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Individuals with mild-to-moderate hip osteoarthritis exhibit altered pelvis and hip kinematics during sit-to-stand

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ABSTRACT

Background: Performance of the sit-to-stand (STS) task is compromised in individuals with advanced hip osteoarthritis (OA). Understanding how STS performance is altered in individuals with mild-to-moderate hip OA may inform interventions to improve function and slow disease progression.

Research question: Do trunk, pelvis, and hip biomechanics differ during a STS task between individuals with mild-to-moderate hip OA and a healthy, age-matched control group?

Methods: Thirteen individuals with mild-to-moderate symptomatic and radiographic hip OA and seventeen healthy, age-matched controls performed a standardized STS task. Data were acquired using a three-dimensional motion capture system. The primary outcome measures were task duration, sagittal and frontal plane trunk, pelvis, and hip joint angles, and sagittal and frontal plane trunk and hip joint moments. Comparisons of lower-limb measures were between the most affected side in the hip OA group and a randomly chosen limb for the control group, termed the index limb, prior to and following lift-off from the chair.

Results: Participants with mild-to-moderate hip OA took longer to perform the STS task compared to controls. Prior to lift-off, the hip OA group exhibited greater posterior pelvic tilt, greater pelvic rise on the index side and less hip joint flexion relative to controls. Following lift-off, the hip OA group exhibited greater pelvic rise on the index side compared to controls.

Significance: Individuals with mild-to-moderate hip OA exhibit subtle alterations in movement strategy compared to healthy controls when completing a STS task similar, to a small extent, to adaptations reported in advanced stages of the disease. Interventions to target these features and prevent further decline in physical function may be warranted in the management of mild-to-moderate hip OA while the opportunity remains.

1. Introduction

The sit-to-stand (STS) task is an important activity of daily living, and is often used to assess functional capacity in clinical populations [1]. Performing STS requires a threshold level of muscle strength and for the hip to move through a range of motion greater than during walking [2]. The STS task may therefore be particularly challenging for individuals with hip osteoarthritis (OA), who typically present with hip pain and associated dysfunction including lower-limb muscle weakness [3,4] and reduced hip range of motion [5].

Studies of STS biomechanics in individuals with hip OA have predominantly focused on individuals with advanced hip OA [6–9] or following hip joint replacement [7,8]. These studies typically report greater lateral trunk lean towards the affected hip, lower joint moments at the affected hip, higher knee joint moments on the non-affected side [6], and other weight-bearing asymmetries that indicate an attempt to unload the affected side [6,9]. To date, only Eitzen et al. [10] has compared hip joint biomechanics during STS in individuals with mild-to-moderate hip OA to healthy controls and observed no between-group differences in movement time, lower-limb kinematics or joint moments. Therefore, Eitzen et al. [10] concluded that individuals with mild-to-moderate hip OA have not yet adopted a STS movement strategy characteristic of advanced hip OA. However, this study reported that the hip OA group produced ~18% lower peak ground reaction force on their affected limb compared to contralateral limb, potentially indicating an altered force production strategy that may unload the

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lower-limb on the affected side.

Trunk biomechanics during a STS task in a mild-to-moderate hip OA population have not been examined, despite the trunk being a major contributor to hip joint loading and STS task execution [11]. Trunk and pelvis biomechanics during the STS task are known to differ among clinical populations [6,7,11] and could reveal differences in movement strategy during STS in hip OA. Further, given previous studies [10] included participants with relatively mild symptomatic hip OA (Harris Hip Score (HHS) = 82 ± 10 out of a possible 100 (no hip problems)) that were closely matched to controls for body weight and body mass index, it may be expected that group differences in STS biomechanics would only begin to emerge in individuals with greater levels of pain, dysfunction, and body mass as reported in individuals with moderate and advanced hip OA [12].

The purpose of this study was to compare trunk, pelvis, and hip biomechanics during a STS task between individuals with both symptomatic and radiographically defined mild-to-moderate hip OA and a healthy control group. We hypothesized that individuals with mild-to-moderate hip OA would perform the STS task using a movement strategy consistent with unloading of their affected limb as reported in advanced hip OA. It was foreseen that this study would help identify the nature and extent of dysfunction during the STS task in individuals with mild-to-moderate hip OA, and thereby inform efforts to improve function and slow disease progression at a stage when potential to alter the disease trajectory remains.

