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A marker set for measuring the kinematics of the lumbar spine and thoracic spine during running: a technical note

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ABSTRACT

A protocol for tracking the motion of the lumbar spine, which uses seven skin mounted markers, has been adopted in previous studies investigating running. However, this configuration of can be difficult to track with passive motion capture systems. This study therefore investigated whether a four-marker configuration could accurately reproduce the pose of the lumbar spine obtained using the seven-marker configuration. The study also investigated two methods of tracking the thorax. The first method consisted of markers attached to the sterum and the second used two markers placed bilaterally over the acromioclavicular joints and another on the posterior thoracic spine. Kinematic data was collect for n=15 male subjects and the pose, calculated using the different tracking configurations, compared for both the lumbar spine and thoracic spine. The results demonstrated a good match between two lumbar tracking marker sets. However, there was considerable difference between the two thoracic markers sets which was likely due to movement of the arms influencing the pose of the thorax. We therefore recommend the use of four makers to track the motion of the lumbar spine and a rigid plate, mounted at the top of the sternum, to track motion of the thoracic spine during running.

Key words: KINEMATIC MEASUREMENT, POSE CALCULATION, THORAX, LOW BACK, LUMBAR, MARKER SET.

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INTRODUCTION

Previous studies analysing the kinematics of the spine during running have tended to define either one or two rigid functional units: a lumbar segment (Schache et al., 2002) and a thoracic segment (Seay et al., 2011). Using this approach it has been possible to understand how spinal motion is coordinated with pelvic movement (Schache et al., 2002; Saunders et al., 2005; Seay et al., 2011). Studies investigating lumbar movement have used either a rigid wand, mounted over a single lumbar vertebrae, (Schache et al., 2002) or alternatively a set of skin-mounted makers placed across the lumbar region (Seay et al., 2008). In a recent paper, Kiernan et al. (2015) suggested that a skin-mounted makers reduce kinematic variability and may therefore be more appropriate when analysing fast movement, such as running. However, the skin-mounted marker set first proposed by Seay et al. (2008), involves the use of seven tracking markers placed across the lumbar spine. This configuration can be difficult to track continuously with a passive capture system. It is therefore it is necessary to understand whether a reduced set of four tracking markers could be used as an alternative to this seven-marker set.

Various configuration of tracking markers have been used in previous studies investigating thorax motion during running. Similar to the lumbar spine, some investigators have used a marker wand, attached to the posterior aspect of the thorax (Seay et al., 2011). In contrast, a number of other studies have been performed using a set of skin-mounted markers placed at a range of different locations on the thorax (Seay et al., 2008; Mason et al., 2014). In a recent study (Mason et al., 2014) we demonstrated good reliability using a rigid plate attached directly to the sternum, as suggested by wu et al. (2005). However, this configuration can also be difficult to track continuously with passive motion capture system, especially at higher speeds when increased arm movements can obscure sternum markers. An possible alternative to this makers set is a configuration of three makers placed on the posterior thoracic spine and bilaterally over the acromioclavicular (AC) joints (Seay et al., 2008). However markers placed upon the acromion of the shoulders can be influenced by humeral movement (Nguyen and Baker, 2004) and this could lead to errors in measurements of thorax movement during running. Consequently, it is necessary to compare these two alternative methods for tracking the thoracic segment.

This technical note sought to quantify the differences between the two lumbar marker sets and the two thoracic marker sets. It was felt this work could inform experimental protocols for future studies aimed at quantifying the kinematics of the lumbar and thoracic spine during running.

METHODS

A total of n=15 male subjects were recruited for this study. The mean (SD) age of the subjects was 25 (5) years, the mean (SD) height 1.78 (6.89) m and the mean (SD) weight 63.1 (6.1) Kg. Ethical approval was granted from the local ethical committee before data collection began. In this technical note, we report only on lumbar and thorax rotations, however, kinematic data was collected from the feet, lower limbs, pelvis, lumbar spine and thoracic spine. This data was used to derive segmental kinematics using a global optimisation technique (Mason et al., 2014). The precise details of the model and kinematic calculations are provided in detail in another publication (Mason et al., 2014) and here we only provide details of the measurement of the pelvis, lumbar and thoracic segments.

