Gait-Related Risk Factors for Exercise-Related Lower-Leg Pain during Shod Running

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ABSTRACT

WILLEMS, T. M., E. WITVROUW, A. DE COCK, and D. DE CLERCQ. Gait-Related Risk Factors for Exercise-Related Lower-Leg Pain during Shod Running. Med. Sci. Sports Exerc., Vol. 39, No. 2, pp. 330-339, 2007. Purpose: Exercise-related lower-leg pain (ERLLP) is a common chronic sports injury. In clinical practice, deviant gait biomechanics are frequently considered to play a role in the development of ERLLP, although there is scarce scientific evidence that gait-related variables predispose athletes to this injury. The purpose of this study was to examine prospectively the gait-related risk factors for ERLLP during shod running in a young, physically active population. Methods: The gait pattern during shod running of 400 physical education students was evaluated at the beginning of their academic study. This was accomplished by means of plantar pressure measurements and 3D gait kinematics. After this evaluation, the same sports physician registered all sports injuries during this study. Results: During the follow-up period, 46 subjects developed ERLLP, of whom 29 subjects had bilateral complaints. Thus, 75 symptomatic lower legs (35 left and 40 right) were classified into the ERLLP group. Bilateral feet of 167 subjects who sustained no injuries at the lower extremities served as the referent group. Cox regression analysis revealed that subjects who will develop ERLLP have an altered running pattern compared with the referent subjects. More specifically, these subjects showed a significantly increased pronation excursion, accompanied by more pressure underneath the medial side of the foot, a delayed maximal eversion, and an accelerated reinversion. Conclusion: The findings of this study suggest that altered gait biomechanics during shod running play a role in the genesis of ERLLP and, thus, should be considered in prevention and rehabilitation of this pathology. Key Words: SHIN SPLINTS, STRESS FRACTURES, KINEMATICS, PLANTAR PRESSURE

Regular physical activity reduces the risk of premature mortality in general and of coronary heart disease, hypertension, colon cancer, obesity, and diabetes mellitus in particular. However, the increasing promotion of physically active lifestyles for their positive effect on physical and mental health brings along the possible problem of increasing the risk of sports injuries. Approximately 50% of all sports injuries are secondary to overuse. These injuries result from repetitive microtrauma that causes local tissue damage. The most common overuse injuries in athletes are Achilles tendinopathy and exercise-related lower-leg pain (ERLLP). Most commonly, runners, track athletes, and athletes participating in jumping sports are diagnosed with ERLLP. This injury is also a common and enigmatic overuse problem in military populations. The term "exercise-related lower-leg pain" will be used in this paper as used by Brukner, because it adequately describes the clinicopathological features of the condition yet remains appropriate for several pathologies or terms, such as shin splints, shin pain, medial tibial stress syndrome, periostitis, compartment syndrome, and stress fractures. The main feature of this complaint is that pain is brought on or is aggravated by loading during intensive, weight-bearing activities, and diminishes or ceases when activity ceases.

Preventing ERLLP requires knowledge of the risk factors that predispose to this injury. The causes of ERLLP are not always easily determined but are often linked to repetitive stress. Previous work has suggested that ERLLP results from a complex interaction of numerous factors. The correlation of ERLLP with extrinsic factors as a rapid increase in training volume, intensity, or weekly running distance is well established. However, in the literature, there are very few studies focusing on identifying intrinsic risk factors for ERLLP, and thus our understanding of the injury causation remains limited. Retrospective studies have noted excessive dynamic foot
pronation in subjects with a history of ERLLP (17,27). In addition, static foot posture in subjects with ERLLP also showed pronated foot alignment (23). A recent prospective investigation, using the same cohort as this study, showed that subjects susceptible for ERLLP showed an altered barefoot running pattern that included a central heel strike, a significantly increased pronation accompanied by more pressure underneath the medial side of the foot, and significantly more lateral roll-off (29). However, most of athletes perform their sports in shod condition; therefore, the purpose of the current study was to prospectively determine gait-related risk factors for ERLLP during shod running. It was hypothesized that the risk factors during shod running were identical to the risk factors during barefoot running.

