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Trunk-Pelvis Coordination During Turning: A Cross Sectional Study of Young Adults With and Without a History of Low Back Pain

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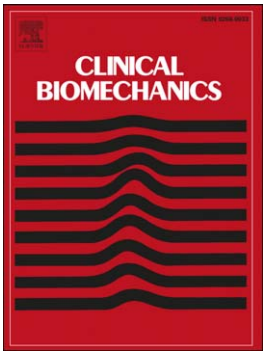

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Trunk-pelvis coordination during turning: a cross sectional study of young adults with and without a history of low back pain

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Abstract

Background

During steady-state locomotion, symptomatic individuals with low back pain demonstrate reduced ability to modulate coordination between the trunk and the pelvis in the axial plane. It is unclear if this is also true during functional locomotor perturbations such as changing direction, or if this change in coordination adaptability persists between symptomatic episodes. The purpose of this study was to compare trunk-pelvis coordination during walking turns in healthy individuals and asymptomatic individuals with a history of low back pain.

Methods

Participants performed multiple ipsilateral turns. Axial plane inter-segmental coordination and stride-to-stride coordination variability were quantified using the vector coding technique. Frequency of coordination mode and amplitude of coordination variability was compared between groups using Wilcoxon signed-ranks tests and paired t-tests respectively.

Findings

During stance phase of the turn, there was no significant difference in either inter-segmental coordination or coordination variability between groups. Inter-segmental coordination between the trunk and the pelvis was predominantly inphase during this part of the turn. During swing phase, patterns of coordination were more diversified, and individuals with a history of low back pain had significantly greater trunk phase coordination than healthy controls. Coordination variability was the same in both groups.

Interpretation

Changes in trunk-pelvis coordination are evident between symptomatic episodes in individuals with a history of low back pain. However, previously demonstrated decreases in coordination variability **were not found** between symptomatic episodes in individuals with recurrent **low back pain** and therefore may represent a response to concurrent pain rather than a persistent change in motor control.

Keywords

Walking turns, trunk, pelvis, coordination, low back pain

1. Introduction

Dynamic control of the trunk is altered in association with low back pain (LBP). This is evident during locomotion, despite the fact that walking is not usually a pain-provoking activity in individuals with LBP. In particular, existing research suggests that individuals with persistent low back pain are less able to modulate phase relations, or inter-segmental coordination, between the trunk and the pelvis than healthy individuals.

Normal trunk-pelvis inter-segmental coordination in the axial plane is characterized by a progressive modulation from primarily inphase to primarily antiphase coordination as locomotor speed increases[1,2,3]. Antiphase coordination may be important to aid fast locomotion by generating elastic recoil between the thorax and the pelvis[4], and to helping to produce arm-swing, which in turn counteracts angular momentum from the lower limbs[5-7]. While inter-segmental coordination is not affected by acute experimental LBP, persons with ongoing, persistent LBP demonstrate reduced ability to transition to antiphase coordination with increasing locomotor speed compared with healthy individuals[8-10]. **In one study, this reduction in antiphase coordination was correlated with pain intensity[1]. Impaired antiphase coordination may contribute to the decreased walking speed and reduced step length that is evident in individuals with low back pain [9,11,12].** Increased inphase inter-segmental coordination during running is also evident after the resolution of a first episode of LBP[13]. Symptomatic individuals with persistent LBP also have significantly reduced stride-to-stride coordination variability between the trunk and the pelvis[8,9]. This loss of motor variability may impair

maintenance of postural stability under changing environmental constraints[14] and may impede normal adaptation of the mode of coordination as locomotor speed changes[11].

However, it is unclear if altered coordination is also evident in individuals with persistent but intermittent LBP (recurrent LBP) when they are between symptomatic episodes. Therefore it has not been determined if this adaptation is directly related to symptoms or represents a persistent change in motor control independent of pain. In order to understand the development and persistence of LBP, and to identify appropriate interventions, it is vital to understand how changes in trunk postural control evolve over time. In part this can be ascertained by investigating individuals with recurrent LBP during the periods of time when they are asymptomatic[15].

