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Original research

Plantar loading changes with alterations in foot strike patterns during a single session in habitual rear foot strike female runners

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Objectives: Characterize plantar loading parameters when habitually rear foot strike (RFS) runners change their pattern to a non-rear foot strike (NRFS).
Design: Experimental.
Setting: University biomechanics laboratory.
Participants: Twenty three healthy female runners (Age: 22.17 ± 1.64 yrs; Height: 168.91 ± 5.46 cm; Mass: 64.29 ± 7.11 kg).
Main outcome measures: Plantar loading was measured using an in-sole pressure sensor while running down a 20-m runway restricted to a range of 3.52–3.89 m/s under two conditions, using the runner's typical RFS, and an adapted NRFS pattern. Repeated measures multivariate analysis of variance was performed to detect differences in loading between these two conditions.
Results: Force and pressure variables were greater in the forefoot and phalanx in NRFS and greater in the heel and mid foot in RFS pattern, but the total force imposed upon the whole foot and contact time remained similar between conditions. Total peak pressure was higher and contact area was lower during NRFS running.
Conclusions: The primary finding of this investigation is that there are distinctly different plantar loads when changing from a RFS to NRFS during running. So, during a transition from RFS to a NRFS pattern; a period of acclimation should be considered to allow for adaptations to these novel loads incurred on plantar regions of the foot.

1. Introduction

Running is a common and popular activity with nearly 40 million Americans yearly participating (Messier, Legaut, Schoenlank, Newman, Martin, & Devita, 2008). The range of incidence of lower extremity overuse injuries was reported to be 19–79% and 76% of recreational runners became injured with the majority of these injuries occurring in the distal lower extremity and in the foot each year (Gent, Siem, Middelkoop, Os, Bierma-Zeinstra, & Koes, 2007). Females are shown to have a 1.5–12 times greater prevalence of stress fractures compared to males (Bennell & Brukner, 1997; Callahan, 2000; Wentz, Liu, Haymes, & Ilich, 2011), Plantar loading may be related to injuries in running or be a predisposing factor for some foot injuries like metatarsal stress fractures (Donahue & Sharkey, 1999; Gross & Bunch, 1989). The role of footwear and barefoot running styles has become an area of increased interest within the running literature in recent years (Bonacci, Saunders, Hicks, Rantalainen, Vicenzino & Spratford, 2013; Kernozek, Meardon, & Vannatta, 2014; Ridge et al., 2013; Shih, Lin, & Shiang, 2013; Willson, Bjorhus, Williams, Butler, Porcari & Kernozek, 2014). Minimalist footwear and barefoot running, in particular, have been associated with a particular running style known as a non-rear foot strike (NRFS) pattern (Goss & Gross, 2012; Lieberman, 2012; Lieberman et al., 2010). However, rather than the type or absence of footwear, foot strike pattern (FSP) has been reported as a major determinant of lower extremity loading during running (Lieberman, 2012; Shih et al., 2013; Williams, Green, & Wurzinger, 2012).

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It has been estimated that 75% of all runners use a rear foot strike (RFS) pattern (Hasegawa, Yamauchi, & Kraemer, 2007). The use of a NRFS running pattern has been associated with decreased ground reaction forces and loading rates (Cavanagh & Lafortune, 1980; Goss & Gross, 2012; Lieberman et al., 2010), decreased energy absorption of the lower extremity, primarily the knee (Williams et al., 2012), and decreased rates of certain forms of lower extremity injuries (Daoud, Geissler, Wang, Saretsky, Daoud, & Lieberman, 2012). However, running with a NRFS has been shown to alter the loading of other articulations of the kinetic chain, for instance, ankle, knee and hip joints (Almonroeder, Willson, & Kernozek, 2013; Bonacci et al., 2013; Kernozek et al., 2014; Kulmala, Avela, Pasanen, & Parkkari, 2013; Shih et al., 2013). For example, NRFS running is associated with increased gastrocnemius muscle activity (Bonacci et al., 2013) and greater Achilles tendon force (Almonroeder et al., 2013). Recent case studies have also reported the use of minimalist footwear (which is often associated with a NRFS) had incidences of metatarsal stress fracture (Giuliani, Masini, Alitz, & Owens, 2011; Salzler, Bluman, Noonan, Chiodo, & de Asla, 2012).

Characterizing the kinematic and kinetic parameters of running gait under different foot strike conditions has been the aim of numerous recent reports (Almonroeder et al., 2013; Hamill, Gruber, & Derrick, 2014; Kulmala et al., 2013; Lieberman et al., 2010; Shih et al., 2013; Williams et al., 2012). Impact loading has been implicated by many researchers since the late 1970s as having a role in lower extremity overuse injury (Cavanagh & Lafortune, 1980; James, Bates, & Osternig, 1978). Greater peak vertical ground reaction force and rate of loading during the impact phase of running have been implicated with injury (Hreljac, Marshall, & Hume, 2000). In addition, plantar loading variables appear to be important to running related injury (Burns, Crosbie, Hunt, & Ouvrier, 2005; Van Ginckel et al., 2009). Based on cadaveric and mechanical models of stress fracture scenarios, the frequent loading of metatarsals in distance runners demonstrated higher bone strains (Donahue & Sharkey, 1999; Gross & Bunch, 1989). Plantar loading changes have been shown to differ with various types of footwear and FSPs (Becker, Howey, Osternig, James, & Chou, 2012; Hennig & Milani, 1995; Kernozek et al., 2014; Wiegerinck, Boyd, Yoder, Abbey, Nunley, & Queen, 2009).