METHODS

Subjects

Four hundred healthy undergraduate physical education students (241 men, 159 women; age range: 17–28 yr; mean age: 18.4 ± 1.1 yr) from three separate freshman cohorts in 2000–2001, 2001–2002, and 2002–2003 in physical education at the Ghent University, Belgium volunteered to participate. All volunteers signed an informed consent form. The study was approved by the ethical committee of the Ghent University Hospital.

At the beginning of their university education, the shod gait pattern of the students was evaluated. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of a surgical procedure involving the lower leg, ankle, or foot, or history of an injury to the lower leg, ankle, or foot within 6 months before the start of the study.

At the university level, the students followed the same sports program under the same environmental conditions for 26 wk per academic year. All students used the same sports facilities, and the safety equipment was uniform. The workout program in the first year consisted of three quarters of an hour of soccer, handball, basketball, and volleyball; 1 h of track and field, gymnastics, karate, and swimming; and 2 h of dance every week. In the second year, the weekly workout program consisted of a half hour of climbing; 1 h of track and field, soccer, handball, basketball, volleyball, karate, and swimming; and 2 h of dance every week. In the third year, the program consisted of a half hour of track and field, volleyball, soccer, gymnastics, orienteering, and swimming, and 1 h of handball, basketball, badminton, dance, and judo every week. Extramural activities (i.e., the amount of physical activities students participate in beyond their sports lessons at school) were also registered.

The students were followed weekly by the same sports physician for occurrence of injury. Freshmen in 2000–2001 were followed for 3 yr, freshmen in 2001–2002 were followed for 2 yr, and freshmen in 2002–2003 were followed for 1 yr. They were asked to report all injuries resulting from sports activities to this physician. All sports injuries, sustained during practice, lessons, and games were registered. The injury definition was based on that of the Council of Europe (26). The definition requires that an injury occurred during physical activity and that the injury has at least one of the following consequences: 1) a reduction in the amount or level of sports activity, 2) a need for (medical) advice or treatment, or 3) adverse social or economic effects. Injury data were recorded on a standardized injury form that captured basic information about the type of injury, the circumstances in which the injury occurred, and the treatment of the injury. All injuries were medically assessed by the physician. When the diagnosis was not clear through this clinical assessment, an x-ray, echography, bone scintigraphy (for diagnosis of stress fractures), or intracompartmental pressure measurement (for diagnosis of compartment syndrome) were performed.

Instrumentation and Protocol

Before the start of their physical education, all students were tested for 3D kinematics combined with plantar pressure measurements and ground reaction forces during shod running. All students wore the same standard neutral running shoe with a flat outsole. Following a standing calibration trial, the subjects were asked to run at a speed of 3.3 m·s⁻¹ within a boundary of 0.17 m·s⁻¹. Before the measurements, all subjects performed habituation trials to get familiarized with the testing environment. Three valid left and three valid right stance phases were measured. A trial was considered valid when the following criteria were respected: a heel strike pattern, running speed within the outlined boundaries, and no visual adjustment in the gait pattern to contact the pressure plate. From all kinetic and kinematic data, the mean of the three trials was calculated.

A foot-scan pressure plate (RSScan International, 2 × 0.4 m, 16384 sensors, 480 Hz) was mounted flush in the middle of a 16.5-m-long wooden running track on a 2-m AMTI-force platform. Video data were collected at 240 Hz using seven infrared cameras (Proreflex and Qualisys software. Marker placement was based on that of McClay and Manal (15,16) (Fig. 1). Retroreflective markers were placed on the upper leg, the lower leg, and the foot. The anatomic markers were placed on the greater trochanter, the medial and lateral femoral condyles, the medial and lateral malleolus, the medial and lateral side of the heel counter, and on the shoe at the lateral border of the head of the first and fifth metatarsals. The tracking markers consisted of a rigid plate with four retroreflective markers secured to the thigh, the shank, and the medial, lateral, and upper markers on the heel counter. This particular orientation enables the markers to define the anatomic coordinate system and to be used to track the motion of the segments (15). Raw marker positioning was filtered with a second-order, bidirectional low-pass Butterworth filter with a padding point, using the reflected method. The cutoff frequency was 18 Hz for the markers of the foot and the lower leg and 6 Hz for the markers of the thigh.
A multisegment model was developed to calculate 3D joint angles (in Visual 3D, C-motion). The 3D motions of the knee and the ankle were investigated through positioning of the segments with respect to each other: rear foot with respect to a laboratory coordinate system, rear foot to lower leg, and lower leg with respect to the upper leg. Joint rotation was calculated around the mediolateral, sagittal, and frontal axis. For movement at the ankle, dorsiflexion–plantarflexion occurs around the mediolateral axis in the sagittal plane, inversion–eversion around the sagittal axis in the frontal plane, and adduction–abduction around the frontal axis in the transverse plane. At the knee, motion around the mediolateral axis constitutes flexion–extension, motion around the sagittal axis constitutes varus–valgus, and motion around the frontal axis constitutes internal–external rotation. All angles were referenced to standing. This study focused on the stance phase during running. Therefore, from the kinematic data, initial position at heel strike, position at push-off, maximal position and timing of this position, excursion, and maximal and mean excursion velocity were identified for the rear foot with respect to a laboratory frame, rear foot to shank, and shank with respect to thigh.