The pelvis segment was defined and tracked using markers placed over the anterior superior iliac spines (ASISs) and the posterior iliac spines (PSISs). The origin of the pelvic coordinate system was positioned midway between the ASISs with the X axis pointing towards the right ASIS and the Z axis pointed vertically upwards. This coordinate system was also used to define the lumbar segment; however, the origin was shifted so that it was positioned 5% along the line from the L5S1 joint space to the pelvic origin. ISB recommendations (Wu et al., 2005) were used to define the thoracic frame using markers positioned at C7, T6, the suprasternal notch (IJ) and the xiphoid process (XP). Further details of this model are provided in Mason et al. (2014).

Two possible configurations of lumbar tracking markers were tested. With the first set (proposed by Seay et al. (2008)) a total of seven markers were used to track this segment. With this approach an elasticon bandage is first wrapped around the lumbar region and three markers placed over the bandage: on the T12-L1 joint space, on the L5S1 joint space and midway between these two markers. Four more markers are then positioned either side of the midline makers (Figure 1a). As explained, this configuration can be difficult to track continuously with a passive capture system and therefore an alternative configuration, consisting of only the four markers positioned away from the spine, was tested. Two possible maker configurations were also compared for tracking the thoracic segment. The first set consisted of a small rigid plate with three non-collinear markers mounted at the top of the sternum (Figure 1b). The second marker configuration also consisted of three makers, two positioned bilaterally on the acromioclavicular (AC) joints and a third over the T12L1 joint space.

Figure 1a. The full seven markers used to track the motion of the lumbar spine. The reduced marker set consisted of the four markers positioned lateral to the spine.