To our knowledge, trunk-pelvis inter-segmental coordination has previously only been studied during treadmill walking and running[7,8,13,16]. Therefore it is unclear how coordination is modulated during locomotor perturbations that are embedded within the locomotor cycle. One such locomotor perturbation is a change in direction, or walking turn. Walking turns are made either ipsilateral or contralateral to the turning stance limb. The change in direction during ipsilateral turns is accomplished either with a pivot on the stance foot during the stance phase of the turn (ipsilateral pivot turn), or with a two-step strategy (ipsilateral crossover turn)[17]. As ipsilateral pivot turns are associated with greater axial angular velocity in the trunk and pelvis, and greater horizontal displacement of the center of mass in comparison with steady-state locomotion[18,19], they also likely require more rapid and complex modulation of trunk-pelvis coordination.

The purpose of this study was to compare the pattern and stride-to-stride variability of axial plane inter-segmental coordination between the trunk and the pelvis

during anticipated 90° ipsilateral walking turns in young healthy individuals and asymptomatic individuals with a history of recurrent LBP. We hypothesized that compared with healthy individuals, asymptomatic individuals with a history of recurrent LBP would demonstrate increased inphase coordination, and decreased coordination variability during both the stance and swing phases of the turn.

2. Methods

2.1 Participants

Twenty-nine young adults between the ages of 22 and 31 years participated in the study (12 males, 17 females). They were recruited via study flyers and word of mouth. Participants in the control group (CTRL) were individually matched to participants with recurrent LBP (RLBP group) by sex, age (**within** five years), height in m (**within** 10 %), weight in kg (**within** 10 %) and activity level in metabolic equivalents (METS, **within** 15 %; Table 1). As one female participant in the RLBP group did not complete the data collection, only the remaining fourteen participants with a history of recurrent LBP were matched to control participants. A priori power analyses of preliminary data collected in our laboratory indicated that a minimum total sample size of twenty (ten per group) would be adequate to determine a statistically significant difference between groups for coordination variability at a power of $\beta = 0.8$ and statistical significance of $\alpha = 0.05$. The Institutional Review Board of the University of Southern California approved the procedures in the study. Participants gave written informed consent after a full explanation of the study procedures and the potential benefits and risks of participating.

Participants were eligible for inclusion in the RLBP group if they were between 18 and 40 years of age with greater than one-year history of recurrent episodes of LBP,

without evidence of significant spinal structural deformity or radiculopathy. The pain had to be primarily unilateral and localized to the area between the twelfth rib and the gluteal fold. Participants had to report at least two functionally-limiting episodes of pain in the preceding year[20]. At the time of data collection, all individuals in the RLBP group were in symptom remission (defined as a score of less than 0.5/10 cm on a visual analogue scale for current pain). Participants were eligible for inclusion in the control group if they could be individually matched to a participant in the RLBP group as previously described and did not have any history of LBP requiring modification of activity or medical care. Disability due to LBP was quantified using the modified Oswestry Disability Index (ODI[21]) and all participants completed a baseline visual analogue scale for current pain (VAS[22]).

2.2 Instrumentation

Kinematic data were collected using an 11-camera digital motion capture system sampling at a frequency of 200 Hz (Qualisys AB, Gothenburg, Sweden). 14 mm retro-reflective markers were attached to anatomical landmarks to define body segments and joint axes. Rigid kinematic models of the pelvis and trunk were tracked using individual markers bilaterally on the anterior superior iliac spines, iliac crests and on the L5/S1 disc space (pelvis) and a rigid triad of markers over the spinous process of T3 (trunk) [23-25]. The custom-made spinal marker triad was validated by static comparison with known angular rotations in all planes and dynamically by comparison with an existing marker set. A five-second standing calibration trial was collected for each participant to establish local segment coordinate systems relative to the global laboratory coordinate system.

Wireless force-sensitive resistor foot switches were attached bilaterally to the sole of participants' shoes under the lateral heel and the first metatarsophalangeal joint (TeleMyo DTS Telemetry, Noraxon USA Inc, Scottsdale, USA, response time 2 ms). After the foot switches were attached to the shoes, tape was applied to the sole in order to ensure similar coefficients of friction at the shoe/floor interface for all participants. Foot switch data were transmitted via a wireless receiver (3000 Hz TeleMyo DTS Telemetry, Noraxon USA Inc, Scottsdale, USA) and synchronized with the kinematic data using photoelectric triggers (Qualisys Track Manager v2.6, Qualisys AB, Gothenburg, Sweden). Participants were also instrumented with intramuscular electromyography electrodes in the paraspinal musculature. Results from these data are reported elsewhere[26].

