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The coordinated movement of the spine and pelvis during running

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ABSTRACT

Previous research into running has demonstrated consistent patterns in pelvic, lumbar and thoracic motions between different human runners. However, to date, there has been limited attempt to explain why observed coordination patterns emerge and how they may relate to centre of mass (CoM) motion. In this study, kinematic data were collected from the thorax, lumbar spine, pelvis and lower limbs during over ground running in $n = 28$ participants. These data was subsequently used to develop a theoretical understanding of the coordination of the spine and pelvis in all three body planes during the stance phase of running. In the sagittal plane, there appeared to be an antiphase coordinate pattern which may function to increase femoral inclination at toe off whilst minimising anterior–posterior accelerations of the CoM. In the medio-lateral direction, CoM motion appears to facilitate transition to the contralateral foot. However, an antiphase coordination pattern was also observed, most likely to minimise unnecessary accelerations of the CoM. In the transverse plane, motion of the pelvis was observed to lag slightly behind that of the thorax. However, it is possible that the close coupling between these two segments facilitates the thoracic rotation required to passively drive arm motion. This is the first study to provide a full biomechanical rationale for the coordination of the spine and pelvis during human running. This insight should help clinicians develop an improved understanding of how spinal and pelvic motions may contribute to, or result from, common running injuries.

1. Introduction

Running is complex movement which requires precise inter-segmental coordination to create forward momentum. Given the integrated nature of running, it is possible that poorly coordinated movement of the pelvis and spine could result in abnormal tissue stress not just in the low back (Seay, Van Emmerik, & Hamill, 2011b), but also within more distal structures of the lower limbs (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). However, before interventions can be developed to address abnormalities in pelvis and spinal movement, it is important to develop a clear biomechanical understanding of the coordination between the spine and pelvis during normal running.

We suggest that there are two constraints which will play a pivotal role in determining coordination patterns between the pelvis and spinal segments. In the sagittal and frontal plane we suggest that coordination patterns will develop which will minimise excessive changes of momentum in the anterior–posterior (AP) and medio-lateral (ML) directions respectively. It is likely that this strategy, suggested as a mechanism for minimising energy consumption, (Heise & Martin, 2001; Williams

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& Cavanagh, 1987), will lead to anti-phase coordination between the pelvis and thorax. This is because rotational movements of the pelvis in either the sagittal or frontal planes during stance will require a rotation of the thorax in the opposite direction to minimise displacement of the centre of mass (CoM).

Rotations of the pelvis or trunk in the transverse plane will not displace the CoM. However, it has been shown that arm motion during running functions to counterbalance the rotational angular momentum of the swinging legs (Arellano & Kram, 2014; Hamner, Seth, & Delp, 2010). Thus a coordination pattern between the pelvis and spine must emerge which facilitates the necessary arm movement for angular momentum balance. It been suggested (Pontzer, Holloway, Raichlen, & Lieberman, 2009) that this coordination is achieved via a mass-damped system in which motion of the arms is driven passively by the motion of the torso. Pontzer et al. (2009) also suggest that thorax motion is driven passively by motion of the pelvis. If this is the case, then a phase lagged coordination pattern would be observed in which rotation of the pelvis precedes that of the thorax.

A number of previous studies have published kinematic data describing the motions of the pelvis and lumbar spine during running (MacWilliams et al., 2014; Saunders, Schache, Rath, & Hodges, 2005; Schache, Blanch, Rath, Wrigley, & Bennell, 2002). However, these studies either failed to include a thoracic segment or did not analyse coordination patterns in detail and therefore provide limited insight into pelvis–spinal coordination during running. Only two studies have investigated the coordination patterns between the pelvis and thorax during running (Seay, Van Emmerik, & Hamill, 2011a; Seay et al., 2011b). However, these studies did not include a lumbar segment, nor did they present accompanying data on CoM motion. Furthermore, it was not possible to infer, from the presented analysis, whether transverse plane motion of the thorax was driven by the pelvis.

The primary objective of this paper was to explore specific ideas around the coordination of the pelvis and spine during running and to interpret these ideas in the context of CoM motion. In order to address this objective, experimental data describing the three-dimensional kinetics of the thorax, lumbar spine, pelvis and lower-limbs were collected from a cohort of human subjects during over ground running. These data was then used to test a number of specific hypotheses relating to the coordination between the thorax and pelvis during stance phase. We hypothesised that there would be an anti-phase relationship between the pelvis and thorax in the sagittal and frontal plane during stance. In the transverse plane, we hypothesised that motion of the pelvis would lead motion of the thorax demonstrating a phase-lagged coordination pattern. These kinematic descriptions were then interpreted in the context of previously observed trunk EMG patterns.

2. Methods

2.1. Subjects and experimental set up

A cohort of 28 subjects (16 male) participated in the study. The mean (SD) age of the subjects was 28 (4) years, mean (SD) height 175 (9) cm and mean weight 63 (9) Kg. Ethical approval was obtained from the Local Ethics Committee before data collection and all subjects gave informed consent to participate in the study. For each subject, kinematic data were collected for the pelvis, thoracic spine, lumbar spine, lower limbs and feet. Each subject ran along a 32 m running track at a target speed of 3.9 ms^{-1} whilst data were collect using a 12-camera Qualisys Pro-reflex system (240 Hz). In order to obtain event information, kinetic data were collected from 3 AMTI force plates (1200 Hz) embedded in the track. Running speed was measured using optical timing gates and 7–10 trials within ±2.5% of the target speed were collected for each subject.

2.2. Protocol and kinematic calculations

A global optimisation algorithm (Mason, Preece, Bramah, & Herrington, 2014) was used to obtain segmental kinematics. With this approach, joint constraints are applied to a multi-link model in which segments could rotate with three degrees of freedom but not translate relative to adjacent segments. Within the nine-segment-model model, constraint points were positioned at the origins of all segment coordinate frames distal to the pelvis and expressed in the pelvis coordinate frame. In our previous analysis (Mason et al., 2014) we defined a pelvic segment which had an anterior–posterior axis pointing from the midpoint of the posterior superior iliac spines (PSIS) to the midpoint of the anterior superior iliac spines (ASIS). However, with this approach, between-subject differences in bony geometry of the pelvis can lead to increased inter-subject variability in pelvic tilt (Preece et al., 2008). Therefore, for the present study, the Z (vertical) axis of the pelvic frame was aligned with the laboratory in standing. The origin of this segment was modelled by a virtual marker that was created midway between two iliac crest makers. These iliac crest markers were positioned at the level of the iliac crests and above the hip centres (which were predicted from the ASIS and PSIS locations (Bell, Brand, & Pedersen, 1989)). The X (ML axis) pointed from the pelvic origin to the right ilicac crest marker and the Y (anterior–posterior) axis was the mutual perpendicular. This pelvic segment was tracked using markers placed on the ASISs and PSISs. The coordinate frames and corresponding tracking markers for the other eight segments were the same as described in our previous repeatability paper analysis (Mason et al., 2014) and are therefore only reviewed briefly in the text below.

The anatomical coordinate system for the lumbar spine was aligned with the pelvic frame with an origin that was positioned at the point 5% from the L5S1 marker to the midpoint of the ASISs. This ensured a linked segment model for the global optimisation calculations. The motion of this segment was tracked using a total of four markers placed on the low back. This