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Relationship between gait biomechanics and inversion sprains: a prospective study of risk factors[☆]

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Abstract

This prospective study determined gait related risk factors for inversion sprains in 223 physical education students. Static lower leg alignment was determined, and 3D-kinematics combined with plantar pressure profiles were collected. After evaluation, the same sports physician registered all sports injuries during the next 6–18 months. During this period, 21 subjects had an inversion sprain, one of whom had a bilateral sprain. Twenty-two ankles, 12 left and 10 right comprised the inversion sprain group and both feet of 36 non-injured subjects acted as controls. Comparison of the two groups revealed that the gait of subjects who are at risk of sustaining an inversion sprain had a laterally situated centre of pressure at initial contact. These subjects also showed a mobile foot type at first metatarsal contact, forefoot flat and heel off. In this type the foot is more pronated over a prolonged period and accompanied by more pressure underneath the medial side of the foot and a delayed maximal knee flexion. Resupination is delayed and roll off does not occur across the hallux, but more laterally, probably because of the diminished support at the first metatarsophalangeal joint. Total foot contact time was also longer in the inversion sprain group compared with controls. The findings of this study suggest that effective prevention and rehabilitation of inversion sprains should include attention to gait patterns and adjustments of foot biomechanics.

Keywords: Ankle sprain; Risk factors; Plantar pressure; Kinematics; Alignment

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1. Introduction

Lateral ankle sprain is a very common athletic injury but little is known about predisposing factors and only a few prospective studies have investigated the underlying risk factors [1–4]. Knowledge of the aetiology of ankle sprains is relevant for prevention and rehabilitation. The aetiology of inversion sprains is most probably multifactorial [5]. Intrinsic risk factors may include age, joint instability, muscle strength, muscle tightness, muscle strength asymmetry, previous injuries, adequacy of rehabilitation, psychosocial stress, and gait. Extrinsic risk factors relate to environmental variables such as the level of sporting expertise, exercise load (amount of competition and practice), amount and standard of training, position played, equipment, playing field conditions, rules, and foul play. Both intrinsic and extrinsic factors can influence each other and are therefore not independent of each other [6–8].

It has been assumed that biomechanical abnormalities in gait are one of the causes of inversion sprains and accurate positioning of the foot at touchdown is very important in gait and sports. It has been frequently hypothesized that contacting the ground in an increased inversion position could result in an ankle sprain [9,10]. A plantar flexed position of the ankle at touchdown, as well as an inverted position of the foot, are potential factors for an ankle sprain, because the ground reaction force moment arm about the subtalar joint increases [10–12]. Thus we hypothesized that increased pressure at the lateral border of the heel at touchdown may also be an underlying cause of an ankle sprain. As the centre of pressure (COP) can be interpreted as a moment arm for the vertical ground reaction force [13], a laterally situated COP may result in a sprain.

In a recent prospective study, increased calcaneal eversion range in women and increased talar tilt in men have been shown as risk factors for ankle sprains [4]. We hypothesized

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that these alignments would affect gait and could be indicative of a mobile foot type, which allows more eversion during stance.

A static foot type has also been investigated as a possible risk factor for ankle sprains, but differing results have been found. Dahle et al. [14] and Barrett et al. [15] found no correlation between foot type and ankle sprains whereas Williams et al. [16] reported a higher incidence of ankle sprains in individuals with a high arch.

Despite the belief that many factors play a role in the development of ankle sprains no prospective studies have been undertaken to determine the role of dynamic gait related risk factors. Therefore, the purpose of this prospective study was to determine gait related risk factors for inversion sprains in a physically active population.

2. Methods

2.1. Subjects

Two hundred and twenty-three physical education students who were freshman in 2001–2002 (93 students) and 2002–2003 (130 students) at the Ghent University in Belgium were evaluated (age: 18.3 years ± 1.0; height: 174.5 cm ± 8.4; body mass: 65.1 kg ± 8.6). Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of an injury to the lower leg, ankle or foot within six months before the start of the study. The Ethical Committee of Ghent University Hospital approved the study and all volunteers gave informed consent. Before the start of their academic study, 3D kinematic, plantar pressure and lower leg alignment data were collected.

The same sports physician registered all sports injuries during a year and a half for the first group and during six months for the second group. Injury data were recorded on a standardised injury form that included information about the type, mechanism and treatment of the injury.

