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Is symmetry of loading improved for injured runners during novice barefoot running?

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ABSTRACT

Background: As barefoot (BF) running provides important sensory information that influence landing patterns, it may also affect loading symmetry.

Research question: The purpose of this investigation was to examine whether symmetry of loading in a group of injured runners would be improved in a novice, barefoot condition.

Methods: Cross-sectional design evaluating 67 injured RFS runners. Each subject ran on an instrumented treadmill, first with their habitual shod pattern and then in a BF condition with a FFS pattern, both at the same self-selected speed. Data were averaged over 10 footstrikes. Variables of interest included vertical average load rate, vertical instantaneous load rate, and resultant instantaneous load rate. Symmetry indices (SI) for full population and within quartiles were compared for each loadrate variable ($P \leq 0.05$) to evaluate changes between conditions.

Results: On average, symmetry of loading was similar in a novice BF condition of injured runners compared with their habitual RFS shod condition. However, a subanalysis of quartiles revealed that the injured runners with the highest asymmetry (greatest SI values) displayed significantly lower asymmetry when running BF for all three loadrate measures.

Significance: The addition of sensory input during barefoot running only improves symmetry of loading when habitual loading is highly asymmetric.

1. Introduction

Walking and running, are considered relatively symmetric activities. When movement patterns become asymmetric, they can disrupt the natural rhythm of the gait. Examples of this include walking with uneven step lengths or with a lateral trunk lean. In theory, these asymmetries can lead to overloading certain musculoskeletal structures, increasing their risk for injury. When ground reaction forces (GRF) become asymmetric, one limb becomes more loaded than the other which can also be associated with injury. For example, Zifchock et al. [1] have shown that the injured limb of runners is associated with the side with the highest impact loading during running. It has been noted that some degree of asymmetry is normal in running [2]. However, when gait asymmetry is above expected differences, the goal of many interventions is to improve the symmetry to reduce injury risk [3–5].

In terms of running, impact loading, specifically GFR loadrates, have been associated with injury in both retrospective [6,7] and prospective [8,9] studies. This impact loading is strongly influenced by footstrike patterns. Runners who land with a forefoot strike (FFS) have significantly lower vertical loadrates compared to those who land with a rearfoot strike (RFS), especially when footwear cushioning is minimized [10,11]. This impact reduction is in part due to the eccentric action of the calf musculature during a FFS landing [12].

Impact loading is also reduced when running barefoot compared with running in cushioned shoes [13]. This has been attributed to two factors. First, barefoot runners are more likely to run with a FFS pattern [14]. This is because the heel pad does not adequately attenuate the impact loads of running and becomes painful when loads exceed those of walking [15]. Additionally, depending on the surface hardness, the sensory input from the plantar surface of the foot influences stiffness of the leg during landing [16,17]. When landing on a hard surface, leg stiffness is reduced and when landing on a soft surface, leg stiffness is increased.

Unfortunately, cushioned footwear may disrupt this important sensory input, likely resulting in altered landing mechanics including dynamic stability [18]. For example, an injured runner may have an associated harder landing on their affected side. The cushioned shoes may make it more difficult to sense this difference in landing. However,

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landing this hard when barefoot may be very painful. Thus, it is possible that the runner will adapt their mechanics to land softer on that side resulting in less asymmetry. If this is the case, running barefoot may be a way to retrain the symmetry of loading.

Therefore, the purpose of this study was to examine differences in asymmetry of loading between shod and novice barefoot conditions. We hypothesize that impact loading will be reduced in both feet in the barefoot conditions. We also expect that the asymmetry of loading variables will be reduced when running barefoot compared to shod.

2. Methods

Subjects in this study were a subset of runners seeking evaluation at a running injury clinic. Force data from the injured RFS runners who were habitually shod were collected as standard of care as part of a running clinic evaluation, and therefore a waiver of informed consent was granted.

2.1. Biomechanical data collection

Prior to the data collection, a retroreflective marker placed on each subjects' right foot was tracked with a 3D motion analysis system (Vicon Motion Systems Ltd. Oxford, UK). These data were used to match the correct force to the corresponding footstrike. As these were patients, they ran in their own footwear. Runners were first provided an opportunity to warm up on the instrumented treadmill (AMTI, Watertown, MA) for approximately 3 min. Once they attained a self-selected pace, force data were collected at 1500 Hz for approximately 20 consecutive footstrikes per limb. Subsequently, each runner removed their shoes and ran on the treadmill a second time while barefoot. Runners were instructed to land softly on the ball of their foot to eliminate vertical GRF impact transients to mimic habitual barefoot running [13,19]. Runners were provided an additional 3 min warm up at the same speed as the shod condition. All runners reported being comfortable with barefoot FFS condition prior to data collection. Data were collected again in a similar manner as in the shod condition. Each runner was asked to provide a Numeric Pain Rating Scale (NPRS) for each condition.

