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http://dx.doi.org/10.1016/j.gaitpost.2016.03.011

# How do elite endurance runners alter movements of the spine and pelvis as running speed increases?

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**Funding**: This project was internally funded by the University of Salford.

**Conflict of interest Disclosure:** None

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## Abstract

Elite endurance runners are characterised by their performance ability and higher running economy. However, there is relatively little research aimed at identifying the biomechanical characteristics of this group. This study aimed to understand how motions of the pelvis, lumbar spine and thorax change with speed in a cohort of elite endurance runners (n=14) and a cohort of recreational runners (n=14). Kinematic data were collected during over ground running at four speeds ranging from 3.3 to 5.6ms$^{-1}$ and a linear mixed model used to understand the effect of speed on both range of motion and mean sagittal inclination. The results showed the two groups to exhibit similar changes in range of motion as speed was increased, with the most pronounced increases being observed in the transverse plane. However, the adaptation of thorax inclination with speed differed between the two groups. Whereas the recreational runners increased thorax inclination as running speed was increased, elite endurance runners consistently maintained a more upright thorax position. This is the first study to identify specific differences in upper body motions between recreational and elite runners and the findings may have implications for training protocols aimed at improving running performance.

## Highlights

- Recreational runners increase thorax inclination as running speed increases
- Elite runners maintain consistent thorax inclination as running speed increases
- Large increases in pelvic & spinal ROM with speed in the transverse plane

## Keywords:

Running, spine, elite, lumbar, pelvis, thorax inclination

## Introduction

Movements of the pelvis, trunk and arms play an important role in running. These segments facilitate the generation of forward momentum from the lower extremities, maintain centre of mass trajectory [1] and balance angular momentum of the swinging legs [2, 3]. Previous research has investigated how motions of pelvis [4, 5] and thorax [4, 6] adapt to changes in running speed. However, studies of pelvic motion have been performed at relatively low running speeds (<3.9ms$^{-1}$) and no previous study has included a lumbar segment. Therefore, at present, there is an incomplete understanding of how motions of the pelvis, lumbar spine and thorax adapt as running speed is increased.

Elite endurance runners are characterised by their performance ability and higher running economy [7, 8]. The intense nature of the training programmes required to achieve elite status requires these individuals to run at relatively higher running speeds, over 5ms$^{-1}$, over prolonged periods. As a result of such intense training, it is possible that elite runners develop specific adaptions of pelvic and spinal motions to speed which enhance performance but which differ from recreational runners. However, although previous research has investigated whether elite running is characterised by differences in spatiotemporal parameters [9] and foot strike patterns [10], there are no data available on pelvic and spinal motions.

This study sought to understand how the magnitude of the motions of the thorax, pelvis and lumbar spine change as speed increases in both recreational and elite runners. In addition, as a number of popular, but controversial , running instruction techniques encourage a forward lean of the trunk [11, 12], the study also sought to compare how thoracic inclination changes with speed and whether such changes differ between recreational and elite runners.

## Methods

A total of 14 (8 male) elite endurance runners and 14 (8 male) recreational runners were recruited for the study. The mean(SD) 10 Km race time for the elite group was 32(2) minutes, range 30-35 minutes and the mean(SD) race time for the recreational group was 43(3) minutes, range 40-47 minutes. There were no significant differences in demographic variables between the two groups, with a mean (SD) age of 28(3) years, weight of 63(9)Kg and height of 1.75(0.09)M across the entire cohort. All subjects consented to participate in the study after ethical approval had been obtained from the local institutional review panel.