2. Methods

2.1. Participants

This study used a convenience sample of participants enrolled concurrently in another study [5]. Individuals 45–80 years of age were recruited via word-of-mouth, advertising, and from hospital orthopaedic waiting lists. Volunteers were screened via radiographic examination and modified HHS [13]. Potential participants underwent bilateral weight-bearing anterior-posterior radiographs, and supine magnetic resonance imaging (MRI) of the pelvis and hip joints. One experienced radiologist electronically measured supero-medial, apical, and supero-lateral joint space width (JSW) and assessed radiographs of both hip joints for OA based on Kellgren-Lawrence (KL) grading (KL grading scale: 0 = no radiographic features of hip OA, through to 4 = large osteophytes). Participants with hip pain and/or functional limitations during activities of daily living (HHS ≤ 95: 0 = extreme hip problems through to 100 = no hip problems), and a KL grade of 2 or 3 for their affected hip(s) and/or JSW ≤ 3 mm [14] were allocated to the hip OA group. Participants in the hip OA group were divided into unilateral or bilateral hip OA sub-groups. The bilateral group met the criteria for the hip OA group for both hip joints, whereas the unilateral sub-group had KL scores ≤ 1 and JSW > 3 mm for their contralateral hip joint. Volunteers with minimal hip pain/dysfunction (HHS > 95) and KL grades ≤ 1 and JSW > 3 mm for both hip joints were allocated to the control group. Volunteers were excluded from the study if they had neurological or lower-limb musculoskeletal conditions other than hip OA. Ethics approval for the study was obtained from the institutional Human Research Ethics Committee (HREC/13/QHC/1614″ (GU Ref No: PES/46/13/HREC)), and all participants provided written informed consent prior to participation.

2.2. Data collection procedures

Participants were seated on a backless fixed-height (45 cm) chair, with their feet placed on separate force plates. Foot position (30 cm apart) was controlled using marked tape. Following a task demonstration, participants performed a single familiarization trial. Only one familiarization trial was used as the STS task can provoke pain and be challenging for this population. Participants were instructed to fold their arms across their chest to limit arm use [1] and to perform the task at a chosen self-selected speed. All individuals were able to perform the STS task without assistance.

The position of 60 retro-reflective markers were acquired at 200 Hz using a 12-camera three-dimensional motion capture system (Oxford Metrics, Oxford, UK). Clusters of four markers (15 mm diameter) were firmly adhered to participant thighs and shanks, and individual markers were placed on pelvis, medial and lateral femoral epicondyles, medial and lateral malleoli, and feet. The trunk and head were defined as a single segment with individual markers placed on the fifth lumbar vertebrae, seventh cervical vertebrae (C7), sternum (xiphoid process), and clavicular notch. Ground reaction forces for each foot were simultaneously acquired at 1000 Hz using two 900 x 600 mm ground-embedded piezoelectric force platforms (Type 9287A, Kistler Instruments, USA).

2.3. Data analysis procedures

Motion capture and ground reaction force data were conditioned and converted to appropriate formats for musculoskeletal modelling using MOtoNMS [15]. Marker positions were filtered using a dual pass, low-pass 2^{nd} order zero-lag Butterworth filter with a 10 Hz cut-off frequency. A generic whole-body musculoskeletal model [16] was implemented in OpenSim [17], and model bodies were linearly scaled [17] using three-dimensional marker positions acquired from an upright static trial. Pelvis and femur bodies were scaled using subject-specific measurements from MRI, to minimise landmark identification errors associated with adipose tissue between skin-surface markers and underlying pelvis bones in our cohort [18]. The locations of the anterior and posterior sacroiliac spines were measured from MRI and used to compute the pelvis scaling factors associated with corresponding dimensions on the generic model. Pelvis scaling factors were 0.92 ± 0.054, 0.88 ± 0.039, and 0.78 ± 0.033 for width, depth, and height, respectively. Mean pelvis width and depth of the scaled models were 0.24 ± 0.014 m and 0.16 ± 0.0073 m, respectively, and were in good agreement with normative values (width: 0.24 ± 0.04 m and depth: 0.14 ± 0.03 m [19]). Femur bodies were uniformly scaled from hip joint centre to knee joint centre. For the purpose of scaling the femur and pelvis bodies, the hip joint centre was estimated from pelvis dimensions from MRI [20]. Knee joint centres were estimated as the mean of medial and lateral femoral condyles measured as the most lateral/medial aspects of the femur from MRI. Ankle joint centres were defined as the mean of medial and lateral malleoli markers [21].