Because pronation is a triplanar motion consisting of the components’ eversion, abduction, and dorsiflexion, we additionally analyzed the 3D pronation angle. The angle is calculated by a vector summation of the three rotation axes. To be more precise, the three angles and rotation axes can be written as $\phi_1r_1$, $\phi_2r_2$, and $\phi_3r_3$, where $\phi_i$, $i = 1, \ldots, 3$, is related to the three angles, and $r_i$, $i = 1, \ldots, 3$, is related to the rotation axes. Hence, the vector summation is given by $\phi_1r_1 + \phi_2r_2 + \phi_3r_3$. The above summation can be written as $\phi_{3D}r_{3D}$, with $\|r_{3D}\| = 1$. Finally, the term $\phi_{3D}$ is defined as the 3D pronation angle.

For each plantar pressure trial, eight anatomic pressure areas were automatically identified by the software, controlled, and, if necessary, adapted by the researcher (Fig. 2; Footscan software 7.0 Gait, RsScan International). These areas were defined as medial heel ($H_M$), lateral heel ($H_L$), metatarsals I–V ($M_1$, $M_2$, $M_3$, $M_4$, and $M_5$), and the hallux ($T_1$).

Temporal data (i.e., time to peak pressure, instants at which the regions make contact, and instants at which the regions end foot contact), peak pressure data, and impulses (mean pressure $\times$ loaded contact time) were calculated for all eight regions. For each trial, besides the total foot contact time, five distinct instants of foot rollover were determined, namely, first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel-off (HO), and last foot contact (LFC). FFC is defined as the instant the foot makes first contact with the pressure plate. FMC is defined as the instant one of the metatarsal heads contacts the pressure plate. FFF is defined as the instant the heel region loses contact with the pressure plate. LFC is defined as the last contact of the foot on the plate. On the basis of these instants, total foot contact could be divided into four phases: initial contact phase (ICP; FFC $\rightarrow$ FMC), forefoot contact phase (FFCP; FMC $\rightarrow$ FFF), foot flat phase (FFF; FFF $\rightarrow$ HO), and forefoot push-off phase (FFPOP; HO $\rightarrow$ LFC) (Fig. 3) (6). A mediolateral pressure ratio was calculated at these five instants of foot contact (ratio $= [(H_M + M_1 + M_2) - (H_L + M_4 + M_5)] \times 100$/sum of pressure underneath all areas).
FIGURE 3—Five distinct instants and phases relative to total foot contact (6,29).

(30). Excursion range of this ratio was calculated over the four phases (ICP, FFCP, FFP, FFPOP).

The x-component (mediolateral) and y-component (anterior-posterior) of the COP, scaled to the shoe width and shoe length, respectively, were analyzed (Fig. 4). The positioning and displacements of the components were calculated at the five instants and in the four phases.

From the vertical ground reaction forces, the magnitude of the impact forces and the mean and maximal rates of impact loading were analyzed. These data were normalized to body weight to allow for comparison between subjects of different mass.