Each participant ran along a 32m running track at four different speeds (3.3, 3.9, 4.8 and 5.6 $ms^{-1}$). Speed was monitored using optical timing gates and only trials within 2.5% of the target speed used for subsequent analysis. Kinematic data were collected from skin-mounted reflective markers using the protocol described in previous publications [1, 13]. With this protocol, the thoracic segment was tracked using a sternum-mounted plate, the lumbar segment tracked with four markers positioned across the low back and the pelvis tracked with markers placed over the anterior superior iliac spines and posterior superior iliac spines. Using the multi-segment model defined previously [1], the Visual 3D software was used to obtain the orientation of the thorax, lumbar spine and pelvis relatively to the laboratory system across a complete gait cycle. From these data, the range of motion (ROM) for each segment and the mean sagittal inclination was calculated for each speed across all participants.

A linear mixed ANCOVA approach was used to model each gait parameter (dependent variable) as a function of the gait speed (covariate). Within this model, the group (elite/recreational) was considered an independent variable and repeated measurements on the same individual, a random variable. The random variable makes it possible to distinguish within-individual variance from between- individual variance. Specially, random error deals with the increase of between- individual variance with gait speed. This model was used to understand whether there was a significant gradient with speed for each gait parameter, and then to establish whether gradients differed between the two groups. All statistical analyses were carried out using R 2.13 (RDevelopment Core Team, 2011), using the “nlme” package to implement a linear mixed model with a critical alpha of 0.05.

## Results

Increases in transverse plane ROM of all segments were more pronounced than increases in sagittal and frontal plane ROM as running speed increased (Table 1). Nevertheless, there was a significant gradient ($p<0.05$) with speed for all segments apart from pelvic ROM in the frontal plane. Interestingly, the data showed minimal difference in the adaptation of segmental ROM to speed between the two groups. However, there was a non-significant ($p=0.06$) trend for the ROM of the pelvis in the sagittal plane to increase more in the elite runners (Table 1).

Analysis of the mean inclination data showed the recreational group to increase thorax inclination as running speed increased (Table 1 & Figure 1). This contrasted to the consistent thorax inclination (with speed) observed in the elite group. Figure 2 shows segmental motion in each plane across the gait cycle at the second speed of $3.9ms^{-1}$ and illustrates that the difference in thoracic inclination was maintained throughout the gait cycle. Inclination of the lumbar and pelvic segment was observed to increase with speed (Table 1); however, there was no difference in the magnitude of this increase between the two groups.

## Discussion

The most pronounced difference between the elite runners and the recreational runners was in the adaptation of thorax inclination to running speed. The data demonstrated an increase of approximately $1^{\circ}$ for every 1 $ms^{-1}$ increment in speed in the recreational group, a result which is consistent with Thorstensson et al. [6]. However, the elite group maintained a consistent thoracic inclination across the range of speeds studied. These findings challenge current training protocols which instruct recreational runners to consciously adopt a forward trunk lean [11, 12]. Other training methods encourage a subtle anterior rotation of the pelvis [14]. However, we did not observe an increased pelvic anterior rotation in the elite runners and so this may not be an appropriate instruction to give runners who want to improve their running style.

It is interesting to consider the biomechanical effect of the 3-4˚ difference in trunk inclination observed between the two groups, at speeds 2-4 (Figure 1). Assuming a head-arms-trunk (HAT) segment of 80-90 cm length, this difference in inclination would shift the centre of mass of the HAT segment anteriorly by 2-3cm. As a results of this shift, the extensor muscles of the low back [1, 15], and possibly the gluteus maximus, would be required to generate more force to control trunk flexion [16] and this may lead to an increase in metabolic cost. A shift in the centre of mass of the HAT segment may also lead to compensatory changes in foot placement position. For example, it is possible that recreational runners may place their foot further in front of the body in order to maintain a similar anterior-posterior distance between the centre of mass and centre of pressure. However, further investigation is required to support this idea.

The observation of relatively large increases with speed in transverse plane ROM for each segments is consistent with data reported by Seay et al. [4] who studied treadmill running at speeds up to 3.8ms$^{-1}$. As running speed increases, angular momentum of the arms must increase to counterbalance the increased angular momentum of the swinging legs [2, 3]. It is likely that the increased ROM of the thoracic, lumbar and pelvic segments facilitates this arm motion [1], and , from our data, it would appear that this pattern is consistent across different running styles. This finding suggests that training programmes designed to limit transverse rotations of the lumbar or thoracic spine during running maybe not be appropriate.

