



Differences in kinetic asymmetry between injured and noninjured novice runners: A prospective cohort study



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ABSTRACT

Purpose: The purpose of this prospective study was to describe natural levels of asymmetry in running, compare levels of asymmetry between injured and noninjured novice runners and compare kinetic variables between the injured and noninjured lower limb within the novice runners with an injury.

Methods: At baseline vertical ground reaction forces and symmetry angles (SA) were assessed with an instrumented treadmill equipped with three force measuring transducers. Female participants ran at 8 and 9 km h⁻¹ and male runners ran at 9 and 10 km h⁻¹. Participants were novice female and male recreational runners and were followed during a 9-week running program.

Results: Two hundred and ten novice runners enrolled this study, 133 (63.3%) female and 77 (36.7%) male runners. Thirty-four runners reported an RRI. At baseline SA values varied widely for all spatio-temporal and kinetic variables. The inter-individual differences in SA were also high. No significant differences in SA were found between female and male runners running at 9 km h⁻¹. In injured runners the SA of the impact peak was significantly lower compared to noninjured runners.

Conclusions: Natural levels of asymmetry in running were high. The SA of impact peak in injured runners was lower compared to noninjured runners and no differences were seen between the injured and noninjured lower limbs.

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1. Introduction

Annually, 19–83% of all runners sustain a running-related injury (RRI) [1,2]. Notwithstanding the high risk of sustaining an RRI, running is still one of the most popular physical activities. Injuries most common sustained among runners are medial tibial stress syndrome, patellofemoral pain syndrome, iliotibial band syndrome, stress fractures of the tibia, fibula or metatarsals, plantar fasciitis and Achilles tendinopathy [3]. Risk factors that put runners at higher risk for developing an RRI have been studied extensively [4–6]. Risk factors for RRIs can be divided into: training, anatomical and biomechanical factors [7]. Because of the high forces applied to the body with each foot strike, kinetic variables like impact peak [7], active peak, and loading rate, were often studied in relation to RRIs [7–12]. Results from these often small and retrospective studies were contradictory. In a recent prospective study among 210 novice runners, no differences in kinetic peak values were found between runners who developed

an RRI and runners who did not [13]. Therefore, magnitude of the impact and active peak forces might not be directly related to the development of an RRI.

Kinetic asymmetries between the left and right leg will expose one of the lower limbs to more stress than the other [14,15]. Therefore, the musculoskeletal tissue of the leg that is exposed to higher levels of stress might be more susceptible to an overuse injury and it could be possible that reduced symmetry may result in RRIs. Only two studies examined this possible relation between kinetic asymmetry and RRIs [14,15]. Both studies did not find differences in asymmetry between injured and noninjured runners. However, due to the retrospective character of both studies these findings might as well be the result of the injury. It can be argued that asymmetry is reduced as result of the injury, to decrease loading on the injured side. A prospective study can elucidate the possible causative nature of kinetic asymmetry on RRIs.

Studying the possible relation of kinetic asymmetry to RRIs is of importance for several reasons. Firstly runners at risk could be easily identified by measuring kinetic variables of both legs. Secondly, preventive measures such as the use of insoles or shoe modifications could be developed and introduced to reduce asymmetry in kinetic variables causative in the development of RRIs [16]. And thirdly, running technique could be modified in a

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way to reduce imbalances in load to the lower extremity and thereby decrease the risk on an RRI [17].

The purpose of this prospective study was threefold. First, describe natural levels of asymmetry. Second, compare levels of asymmetry between novice runners who sustained an RRI and novice runners who did not sustain an RRI. Third, compare kinetic variables between the injured and noninjured lower limb within the novice runners who sustained an RRI. It was hypothesized that runners who had higher levels of asymmetry in impact peak, active peak and loading rate were more likely to sustain an RRI on the side where loading was highest.