Statistical Analysis

SPSS for Windows (version 11.0) was used for statistical analysis. The students were divided into two groups: an uninjured group as the referent group (group 1), and a group with subjects who developed ERLLP (group 2). Group 1 consisted of both lower legs of subjects who did not have any injury to either leg in the period they were observed in this study. Subjects for whom data were missing or who developed injuries other than ERLLP (N = 187) were excluded from the comparison. For group 2, data from only the injured legs were used for analysis. A univariate Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the athletes were at risk. This approach has been chosen for statistical analysis because this method can adjust for variations in the amount of sport participation between the students. The time from the start of the follow-up period until the first symptoms of ERLLP, or the end of follow-up for students who were not injured, was the main variable. For subjects with bilateral symptoms, time until the first symptoms of the first injury occurrence was used, because in most cases, symptoms appeared in both legs approxi-
ERLLP, exercise-related lower-leg pain.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No Injury (N = 334)</th>
<th>Hazard Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion–extension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial position (*)</td>
<td>7.47 ± 7.01</td>
<td>9.00 ± 6.21</td>
<td>0.965</td>
</tr>
<tr>
<td>Maximal position (*)</td>
<td>43.87 ± 5.26</td>
<td>43.99 ± 5.83</td>
<td>1.000</td>
</tr>
<tr>
<td>Flexion excursion (*)</td>
<td>36.42 ± 6.42</td>
<td>35.11 ± 5.31</td>
<td>1.045</td>
</tr>
<tr>
<td>Push-off position (*)</td>
<td>15.53 ± 6.15</td>
<td>15.98 ± 6.08</td>
<td>1.005</td>
</tr>
<tr>
<td>Maximal flexion velocity (°.s−1)</td>
<td>613.06 ± 132.33</td>
<td>587.93 ± 129.47</td>
<td>1.001</td>
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<tr>
<td>Mean flexion velocity (°.s−1)</td>
<td>315.04 ± 60.82</td>
<td>300.79 ± 47.87</td>
<td>1.005</td>
</tr>
<tr>
<td>Timing of maximal flexion (% of stance phase)</td>
<td>47.48 ± 4.97</td>
<td>46.43 ± 4.70</td>
<td>1.029</td>
</tr>
<tr>
<td>Varus–valgus (+/−)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial position (*)</td>
<td>−2.30 ± 4.03</td>
<td>−1.39 ± 3.19</td>
<td>0.935</td>
</tr>
<tr>
<td>Maximal position (*)</td>
<td>4.58 ± 4.89</td>
<td>5.27 ± 4.85</td>
<td>0.981</td>
</tr>
<tr>
<td>Varus excursion (*)</td>
<td>7.57 ± 2.57</td>
<td>6.94 ± 3.51</td>
<td>1.058</td>
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<tr>
<td>Push-off position (*)</td>
<td>−2.71 ± 3.55</td>
<td>−1.69 ± 4.18</td>
<td>0.952</td>
</tr>
<tr>
<td>Maximal varus velocity (°.s−1)</td>
<td>222.89 ± 73.59</td>
<td>196.78 ± 92.83</td>
<td>1.003</td>
</tr>
<tr>
<td>Mean varus velocity (°.s−1)</td>
<td>85.19 ± 34.73</td>
<td>90.72 ± 37.38</td>
<td>1.003</td>
</tr>
<tr>
<td>Timing of maximal varus (% of stance phase)</td>
<td>44.66 ± 12.93</td>
<td>42.32 ± 16.30</td>
<td>1.010</td>
</tr>
<tr>
<td>Internal–external rotation (+/−)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Initial position (*)</td>
<td>−9.15 ± 4.88</td>
<td>−9.51 ± 6.64</td>
<td>1.011</td>
</tr>
<tr>
<td>Maximal position (*)</td>
<td>4.29 ± 4.92</td>
<td>5.66 ± 5.81</td>
<td>1.024</td>
</tr>
<tr>
<td>Internal rotation excursion (*)</td>
<td>14.73 ± 4.76</td>
<td>14.18 ± 4.53</td>
<td>1.026</td>
</tr>
<tr>
<td>Push-off position (*)</td>
<td>−6.36 ± 4.44</td>
<td>−5.83 ± 6.82</td>
<td>0.990</td>
</tr>
<tr>
<td>Maximal internal rotation velocity (°.s−1)</td>
<td>388.97 ± 108.51</td>
<td>338.05 ± 108.57</td>
<td>1.002</td>
</tr>
<tr>
<td>Mean internal rotation velocity (°.s−1)</td>
<td>113.98 ± 55.03</td>
<td>104.05 ± 46.10</td>
<td>1.003</td>
</tr>
<tr>
<td>Timing of maximal internal rotation (% of stance phase)</td>
<td>50.22 ± 13.17</td>
<td>52.03 ± 14.19</td>
<td>0.992</td>
</tr>
</tbody>
</table>