It has been suggested that pelvic motion in the frontal plane functions to extend stride length by elevating the swing limb at toe off [1]. However, although Seay et al. [4] observed an increase of approximately 5˚ in frontal plane pelvic movement as speed was increased from 2.3 to 3.8 ms$^{-1}$, we observed minimal change in this motion over our range of speeds. It is possible that further increases in frontal plane pelvic motion above approximately 4ms$^{-1}$ would result in excessive medio-lateral deviation of the centre of mass and so are minimised in a consistent manor across different running styles.

## References

[1] Preece SJ, Mason D, Bramah C. The coordinated movement of the spine and pelvis during running. Human movement science 2016;45:110-8.
[2] Pontzer H, Holloway JH, Raichlen DA, Lieberman DE. Control and function of arm swing in human walking and running. J Exp Biol 2009;212:523-34.
[3] Hamner SR, Delp SL. Muscle contributions to fore-aft and vertical body mass center accelerations over a range of running speeds. Journal of biomechanics 2013;46:780-7.
[4] Seay J, Van Emmerik REA, Hamill J. Influence of Low Back Pain Status on Pelvis-Trunk Coordination During Walking and Running. Spine 2011;36:E1070-E9.
[5] Chumanov ES, Wall-Schefer C, Heiderscheit BC. Gender differences in walking and running on level and inclined surfaces. Clinical biomechanics 2008;23:1260-8.
[6] Thorstensson A, Nilsson J, Carlson H, Zomlefer MR. Trunk movements in human locomotion. Acta Physiologica Scandinavica 1984;121:9-22.
[7] Lorenz DS, Reiman MP, Lehecka BJ, Naylor A. What performance characteristics determine elite versus nonelite athletes in the same sport? Sports health 2013;5:542-7.
[8] Foster C, Lucia A. Running economy - The forgotten factor in elite performance. Sports medicine 2007;37:316-9.
[9] Padulo J, Annino G, Migliaccio GM, D'Ottavio S, Tihanyi J. Kinematics of running at different slopes and speeds. Journal of Strength and Conditioning Research 2012;26:1331-9.
[10] Hasegawa H, Yamauchi T, Kraemew WJ. Foot strike patterns of runners at the 15-km point during an elite-level half marathon. Journal of Strength and Conditioning Research 2007;21:888-93.
[11] Dallam GM, Wilber RL, Jadelis K, Fletcher G, Romanov N. Effect of a global alteration of running technique on kinematics and economy. Journal of sports sciences 2005;23:757-64.
[12] Dreyer D, Dreyer K. ChiRunning: A Revolutionary Approach to Effortless, Injury-Free Running: Touchstone; 2009.
[13] Mason DL, Preece SJ, Bramah CA, Herrington LC. Reproducibility of kinematic measures of the thoracic spine, lumbar spine and pelvis during fast running. Gait & Posture 2016;43:96-100.
[14] Goss DL, Gross MT. A Comparison of Negative Joint Work and Vertical Ground Reaction Force Loading Rates in Chi Runners and Rearfoot-Striking Runners. Journal of Orthopaedic & Sports Physical Therapy 2013;43:685-92.
[15] Thorstensson A, Carlson H, Zomlefer MR, Nilsson J. Lumbar back muscle activity in relation to trunk movements during locomotion in man. Acta Physiol Scand 1982;116:13-20.
[16] Lieberman DE, Raichlen DA, Pontzer H, Bramble DM, Cutright-Smith E. The human gluteus maximus and its role in running. J Exp Biol 2006;209:2143-55.