For this analysis, only runners who were rearfoot strikers (RFS) were included. Additionally, to reduce the influence of speed on mechanics, only those with the average self-selected speed of 2.56 ± 0.25 m/s (8.30–10.11 km per hour) were included. Finally to minimize the influence of pain on mechanics, only those with an NPRS of < 3, and with no change in pain between shod and barefoot conditions, were included.

2.2. Data processing and video analysis

GRF data were processed with a 4th order, 50 Hz low-pass filter were used to calculate loadrates. Vertical average loadrate (VALR) was represented as the slope (BW/s) of the most linear portion of the first rise to peak of the vertical GRF. This ALR region was usually defined as the region between 20 and 80% of the force at the point of interest (POI). The POI was defined as the first point, above 75% of the patient's body weight (75% BW), for which the instantaneous slope of the vertical GRF was below 15BW/s (Fig. 1). 75% BW was chosen to ensure that early changes in the slope when forces were low would be avoided. 15BW/s was chosen as it coincides with when the slope of the curve is observed visually to level off.

VALR was then calculated as the average slope in the largest continuous region in the 20–80% POI force region for which the slope was above 15% BW/s. In the vast majority of cases, this includes the entirety of the 20–80% POI force region. Vertical instantaneous loadrate (VILR) was calculated as the peak slope between 20 and 100% of the force at the POI. Studies of impact loading have included the assessment of both VILR and VALR as it has yet to be determined which is more important in terms of injury. Resultant instantaneous loadrate (RILR) was the peak resultant of component (vertical, anteroposterior and mediolateral) instantaneous loadrates as reported previously [11,20]. Recent studies suggest that RILR should be included when assessing impacts as this incorporates all components of the loadrates experienced by the body [11,20].

The symmetry Index (SI) was used to measure differences in symmetry for each left (L) and right (R) side for a given variable (X) using the following equation:

$$\mathrm{SI} = \frac{|X^L - X^R|}{(X^L + X^R)/2} x100$$

An SI value of 0 represents complete symmetry between sides, with increasing SI values corresponding to greater degrees of asymmetry. SI was calculated for VALR, VILR, RILR and averaged over the first 10 consecutive left and right foot strikes for each subject.

2.3. Statistical analysis

Data are presented as mean values (± standard deviation). Differences in each kinetic variable of interest (VALR, VILR, RILR) and for SI values derived from kinetic variables were compared using paired two tailed *t*-tests ($p < 0.05$). Additionally, in order to further explore the data, SI was compared between the shod and BF conditions across quartiles of RILR based upon the shod condition using ANOVA.

3. Results

The study group was comprised of 67 runners (34 female, 33 male, average age 37.2 yrs) meeting the inclusion criteria. Runners presented with a variety of running related injuries. Data on demographics and information on recent injury was available on 66 of 67 runners. Thirty-nine of the runners had unilateral injuries and 33 runners localized one or more recent injury to a joint (hip, knee or ankle). All runners completed both condition with nearly no pain. (NPRS = 0.15 ± 0.52). Only 6 of the 67 runners ran with any report of pain, and all were < 3/10 on a NPRS. Average VALR, VILR, and RILR were lower for novice BF condition compared to habitual shod running (Fig. 2).

The SI of VALR, VILR, and RILR was each similar in the novice BF (FFS) condition compared to the habitual shod (RFS) condition (Fig. 3) across all runners.

When assessing the data by quartiles, the shod SI decreased from the 1st to the 4th quartiles while the barefoot SI remained fairly constant (Fig. 4). This resulted in significant differences ($p < 0.05$) for the 1st, 3rd and 4th quartiles.

4. Discussion

The purpose of this investigation was to compare symmetry of loadrates between shod and barefoot conditions. We hypothesized that asymmetry would be reduced when additional sensory input was provided. However, we only found this to be true only for runners with the highest degree of asymmetry in their shod condition.

Contrary to our hypotheses, loading symmetry did not improve when sensory input was increased in the BF condition across subjects. When assessing the shod symmetry data by quartiles, some differences between BF and shod conditions were found. However, these differences were mainly due to the BF symmetry remaining largely unchanged across the quartiles of shod asymmetry. This suggests there may be a level of asymmetry that is maintained in the BF condition regardless of the degree of asymmetry in the shod condition, and may be in response to the additional sensory input received while BF. As being BF is our natural state, this may indicate our natural amount of loading asymmetry during running [19]. From a clinical standpoint, this also suggests that barefoot training may be most important with