2.3 Experimental task

Each locomotor trial consisted of three laps of a walking circuit. The circuit required both straight locomotion and a series of turns. Average speed was controlled at 1.5 m/s (plus or minus 5 %). In each repetition of the circuit, the first turn was made by stepping into an outlined 70 cm by 70 cm area with the foot ipsilateral to the turn direction (hereafter referred to as the "turn limb") and turning briskly 90° to the ipsilateral side (Figure 1). Cones outlined the turning area. All participants spontaneously used a pivot strategy to complete the turn, with the change in direction being accomplished by a pivot on the turn limb[17]. Each participant practiced the circuit until they were consistently able to achieve the correct average speed and foot placement. At least seven successful trials of the circuit were collected for each participant, resulting in a total of at least 21 ipsilateral pivot turns in the defined turning area for analysis.

Preliminary data indicated minimal differences in kinematic variables with different turn directions. Therefore, for consistency each RLBP participant and their matched CTRL turned in the opposite direction to their symptomatic side (for example, an individual with pain on the left side, and her matched CTRL both turned toward the right).

2.4 Data processing

Between 15 and 21 trials were analyzed for each participant. Although there is little consensus regarding the minimum number of trials that are required for stable estimates of coordination and variability[27-30], preliminary data indicated that analysis of at least 15 trials resulted in the most stable estimates of the primary variables.

Kinematic data were first processed using Visual3D™ software (C-Motion Inc., MD, USA). Marker trajectories were low-pass filtered with a 10 Hz recursive fourth order Butterworth filter. This frequency was supported by published data and by analysis of the frequency spectrum of preliminary data[31]. The stride cycle, stance phase and swing phase of each ipsilateral pivot turn were determined using the voltage signals of the foot switches and confirmed with a visual check of the horizontal velocity of the distal heel marker. Local coordinate systems for the segments were determined from the static calibration trial and then segment rotations were calculated across the turn stride cycle using Cardan angles and a rotation order of XYZ (flexion/extension; abduction/adduction; axial **rotation)**[32]. The alignment of the trunk segment was normalized to the static standing trial to account for individual postural alignment[23]. For each stride cycle, pelvic and total trunk motion in the axial plane relative to the global

coordinate system were calculated and time-normalized to 100%[33]. Data were then exported to MATLAB® for additional processing (MathWorks, MA, USA).

2.5 Data analysis

Inter-segmental coordination between the trunk and the pelvis in the axial plane was quantified using the vector coding technique. Of the several available methods for quantifying inter-segmental coordination, the vector coding approach is the most appropriate for analyzing walking turns. Unlike other methods, its interpretation is not reliant on an assumption of sinusoidal kinematic trajectories and it does not require amplitude normalization of the motion data[34,35]. In addition, vector coding facilitates a continuous assessment of time-varying coordination across the time-series of the task and the relative predominance of motion in one segment or the other[33]

Vector coding is based on methods originally described by Sparrow et al.,[36] to quantify and compare coordination behavior between two segments or joints using a coupling angle. The coupling angle can be visualized as the angle from the right horizontal of a vector connecting two consecutive data points on an angle-angle plot of the motion of two segments of interest[36,37]. The coupling angle is calculated for each successive interval in the time series. The coordination mode between the trunk and the pelvis is then defined using 45-degree bin widths[13,25,27,33,37,38]. Coupling angles between 22.5 and 67.5/202.5 and 247.5 denote inphase coordination (trunk and pelvis rotating in the same direction at the same time). Coupling angles between 112.5 and 157.5/292.5 and 337.5 denote antiphase coordination (trunk and pelvis rotating in opposite directions at the same time). Coupling angles between 0 and 22.5, 157.5 and 202.5 and 337 and 360

indicate pelvic phase (predominantly motion of the pelvis) and coupling angles between 67.5 and 112.5/247.5 and 292.5 indicate trunk phase (predominantly motion of the trunk).