## Tables:

Table 1: Linear mixed model analysis of the ROM in each body plane and mean sagittal inclination. Linear gradients (in the units of ° per $ms^{-1}$) describing the change in each parameter with speed are reported for each group. Associated p-values are reported for the test of non-zero gradient with speed and for the test of a difference in gradient between the two groups.

| | | Elite gradient with speed mean (std. error) per $ms^{-1}$ | Recreational gradient with speed Mean (std. error) per $ms^{-1}$ | p-value for non-zero gradient | p-value for difference in gradients |
|---|---|---|---|---|---|
| *Sagittal ROM (°)* | *Thorax* | 0.7 (0.2) | 0.6 (0.3) | 0.003 | 0.71 |
| | *Lumbar* | 1.6 (0.3) | 1.1 (0.5) | <0.001 | 0.27 |
| | *Pelvis* | 0.9 (0.2) | 0.3 (0.3) | <0.001 | 0.06 |
| *Frontal ROM (°)* | *Thorax* | 1.3 (0.2) | 1.3 (0.3) | <0.001 | 1.0 |
| | *Lumbar* | 0.7 (0.4) | 0.2 (0.5) | 0.04 | 0.32 |
| | *Pelvis* | 0.6 (0.4) | 0.6 (0.6) | 0.17 | 0.97 |
| *Transverse ROM (°)* | *Thorax* | 3.4 (0.5) | 3.4 (0.7) | <0.001 | 0.90 |
| | *Lumbar* | 2.4 (0.4) | 2.8 (0.6) | <0.001 | 0.59 |
| | *Pelvis* | 3.7 (0.4) | 4.3 (0.5) | <0.001 | 0.26 |
| *Mean Sagittal inclination (°)* | *Thorax* | 0.1 (0.4) | 1.1 (0.5) | 0.89 | 0.049 |
| | *Lumbar* | 2.1 (0.75) | 1.6 (0.5) | 0.003 | 0.54 |

| | | | | |
|---|---|---|---|---|
| *Pelvis* | 1.4 (0.4) | 1.5 (0.3) | <0.001 | 0.73 |