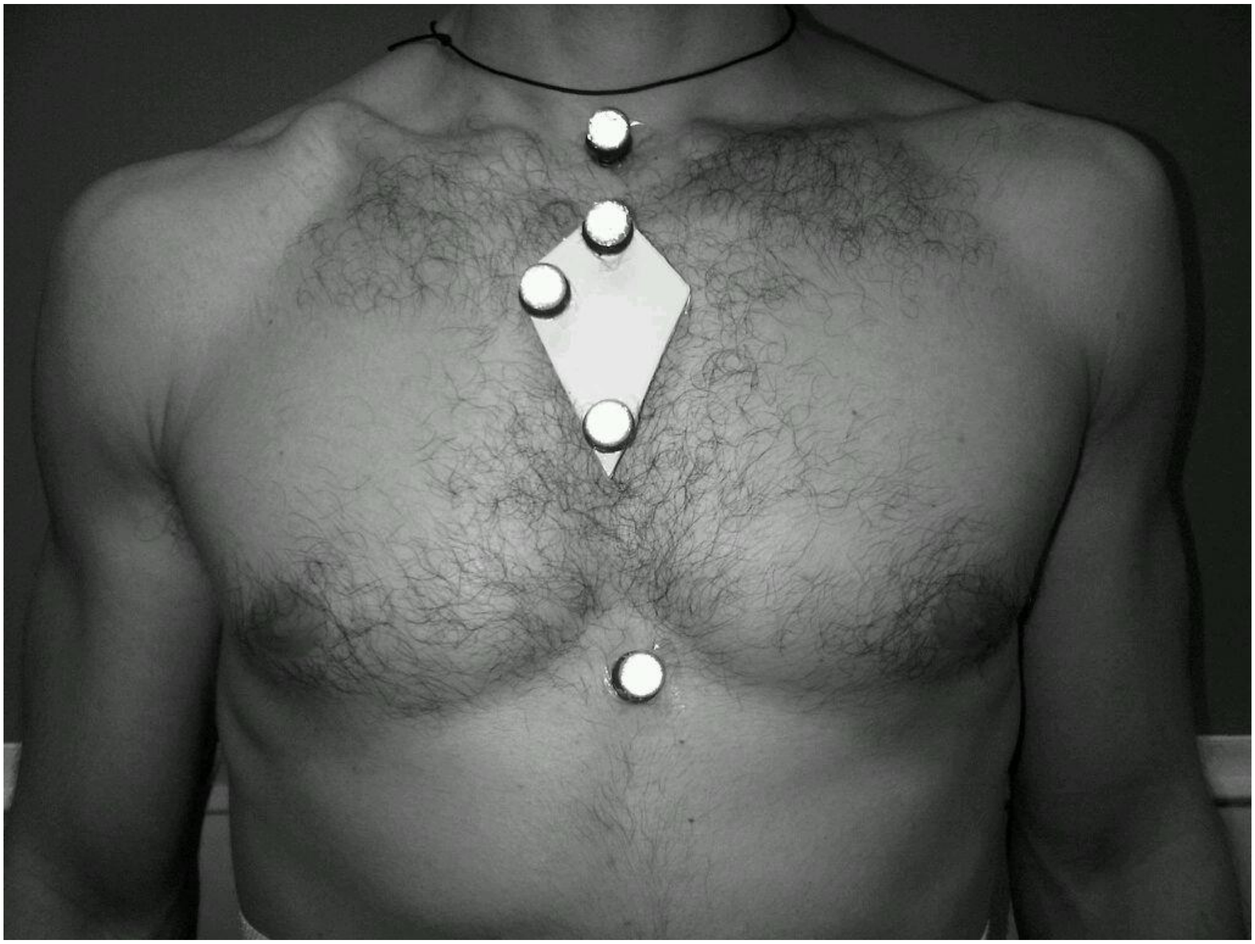

Figure 1b: The rigid cluster, mounted at the top of the sternum, used to track the motion of the thorax.

Each subject ran over ground along a 32m running track at 5.6 (±2.5%) ms^{-1} whilst kinematic data (240Hz) was collected using a Qualisys Pro-reflex system. Running speed was monitored using optimal timing gates and force data (1200Hz), collected using an AMTI force platform, used to define gait events. Subject completed between 7-10 acceptable trials and for each trial, kinematic data from all possible tracking marker configurations was collected. A global optimisation algorithm (Mason et al., 2014), implemented using Visual 3D (c-motion), was then used to calculate the pose of the lumbar and thoracic segment with respect to the global (laboratory) coordinate system. These calculations were carried out separately for each of the two lumbar and each of the two thoracic tracking marker configurations.

Two different metrics were used to compare the two lumbar spine marker configurations and the two thoracic marker configurations. The first metric is known as the coefficient of multiple correlation (CMC) and gives a measure of waveform similarity which tends to one for identical waveforms and zero for dissimilar waveforms. The second metric was the standard error of measurement (SEM) averaged over a complete gait cycle, which quantifies the absolute difference, in degrees, between two measurements. For both segments, we calculated a between-marker set variability (bCMC and bSEM) which quantified the differences in pose between the two different marker sets. We then calculated a within-marker set variability (wCMC and wSEM) in order to understand the level of trial-to-trial movement variability.

RESULTS

For the lumbar spine segment there was excellent agreement between the two marker sets bCMC (Table 1) and bSEM (Table 2) in the frontal and transverse plane. Although agreement was slightly lower in the sagittal plane, the bCMC was above the threshold of 0.8 generally considered to indicate waveform similarity and the wSEM was beneath the threshold of 2° suggested to indicate good reproducibility (McGinley et al., 2009). Furthermore, the wSEM of 1.5° in the sagittal plane (Table 2) illustrates a comparable degree of trial-to-trial movement variability.

Agreement between the two thoracic marker sets was poor in the sagittal plane (Table 1 and 2) with a bSEM of 4.5°. However, agreement was good in the frontal plane. In the transverse plane the bSEM was just above the above the 2° threshold suggested by McGinley (2009) but was comparable with the relatively large trial-to-trial variability of 1.9°.

Table 1. Coefficient of multiple (CMC) correlation values to compare the kinematic waveforms between the two lumbar maker sets and the two thoracic marker sets. bCMC indicates the between-marker set CMC and wCMC indicates the within-marker set CMC.

	bCMC (sagittal)	bCMC (frontal)	bCMC (transverse)	wCMC (sagittal)	wCMC (frontal)	wCMC (transverse)
Lumbar spine with respect to the lab	0.813	0.972	0.999	0.902	0.944	0.967
Thorax spine with respect to the lab	0.692[1]	0.952	0.972	0.943	0.952	0.983

Foot Note: [1] Note all values represent an average across all n=15 participant apart from the thoracic with respect to the lab in the sagittal plane for which the bCMC averaged across n=12 participants and it was indeterminate for the remaining n=3.