Mean coupling angle and the variability of inter-segmental coordination across repeated trials by each participant were calculated using circular statistics[33,37,38]. **Circular statistics provide measures of central tendency and variance for directional or circular data, including angular measures, where there is no true zero.** The frequency that each coordination mode occurred as a percentage of the total coordination was then calculated for the entire stride cycle and for the stance and swing phases of the stride cycle for each individual. The variability of the coordination was also calculated using the angular deviation of the mean coupling angle at each time interval in the time series[34,37] and the mean angular deviation across the stride cycle, stance phase and swing phase was calculated for each individual.

In addition, the test-retest reliability and between-day standard error of the measurement (SEM) of the primary variables was calculated by performing the same data collection twice on four healthy individuals, at least three days apart. Intra-class correlation coefficients (ICC [3,15]) were calculated for the frequency of each mode of coordination and mean angular deviation and the SEM was calculated as SEM = $s\sqrt{1-ICC}$ where s is the standard deviation.

2.6 Statistical analysis

Data were screened for normality of distribution, homoscedasticity and outliers[39]. For parametric data, differences in dependent variables between groups were compared using paired t-tests. For non-parametric data, differences between groups were compared

using Wilcoxon signed rank tests. To correct for multiple planned comparisons a Bonferroni correction was used for each hypothesis, with level of significance set at α = .01 (.05/5 comparisons). Effect sizes for parametric data were calculated using Cohen's *d*, with .8 indicating a large effect size, .5 a medium effect size and .2 a small effect size. Effect sizes for non-parametric data were calculated using Cohen's *r* with .5 indicating a large effect size, .3 a medium effect size and .1 a small effect size[40]. All statistical analyses were performed using PASW Statistics (Version 18, IBM Corp., Armonk, NY).

3. Results

3.1 Participant characteristics

Participant characteristics are shown in Table 1. Individuals in the RLBP reported a median (interquartile range) of 5.8 (4.2) years of back pain, but were minimally disabled by their symptoms (median (interquartile range) ODI score 18 (15) %.)

3.2 Standard error of the measurement

Test-retest reliability for frequency of each mode of coordination and mean coordination variability across the stride cycle of the walking turn was generally excellent (Table 2).

3.3 Axial plane inter-segmental coordination

During stance phase, there was no significant difference in the percentage of any coordination mode utilized by each group (Table 3). Stance was characterized in both groups by predominantly inphase coordination (Figure 2). Just prior to toe-off of the stance limb, coordination became primarily trunk phase. (Figure 2[33]). During swing phase, individuals with a history of LBP had significantly greater trunk phase coordination than healthy controls (p = .009, r = .49; Figures 2 & 3, Table 3). This was

accompanied by a reduction in inphase and pelvic-phase coordination in individuals with RLBP, although these group differences did not achieve statistical significance (Table 3). In both groups, the percentage of inphase coordination was lower during swing compared with stance whereas the percentage of antiphase, pelvic and trunk coordination increased. The first half of swing was dominated by trunk phase coordination. Towards the end of swing phase the pattern of relative motion then transitioned into antiphase coordination as the trunk rotated opposite to the pelvis and swing limb.

3.4 Coordination variability

There was no significant difference between groups for mean coordination variability across either the stance and swing phases of the turn (mean (SD) stance RLBP 8.51 (2.42)°, CTRL 7.26 (1.95)°, p = .176, d = 0.56; swing RLBP 24.89 (9.93)°, CTRL 22.20 (6.88)°, p = .407, d = 0.31). In all individuals, inter-segmental coordination variability between the trunk and the pelvis was lower during stance than during swing (Figure 2).

4. Discussion

The purpose of this study was to examine the modulation of trunk-pelvis coordination in the axial plane during walking turns in individuals with and without a history of LBP. We hypothesized that individuals with a history of LBP would demonstrate more inphase coordination and reduced coordination variability, suggestive of reduced adaptability of coordination, in comparison with healthy controls.

