Gait & Posture 48 (2016) 220–225

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Surface effects on dynamic stability and loading during outdoor running using wireless trunk accelerometry

Kurt H. Schütte[a,c,*], Jeroen Aeles[a], Tim Op De Beéck[b], Babette C. van der Zwaard[c], Rachel Venter[c], Benedicte Vanwanseele[a]

[a] Human Movement Biomechanics Research Group, Department of Kinesiology, KU Leuven, Leuven, Belgium
[b] Department of Computer Science, KU Leuven, Leuven, Belgium
[c] Movement Laboratory, Department of Sport Science, Stellenbosch University, Stellenbosch, Western Cape, South Africa

ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form 27 April 2016
Accepted 29 May 2016

Keywords:
Running gait
Running surface
Trunk accelerometer
Dynamic stability
Dynamic loading

ABSTRACT

Despite frequently declared benefits of using wireless accelerometers to assess running gait in real-world settings, available research is limited. The purpose of this study was to investigate outdoor surface effects on dynamic stability and dynamic loading during running using tri-axial trunk accelerometry. Twenty eight runners (11 highly-trained, 17 recreational) performed outdoor running on three outdoor training surfaces (concrete road, synthetic track and woodchip trail) at self-selected comfortable running speeds. Dynamic postural stability (tri-axial acceleration root mean square (RMS) ratio, step and stride regularity, sample entropy), dynamic loading (impact and breaking peak amplitudes and median frequencies), as well as spatio-temporal running gait measures (step frequency, stance time) were derived from trunk accelerations sampled at 1024 Hz. Results from generalized estimating equations (GEE) analysis showed that compared to concrete road, woodchip trail had several significant effects on dynamic stability (higher AP ratio of acceleration RMS, lower ML inter-step and inter-stride regularity), on dynamic loading (downward shift in vertical and AP median frequency), and reduced step frequency ($p < 0.05$). Surface effects were unaffected when both running level and running speed were added as potential confounders. Results suggest that woodchip trails disrupt aspects of dynamic stability and loading that are detectable using a single trunk accelerometer. These results provide further insight into how runners adapt their locomotor biomechanics on outdoor surfaces in situ.

1. Introduction

Worldwide millions of people participate in recreational and competitive running. It is an easily accessible sport with numerous proven health benefits. However, repetitive collisions with the ground also make running a sport with a high incidence of chronic overload injuries [1]. Dynamic loading related variables such as higher vertical loading rates [2] or peak tibial accelerations [3] have been prospectively associated with lower-limb overuse running injuries such as stress fractures. It is commonly believed that these dynamic loads and subsequently overuse injury risk is exacerbated on harder surfaces such as concrete or asphalt. However, epidemiological research has thus far failed to find any relationship between surface hardness and injury, possibly due to difficulty in accurately quantifying time and intensity on typical running surfaces [4]. Identifying how dynamic loads are moderated on typical running surfaces could therefore add insights into appropriate preventative strategies for overuse running injury.

Laboratory studies have shown that small alterations in running surface can induce changes in human running mechanics. For example, it is known that softer [5–7] or uneven [8,9] running surfaces cause runners' to rapidly increase their leg stiffness, while peak ground reaction forces are mostly moderated with a stable centre of mass (CoM) trajectory [5–7]. Although, Dixon et al. [10] reported individual specific adaptations in knee kinematics between asphalt and a softer rubber-modified surface, they [10] also observed an overall reduction in vertical loading rates when switching to the softer surface. While these aforementioned studies provide essential insights, the mechanisms for moderating are perhaps not directly applicable to "real-world" running surfaces that naturally vary in composites of hardness, evenness, and gradient.

In attempt to secure ecological validity, some researchers have investigated how runners adapt their loading and mechanics to

---

* Corresponding author.
E-mail address: kurtschutte.sa@gmail.com (K.H. Schütte).

http://dx.doi.org/10.1016/j.gaitpost.2016.05.017
0966-6362/

typical outdoor running surfaces. Using cinematography, Creagh et al., [11] found that running in long grass decreased step lengths while increased hip vertical displacement, knee lift and peak upper leg angles compared to running on tarmac. Others who have used portable wearable devices such as in-shoe plantar pressure measurements or tibial accelerometry have found conflicting results. For example, Tessutti et al. [12] reported higher central and lateral peak plantar pressures along with shorter contact times when running on asphalt compared to natural grass. In contrast, no differences in peak plantar pressure [13], impulse [14], tibial shock [13] or contact times [13,14] have been found between concrete, grass, or synthetic track. Discrepancies in findings could be attributed to large inter-individual responses [10]. It appears that there is a need for a better understanding of how runners moderate their loading and gait in response to “real-world” surfaces.

