Journal of Bodywork & Movement Therapies xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Three-dimensional kinematics of the thorax during over-ground running

Dominic Fisher [a,*], Quinette Louw [a], John Cockcroft [a], Nassib Tawa [a,b]

[a] Stellenbosch University, Faculty of Medicine and Health Sciences, Division of Physiotherapy, PO Box 241, Cape Town, 8000 South Africa
[b] Department of Rehabilitation Sciences, School of Medicine, College of Health Sciences, Jomo Kenyatta University of Agriculture & Technology, University of Stellenbosch, South Africa

Keywords:
Speed running
Thorax
3D kinematics
Gender

A B S T R A C T

Background: Given the size and mass of the thoracic segment, understanding its neuromotor control demand during over ground running at different speeds is important in the rehabilitation and research setting. This study describes key kinematics characteristics as proxy measures for thoracic neuromotor control. We hypothesized that thoracic kinematics would differ significantly when running at different running speeds and that speed related thoracic kinematic changes would not differ between gender.
Methods: Three-dimensional thoracic kinematics of 19 healthy runners were recorded using an optical 3D motion capture system. We compared peak kinematic angles and range of motion of the thorax in each anatomical plane, in three running speeds during the stance phase. The Wilcoxon Signed Rank Test was used to analyse thoracic kinematics differences across different speeds.
Results: There was increased group peak kinematic angles and total range of motion during ***slower*** and ***faster*** than self-selected pace compared to self-selected pace in all three planes. There were gender differences in the changes in kinematic measures at different running speeds.
Conclusion: Our findings suggest that the differences in thoracic kinematics as a result of non-self-selected running speed may be due either to the increased neuromotor demands inherent to that running speed or due to the individual's adjustment to running at an unfamiliar speed. Further investigation is required to determine whether protocols that require participants to run at speeds other than self-selected pace confound the results. We therefore recommend normative data set protocols that avoid potential confounding by employing only self-selected pace. Our findings further suggest kinematic changes due to speed differed across gender, most notably in the transverse plane. Thus, we propose that gender specific normative data sets may be required.

1. Introduction

The thorax comprises more than fifty percent of body weight and has a significant effect on the position of the body's centre of mass, movement energetics and the forces acting on the lower limbs (Plagenhoef et al., 1983). Understanding 3D thoracic kinematics under different speed conditions, provides insight about the neuro-motor control demand of the thorax under changing physical demands. By observing how peak thoracic angles and total segmental range of thoracic motion change during the stance phase of different running speeds we gain insight into how changing intrinsic and extrinsic forces affect equilibrium of this large body segment. Furthermore, the effect of running speed and associated temporal spatial dynamics on thoracic movement could affect running economy and performance and thus influence coaching strategies and rehabilitation strategies.

To our knowledge, previous studies focusing on 3D thoracic kinematics have not highlighted the effect of changes in running speed or investigated whether these differ between gender. Three-dimensional thoracic motion in healthy cross-country runners during the stance phase of treadmill running has been described previously (Ford et al., 2013) but the authors cautioned that their findings on treadmill running are not generalizable to over-ground running. Gender specific factors may also have an effect on thoracic kinematics during running (White et al., 2009). It is reasonable to assume running speed influences thoracic kinematics due to the

* Corresponding author.
E-mail address: dominic@sun.ac.za (D. Fisher).

http://dx.doi.org/10.1016/j.jbmt.2017.08.003
1360-8592/

differing neuromotor demands on the body. Gender differences may influence how thoracic kinematics change in response to speed changes. Researchers (Seay et al., 2011) have reported differences in the movement and coordination between the pelvis and thorax in males and females with low back pain or a history of low back pain compared to healthy controls during treadmill running. It was found that there were no differences in thoracic movement between female runners with ilio-tibial band syndrome (ITBS) and healthy controls (Seay et al., 2011; Foch and Milner, 2014). However, the confounding effect of gender on thoracic kinematics during running remains under-researched. Thus, thoracic kinematics during over-ground running, and it's response to changes in running speed, is investigated in the present study.

In clinical practice, it is customary to utilize normative kinematic patterns as a reference for identifying abnormal patterns. A number of factors must be considered when developing a comparative normative data set with running speed and gender being foremost considerations. Normative data sets may thus require subgroupings to ensure that valid and relevant comparisons can be made. The aim of this study was *firstly;* to determine the effect of running speed on 3D thoracic kinematics in a group of healthy male and female runners. *Secondly;* to determine within gender differences across the three running speed conditions and *thirdly*; to determine whether the running speed induced kinematic changes were different according to gender. We hypothesized that thoracic kinematics would differ when running:

- Slower compared to self-selected speed
- Faster compared to self-selected speed
- Faster speed compared to slower speed

2. Methodology

A cross-sectional, descriptive study was conducted at the institution's neuromechanics laboratory. Ethical approval was obtained from the Institutional Committee for Human Research (Ethics reference number: S12/07/196). The protocol was not violated and no harm occurred to participants from participating. All participants provided written informed consent.