Inverse kinematic analysis was used to determine sagittal and frontal plane angles for the trunk, pelvis, and hip joint. Inverse dynamic analysis was used to compute sagittal and frontal plane moments for the trunk and hip joint. Net joint moments were expressed as internal (muscle) moments normalised to body mass (Nm/kg). Root mean squared errors for marker positions during scaling were averaged for each participant, then subsequently averaged across participants (0.013 ± 0.003 m). Root mean squared errors for inverse kinematics were calculated as the mean error for all marker positions across a STS trial for each participant, and subsequently across participants (0.027 ± 0.004 m). Maximum root mean squared error was calculated as the single largest error from a marker during a STS trial for each participant, and was 0.054 ± 0.015 m when averaged across participants. The errors associated with scaling and inverse kinematics were considered acceptable relative to recommended tolerances [17].

The test limb for the unilateral hip group was the OA-affected limb. For participants with bilateral hip OA, the test limb was defined as the most affected hip, and the test limb was randomly assigned for healthy controls. In all cases, the test limb will now be referred to as the "index" limb. The STS task was analysed in two phases: support and stance. The support phase was defined from initial forward trunk lean (i.e., movement of C7 vertebra marker) to the first instance of standing (i.e., point at which the sum of vertical ground reaction forces from both force plates was equal to body weight, indicating full support of body mass). Stance phase was defined as the first instance of full support of body mass to maximum extension (i.e., peak height of C7 marker). Both phases were time normalized to 101 points. Data analysis was undertaken using MATLAB (release 2014b, The Mathworks Inc., MASS, USA).

2.4. Statistical analysis

Data were assessed for normality by inspecting Q–Q plots and using Shapiro-Wilk tests. Homogeneity of variance was assessed using Levene's test. Participant characteristics and task completion time were compared between groups using independent *t*-tests or Pearson's chi-square. Between-group differences in continuous sagittal and frontal plane angles for the trunk, pelvis, and hip and moments for the trunk and hip were evaluated using an independent sample *t*-test with statistical parametric mapping methods [22]. T-values that exceeded the t* threshold were interpreted to indicate between-group differences. All data are reported as the mean ± one standard deviation, with the exception of the figures, where data are reported as the mean ± one standard error. Statistical Package for the Social Sciences (SPSS), version 22.0 (IBM, NY, USA) and MATLAB (release 2014b, The Mathworks Inc., MASS, USA) were used for all statistical analyses. Significance level was set at $p < 0.05$.

3. Results

3.1. Participant characteristics

The hip OA group consisted of 6 participants with unilateral hip OA and 7 with bilateral hip OA. There were no significant differences in age, height, body mass, or body mass index between the unilateral and bilateral hip OA sub-groups. The hip OA group had significantly higher body mass and body mass index compared to controls (Table 1). The hip OA group had an overall HHS of 72 ± 15, and subscale scores of 39.6 ± 5.6 and 27.1 ± 8.4 for pain and function, respectively. Individuals in the control group had an overall HHS that was greater than or equal to 99.

3.2. Sub-group analysis of spatial-temporal, kinematic and kinetic measures

A sub-group analysis revealed that the unilateral hip OA group had significantly more anterior pelvic tilt for 11–56% of the stance phase than the bilateral group (Supplementary Fig. 2C). As there were no other differences in demographic, spatial-temporal (Supplementary Table 1), kinematic or kinetic measures between the unilateral and bilateral hip OA sub-groups (Supplementary Figs. 1–3), hip OA data were pooled for subsequent analyses.