During the stance phase of the turn, inter-segmental coordination did not differ between groups. However, during swing, the percentage of trunk phase coordination was significantly larger in the RLBP group than in the CTRL group. Inspection of the single

segment kinematic trajectories (Figure 2) indicates that the trunk continues to rotate into the direction of the turn through stance and into swing phase. This may be necessary to complete the reorientation of the body within a single stride cycle. In healthy individuals, pelvic motion is characterized by rapid rotation during stance, with an initial further oscillation of the pelvis into the direction of the turn during the first half of swing followed by rotation in the opposite direction as the turn limb swings forward prior to its second initial contact. The individuals with a history of LBP had smaller amplitude of pelvic motion during the early swing phase, resulting in relatively greater trunk phase coordination. While the RLBP group rotated the trunk sufficiently to complete the reorientation, and could therefore successfully perform the turn, they may have had difficulty dissociating the trunk and pelvis adequately to allow for rapid, oscillatory pelvic rotation to occur at the same time. This is consistent with the previous studies investigating both locomotion and other motor tasks that have indicated reduced trunk-pelvis dissociation in symptomatic individuals with LBP[41]. This may be due to increased trunk stiffness[4,42]. **An advantage of vector coding analysis is that it not only quantifies if the motion of two segments is in the same direction, but also if motion is primarily occurring in one rather than both segments**. In comparison, other common methods of quantifying coordination such as continuous relative phase or continuous relative Fourier phase only determine if the coordination mode is primarily inphase or antiphase.

This study did not find decreased coordination variability in participants with history of recurrent LBP. This is in contrast with previous studies investigating symptomatic individuals with chronic LBP[9,11,42]. Seay et al.,[3] also reported no difference in coordination variability in the axial plane during steady-state locomotion in a sample

of individuals who had fully recovered from a single bout of LBP. However, in that study, group differences were evident during running. This suggests that during tasks with greater mechanical demand than steady-state locomotion or turning, changes in inter-segmental coordination variability may persist even after the resolution of symptoms. Although ipsilateral pivot turns exert a greater postural demand on the trunk than steady-state locomotion, it may be that this task is still not sufficiently demanding to highlight changes in variability in an asymptomatic population. The size of the subject sample in this study is commensurate with previous studies comparing healthy individuals and individuals with low back pain[13,42], and exceeded the target number of subjects suggested by a power analysis utilizing pilot data collected in our lab. Therefore, the authors believe that the study was adequately powered to detect any group differences. While the level of disability due to LBP in participants in the present research was similar or greater than that reported in previous studies, our participants were substantially younger than those in previous investigations of chronic LBP[11,13,42]. Therefore, it is possible that greater changes in coordination variability would have been evident in older asymptomatic individuals with a persistent history of LBP.

Walking turns are a very common locomotor perturbation, with changes in direction estimated to occur for four steps out of every ten[43]. Despite this, the modulation in trunk-pelvis coordination that occurs during turning has not previously been established. The present study shows for the first time that the stance phase of the turn, during which the pivot occurs, is dominated by inphase coordination. Taylor et al., [19] hypothesized that axial plane motion in the trunk and pelvis provides angular momentum for the pivot. However, as the pelvis and trunk contribute very little to total angular

momentum during steady state locomotion[7], it may be more likely that the movement of the arms that is associated with inphase trunk and pelvis rotation during stance may generate some angular momentum[6,16,44] while the primary power generation for ipsilateral pivot turns comes from the plantarflexors and hip abductors and extensors of the turn limb[45,46]. All four modes of coordination were evident during the swing phase of the turn. Interestingly, the relative frequency of each pattern of coordination during swing phase was very similar to that previously described in studies of steady-state walking using the vector coding approach[13,47]. The similarity between the frequencies of coordination mode in these studies and the swing phase in the present study suggests that the normal locomotor phase relations between the trunk and the pelvis are rapidly re-established during the turn swing phase prior to the continuation of walking in the new line of progression.

In all participants, coordination variability was low during the stance phase of the turn and higher during the swing phase of the turn. The amplitude of variability may increase during swing as this part of the turn involves a transition from primarily inphase coordination back to the pattern of coordination observed during steady-state locomotion. Previous studies investigating coordination variability have suggested that the magnitude of variability peaks when the coordination between two oscillating segments transitions from one stable pattern or mode of coordination to another[2,48]. However, studies investigating limb coordination as the locomotor pattern changes from walking to running have not consistently supported this theory[49-51]. The magnitude of coordination variability at locomotor transitions may be constrained by the mechanical requirements of maintaining postural stability. It is therefore more probable that the increase in

coordination variability during swing phase reflects small differences in coordination across turn stride cycles that result from corrections of minor errors in the deceleration and control of the turn prior to walking in the new line of progression.