## Figures:

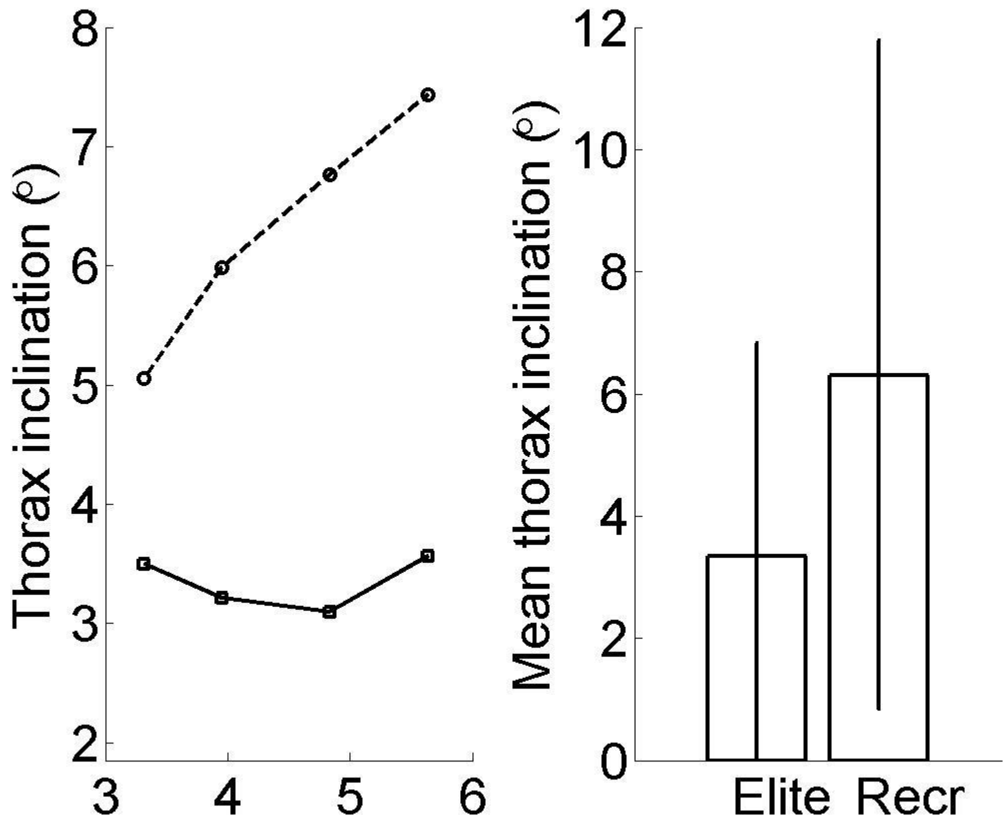


Figure 1: (a) Mean thorax inclination at each speed, averaged across the elite group (solid line) and the recreational group (dotted line) and (b) mean thorax inclination, averaged across the four speeds, for each group.

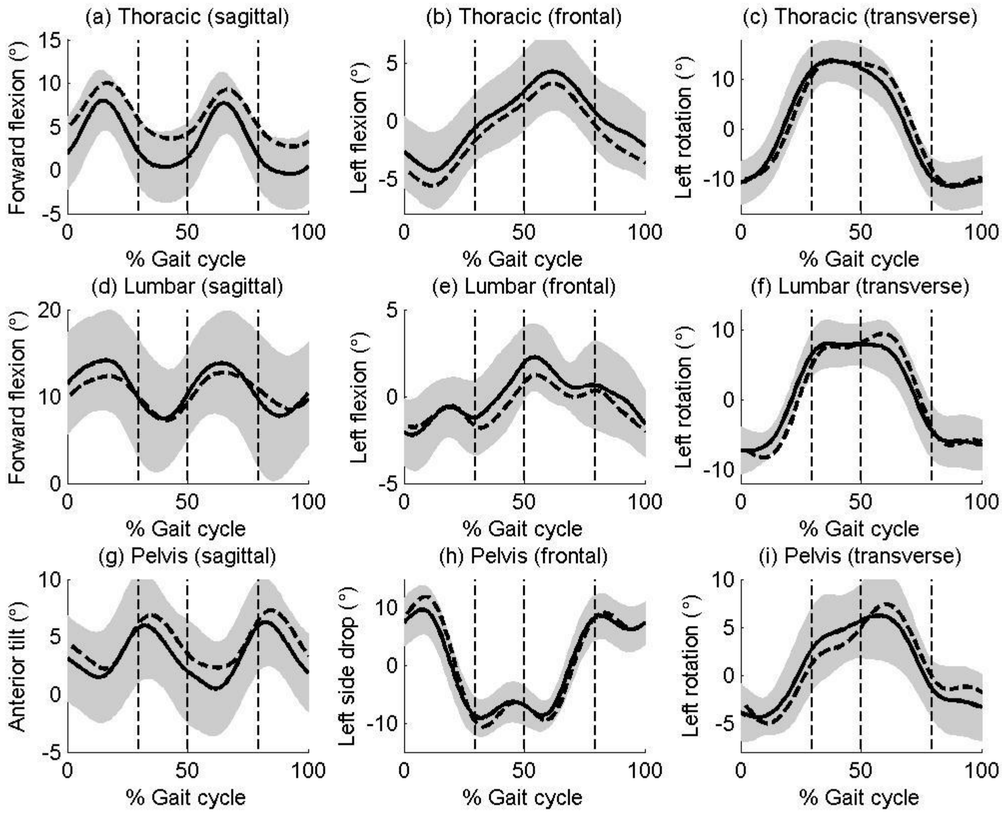


Figure 2: Ensemble curves showing the motion of each segment in each plane over the gait cycle at a running speed of 3.9 $ms^{-1}$ (speed 2). Solid lines show ensemble averages for the elite runners and dotted lines show ensemble averages for recreational runners. The shaded area represents the SD of the elite group.