3.3. Spatial-temporal measures

The hip OA group performed the STS task over a significantly longer duration (1.7 ± 0.4 s) than controls (1.1 ± 0.2 s) ($p < 0.01$) as a result of a significantly longer support phase (hip OA: 0.8 ± 0.3 s, control: 0.4 ± 0.1 s, $p < 0.01$) and stance phase (hip OA: 0.9 ± 0.2 s, control: 0.7 ± 0.1 s, $p < 0.05$). There were no group differences in mean foot width (hip OA: 0.29 ± 0.05 m, control: 0.30 ± 0.05 m, $p = 0.80$).

3.4. Trunk, pelvis, and hip joint kinematics and kinetics

Compared to controls, the hip OA group had a more posteriorly tilted pelvis from 8 to 74% of the support phase (Fig. 1C, $p < 0.05$) and greater pelvic rise from 42 to 100% of the support phase (Fig. 1D, $p < 0.05$). The hip OA group also exhibited less hip flexion (Fig. 1E, $p < 0.05$) from 33 to 74% of the support phase (Fig. 1E, $p < 0.05$) compared to controls. The hip OA group exhibited greater pelvic rise on the index side from and 1–49% of the stance phase compared to controls (Fig. 2D, $p < 0.05$). No significant between-group differences were detected in mass normalised trunk or hip joint kinetics (Fig. 3).

4. Discussion

This study investigated trunk, pelvis, and hip biomechanics during a STS task in individuals with symptomatic and radiographic mild-to-moderate hip OA and healthy controls. The main findings were that individuals with hip OA took longer to perform the STS task, and had greater pelvic rise on the index side in early stance. In contrast to findings from a prior study of STS biomechanics in individuals with a less symptomatic form of hip OA (HHS = 82 ± 10) where no differences in STS biomechanics were reported relative to controls [10], the present study of individuals with more severe pain and dysfunction (HHS = 72 ± 15) and greater BMI relative to controls (29 ± 5 kg/m^2 vs 24 ± 4 kg/m^2), identified subtle differences in pelvis kinematics. The hip OA group also required more time to complete the STS task, which may reflect an attempt to minimize pain or compensate for postural instability and/or muscle weakness. Interventions to target some of these biomechanical alterations and prevent further decline in physical function may be warranted in the management of mild-to-moderate hip OA.

Individuals with hip OA required, on average, 118% more time in the support phase and 19% more time in the stance phase of the STS task compared to controls. Individuals with hip OA are known to take

Table 1
Participant characteristics of the hip osteoarthritis (OA) and control groups.

	Hip OA (n = 13)						Control (n = 17)		F, p
	Unilateral (n = 6)		Bilateral (n = 7)		Combined				
Males (n)	1 (14%)		3 (42%)		4 (29%)		4 (22%)		n/a, 0.44
Age (years)	59.3 ± 7.2		62.2 ± 6.5		60.9 ± 6.7		59.1 ± 8.3		0.05, 0.49
Height (m)	1.7 ± 0.6		1.7 ± 0.1		1.7 ± 0.1		1.7 ± 0.07		0.72, 0.75
Body mass (kg)	79.4 ± 16.5		84.5 ± 17.9		82.1 ± 16.7		68.5 ± 8.1		4.41, < 0.01*
BMI (kg/m^2)	28.6 ± 5.6		29.3 ± 4.6		29.0 ± 4.9		24.6 ± 3.5		2.33, 0.01*
	Index (Affected)	Non-index (Unaffected)	Index (Most affected)	Non-index (Least affected)	Index	Non-index	Index	Non-index	
JSW (mm)	1.9 ± 0.8	3.4 ± 0.9	3.0 ± 1.0	2.9 ± 0.7	2.5 ± 1.1	3.2 ± 0.8	4.1 ± 0.7	3.8 ± 0.4	22.80, < 0.01*
KL 0	–	4	–	–	–	4	9	9	
KL 1	–	2	–	–	–	2	8	8	
KL 2	2	–	3	4	5	4	–	–	
KL 3	4	–	4	3	8	3	–	–	
KL 4	–	–	–	–	–	–	–	–	

Reported values represent mean ± one standard deviation unless otherwise stated; asterisk (*) indicates significance $p < 0.05$; JSW – joint space width; BMI – body mass index; KL – Kellgren-Lawrence Grade.