2. Methods

Novice runners between the 18 and 65 years old who had not sustained an injury of the lower extremity in the last 3 months before inclusion were recruited from the GRONORUN 2 study population [13]. The GRONORUN 2 study was a randomized control trial which studied the effect of a preconditioning program on the incidence of RRIs. An RRI was defined as any self-reported musculoskeletal complaint of the lower extremity or back causing a restriction of running for at least 1 week. After baseline measurements and informed consent, participants were randomly assigned to the 4 week preconditioning program group or the control group. After inclusion in the GRONORUN 2 study a random selection of 272 participants was asked to participate in the additional treadmill running test. The GRONORUN 2 study showed no effect of the four week preconditioning program in reducing RRIs in novice runners. Therefore, data from both groups were pooled, and in the multivariate analysis controlled for group allocation. The study design, procedures, and informed consent procedure were approved by the Medical Ethics Committee of the University Medical Center Groningen, The Netherlands; 2007.217.

2.1. Baseline measurements

The treadmill measurements started with a 5 min walk at 5 km h⁻¹. After this warming-up, female runners were tested at a running speed of 8 and 9 km h⁻¹ and male runners were tested at a running speed of 9 and 10 km h⁻¹ for 1 min. Vertical ground reaction forces (vGRFs) were measured during treadmill running. During the measurements, participants were running on their personal running shoes.

The instrumented treadmill used in this study (Entred, Forcelink, Culemborg, the Netherlands), had a stiff running surface of 1.60 m in length and 0.60 m in width, and was driven by a 1.8 kW motor. The treadmill was equipped with three force transducers (ACB-500kg, Vishay Revere Transducers, Breda, The Netherlands) which had a sample frequency of 1000 Hz and were connected to bridge amplifiers. The signals from the amplifiers were digitized into a 16-bit signal by an AD converter (PCI-6220, National Instruments, Austin, TX, USA) and were connected to a computer. In a recent study the treadmill was validated using a Bertec force platform (0.60 m × 0.40 m) mounted in the middle of a 17.5 m long runway [18].

2.2. Data analysis

Vertical GRF data from the treadmill were processed using custom programs written in MATLAB R2010a (The MathWorks Inc., Natick, MA). A 13-point moving average low-pass filter with a cut-off frequency of 33.3 Hz was used to filter the vGRF data that was captured during the treadmill test. Foot strikes were detected with a threshold of 30 N for impact and toe-off phase during running. For each running speed the last 10 right and 10 left foot steps were analyzed and averaged.

A distinction between heelstrike and non-heelstrike runners was made based on the existence of an impact peak. A heelstrike runner was defined as a runner in which an impact peak could be identified in 70% of the steps. Non-heelstrike runners were excluded from analysis to eliminate type of foot strike as a possible confounding variable.

The symmetry angle (SA) as proposed by Zifchock et al. was used to quantify level of symmetry in kinetic variables between the left and the right leg [19]. The SA is a measure related to the angle formed by the vector of two values (left and right) when plotted in a Cartesian coordinate system where values of the right leg are plotted on the x-axis and values of the left leg on the y-axis. When there is no difference between the left and right leg both values will form a vector of perfect symmetry which has an angle of 45° with the x-axis. The deviation from the vector of perfect symmetry is a measure of asymmetry between the two values. When this deviation is normalized to the maximum deviation which is 90°, an SA value of 0% indicates perfect symmetry, while 100% indicates that two values are equal and opposite. Taking into account that all kinetic variables are positive, the symmetry angle was calculated with the following equation:

$$SA = \left| \frac{45^\circ - \arctan(X_{\text{left}}/X_{\text{right}})}{90^\circ} \right| \times 100\% \quad (1)$$

SA values were calculated for each of the seven kinetic variables for all female and male runners running at respectively 8 km h⁻¹ and 9 km h⁻¹ or 9 km h⁻¹ and 10 km h⁻¹. To test for differences in symmetry between the injured and noninjured

runners, SA values were calculated at a running speed of 9 km h⁻¹. For all runners exposure time (in hours of exposure) was calculated from the time a participant started the running program until the runner reported an RRI or until the end of the program.