2.2. Instrumentation

Plantar pressure data, 3D-kinematic data and lower leg alignment data were collected. A footscan pressure plate (RsScan International, 2m × 0.4 m, 16384 sensors, 480 Hz) was mounted flush in the middle of a 16.5 m long wooden running track upon 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 [17,18]. Retro-reflective markers were placed on the thigh, lower leg and rearfoot. The anatomical markers were placed on the greater trochanter, the medial and lateral femoral condyles, the medial and lateral malleolus, the medial and lateral part of the calcaneus and on the head of the first and fifth metatarsals. The tracking markers consisted of a rigid plate secured to the thigh, and the shank and the medial, lateral and upper markers on the calcaneus.

Following a standing calibration trial, the subjects were asked to run barefoot at a speed of 3.3 m/s within a boundary of 0.17 m/s. All subjects were allowed to familiarise themselves with the procedures before data collection. Three valid left and three valid right stance phases were measured. A trial was considered to be valid when the following criteria were met: a heel strike pattern, running speed within the outlined boundaries, no adjustment in step length or step frequency to aim on the pressure plate.

Static lower leg alignment characteristics comprised plantar and dorsiflexion range at the talocrural joint, inversion and eversion range at the subtalar joint, flexion and extension range at the first metatarsophalangeal joint (MTPJ 1), hip internal and external rotation and position of the calcaneus in stance.

2.3. Data analysis

For each trial, eight anatomical pressure areas were identified by the researcher, based on the peak pressure footprint (Fig. 1; Footscan software 6.3.4 mst, RsScan international). These areas were defined as medial heel (H_1), lateral heel (H_2), metatarsal heads I–V (M_1, M_2, M_3, M_4 and M_5) and the hallux (T_1) (heel areas: 2.1 cm × 1.5 cm; metatarsal areas and hallux: 1.4 cm × 1.0 cm).

Temporal data (i.e. time to peak pressure, instants on which the regions make contact and instants on which the regions end foot contact), peak pressure data and absolute impulses (mean pressure × loaded contact time) and relative impulses (absolute impulse × 100/sum of all impulses) were calculated for all eight regions. As well as the total foot contact time, five distinct instants of foot rollover were determined for each trial. These were: first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF),

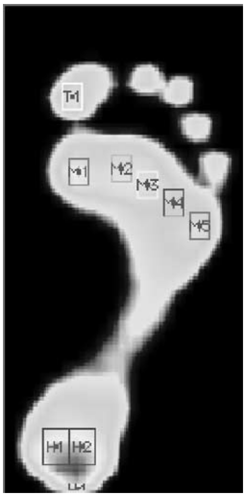

Fig. 1. The location of eight anatomical important areas on the peak pressure footprint. (Footscan software 6.3.4 mst, RsScan International).

