07 (1.21)	47.40 (1.07)	47.23 (1.13)	†, §, a, c, d
Norm Ankle Dor/Pln Range	23.35 (0.81)	23.67 (1.15)	21.66 (0.83)	22.23 (1.13)	22.17 (0.73)	22.52 (0.98)	21.77 (0.96)	20.67 (0.86)	§
Joint Kinematics at Peak Toe Clearance - Stance Leg (°)									
Norm Hip Flx/Ext Angle	-12.01 (1.86)	-13.38 (1.66)	-13.10 (1.83)	-12.00 (1.50)	-9.78 (1.94)	-11.68 (1.34)	-13.40 (1.73)	-11.82 (1.77)	†, §
Norm Knee Flx/Ext Angle	8.07 (1.47)	7.60 (1.04)	4.44 (1.14)	3.80 (1.16)	8.34 (1.56)	7.45 (1.20)	3.62 (1.15)	2.48 (1.21)	†, §, a, c, d
Norm Ankle Dor/Pln Angle	0.61 (0.37)	1.41 (0.43)	-0.69 (0.45)	0.35 (0.38)	2.37 (0.78)	3.64 (0.94)	2.27 (0.82)	1.44 (0.74)	§
Joint Kinematics at Peak Toe Clearance - Swing Leg (°)									
Norm Hip Flx/Ext Angle	18.85 (1.52)	15.82 (1.60)	16.67 (1.92)	19.28 (1.31)	22.27 (1.78)	19.29 (1.54)	19.89 (1.83)	22.21 (1.53)	§
Norm Knee Flx/Ext Angle	11.04 (1.62)	10.00 (2.07)	7.52 (1.66)	7.25 (1.04)	22.00 (3.80)	16.11 (3.24)	8.69 (1.45)	7.64 (1.20)	§, a, c, d
Norm Ankle Dor/Pln Angle	1.32 (0.59)	1.10 (0.81)	-0.65 (0.52)	1.18 (0.85)	-5.82 (1.01)	-3.71 (1.13)	-2.82 (1.00)	-3.09 (0.59)	†, §

ns. No significant differences between the groups ($p > 0.05$)

† Significant Surface*Group interaction ($p < 0.05$)

§. Firm surface significantly different to foam surface ($p < 0.05$)

a. PD significantly different to Controls ($p < 0.05$)

b. PD Fallers significantly different to PD Non-Fallers ($p < 0.05$)

c. PD Fallers significantly different to Control Fallers ($p < 0.05$)

d. PD Fallers significantly different to Control Non-Fallers ($p < 0.05$)