ERLLP, exercise-related lower-leg pain.
Table 3 shows the results from the univariate Cox regression analysis for the plantar pressure data. The analysis showed that the impulse underneath $M_S$ and $H_L$ is significantly decreased in the injury group ($P = 0.026$ and $0.045$, respectively). The significant difference between the mediolateral pressure ratio showed that a higher pressure underneath the medial side of the foot at foot flat ($P = 0.026$) and at heel-off ($P = 0.019$) increased the risk of ERLLP. In subjects susceptible to ERLLP, there was a significantly higher medial displacement of the pressure distribution during the initial contact phase ($P < 0.001$) and a smaller medial displacement during the foot flat push-off phase ($P = 0.017$).

The analyses of the COP (Table 4) showed a significant difference in the position of the mediolateral component of the COP at first foot contact ($P = 0.013$), which was more laterally positioned in the ERLLP group. In the injured subjects, during the initial contact phase ($P < 0.001$), there was a significantly higher medial displacement of the COP, and in the foot flat push-off phase ($P = 0.004$), there was less medial displacement. The anterior–posterior component of the COP did not show significant differences between the groups.

Ground Reaction Forces

No significant differences were found between the groups for the vertical force impact peak, nor for the mean and maximal loading rates (Table 5).

**Discussion**

The purpose of this study was to investigate the gait-related risk factors for ERLLP during shod running. There have been some retrospective studies comparing the running pattern of healthy subjects and subjects with ERLLP; however, to date, besides our previous study (29), no such prospective studies have been published. An additional purpose of this study was to compare the results of our earlier study in barefoot running with the results of this current study. The rationale to investigate the sho
condition is that athletes mostly perform their sports activities wearing sport shoes, and the effect of sport shoes on the identified risk factors during barefoot running is not known but is clinically very important.

As mentioned in the introduction, ERLLP is a common overuse injury in different kinds of populations with different kinds of physical activity levels. ERLLP not only involves professional athletes or military recruits but also recreational athletes. In this study, the population consists of physical education students, in which all kinds and levels of physical activity are present. The results of this study, therefore, cannot be generalized to professional athletes, runners, or jumpers, or to a military population.

This study reveals that the shod running pattern of subjects who developed ERLLP differed from that of subjects who remained injury free. Kinematic variables and plantar pressure data showed similar results. Summarized, the altered biomechanics included an increased pronation and prolonged eversion with a higher loading underneath during this phase, accompanied by a decreased impulse which indicated a higher medial pressure displacement during the initial phase in the subjects with subsequent ERLLP, and increased medial displacement of the COP in the initial position (injured: on average 10° more inverted vs referents). For the abduction excursion, the significant difference is mainly attributable to the enhanced minimal position after initial heel contact (injured: on average 0.5° more plantarflexed vs referents). For the dorsiflexion excursion, the significant difference is mainly attributable to the enhanced minimal position (injured: on average 1° more dorsiflexed vs referents), because the foot first slightly plantarflexes before going into dorsiflexion and partly by the increased maximal dorsiflexion (injured: on average 1° more dorsiflexed vs referents). For the abduction excursion, this significant difference is mainly attributable to the enhanced minimal position (injured: on average 1° more adducted), because the foot is first slightly adducting before going into abduction. These small differences at first foot contact and shortly after could indicate a less stable initial contact in the injured subjects, possibly because of proprioceptive deficits. Additionally, in these subjects, there is potentially an increased leverage at the subtalar joint, which could provoke increased initial pronation. This suggestion is in accordance with the more laterally positioned COP at first foot contact and the increased mediolateral pressure ratio and increased medial displacement of the COP in the initial contact phase in the subjects with subsequent ERLLP, which indicated a higher medial pressure displacement during this phase, accompanied by a decreased impulse underneath H, subsequently in the foot roll-off, this leads to a higher medial pressure distribution at forefoot flat and

