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The geometric curvature of the spine of runners during maximal incremental effort test

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ABSTRACT

This study sought to analyse the behaviour of the average spinal posture using a novel investigative procedure in a maximal incremental effort test performed on a treadmill. Spine motion was collected via stereo-photogrammetric analysis in thirteen amateur athletes. At each time percentage of the gait cycle, the reconstructed spine points were projected onto the sagittal and frontal planes of the trunk. On each plane, a polynomial was fitted to the data, and the two-dimensional geometric curvature along the longitudinal axis of the trunk was calculated to quantify the geometric shape of the spine. The average posture presented at the gait cycle defined the spine Neutral Curve. This method enabled the lateral deviations, lordosis, and kyphosis of the spine to be quantified noninvasively and in detail. The similarity between each two volunteers was a maximum of 19% on the sagittal plane and 13% on the frontal ($p < 0.01$). The data collected in this study can be considered preliminary evidence that there are subject-specific characteristics in spinal curvatures during running. Changes induced by increases in speed were not sufficient for the Neutral Curve to lose its individual characteristics, instead behaving like a postural signature. The data showed the descriptive capability of a new method to analyse spinal postures during locomotion; however, additional studies, and with larger sample sizes, are necessary for extracting more general information from this novel methodology.

1. Introduction

Running is likely the physical exercise with the most participants in the world, and this broad adherence leads to many people being affected by orthopaedic injuries (Paluska, 2005). It is suggested that the propagation of shock waves from foot to head is an important cause of vertebral injury (LaFortune et al., 1996).

A moderate curvature minimises overload in the lumbar region during movements where the spine is subjected to compression (Adams et al., 1994; Srbinoska et al., 2013). Vast experience with medical images of the vertebral column in the static position indicates the existence of an ideal spinal posture for each person (Vrtovec et al., 2009). However, in dynamic situations such as running, research on the existence of subject-specific characteristics in spinal curvature are still incipient.

Wade et al. (2012) investigated postural signatures in the lumbar region of gymnasts, finding correlations among the postures adopted during the landing of three gymnastic skills, the sitting posture, and the orthostatic position. In the case of running, in preliminary studies, Campos et al. (2009) and Deprá et al. (2012) observed that two-dimensional geometric curvature of the spine oscillated around a stable average curve called the Neutral Curve (KN). The authors hypothesised that the KN has individual characteristics, similar to a signature. Reinforcing this idea, Smoliga (2007) had previously speculated that the upper body produces oscillations around an average posture during running to minimise energy costs.

Treadmill effort tests facilitate the estimation of aerobic power and have been thoroughly explored in studies on the behaviour of physiological variables in different running conditions (Bosquet et al., 2002). Maximal incremental test protocols with controlled increases in speed induce a fatigue situation and make it possible to identify individualised training speeds (Lourenço et al., 2011). In running, several biomechanical variables are affected by speed (Novacheck, 1998) and fatigue (Elliot and Ackland, 1981; Koblbauer et al., 2014; Mercer et al., 2003). However, there appear to be no data on the behaviour of spinal curvature during effort tests.

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Most of the previous studies on spinal posture during running have adopted angular variables for its quantification (Saunders et al., 2005; Schache et al., 1999, 2001, 2002a, 2002b; Smoliga, 2007). There are many models based on angular variables for trunk kinematic analysis during locomotion that provide very different kinematic patterns and ranges of motion (Leardini et al., 2009). Angular results must be used and interpreted extremely carefully (Leardini et al., 2009; Schache et al., 2002a; Vrtovec et al., 2009), as two spines with different concavities can have equal angles (Vrtovec et al., 2009; White and Panjabi, 1990). The measurement of the geometric curvature of the spine during running is an unexplored approach that can help elucidate the human posture.

This study sought to analyse the behaviour of the average spinal posture using a novel investigative procedure in a maximal incremental effort test performed on a treadmill. The work was based on the hypothesis that the KN has subject-specific characteristics, similar to a signature, that are maintained in different running conditions.

2. Materials and methods

2.1. Participants and measurement protocol

The study included 13 male amateur athletes (Table 1) with experience in competitions of 10 km or more. They wore shorts, running shoes, and a mask connected to a gas analyser. All participants signed terms of free and informed consent to participate in the research, which was approved by the University Research Ethics Committee.

Adhesive retro-reflective markers (plane, square [8×8 mm]) were placed to mark and identify anatomical points on the back (Fig. 1). Markers were placed at the point of intersection between the medial border and the spine of the scapula (SC), at the two posterior superior iliac spines (PSIS) and at the spinous process of the second sacral vertebra (S2), fourth lumbar vertebra (L4), and twelfth, sixth, and first thoracic vertebrae (T12, T6, T1). Laterally and at the height of each of the L4, T12, T6, and T1 spinous processes, following the alignment of the PSIS, a pair of bilateral markers was placed for use as reference points in the analysis. After marking the above points, the line defined by the spinous processes of the vertebrae was filled with regularly spaced markers, approximately every 2 cm.