Table 2. Standard error in the measurement (SEM) values to compare kinematic waveforms between the two lumbar and the two thoracic marker sets. bSEM indicates the between marker set SEM and wSEM indicates the within marker set SEM. All values are given in degrees and represent an average across the gait cycle.

	bSEM (sagittal)	bSEM (frontal)	bSEM (transverse)	wSEM (sagittal)	wSEM (frontal)	wSEM (transverse)
Lumbar spine with respect to the lab	1.9°	0.7°	0.5°	1.5°	1°	1.8°
Thorax spine with respect to the lab	4.5°	1.2°	2.2°	1.4°	1.2°	1.9°

DISCUSSION

The first aim of this paper was to establish if a simple four-marker configuration could be used to reproduce the pose of the lumbar spine obtained using the seven-marker configuration originally proposed by Seay et al. (2008). There was good agreement between the marker sets with SEM differences below 2° in all body planes. In a previous study, we investigated the between-day variability associated with the full seven-marker configuration (Mason et al., 2014). SEMs for this study were found to range from 2.2-3.1°. Given that these differences are larger than those found in the present study, it would appear that the reduced four-marker tracking configuration is suitable for kinematic assessment of the lumbar spine during running.

The second aim of this paper was to compare the pose of the thoracic segment, tracked using a rigid plate mounted to the sternum, with the pose obtained using markers placed bilaterally on the AC joints and the T12L1 joint space. This comparison showed marked differences between the two tracking configurations with SEMs up to 4.5°. These differences were larger than those observed in our previous study (maximum 2.3°) which investigated between-day differences in the pose of the thoracic spine with the sternum-mounted cluster. A possible interpretation of these differences is that the marker set based on the AC locations, resulted in artefact due to arm movement (Nguyen and Baker, 2004). Alternatively, there may have been a large degree of relative movement between the markers placed at AC joints and the T12L1 joint space, especially in the sagittal plane. This would invalidate the rigid body assumptions and lead to inaccuracies in the kinematic calculations. In order to overcome this problem, Saey et al. (2011) later proposed using a marker wand, mounted on the posterior aspect of the thorax. However, as suggested by Kiernan et al. (2015), this approach can lead to increased variability when compared to a skin-mounted marker set. We therefore suggest that the best option for tracking the thoracic spine during running is a rigid plate mounted at the top of the sternum.

REFERENCES

1. Kiernan, D., Malone, A., O'Brien, T., Simms, C. K. (2015). A quantitative comparison of two kinematic protocols for lumbar segment motion during gait, *41*, 699-705.
2. Mason, D. L., Preece, S. J., Bramah, C. A., Herrington, L. C. (2014). Reproducibility of kinematic measures of the thoracic spine, lumbar spine and pelvis during fast running. Gait & Posture (http://dx.doi.org/doi:10.1016/j.gaitpost.2013.11.007).
3. McGinley, J. L., Baker, R., Wolfe, R., Morris, M. E. (2009). The reliability of three-dimensional kinematic gait measurements: a systematic review. *Gait & posture, 29*, 360-9.
4. Nguyen, T. C., Baker, R. (2004). Two methods of calculating thorax kinematics in children with myelomeningocele, *19*, 1060-1065.
5. Saunders, S. W., Schache, A., Rath, D., Hodges, P. W. (2005). Changes in three dimensional lumbo-pelvic kinematics and trunk muscle activity with speed and mode of locomotion. *Clinical biomechanics, 20*, 784-93.
6. Schache, A. G., Blanch, P., Rath, D., Wrigley, T., Bennell, K. (2002). Three-dimensional angular kinematics of the lumbar spine and pelvis during running, *21*, 273-293.
7. Schache, A. G., Blanch, P. D., Rath, D. A., Wrigley, T. V., Starr, R., Bennell, K. L., 2002. Intra-subject repeatability of the three dimensional angular kinematics within the lumbo-pelvic-hip complex during running, *15*, 136-145.
8. Seay, J., Selbie, W. S., Hamill, J. (2008). In vivo lumbo-sacral forces and moments during constant speed running at different stride lengths. *J Sport Sci, 26*, 1519-1529.
9. Seay, J. F., Van Emmerik, R. E., Hamill, J. (2011). Low back pain status affects pelvis-trunk coordination and variability during walking and running. *Clinical biomechanics, 26*, 572-8.
10. Seay, J. F., Van Emmerik, R. E. A., Hamill, J. (2011). Influence of Low Back Pain Status on Pelvis-Trunk Coordination During Walking and Running, *36*, E1070-E1079.
11. Wu, G., van der Helm, F. C. T., Veeger, H. E. J., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., Wang, X. G., Werner, F. W., Buchholz, B. (2005). ISB recommendation

on definitions of joint coordinate systems of various joints for the reporting of human joint motion - Part II: shoulder, elbow, wrist and hand, *38*, 981-992.