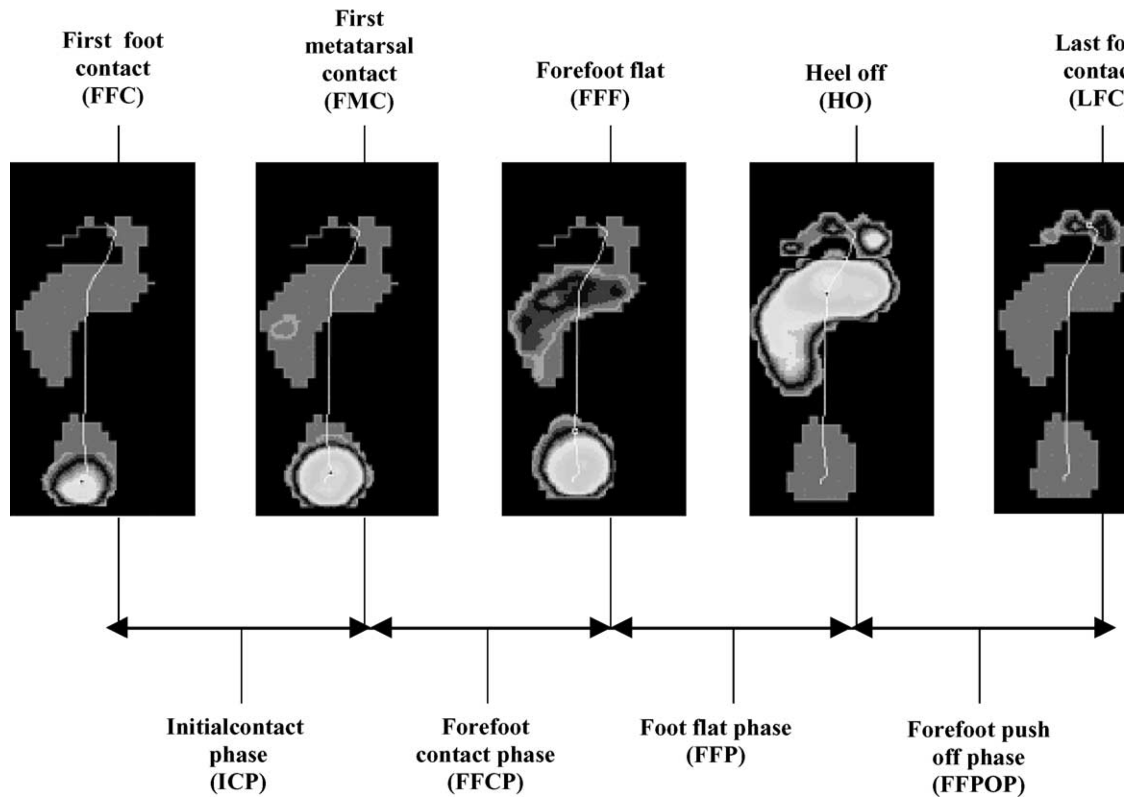

Fig. 2. Five distinct instants and phases relative to total foot contact.

heel off (HO) and last foot contact (LFC). FFC was defined as the instant the foot made first contact with the pressure plate. FMC was defined as the instant when one of the metatarsal heads contacted the pressure plate. FFF was defined as the first instant all metatarsal heads made contact with the pressure plate. HO was defined as the instant the heel region lost contact with the pressure plate. LFC was defined as the last contact of the foot on the plate. Based on these instants, total foot contact could be divided into four phases: initial contact phase (ICP; FFC → FMC), forefoot contact phase (FFCP; FMC → FFF), foot flat phase (FFP; FFF→ HO) and forefoot push off phase (FFPOP; HO→ LFC) (Fig. 2). Two medio-lateral pressure ratios were calculated at these five instants of foot contact (Ratio 1 $= [(H_1 + M_1 + M_2) - (H_2 + M_4 + M_5)]/$sum of pressure underneath all areas; Ratio 2 $= (M_1 - M_5)/$sum of pressure underneath all metatarsal heads). Ratio 1 describes the pressure distribution in the whole foot and ratio 2 the pressure distribution in the forefoot. Excursion ranges of these ratios were calculated over the four phases (ICP, FFCP, FFP, FFPOP).

The X-component (medio-lateral) and Y-component (anterior-posterior) of the centre of pressure (COP) scaled to the foot width and foot length, respectively, were analysed (Fig. 3). The positioning and displacements of the components were calculated at the five instants and in the four phases.

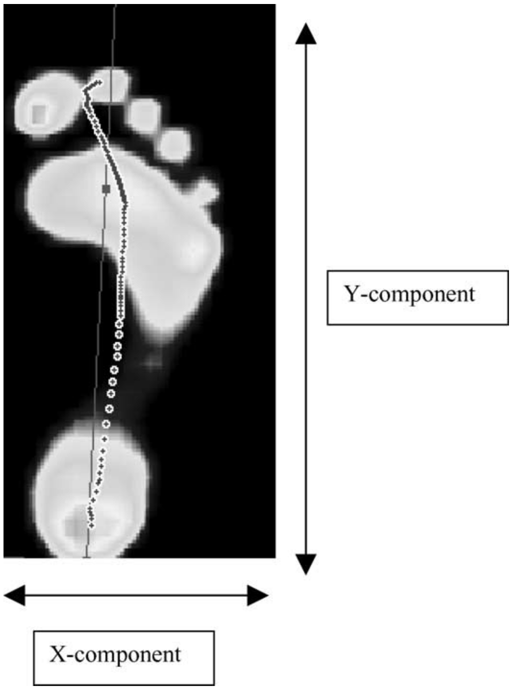

Fig. 3. The X-component (medio-lateral) and Y-component (anterior-posterior) of the centre of pressure. The X-component is positive when it is positioned medially of the heel-M2 axis and negative when it is laterally positioned.