A maximum-effort running test with an incremental protocol was adopted, with a fixed 1% slope on the treadmill, as proposed by Lourenço et al. (2011). Initially, the running speed was set to 9.3 km/h for three minutes. Thereafter, the speed was increased by 0.3 km/h every 25 s. The test was stopped at the speed of the volitional exhaustion. Four volunteers (v01–v04) performed the test again, two weeks later.

2.2. Marker tracking and 3D reconstruction

Illuminators with 20 LEDs were constructed and placed around the lenses of three JVC GR-DVL9500 camcorders, used to record the movement of the back at 60 Hz (Fig. 2). Before the experiment, the focus, shutter speed (1/500), and all other parameters of the cameras were regulated and set.

Image processing and all data processing were performed using Matlab® software (The MathWorks, Natick, Massachusetts, USA). System calibration was performed by registering points with a known location, which enabled the three-dimensional (3D) reconstruction using the DLT method (Abdel-Aziz and Karara, 1971) and the intra-frame synchronisation of the records of the camcorders

Table 1
Characteristics of the subjects.

Volunteer	Age (yr)	Height (m)	Mass (kg)	Volunteer	Age (yr)	Height (m)	Mass (kg)
v01	52	1.67	65.3	v09	57	1.74	63.0
v02	61	1.63	62.0	v10	22	1.77	60.2
v03	36	1.77	64.5	v11	35	1.74	69.0
v04	53	1.71	74.0	v12	39	1.74	90.0
v05	46	1.73	67.3	v13	28	1.95	91.0
v06	46	1.70	68.6	Mean	40.8	1.75	70.3
v07	31	1.82	67.5	SD	12.8	0.08	09.7
v08	24	1.81	72.0				

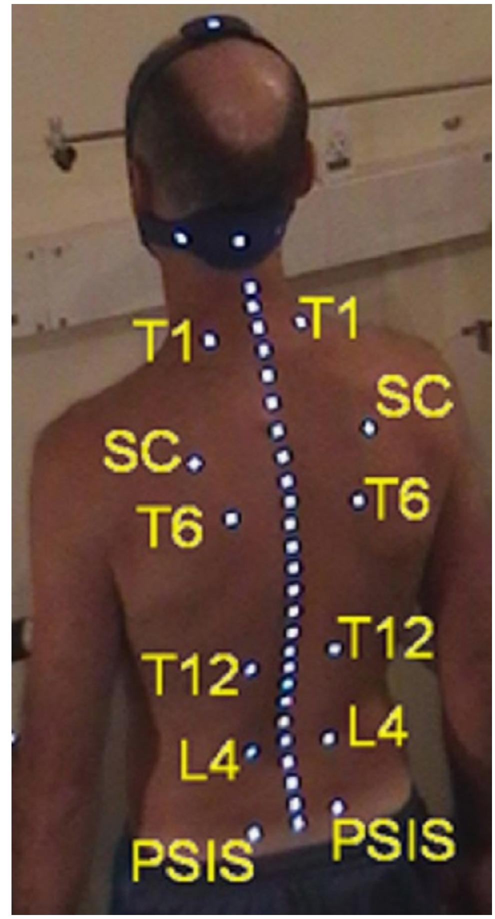

Fig. 1. Illustration of dorsal demarcation.

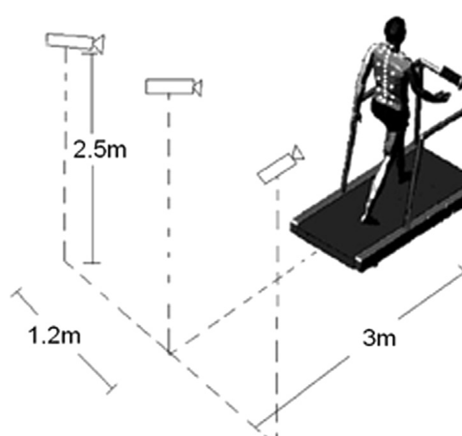

Fig. 2. Illustration of the experimental environment.

(Yeadon and King, 1999). A function was developed (Campos and Brenzikofer, 2009) to track the markers, and its centroid was localised at the barycentre (Gruen, 1997). The system's systematic error was 0.51 mm, and the random error was 0.61 mm, estimated using a rigid bar carrying two markers placed at a known distance that moved within the calibrated volume.

2.3. Data reduction and spine posture quantification

The vertical position of the pelvis, represented by the vertical coordinate of S2, was analysed for defining the gait cycles. The systematic oscillation of the S2 height showed a typical running pattern, presenting one cycle per step. It was assumed that for each step, the lowest vertical coordinate of S2 occurs during the middle portion of the stance phase (Novacheck, 1998). During this work, a complete gait cycle (two steps) was defined between three minimum peaks of the vertical