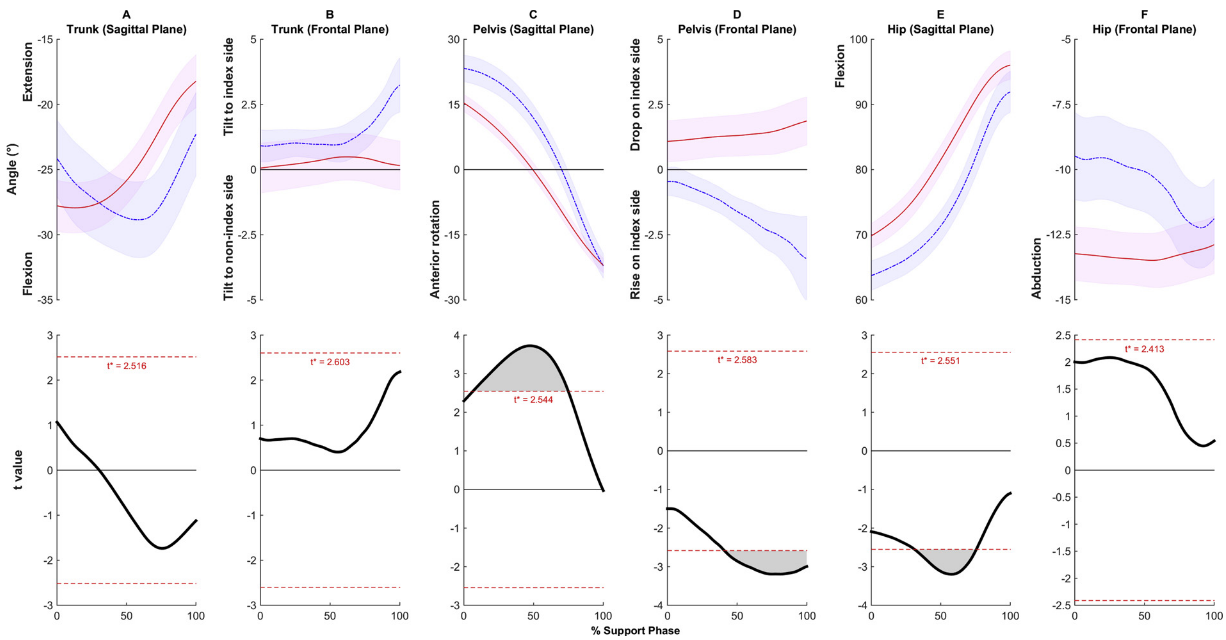

Fig. 1. Top row: Ensemble average (± standard error) joint kinematics for hip osteoarthritis (OA) (n = 13) (blue - dashed) and control (n = 17) (red - solid) groups over the support phase of the sit-to-stand task. Bottom row: Corresponding t-values (black - solid) and t-threshold (red - dashed) from statistical parametric mapping. T-values that exceeded the t* threshold were interpreted to indicate between-group differences ($p < 0.05$) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

greater precautions as a direct or indirect consequence of pain or fear of pain [23], which could slow task execution. This finding of greater task completion time is consistent with clinical observations that individuals with hip OA take longer to complete functional tasks [24]. Greater time to complete STS has been reported in individuals with balance disorders [1,25] and in overweight individuals (BMI > 30 kg/m^2) [26]. In the present study, slower STS execution in the hip OA group could be explained by a combination of pain and greater BMI compared to the control group, together with possible muscle weakness and associated postural instability. Eitzen et al. [10] found no difference in STS task execution time, but this perhaps reflects the less symptomatic disease state and absence of between-group difference in BMI in their study. Our finding of slower STS task execution is consistent with findings of lower limb muscle weakness [3] and slower self-selected gait speed and hence longer stride time [5] in the same cohort of participants.