Clinically, this study adds valuable information regarding the development of the kinematic changes that occur in association with LBP and how these changes are associated with symptoms. This is important to assist in effective sub-grouping of individuals with low back pain for the purposes of treatment and research and for determining when interventions targeting these altered kinematics is indicated. **In particular, our findings suggest that even between symptomatic episodes it may be helpful to assess the relationship between trunk-pelvis coordination and impairments in walking speed and the ability to rapidly change direction in these individuals.** To the authors' knowledge, this is also the first time that the test-retest reliability of using the vector coding method to quantify inter-segmental coordination and coordination variability has been demonstrated. Our results suggest that these measures are robust and stable features of locomotion over time. Therefore, this walking turn paradigm may provide a useful method of quantifying impairments in trunk-pelvis coordination in other patient populations such as individuals with Parkinson's disease or post-stroke.

5. Conclusions

The findings from this study clarify the association between altered trunk-pelvis coordination and persistent LBP, indicating that changes in coordination in individuals with LBP **are evident** between symptomatic episodes. For the first time this study also

establishes the task-dependent modulation of inter-segmental coordination and coordination variability during ipsilateral walking turns.

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6. References

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Table 1

Participant demographics: median (inter-quartile range)

	CTRL[a]	RLBP[a]	*p*
Age (years)	24.5 (1.75)	26.5 (4.75)	.068
Height (m)	1.73 (0.05)	1.73 (0.09)	.664
Mass (kg)	66.68 (14.97)	67.70 (23.42)	.152
PAS score (MET-time)	47.60 (5.00)	48.20 (7.55)	.470
Duration of LBP (years)	-	5.8 (4.2)	-
Baseline VAS (cm)	0.00	0.12 (0.24)	-
ODI (%)	-	18.0 (15)	

[a]n = 14 in each group, 8 females, 6 males

Table 2

Between-day reliability and SEM for primary variables (ICC – intra-class correlation coefficient, SD = standard deviation, SEM = standard error of the measurement)

	ICC	SD	SEM
% antiphase coordination	0.78	0.77	0.36%
% inphase coordination	0.96	10.18	2.04%
% pelvic phase coordination	0.43	1.28	0.97%
% trunk phase coordination	0.95	9.4	2.10%
Mean coordination variability	0.98	1.62	0.23°

Table 3

Mode of coordination: frequency of coordination as a % of stance/swing phase, median (inter-quartile range)

	CTRL	RLBP	*p*	Cohen's *r*
Antiphase coordination				
stance	0.00 (0.00)	0.00 (0.00)	.686	0.08
swing	16.91 (15.50)	20.18 (15.08)	.683	0.08
Inphase coordination				
stance	93.39 (13.01)	91.76 (13.31)	.182	0.25
swing	42.04 (17.64)	34.31 (15.88)	.249	0.22
Pelvic phase coordination				
stance	0.00 (0.00)	0.00 (0.00)	.593	0.10
swing	12.87 (14.33)	7.86 (9.15)	.347	0.18
Trunk phase coordination				
stance	3.13 (9.15)	6.75 (7.01)	.388	0.16
swing	24.34 (15.54)	34.46 (20.72)	**.009**	**0.49**

Figure legends

Figure 1. Stride cycle of an ipsilateral walking turn to the right. Stride cycle commences with initial contact of foot ipsilateral to turn direction (turn limb). Re-orientation is achieved in part by a pivot on the turn limb. The stance phase of the turn ends with the initial contact of the foot contralateral to the turn direction and toe-off of the turn limb, and the stride cycle is completed by the second initial contact of the turn limb.

Figure 2. Time series of the turn stride cycle. Trunk and pelvis segment axial rotation relative to the global coordinate system, coupling angle between the trunk and the pelvis, and mean coordination variability. IC = initial contact of turn limb TO = toe-off of turn limb. a) Exemplar data from one CTRL individual (participant # CTRL5). b) Exemplar data from matched individual with RLBP (participant # RLBP5).

Figure 3. Frequency that each coordination pattern occurred, as a percentage of stance and swing. CTRL group n = 14, RLBP n = 14. Paired t-tests revealed a significant difference between groups for trunk phase coordination during swing, with a large effect size.

