Journal of Science and Medicine in Sport 17 (2014) 419–424

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Kinematic changes during running-induced fatigue and relations with core endurance in novice runners

Ian F. Koblbauer[a], Kimberley S. van Schooten[b], Evert A. Verhagen[c,*], Jaap H. van Dieën[b]

[a] University of Glasgow, Institute of Cardiovascular and Medical Sciences, School of Medicine, Glasgow, Scotland, United Kingdom
[b] MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands
[c] VU University Medical Center, EMGO Institute, Department of Public and Occupational Health, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 6 November 2012
Received in revised form 29 April 2013
Accepted 23 May 2013
Available online 19 June 2013

Keywords:
Biomechanics
Pronation
Jogging
Exercise movement techniques

ABSTRACT

Objectives: This study aimed to investigate kinematic changes experienced during running-induced fatigue. Further, the study examined relations between kinematic changes and core endurance.
Design: Repeated measures and correlation.
Methods: Seventeen novice runners participated in a running-induced fatigue protocol and underwent core endurance assessment. Participants ran at a steady state corresponding to an intensity of 13 on the Borg scale and continued until 2 min after a Borg score of 17 or 90% of maximum heart rate was reached. Kinematic data were analyzed for the lower extremities and trunk throughout a running protocol and, on separate days, core endurance measures were recorded. Changes in pre- and post-fatigue running kinematics and their relations with core endurance measures were analyzed.
Results: Analysis of peak joint angles revealed significant increases in trunk flexion (4°), decreases in trunk extension (3°), and increases in non-dominant ankle eversion (1.6°) as a result of running-induced fatigue. Post-fatigue increased trunk flexion changes displayed a strong to moderate positive relation with trunk extensor core endurance measures, in contrast to expected negative relations.
Conclusions: Novice runners displayed an overall increase in trunk inclination and increased ankle eversion peak angles when fatigued utilizing a running-induced fatigue protocol. As most pronounced changes were found for the trunk, trunk kinematics appear to be significantly affected during fatigued running and should not be overlooked. Core endurance measures displayed unexpected relations with running kinematics and require further investigation to determine the significance of these relations.

1. Introduction

Increased levels of physical activity are currently being promoted in an attempt to curtail rising rates of disease associated with sedentary behavior. A popular form of physical exercise is recreational running. Literature has shown that runners experience a high number of running-related injuries (RRI),[1] this number being particularly high in novice runners.[2,3] While there is little consistency in literature regarding causes of RRI,[1] measures such as high BMI, previous injury, and previous sports activity without axial loading have been shown to be risk factors in novice male runners.[4]

It is generally assumed that suboptimal lower limb movement patterns may increase injury risk in runners. Specifically, excessive pronation and its main component, rearfoot eversion, have been linked to RRI.[5] It has also been reported, for experienced runners, that rearfoot eversion during running may increase with fatigue.[6–8] The latter suggests that fatigue may increase injury risk due to adverse effects on lower limb kinematics and may be even more so in novice runners. However, effects of running-induced fatigue on lower limb kinematics have, to our knowledge, not been studied in novice runners.

Lower extremity loading while running would be increased by a lack of control of the trunk center of mass position over the stance leg hence sufficient strength of muscles that stabilize the pelvis and trunk has been emphasized in relation to injury risk.[9–11] In accordance with this, the effect of trunk kinematics on injury risk during running has gained increasing interest in recent years. Indeed, relations between hip muscle strength and dynamic endurance and running kinematics[12,13] as well as injury risk in experienced athletes[14] have been demonstrated. Moreover, it has been shown that trunk muscle fatigue, caused by isolated trunk extension exercise, causes an increase in trunk flexion and inclination during running.[15] It is, therefore, conceivable that fatigue of these muscles developing during sustained running may cause progressive changes of trunk kinematics. In line with this, training and testing of

* Corresponding author.
E-mail address: e.verhagen@vumc.nl (E.A. Verhagen).

1440-2440/$ – see front matter
http://dx.doi.org/10.1016/j.jsams.2013.05.013

endurance of muscles stabilizing the pelvis and trunk, often coined core endurance, is deemed important in practice. However, to our knowledge, neither the effect of running-induced fatigue on trunk kinematics, nor the relation between changes in trunk kinematics in running and commonly used static core endurance measures have been established in novice runners.

Given the lack of literature concerning effects of fatigue in novice runners as well as the lack of evidence regarding the role of core endurance in this context, the aim of this study was to investigate trunk and lower extremity kinematics in novice runners using a running-induced fatigue protocol simulating a typical running session. The study additionally aimed to gain insight into relations between running kinematics and measures of core endurance. It was hypothesized that fatigue would result in increased rearfoot eversion and trunk flexion and that potential changes in running kinematics would be more pronounced in runners with low core endurance. In addition, since changes in trunk kinematics with fatigue during running do not necessarily result from fatigue of proximal musculature as changes in lower extremity kinematics can also affect pelvis and trunk movements, we performed a comprehensive analysis of lower extremity kinematics.