### TABLE 4

<table>
<thead>
<tr>
<th>ERLLP (N = 75)</th>
<th>No Injury (N = 334)</th>
<th>Hazard Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-component FFC</td>
<td>-25.58 ± 11.38</td>
<td>-20.96 ± 9.35</td>
<td>0.965</td>
</tr>
<tr>
<td>x-component FMC</td>
<td>-10.74 ± 5.81</td>
<td>-9.41 ± 6.95</td>
<td>0.985</td>
</tr>
<tr>
<td>x-component FFF</td>
<td>-8.78 ± 6.38</td>
<td>-9.84 ± 6.02</td>
<td>1.027</td>
</tr>
<tr>
<td>x-component HD</td>
<td>-6.25 ± 6.94</td>
<td>-7.86 ± 7.19</td>
<td>1.029</td>
</tr>
<tr>
<td>x-component LFC</td>
<td>-2.76 ± 9.32</td>
<td>-1.14 ± 10.05</td>
<td>0.984</td>
</tr>
<tr>
<td>x-component ICP (Δ)</td>
<td>15.96 ± 7.64</td>
<td>11.25 ± 7.73</td>
<td>1.053</td>
</tr>
<tr>
<td>x-component FFCP (Δ)</td>
<td>1.96 ± 6.10</td>
<td>0.07 ± 6.23</td>
<td>1.034</td>
</tr>
<tr>
<td>x-component FFP (Δ)</td>
<td>2.69 ± 6.46</td>
<td>1.76 ± 5.99</td>
<td>1.016</td>
</tr>
<tr>
<td>x-component FFPPO (Δ)</td>
<td>3.49 ± 8.53</td>
<td>6.78 ± 8.97</td>
<td>0.956</td>
</tr>
<tr>
<td>y-component FFC</td>
<td>6.48 ± 2.32</td>
<td>6.73 ± 2.64</td>
<td>0.985</td>
</tr>
<tr>
<td>y-component FMC</td>
<td>20.01 ± 2.56</td>
<td>19.82 ± 2.91</td>
<td>1.031</td>
</tr>
<tr>
<td>y-component FFF</td>
<td>32.10 ± 5.49</td>
<td>33.44 ± 6.74</td>
<td>0.975</td>
</tr>
<tr>
<td>y-component HD</td>
<td>62.66 ± 5.15</td>
<td>63.80 ± 5.08</td>
<td>0.963</td>
</tr>
<tr>
<td>y-component LFC</td>
<td>92.41 ± 6.73</td>
<td>92.61 ± 6.27</td>
<td>0.968</td>
</tr>
<tr>
<td>y-component ICP (Δ)</td>
<td>13.53 ± 4.43</td>
<td>13.08 ± 4.20</td>
<td>1.021</td>
</tr>
<tr>
<td>y-component FFCP (Δ)</td>
<td>12.10 ± 5.13</td>
<td>13.63 ± 7.06</td>
<td>0.970</td>
</tr>
<tr>
<td>y-component FFP (Δ)</td>
<td>30.56 ± 7.63</td>
<td>30.35 ± 8.31</td>
<td>0.999</td>
</tr>
<tr>
<td>y-component FFPPO (Δ)</td>
<td>29.75 ± 7.05</td>
<td>27.73 ± 6.87</td>
<td>1.044</td>
</tr>
</tbody>
</table>

The x-component is positive when it is medially off the heel-M2/3 axis and negative when it is positioned laterally. ERLLP, exercise-related lower-leg pain; FFC, first foot contact; FMC, first metatarsal contact; FFF, forefoot flat; HD, heel-off; LFC, last foot contact; ICP, initial contact phase; FFCP, forefoot contact phase; FFP, foot flat phase; FFPPO, forefoot push-off phase. *P < 0.05.

### TABLE 5

<table>
<thead>
<tr>
<th>ERLLP (N = 75)</th>
<th>No Injury (N = 334)</th>
<th>Hazard Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact peak force (BW)</td>
<td>1.92 ± 0.31</td>
<td>1.94 ± 0.35</td>
<td>0.720</td>
</tr>
<tr>
<td>Maximal loading rate (BW s⁻¹)</td>
<td>124.00 ± 39.83</td>
<td>133.30 ± 45.38</td>
<td>0.997</td>
</tr>
<tr>
<td>Mean loading rate (BW s⁻¹)</td>
<td>97.77 ± 17.53</td>
<td>71.10 ± 18.70</td>
<td>0.994</td>
</tr>
</tbody>
</table>