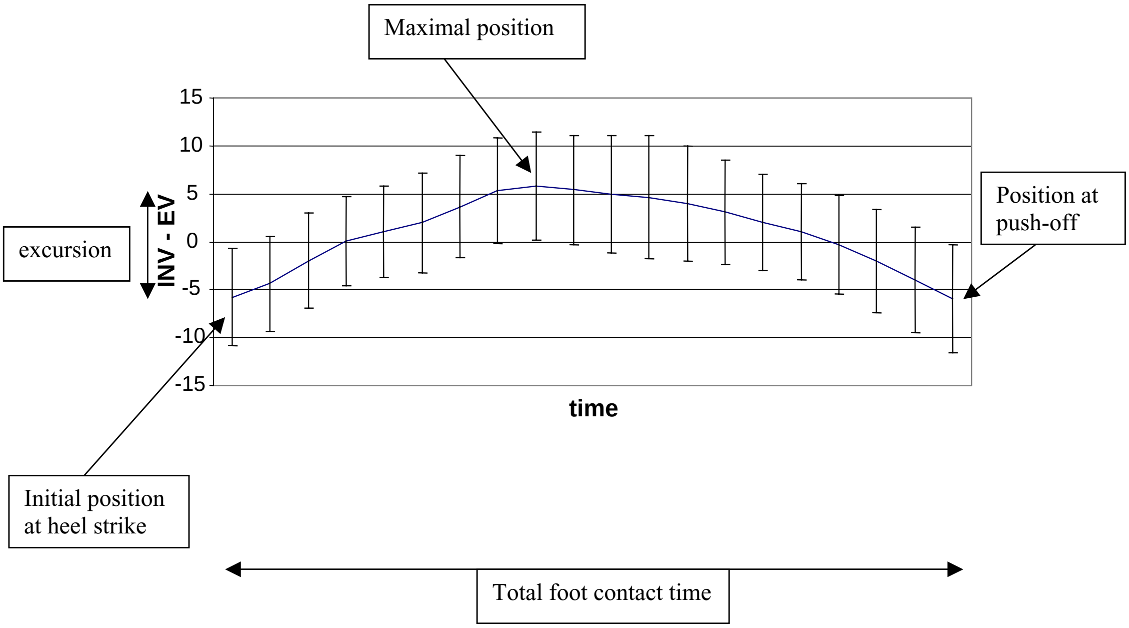

Fig. 4. Indication of the identified kinematic variables (total foot contact time, initial position at heel strike, position at push-off, maximal position and excursion) on the mean curve for inversion–eversion movement of the rearfoot with respect to the lower leg as example.

A multi-segment model was developed to calculate 3D joint coordinate system angles (Visual 3D, S. Selbie, USA). The three-dimensional motions of the knee and the ankle were investigated through positioning of the segments with respect to each other: rearfoot with respect to a laboratory coordinate system, rearfoot to the lower leg and the lower leg with respect to the thigh. Joint rotation was calculated around the medio-lateral, sagittal and frontal axes. 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, relative time to maximal position, excursion, maximal and mean velocity and time to maximal velocity were identified for rearfoot with respect to a laboratory frame, rearfoot to lower leg and lower leg with respect to thigh (Fig. 4).

The mean of all kinetic and kinematic data was taken from the three trials. Previous research has shown that the mean of three trials is sufficient for analysis [19,20].

2.4. Statistical analysis

During the injury registration period, 21 subjects (13 male and eight female) had an inversion sprain; one subject had a bilateral sprain. The inversion sprain group comprised 22 ankles (12 left and 10 right ankles). As control group, both feet of 36 uninjured subjects were selected out of the group of subjects who were followed for 18 months. This avoided the inclusion of subjects who were still at risk of an ankle sprain. None of these 36 subjects (23 male and 13 female) had any lower extremity injury.

SPSS for Windows (version 10.0) was used for statistical analysis. A binary logistic regression analysis [21] was performed to identify the intrinsic risk factors for inversion sprains. Student's *t*-tests (if the distributions of the data were normal) or Mann–Whitney *U*-tests (if no normal distribution of the data was obtained) were undertaken firstly to reduce the number of variables. All variables showing a *P*-value <0.1 in the univariate analysis were entered separately into the logistic regression analysis. A significance level of $\alpha \leq 0.05$ was used for the logistic regression analysis.