Measures derived from wireless tri-axial trunk accelerometers have become a popular approach to reliably and unobtrusively capture dynamic loading and CoM stability in various environments. The acceleration root mean square (RMS) as well as the autocorrelation-based coefficients referred to as inter-step and inter-stride regularity have identified a wide variety of impaired or asymmetrical stability patterns related to ageing [15], lower limb prosthesis [16], hemiplegia [17], and gross motor function [18]. When applied to running gait, these measures can detect compensations in dynamic stability due to fatigue [19,20], predict oxygen consumption [21], and classify athletes based on their training background [22]. The current paper includes stability and impact frequency components of running gait, which may be more sensitive to changes in surface relative to other measures i.e. spatio-temporal or impact peaks. However, these accelerometer measures have usually been investigated on a single running surface, thus limiting multi-terrain generalizability.

Woodchip trails are becoming popular running surfaces that are specifically constructed to have “structural dampening” to reduce impact-loading related injuries and enhance participation of recreational running. Indeed, animal studies suggest that woodchip surfaces have injury preventative properties. For example, adult sheep that were exposed to prolonged activities on woodchips were less prone to development of knee osteoarthritis compared to sheep exposed to activities on hard concrete [23]. In addition, hoof impact accelerations were significantly more dampened when horses trotted at $\sim 4\,\mathrm{m\,s^{-1}}$ on woodchip surface compared to asphalt [24]. Unfortunately, previous research on human running has primarily focused on other outdoor surfaces such as grass [11–14], with no apparent evidence on woodchip trails. The purpose of this study was to investigate outdoor surface effects on dynamic stability and loading during running using tri-axial trunk accelerometry. Based on previous laboratory research indicating smoothness of CoM trajectory under different surface conditions, we hypothesized that trunk accelerometry measures of dynamic stability and loading would be minimally affected by running surface.

2. Methods

2.1. Participants

Two predetermined age-matched groups of endurance runners aged 18 to 33 years of mixed gender (# women 14, 50%) were recruited for this study; highly-trained runners (mileage $>50\,\mathrm{km\,week^{-1}}$, n = 13) and recreational runners (mileage $<30\,\mathrm{km\,week^{-1}}$, n = 17). All participants were screened to have no history of lower extremity injury within the past three months. Written informed consent was received from all runners prior to participation in accordance with the Declaration of Helsinki. The study was approved by the local ethics committee (Commissie Medische Ethiek KU Leuven).

2.2. Experimental protocol

All runners (n = 17 recreational; n = 13 highly-trained) performed a standardized warm-up. Outdoor running was performed on 90 m of straight and flat concrete road, synthetic track, and woodchip trail. Photo electronic timing gates (RaceTime 2 system, Microgate, Bolzano, Italy) were positioned to capture average running speed from the 10 m to 70 m mark. A practice trial was provided to familiarize participants to each surface. The self-selected running speed on concrete was used as control speed on the other surfaces, and trials on subsequent running surfaces were discarded if the running speed differed by $\pm 1\,\mathrm{m\,s^{-1}}$ of control speed. The order of the other two surfaces was randomized. To avoid any fatigue effect runners were allowed to rest during five minutes between each surface.

2.3. Accelerometry measurements

Tri-axial accelerometry (X50-2 wireless accelerometer, range ±50 g, sampling at 1024 Hz, 0.016 g/count resolution, 33 g weight, Gulf Coast Data Concepts, MS, USA) was acquired during each running trial. The accelerometer was securely positioned over L3 spinous process of the trunk [25], and directly mounted to the skin using double sided tape and adhesive spray. Accelerometer position was unaltered between all running trials and was routinely checked between running trials for security. Trials were discarded in the case the investigators deemed the accelerometer to be not securely fastened upon its removal (after data collection).

All signal processing of acceleration curves was performed using customized software in MATLAB version 8.3 (The Mathworks Inc., Natick, MA, USA). Accelerometry-derived parameters were computed from the middle ten consecutive strides of the 10–70 m measurement zone, that were first trigonometrically tilt-corrected and filtered using a zero-lag 4th order low-pass Butterworth filter (cut-off frequency 50 Hz) [20,25]. Accelerometry-derived parameters were averaged over two running trials per surface per participant.

2.4. Outcome measures

Spatio-temporal parameters were quantified by step frequency and stance time. The former was acquired using the time lag of the first dominant peak of the vertical acceleration’s unbiased autocorrelation [20,25]. The latter was acquired based on the heuristic that as long as the body is accelerating upwards, the foot should still be in contact with the ground [26]. Therefore, zero crossings of vertical accelerations identified periods where the vertical acceleration was positive and accelerating upwards (initial contact to final contact) [26].

Dynamic postural stability parameters were quantified from tri-axial (vertical, ML, AP) accelerations firstly using the ratio of each linear acceleration axis root mean square (RMS) relative to the resultant vector RMS to capture variability [21]; secondly using step and stride regularity (unbiased autocorrelations procedure) to capture symmetry and consistency of running steps and strides respectively, with perfect regularity equivalent to one [25]; and thirdly using sample entropy from raw accelerations to capture the waveform predictability, with higher values indicating less periodicity or more unpredictability [27]. Detailed procedures and algorithm inputs for the computation and extraction of these dynamic postural stability parameters are explained previously [20].