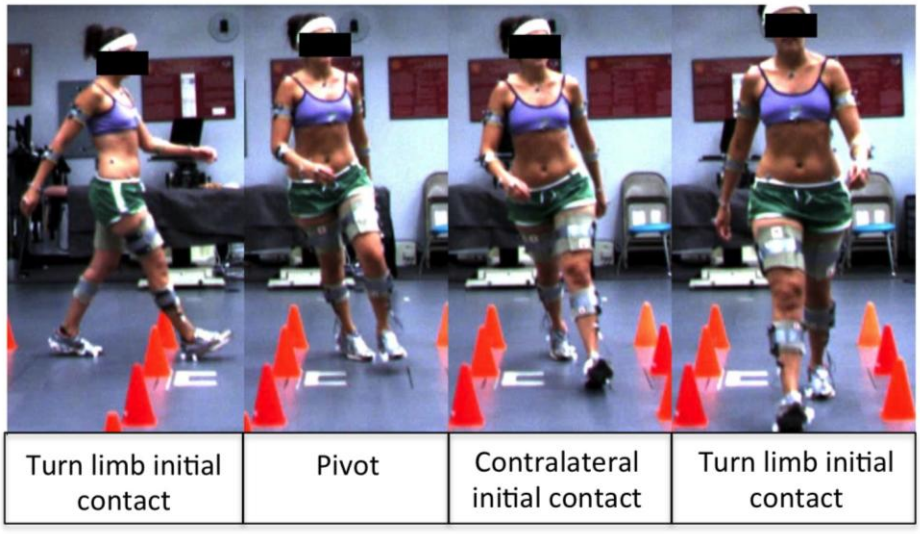

Figure 1

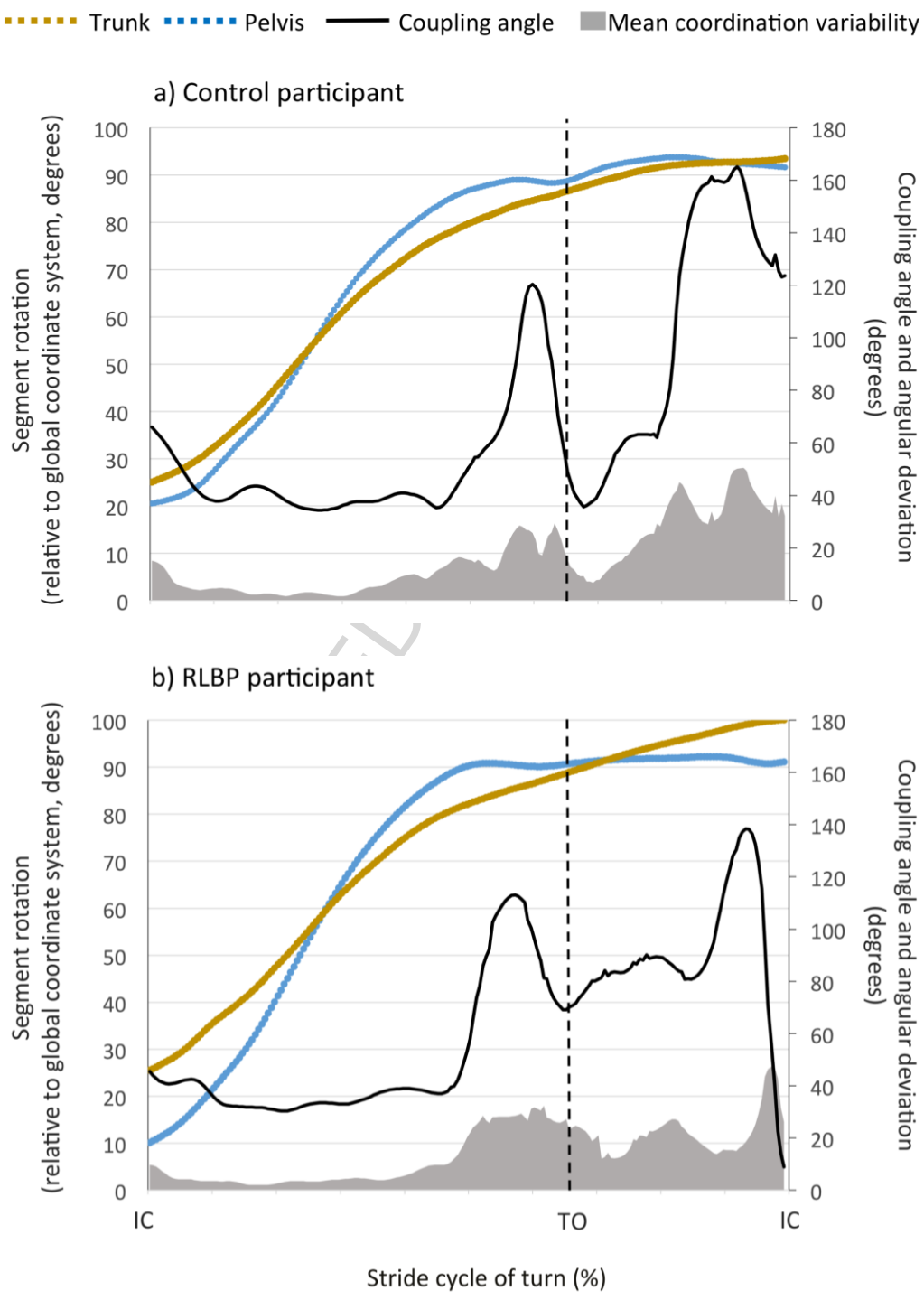

Figure 2

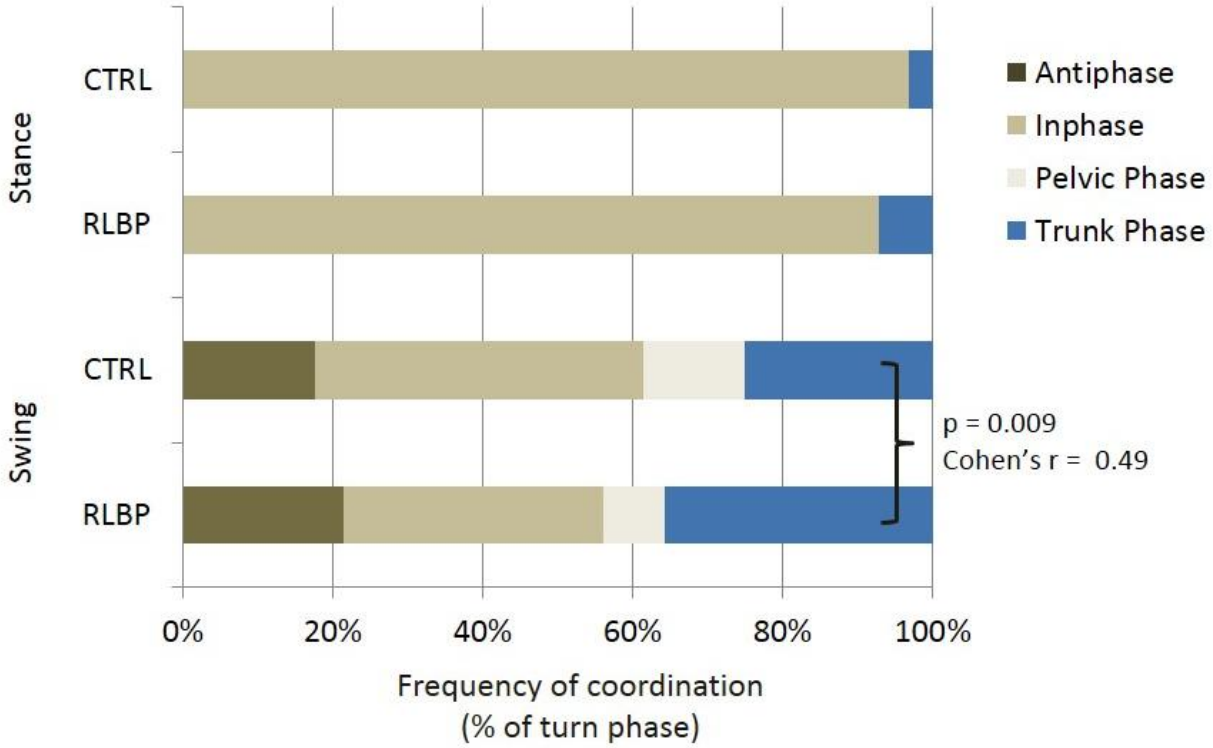

Figure 3

Highlights

We investigated axial plane trunk-pelvic coordination during walking turns.

We compared asymptomatic young adults with and without a history of low back pain.

During swing, individuals with low back pain had greater trunk phase coordination.

Coordination variability did not differ between groups.