Compared to the control group, the hip OA group exhibited greater pelvic rise on the index side at the end of support and beginning of stance during the STS task. Although not statistically significant, we

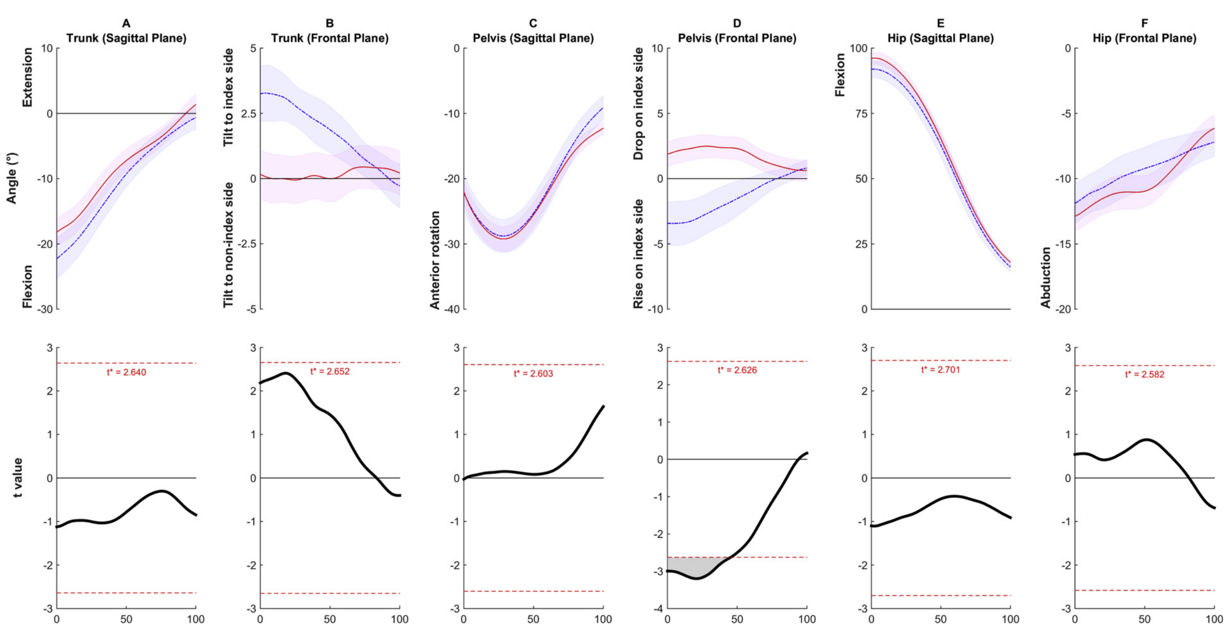

Fig. 2. Top row: Ensemble average (± standard error) joint kinematics for hip osteoarthritis (OA) (n = 13) (blue - dashed) and control (n = 17) (red - solid) groups over the stance phase of the sit-to-stand task. Bottom row: Corresponding t-values (black - solid) and t-threshold (red - dashed) from statistical parametric mapping. T-values that exceeded the t* threshold were interpreted to indicate between-group differences ($p < 0.05$). Pelvic rise/drop refers to the affected (unilateral hip OA), more affected (bilateral hip OA) or test hip (controls) (i.e., index limb) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