Indeed studies that have investigated the ability of runners to convert their habitual strike pattern proposed that runners can convert quickly from a habitual RFS to a NRFS that is mechanically similar to habitual NRFS (Rooney & Derrick, 2013; Williams, McClay, & Manal, 2000). However, a description of the plantar loads that are experienced by runners when changing their FSP while using a cushioned shoe has not been systematically investigated. It is intuitive that plantar loads would differ when using a different FSP during running, however the magnitude of these changes and the precise locations of any differences in loading have yet to be described when a runner changes his or her FSP. Habitually RFS runners following their change in FSP to a NRFS would have different total and regional plantar loads.

Thus, it is the aim of this study to characterize plantar loading parameters in total foot and in 7 regions (heel, mid foot, medial, central and lateral forefoot, medial and lateral phalanx) when habitual RFS runners change their FSP to a NRFS.

2. Methods

2.1. Subjects

Based on the sample size estimates provided by Stevens (1992), with an estimated power of 0.7 using an alpha = 0.05 with a medium effect size for using a multivariate analysis of variance with 3–6 outcome variables, 23 participants is estimated to yield a medium effect size. Twenty-three healthy females 18–35 years old participated in this study (Age: 22.17 ± 1.64 yrs; Height: 168.91 ± 5.46 cm; Mass: 64.29 ± 7.11 kg; Weekly running distance: 33.69 ± 17.99 km, Tegner score: 6.26 ± 0.45). Inclusion criteria consisted of a self-reported running routine of greater than 10 miles per week, self-reported RFS pattern (first contact with the ground made with the heel) while running and a score of 5 or greater on the Tegner activity scale (a measure of regular participation in recreational sports activities that require running or jumping) (Tegner & Lysholm, 1985). Exclusion criteria included pregnancy, cardiovascular pathology, surgery on either lower extremity in the last 12 months, traumatic injury to either lower extremity in the past 6 months. All subjects gave their informed consent to the testing protocol as approved by the Institutional Review Board at the university.

2.2. Protocol

First, the subject's FSP was determined using several practice trials down the runway at the prescribed pace. Each participant had demonstrated a RFS as their typical pattern as described below. After the completion of these practice running trials, participants ran down a 20-m runway under two conditions: using 1) their typical RFS pattern, and 2) a NRFS pattern after simple instruction to "contact the ground on the ball of the foot". The order of these conditions was randomized. All participants were fitted with the same model of footwear (Model 629, New Balance, Boston, MA) for testing. These training shoes have a cushioned heel and forefoot similar to many cushioned distance running shoes which each participant used when running. Speed was restricted to a range of 3.52–3.89 m/s (Almonroeder et al., 2013; Williams et al., 2000) using a photoelectric timing system, located in the middle of 15 m runway. The photocells were 3 m apart. Dominant leg was determined by asking participants to kick a ball. Foot strike pattern of the dominant leg was verified after each trial via the using a 2-mm thick in-sole pressure sensor consisting of 99 individual sensors that were sampled at a rate of 150 Hz (Novel GMBH, Munich, Germany, Minneapolis/St. Paul, USA). Prior to collecting data, the insole sensor was calibrated from 0 to 600 kPa in an air-bladder-based pressure chamber as described by Kernozek and Zimmer (2000). All participants practiced for 3–5 min to learn a NRFS pattern. These were verified by checking their COP when running down the runway for each trial. Rear foot strike was defined as the subject's center of pressure (COP) occurring in the rear third of the overall foot length at initial contact as previously defined by Cavanagh and Lafortune (1980). A NRFS was any pattern where the COP was located in the anterior 66% of foot length upon initial contact. A total of five trials were completed under each condition.

2.3. Analysis

Data from average of five trials (Almonroeder et al., 2013) of the testing session were extracted for analysis using Novel Scientific Analysis Software package (Novel GMBH). These data from the RFS and NRFS patterns were further processed by masking the in-shoe sensor into seven regions corresponding to the heel; mid-foot; medial, central, and lateral forefoot; and, medial and lateral phalanx regions (Fig. 1).

Regional peak force (PF), force time integral (FTI), peak pressure (PP) and pressure time integral (PTI), in addition, mean total foot contact time (CT), contact area (CA), PF, FTI, PP and PTI were calculated. PF and FTI data were normalized to each runner's body weight. PF was the maximum force on the total foot or region, FTI