ERLLP, exercise-related lower-leg pain.
When the rear foot pronates, the foot becomes a mobile bones of the midfoot become locked up, thus allowing the COP during the forefoot push-off phase indicated an pressure ratio and the mediolateral component of the to the increased reinversion velocity, the mediolateral ERLLP was an increased reinversion velocity. According pathophysiological traction theory (3,18).

periosteum, and this assumption could be linked with the traction, some authors suggest an inflammation of the posterior region of the tibia. Because of the excessive musculature, which have their origin on the medial and eccentric traction to the plantar flexor and invertor attempts to control the motion. This may lead to excessive pronation as the supination musculature with a possibly altered landing strategy. However, in our injured subjects, no increased internal rotation at the knee was observed. Therefore, we suggest that these motions could be absorbed by musculoskeletal structures in the lower leg itself. This could lead to excessive midtibial torsion stress during the stance phase. This explanation would support the bone stress theory, which suggests that ERLLP is a bone stress reaction (19). However, we are aware that it is difficult to confirm this hypothesis with the current data because of the limited accuracy of the measurements of the transversal movements of the lower extremity with skin-mounted markers (8). On the other hand, increased supination moments may be associated with the excessive pronation as the supination musculature attempts to control the motion. This may lead to excessive eccentric traction to the plantar flexor and invertor musculature, which have their origin on the medial and posterior region of the tibia. Because of the excessive traction, some authors suggest an inflammation of the periosteum, and this assumption could be linked with the pathophysiological traction theory (3,18).

Another characteristic identified as risk factor for ERLLP was an increased reinversion velocity. According to the increased reinversion velocity, the mediolateral pressure ratio and the mediolateral component of the COP during the forefoot push-off phase indicated an increased lateral push-off. During the reinversion phase, bones of the midfoot become locked up, thus allowing the foot to become more stable and act as a rigid lever for push-off. During the pronation phase, an excessive pronation took place, which led to a less stable foot. To compensate for this excessive pronation, of which the maximal eversion was also delayed, an accelerated reinversion could occur to provide the rigid lever for push-off.

Although it has been frequently assumed in the literature that there is a potential association between impact forces and running-related injuries, we could not find significant differences for the impact peak force and the loading rate between the groups. Therefore, we do not support the concept of impact forces as one of the reasons for the onset of ERLLP.

An additional purpose of this investigation was to compare the identified risk factors for ERLLP during shod running and those during barefoot running. Because the investigated population is identical and the methods and statistical analysis used are similar in our current and the previous investigation (29), we can compare both results.

In general, the identified risk factors during shod running are similar to those identified during barefoot running. However, the identified shod risk factors are less pronounced than the barefoot risk factors, because some significant differences identified in the barefoot condition only show a trend toward significance, or they disappeared in the shod condition.

The findings of an association between ERLLP and an increased pronation accompanied with a higher medial pressure distribution and accelerated reinversion during shod running affirm earlier similar findings during barefoot running (29). However, some small differences between the shod and barefoot conditions should be highlighted.

In contrast to the barefoot condition, in which the eversion excursion was a significant risk factor for ERLLP, the eversion excursion here only indicated a trend towards significance between the injured and referent groups. In this investigation, we observed that during the shod condition, the eversion excursion increased by approximately 6° when wearing shoes compared with barefoot running. Other previous investigations with shoe-mounted markers showed the same increased eversion excursion during shod running (24). However, in a more recent study by Stacoff et al. (25), in which barefoot running was compared with shod running using intracortical bone pins, it was shown that the differences between the two conditions were small and unsystematic. The authors suggest that shoe-mounted markers did not describe the real inversion–eversion movements of the foot and that there is an overestimation with externally mounted markers (25). The unsystematic differences in movements around the sagittal axis between the barefoot and shod condition could explain why no significant differences were observed between injured and noninjured subjects for the eversion excursion during shod running. The disappearance of the significant difference in abduction and eversion velocities between the two groups present in the barefoot condition could be attributed to the delay of the maximal eversion in the shod condition.

During the barefoot condition, a more central heel contact was identified as a risk factor for ERLLP (29). This was indicated by the anterior–posterior component of the COP, which was positioned further forward at initial foot contact in the injury group compared with the referent group. However, in the shod condition, this significance is not observed, possibly because of the altered heel touchdown in shod running compared with barefoot running (7).