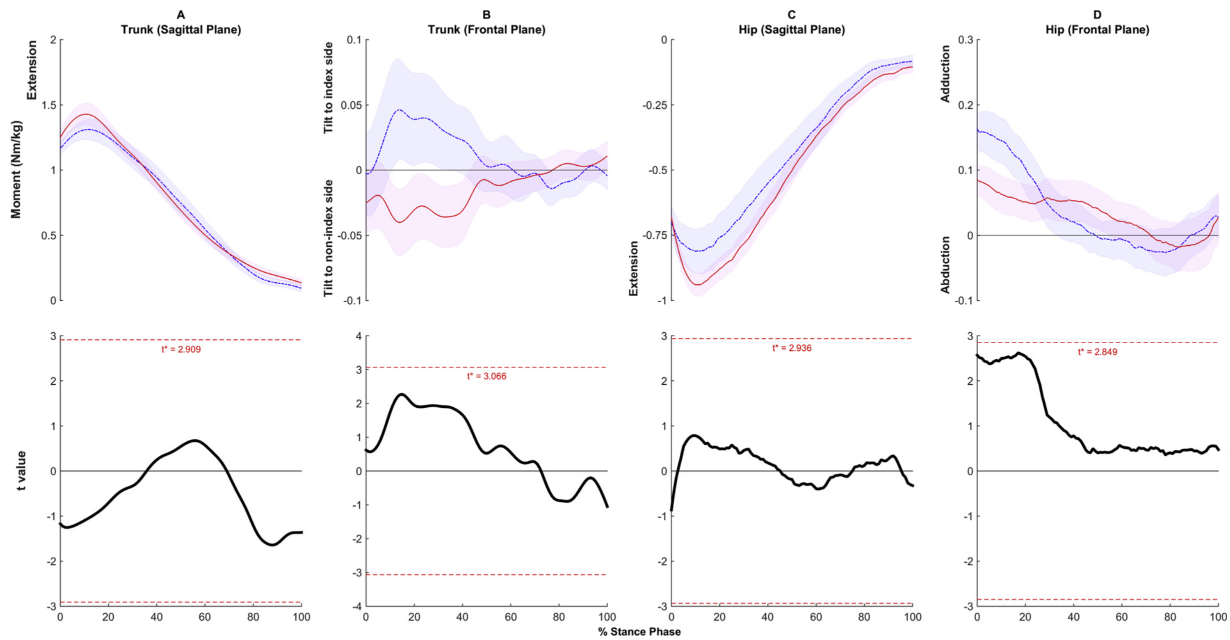

Fig. 3. Top row: Ensemble average (± standard error) joint kinetics for hip osteoarthritis (OA) (n = 13) (blue - dashed) and control (n = 17) (red - solid) groups over the stance phase of the sit-to-stand task. Bottom row: Corresponding t-values (black - solid) and t-threshold (red - dashed) from statistical parametric mapping. T-values that exceeded the t* threshold were interpreted to indicate between-group differences ($p < 0.05$) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

also noted a tendency for the hip OA group to lean the trunk towards the (most) affected limb early in the stance phase. Greater pelvic rise [27], together with an accentuated trunk lean towards the affected side [27–29], have been reported in advanced hip OA during walking and stair climbing relative to healthy controls, and appear to be stereotypical movement patterns in advanced hip OA. Trunk lean towards the index side is believed to be a strategy that lowers the mechanical demands on hip muscles by positioning the trunk centre of mass closer to the hip [30]. The lesser hip flexion during support in hip OA is most likely a compensation for greater posterior pelvic rotation and were accompanied by subtle alterations in frontal plane pelvis motion. Overall, the observed group differences in pelvis and hip kinematics from the present study appear to reflect the early signs of the more pronounced alterations observed in advanced hip OA. In contrast, the absence of group differences in hip joint moments in the present study suggests that the lower internal hip abduction moment on the index side as observed in advanced hip OA and following arthroplasty [6,27], is a feature only of more advanced stages of the disease.

Trunk and pelvis biomechanics, which can alter hip joint loading [11,29], were investigated for the first time during a STS task in mild-to-moderate hip OA in this study. A further strength was that eligibility was based on radiographic and symptomatic criteria, which minimized the risk of participant misclassification. Further, MRI was used to scale the pelvis and femur in order to reduce error in kinetic measures, particularly for participants with substantial adipose tissue between skin-surface markers and underlying bony landmarks [18]. The main limitation of the study is the small sample size, especially for the hip OA sub-groups, which may limit the generalizability of findings to the broader hip OA population. A further limitation of our study was that the dynamic consistency of the model was not verified. Efforts to improve measures of pelvis kinematics, such as via use of a virtual marker-pointer system [31], are also warranted in future studies. Future investigations should aim to include measures of regional articular loading to identify the effect of altered STS strategies in hip OA on the local mechanical environment of the hip. The relationship between the movement strategy adopted in the hip OA group and factors including pain and strength, and any implications for disease progression also requires further investigation.

5. Conclusion

Individuals with mild-to-moderate hip OA exhibit subtle alterations in movement strategy in the STS task that reflect, to a small extent, adaptations reported in advanced stages of the disease. Interventions to target these features and prevent further decline in physical function appear warranted in the management of mild-to-moderate hip OA while the opportunity remains.

Conflict of interest statement

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.05.008.

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