2. Methods

A total of 17 participants (10 females, 7 males) participated in the study. Participants had a mean age of 26.4 (SD 3.1) years, weight of 66.9 (SD 11.0) kg, height of 172 (SD 10.2) cm, and BMI of 22.5 (SD 2.7). Novice runners free of injury were recruited from the general population. To be eligible to take part in the study, participants were required to be between 20 and 45 years of age and having ran less than 2–3 times per week for <10 km and/or <45 min per session, but having the physical capacity to run at a self-selected pace for approximately 30 min and/or 5 km at a time. Individuals reporting a history of lower extremity injury requiring surgery or formal rehabilitation, severe back pain in the previous year, cardiovascular risks for physical exercise, formal core stability training, previous running experience at a competitive level, or clinical obesity (BMI $\geq$ 30) were excluded. All participants provided written informed consent and the study was granted ethical approval by the Ethical Committee of the Faculty of Human Movement Science of the VU University Amsterdam, The Netherlands; 2011-16R.

Participants were asked to come to the lab on two separate days. On the first day, core endurance measures were performed. The core endurance measures were performed on a standard plinth and consisted of the lateral musculature test (side-bridge), the flexor endurance test, and the back extensor test.[16] The lateral musculature test involves the participants lifting their hips off the plinth while supporting themselves with their elbow and feet. The flexor endurance test involves the participants holding a sustained trunk flexion angle of 55° with knees bent and feet supported while sitting on the plinth. The back extensor test involves the participants lying prone with their trunk over the edge of the plinth (holding neutral position) while legs are supported. Additionally, a modified Trendelenburg test,[17] in which the participants are asked to hold their hips at neutral in one-legged stance, was performed bilaterally to measure hip abductor endurance. For all measures, participants were asked to sustain static positions at neutral and were timed in seconds using a stopwatch. Failure was determined when the participants lost their neutral postures at which point the timer was stopped. Participants were given a 2-min rest period between all measures to allow for recovery. All measures were performed in randomized sequence. Participants were blinded regarding measures of performance throughout the testing procedure. Anthropometric characteristics were taken on days corresponding with core endurance measures.

On the second day, participants took part in a steady state running-induced fatigue protocol[7] on a treadmill (Biostar Giant™, Biometrics, Almere, The Netherlands). Minor alterations were made to the protocol utilized by Dierks et al.[7] to best suit our population. Participants started walking on the treadmill at a speed of 6 km/h. They were asked to rate their perceived exertion by means of the 15-point Borg scale[18] and were monitored for heart rate (Polar RS100, Polar Electro Oy, Woodbury, NY) by an examiner every minute throughout the trial. Speed was increased in increments of 1 km/h every 2 min until an intensity of 13 (somewhat hard) on the Borg scale was reached. Participants continued to run at the given steady state speed until a Borg score of 17 (very hard) or 90% of maximum heart rate (HR_{max} estimated as 220 − age)[19] was reached, at which point they continued to run for 2 additional minutes. Participants then performed a cool-down at a self-selected speed.

All participants were provided with new neutral running shoes (Nike Air Pegasus) for the running protocol. The dominant leg was defined as the leg the participant would use to kick a ball. No visual or verbal stimuli were provided throughout the protocol and participants were blinded with regards to speed and duration of the trial.

Trunk and lower extremity kinematics were recorded at a sample rate of 100 samples/s throughout the running protocol using an Optotrak motion capture system (Optotrak Certus®, Northern Digital Inc., Waterloo, Ontario). Two 3-camera arrays were positioned behind the participant, 40° from the midline. Optical cluster markers consisting of three diodes fixed to rigid plates were fastened with Velcro to neoprene sleeves for the lower extremities, a neoprene belt for the pelvis, and a neoprene harness for the trunk to obtain kinematic data. Plates were fastened to the heel of the shoes using adhesive tape.

Before the experiment, the positions of the cluster markers were related to anatomical landmarks[20] using a 6-marker pointer to indicate the location of anatomical landmarks defining anatomical segment axis systems. Prior to data analysis, marker coordinates were filtered using a 4th order low-pass Butterworth filter with a cut-off frequency of 15 Hz. Data were extracted for analysis 1 min after steady state was reached and 1 min after fatigue (Borg 17/90% HR_{max}) was reached. Subsequently, based on the anatomical calibration and cluster marker data instantaneous orientations of the anatomical axis systems for all segments of interest were determined and orientation of distal segments were expressed relative to proximal segments. Euler decomposition of the resulting local orientation matrices, in the order, flexion/extension, lateral flexion or abduction/adduction or eversion/inversion, and finally torsion was used to obtain joint angles. Heel strikes were defined as lowest point of the right foot during stance, and a stride cycle as the time between two consecutive heel strikes. Data corresponding to timeframes of twenty consecutive stride cycles of the right foot were averaged. In the event of obstructed markers during strides, affected strides were removed and averaged over a minimum of nineteen stride cycles. Maximal and minimal joint angles during the averaged stride cycle were extracted to determine peak angles. To determine changes in peak angle, mean differences between pre- and post-fatigue data were calculated.

All kinematic variables were analyzed in Matlab version R2011a (The MathWorks Inc., Natick, MA) using the 3-dimensional (3D) linked segment model developed by Kingma et al.[21] All joint angles were referenced from anatomical posture. Trunk and hip, knee, and ankle kinematics were analyzed. Both dominant and non-dominant sides were analyzed to ensure no major discrepancies were evident. Given inherent measurement error associated with hip, knee, and ankle rotation, as well as hip and knee movement in the frontal plane,[22,23] data were not analyzed for these variables.