Surprisingly, in the shod condition, we could not identify significant differences between the two groups for the mediolateral component of the COP at forefoot flat and
heel-off, although these variables were identified as risk factors in the barefoot condition. Because the pronation and the mediolateral ratios remain significantly different between the two groups, we cannot find a straightforward explanation for this discrepancy between the barefoot and shod conditions in the positioning of the COP.

As in the barefoot condition, in the shod condition, the increased reinversion velocity and increased lateral roll-off were identified as risk factors for ERLLP. Because the population is identical in both investigations, we suggest that we can link these findings with the diminished support at the first metatarsophalangeal joint, which showed a very mobile extension range of motion in the injured subjects compared with the referents. Although the shoe partly covers what the foot is doing inside the shoe, the shoe sole is probably not rigid enough to stabilize the first metatarsophalangeal joint and thus alter the running pattern of the subjects in the ERLLP group during push-off.

The findings of this study during shod running show the same trends of increased pronation and accelerated reinversion as during barefoot running (29). However, we have the impression that the shoe partly masked the intrinsic biomechanics at the foot and that some intrinsic risk factors identified during the barefoot condition were therefore less pronounced during the shod condition. Several reasons can be suggested. First, limitations include the externally mounted markers on the shoe, which do not precisely describe the movements of the foot. On the other hand, wearing shoes artificially broadens and lengthens the foot. The less differentiating power of the pressure variables could also be attributable to the use of another software system to analyze the pressure data during shod running. During shod running, it is not possible to overlay zones on the detected metatarsal heads as in the barefoot condition. Therefore, a new software package was developed with a standard scalable anatomic foot mask through which the analyzed surface underneath the anatomic regions of interest were enhanced. Analyzing the shod running pattern could also be performed with insoles; however, we chose to measure with the pressure plate. Future research could elucidate the differences between these two measurement systems.

Although the barefoot and the shod conditions show the same trends of risk factors, we propose that, when performing a gait analysis, either to prevent or to diagnose an overuse injury, one should first consider the barefoot analysis, and then the shod-condition analysis. When a choice needs to be made between performing plantar pressure measurements or the standard 3D kinematics as used in the current study, we recommend the plantar pressure measurement because the strongest risk factors for ERLLP during barefoot running were plantar pressure variables (29).

An important point that also needs to be highlighted is that the relationships were identified in a cohort population. This means that the identified risk factors would not always exist on an individual level. Not every identified risk factor was present in every subject who developed ERLLP, and not every subject who presented the risk factor developed the injury, either.

Clearly, prevention or early intervention of an injury is preferable to treating the injury (9,28). Prevention screening should take place to assess risk factors that could lead to sports injury problems. In the literature, very few studies are available on injury prevention, given the limited information available on risk factors and injury mechanisms (2,21).

The findings of this study suggest that altered biomechanics play a major role in the genesis of ERLLP. We suggest that to decrease the incidence of ERLLP, athletes should be screened on their gait pattern.

Because the results of this investigation during shod running are similar to, but less pronounced than, those during barefoot running, the worn neutral sport shoes used in this investigation do not alter the intrinsic risk factors in subjects susceptible to ERLLP. Thus, research is needed for developing strategies that could effectively alter the identified intrinsic risk factors in subjects susceptible to ERLLP. We suggest that the primary objective of these strategies should be to minimize the pronation excursion and the medial pressure distribution, because these variables can be linked with the pathophysiological development of the injury. However, the extent to which the latter gait variables should be corrected it is not yet clear. Pronation indeed forms an integral part of the normal foot unroll. It seems wise to "correct" these variables in a gentle, individualized way. The correcting strategies could consist of tape, inserts, or orthotics in the shoe or specially designed, adequate, antipronation shoes. Similarly, these strategies may decrease the increased reinversion velocity. Future investigations are needed to concentrate on the development of strategies to optimize gait pattern.

In conclusion, this is the first prospective study to identify an increased pronation excursion and accelerated reinversion during shod running as risk factors for ERLLP. The results are in accordance with previous research regarding barefoot running (29). To prevent these overuse injuries, athletes should be screened on identified risk factors, and these parameters should be adapted.

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REFERENCES


RISK FACTORS FOR ERLLP DURING SHOD RUNNING