For comparison of the injured versus the noninjured side in one sided injured runners, a ratio (injured side/noninjured side × 100%) was calculated for each kinetic variable. When ratio values were above 100%, load was higher on the injured side and vice versa.

Percentiles were calculated for symmetry angles of each kinetic variable. Subsequently, plots of relative incidence of RRI against level of asymmetry (lowest 25% of SA values, mid 50% of SA values, or highest 25% SA values of the sample) were made for impact peak, active peak, loading rate and contact time for both male and female runners. Relative incidence of RRI was calculated as number of injuries reported per 100 runners at risk.

2.3. Statistical analysis

Sample size was determined based on differences in loading rate. A previous study showed differences in loading rate between subjects with and without stress fracture of respectively 92.56 BW s⁻¹ (SD 24.74) and 79.65 BW s⁻¹ (SD 18.81) [12]. With an alpha 0.05, 80% power and an expected injury incidence of 15% [1] a minimum of 172 participants were needed in the uninjured group and 26 were needed in the injured group to detect clinically relevant differences in all variables between groups. The kinetic SA values were not normally distributed and data transformation did not result in statistical normality. Therefore, nonparametric tests were used to compare SA values at baseline measurements between different running speeds, gender and between injured and noninjured runners at 9 km h⁻¹. Pearson's chi-square tests were used to test for significant associations in the relative RRI incidence plotted against level of asymmetry. To test for differences between the injured and noninjured side within the injured runners, paired *t*-tests were conducted. Differences were considered statistically significant at *p* < 0.05.

The symmetry angles of kinetic variables as potential factors associated with RRI were first analyzed to observe the independent link with RRI. Variables independently associated (*p* ≤ 0.25) with RRI were entered into the Cox regression model. Hazard Ratios (HR) and the corresponding 95% CI were calculated for the SA values associated with RRI. The weight for each risk factor was adjusted for BMI, age, gender, leg length and (intervention) group. The final outcome was a hazard ratio for risk of RRI compared to participants without RRI identified in the model. All analyses were performed using SPSS version 18.0 (SPSS Inc., Chicago).

3. Results

Two hundred ten novice runners enrolled in the study, 133 (63.3%) female and 77 (36.7%) male runners. Mean age was 37.2 ± 11.2 years, body mass index (BMI) was 23.9 ± 3.4 kg m⁻². Age (35.9 ± 10.7 versus 39.6 ± 11.4 years) and BMI (23.5 ± 3.5 versus 24.7 ± 3.1) in female runners were significantly lower compared to male runners. Leg length of female runners (0.91 ± 0.09) was significantly shorter than the male runners (0.96 ± 0.05). The incidence of an RRI during the 9-week running program was 16.2%. Twenty-three female (17.3%) and 11 (14.3%) novice male runners reported an RRI. Most frequent injured body parts were knee (38.2%), lower leg (26.5%) and ankle/foot (11.8%).

3.1. Natural levels of asymmetry

Kinetic variables and corresponding SA values for female running at 8 and 9 km h⁻¹ and male participants running at 9 and 10 km h⁻¹ can be found in respectively Table 1. In female runners SA values for step length were significantly smaller when running at a 9 km h⁻¹ compared to 8 km h⁻¹. For male runners, no significant differences in symmetry were found between both running speeds.

3.2. Injured versus noninjured runners

A comparison of injured and noninjured runners with respect to kinetic variables and corresponding SA values can be found in Table 2. Injured runners had significant higher SA for contact time and significant lower SA values for impact peak. These results are visualized in Fig. 1 which displays the impact forces and contact times of the right and left leg in a box plot which differentiates between injured and noninjured runners. As shown in Fig. 2, the

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