2.1. Characteristics of participants

Runners aged between 22 and 44 years old were recruited from local, registered running clubs. Participants were eligible if they could complete a 10 km race within 35–60 min, a time representative of recreational runners. Runners were excluded if they had skeletal abnormalities (i.e. scoliosis, spontaneous/congenital fusion), spinal or lower limb surgery, neurological disorders, locomotor problems, spinal and lower limb musculoskeletal pain or other functional limitations when performing functional, occupational, sports or recreational activities in the past 6 months. Runners who run more than 60% of the time on a treadmill were also excluded since treadmill running may increase stance time (Ford et al., 2013).

Nineteen recreational runners (10 females and 9 males) participated in the study. There was a statistical difference in weight ($p = 0.0007$) and height ($p = 0.0001$) between males and females, but age was not significantly different (Table 1).

Table 1
Participant anthropometric and demographic characteristics.

	Female (n = 10)	Male (n = 9)
	Mean (Min-Max)	
Age-years	31.9 (22–44)	36.7 (23–44)
Height-m	1.7 (1.5–1.8)	1.81 (1.7–1.9)
Mass-kg	60.1 (49.3–83.3)	85.9 (58.4–108.9)

2.2. Sampling error

We determined the standard error of the mean (which is the standard deviation of the sample-mean's estimate of a population mean). With a sample of 19 participants and a standard deviation of 7° (the largest standard deviation reported in Table 3), the true mean of the population may fall within 3° of the sample mean at a 95% confidence interval. Considering a standard deviation of about 3° (smallest standard deviation reported in Table 3), the population mean should fall within 1° of the sample mean.

2.3. Procedures

Three-dimensional (3D) kinematics of the thorax and lower limbs was measured at 200 Hz with eight Vicon T-series cameras (Vicon Motion Systems (Ltd), Oxford, UK). Camera calibrations were performed using a standard 5-marker wand procedure and data was collected using the standard Vicon software (Nexus version 1.8) and marker set (Plug-in-Gait) ("Plug-in Gait (Product Guide)", 2008).

2.3.1. Subject preparation

Anthropometric measurements including height, weight, leg length, knee and ankle width were taken according to the Vicon Plug-in Gait protocol ("Plug-in Gait (Product Guide)", 2008). Twenty two retro-reflective markers (14 mm diameter) were placed on subject's bony landmarks according to the Plug-in Gait model (lower limb markers were placed on the anterior and posterior superior iliac spines, lateral knee, lateral malleolus, second metatarsal head, heel, lateral thigh and tibia).

To assure intra-rater reliability, the same researcher applied all the markers on all participants. The researcher who placed the markers had received prior training and had three years of experience in placing markers.

Subject calibrations consisted of a conventional static T-pose trial. Additionally, during the static trial, a marker placed on the medial malleolus was used to calculate the Plug-in-Gait model parameters required for calibrating the shank segment definition (shank rotation offset and tibial torsion). The thigh rotation offset model parameter, used to define the orientation of the Plug-in Gait model knee axis relative to the thigh markers, was optimized for a single walking trial using the numerical minimization of varus-valgus variance.

2.3.2. Plug-in-Gait definition of the thorax

The markers defining the thorax were placed on the suprasternal notch (CLAV), the xiphoid process of the sternum (STRN), the spinous process of the 7th cervical vertebra (C7) and the spinous process of the 10th thoracic vertebra (T10). It was not always possible to place the marker on the sternum due to female breasts. If this was the case, the marker was placed on the strapping of the sports brazier.

The primary axis (Z) is the axis of the thorax perpendicular to the thorax transverse plane. The direction is defined as from the midpoint of the line between the STRN to T10 to the midpoint of CLAV and C7. A secondary axis (X), perpendicular to the coronal plane, points forwards from the midpoint of C7 and T10 to the midpoint of CLAV and STRN pointing forwards. The Y axis points to the left. The origin of the thorax is defined as half a marker diameter back from the CLAV marker along the X axis. Our analysis of the

Please cite this article in press as: Fisher, D., et al., Three-dimensional kinematics of the thorax during over-ground running, Journal of Bodywork & Movement Therapies (2017), http://dx.doi.org/10.1016/j.jbmt.2017.08.003