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Reproducibility of kinematic measures of the thoracic spine, lumbar spine and pelvis during fast running

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ABSTRACT

This study evaluated the reproducibility of the angular rotations of the thoracic spine, lumbar spine, pelvis and lower extremity during running. In addition, the study compared kinematic reproducibility between two methods for calculating kinematic trajectories: a six degrees of freedom (6DOF) approach and a global optimisation (GO) approach. With the first approach segments were treated independently, however with GO approach joint constraints were imposed to stop translation of adjacent segments. A total of 12 athletes were tested on two separate days whilst running over ground at a speed of 5.6 ms^{-1}. The results demonstrated good between-day reproducibility for most kinematic parameters in the frontal and transverse planes with typical angular errors of 1.4–3°. Acceptable repeatability was also found in the sagittal plane. However, in this plane, although kinematic waveform shape was preserved between testing session, there were sometimes shifts in curve offset which lead to slightly higher angular errors, typically ranging from 1.9° to 3.5°. In general, the results demonstrated similar levels of reproducibility for both computational approaches (6DOF and, GO) and therefore suggest that GO may not lead to improved kinematic reproducibility during running.

1. Introduction

Developing a reproducible kinematic protocol for quantifying spinal kinematics during running is difficult for a number of reasons. Firstly, the spine is a multi-articulate structure and, in order to describe its motion using a skin-based marker system, it is necessary to develop a simplified rigid body model in which all motion is assumed to occur at a small number of joints. Secondly, with increased movement speed, there is an increase in soft tissue movement and the potential for increased shock loads to cause unwanted vibration in skin mounted marker sets [1]. Finally, with any human movement, there is an associated degree of between-trial variability [2]. These different sources of variability will combine with the instrumental errors of a motion capture system (typically 1°) and any between-day variability in marker placement to give a fundamental limit to the accuracy of kinematic measurement.

There have been a number of studies investigating the kinematic reliability of spinal and pelvic motion during walking [3,4]. However, although a few authors have attempted to describe pelvic/spinal motion during running [5–7], there has only been one study investigating kinematic reliability [8]. This study investigated the reproducibility of pelvic motion, using markers attached to the anterior superior iliac spines (ASIS) and sacrum, and lumbar spine motion using a wand mounted over the 12th thoracic spinous process. Although Schache et al. [8] were able to demonstrate good reproducibility in most body planes, there were a number of limitations to the study. Firstly, data was collected during treadmill rather than over ground running and participants ran at a relatively slow speed of 3.9 ms^{-1}. It is therefore not clear whether good reproducibility would be obtained at higher running speeds, typical of elite distance runners. Secondly, although the marker wand gave repeatable results at this slow speed, it is possible that, at higher running speeds, there could be increased inertial motion leading to greater measurement variability. Finally, Schache et al. did not include a thoracic segment in their kinematic protocol.

In order to minimise the effect of soft tissue artefact on derived segmental kinematics, Lu and O'Connor [9] have proposed the use of a global optimisation (GO) technique which imposes specific joint constraints. Using modelling approaches, this approach has been shown to produce kinematic trajectories which are closer to true bone motion than trajectories obtained using a 6DOF (degrees of freedom) approach [9,10]. It is claimed that GO reduces the

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effect of soft tissue artefact. However, no experimental studies have investigated whether it could reduce kinematic variability during running.

We undertook the current study to assess the reproducibility of a new protocol for quantifying pelvic and lumbar/thoracic spine motion during over ground running at a fast speed. In addition, we sought to compare measures of reproducibility derived using GO with a 6DOF approach. In order to compare with previous running studies, we also quantified the kinematic reproducibility of lower limb kinematics.

2. Methods

2.1. Subjects, procedures and instrumentation

A cohort of 12 subjects (11 males), who all ran regularly at a competitive level, were recruited for this study. The mean (SD) age of the subjects was 23.25(4.3) years, mean height 1.64 (0.063) m and mean weight 60.45(8.13) kg. Ethical approval was obtained from the Local Ethics Committee prior to the commencement of data collection.

Kinematic data were collected from each subject from the thoracic spine, lumbar spine, pelvis, thigh, shank and foot using 15 mm markers. To track the motion of the thoracic spine, a rigid plate with three attached markers, was attached to the sternum [11] (Fig. 1a). In order to define an anatomical reference frame for this segment, markers were attached to C7, the spinous process of the sixth thoracic vertebra (T6), the suprasternal notch (IJ) and the xiphoid process (XP) [12]. Pilot work was performed in which the movement of a marker wand, similar to that used by Schache et al. [8], was recorded using a high-speed video camera. These images demonstrated considerable oscillation of the wand at higher running speeds (>4 ms^{-1}). Therefore, in order to track the motion of the lumbar segment, a protocol proposed by Seay et al. [7] was used. With this approach an elasticon bandage is wrapped around the lumbar region from the level of the posterior superior iliac spine to the rib cage at the level of the T12-L1 joint space. Three markers were then placed over the lumbar spine at the T12-L1 joint space, L5-S1 joint space and midway between these two markers. Four more markers were then placed on the bandage either side of the midline markers (Fig. 1b).

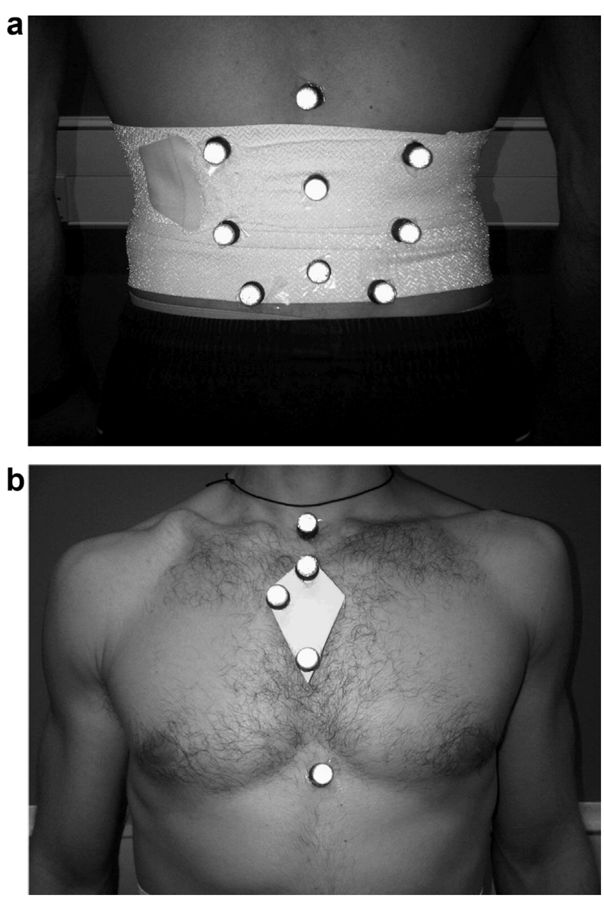

Fig. 1. (a) Image of the marker set used to track the lumbar spine during running. (b) Image of the marker set used to track the thoracic spine during running.

A pelvic segment was defined and tracked using markers placed over both ASISs and both posterior superior iliac spines (PSIS). Rigid plates, attached laterally at the distal end, were used to track motions of the thigh and shank segments and calibration markers were attached to the femoral epicondyles and ankle malleoli. The foot segment was defined using the malleoli markers and markers attached to the shoe over the first and fifth metatarsal heads. This segment was tracked using the metatarsal markers and a marker placed at the back of the shoe.

Kinematic data was collected using a 12-camera Qualisys Pro-reflex system, sampling at 240 Hz, and kinetic data collected from 2 AMTI force plates embedded in the running track, sampling at 1200 Hz. Static markers were removed after the calibration trial and subjects given time to warm up. Running data were then captured on a 32 m indoor running track giving subjects sufficient distance to accelerate to the correct speed of 5.6 m/s (30:00 10k pace). Running speed was measured using optical timing gates and 7–10 trials within ±2.5% of the target speed collected for each subject. The same investigator, an experienced physiotherapist, performed all static marker placements and subjects returned for a repeat test between 5 and 10 days following their initial visit. Both tests were conducted at the same time of day and subjects performed a similar level of exercise history in the 24 h prior to testing.

2.2. Derivation of kinematic data and statistical analysis

In order to implement a GO model, it is necessary to impose constraints which limit rotation and/or translation between adjacent segments. This is achieved by defining a constraint point between each segment, which corresponds to the joint centre. With the GO model used for this investigation, constraint points were positioned at the origins of all segment coordinate frames distal from the pelvis and expressed in the pelvic coordinate frame. The precise location of this coordinate frame did therefore not influence the GO calculations. The origin the of pelvic frame was positioned at the midpoint between the ASISs with the X-axis pointing towards the RHS ASIS. The Y-axis for this frame pointed from the origin away from the midpoint of the PSIS markers and the Z-axis was the common perpendicular and pointed upwards.

An anatomical coordinate frame for the thorax was constructed similar to ISB recommendations [12]. Firstly, a Z-axis was defined as the line connecting the midpoint between PX and T6 and the midpoint between IJ and C7 and pointing upwards. The X-axis was then defined as the line perpendicular to the plane formed by IJ, C7 and the midpoint between PX and T6 pointing right and the Y-axis defined as the common perpendicular to the Z- and X-axes, pointing forward. In order to define an appropriate constraint point, the origin of the thorax coordinate frame was then shifted to a position 5% along the line from T12 to XP.

It is difficult to define an anatomical coordinate system for the lumbar spine and therefore the lumbar frame was aligned with the pelvic frame. However, the origin was positioned at a point 5% from the L5S1 marker to the pelvic origin (mid point between the ASISs) [7], again to ensure an appropriate constraint point for the global optimisation calculations. For each thigh, the Z-axis pointed