3. Results

Logistic regression analysis revealed that the absolute impulse underneath M_1 was significantly higher ($P = 0.050$) and the relative impulse underneath M_5 was significantly lower ($P = 0.039$) in the inversion sprain group. No significant differences were found between the two groups for the peak pressure underneath the eight anatomical areas. Mean and standard deviations for peak pressure, absolute impulse and relative impulse underneath the eight anatomical areas are shown in Table 1. Analyses revealed that total contact time was significantly longer in the inversion sprain group compared to controls ($P = 0.017$). Through logistic regression, no significant differences were found between the two groups for the other temporal pressure data (Table 2). The medio-lateral ratios (Table 3) show that pressure distribution was more medially directed at first metatarsal contact (ratio 2, $P = 0.004$), forefoot flat (ratio 1, $P = 0.038$; ratio 2, $P = 0.022$) and heel off (ratio 1, $P = 0.040$; ratio 2, $P = 0.049$)

Table 1
Mean and standard deviation for peak pressure, absolute impulse and relative impulse underneath the eight anatomical areas

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
PmaxT1 (N/cm^2)	39.77	17.82	37.08	23.62	0.569	–
PmaxM1 (N/cm^2)	50.35	21.38	60.62	32.17	0.087	0.103
PmaxM2 (N/cm^2)	58.95	15.48	62.87	22.05	0.353	–
PmaxM3 (N/cm^2)	49.71	11.44	50.60	10.69	0.747	–
PmaxM4 (N/cm^2)	39.02	13.13	36.13	8.07	0.333	–
PmaxM5 (N/cm^2)	38.35	17.08	30.81	15.37	0.067	0.072
PmaxH1 (N/cm^2)	90.69	27.39	82.01	24.74	0.188	–
PmaxH2 (N/cm^2)	83.46	28.71	75.78	26.47	0.267	–
AbsImpulsT1 (Ns/cm^2)	3.36	1.83	3.09	2.15	0.568	–
AbsImpulsM1 (Ns/cm^2)	4.74	1.97	6.09	3.61	0.026[a]	0.050[a]
AbsImpulsM2 (Ns/cm^2)	6.40	1.75	7.37	2.89	0.149	–
AbsImpulsM3 (Ns/cm^2)	5.29	1.25	5.69	1.46	0.211	–
AbsImpulsM4 (Ns/cm^2)	3.89	1.30	3.77	0.98	0.681	–
AbsImpulsM5 (Ns/cm^2)	3.43	1.62	2.81	1.49	0.112	–
AbsImpulsH1 (Ns/cm^2)	2.33	0.84	2.51	1.05	0.409	–
AbsImpulsH2 (Ns/cm^2)	1.97	0.85	1.95	0.92	0.936	–
RelImpulsT1 (%)	10.66	5.32	8.94	5.16	0.185	–
RelImpulsM1 (%)	15.21	5.99	17.80	7.93	0.106	–
RelImpulsM2 (%)	20.37	4.84	22.14	6.80	0.180	–
RelImpulsM3 (%)	16.85	3.17	17.36	4.56	0.551	–
RelImpulsM4 (%)	12.31	3.27	11.60	3.55	0.384	–
RelImpulsM5 (%)	10.89	4.41	8.59	4.33	0.034[a]	0.039[a]
RelImpulsH1 (%)	7.41	2.44	7.58	3.11	0.786	–
RelImpulsH2 (%)	6.29	2.68	5.99	2.77	0.649	–

(PMax: maximal peak pressure, AbsImpuls: absolute impulse, RelImpuls: relative impulse). Significance level for *t*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

[a] Significant difference between the two groups ($P \leq 0.05$).

Table 2
Mean and standard deviation for total contact time, time of first metatarsal contact, forefoot flat and heel off, relative first contact time and relative end of contact to total foot contact for the eight anatomical regions

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
Total contact time (s)	0.217	0.017	0.228	0.019	0.013[a]	0.017[a]
First metatarsal contact (s)	0.018	0.009	0.017	0.009	0.619	–
Forefoot flat (s)	0.039	0.011	0.038	0.014	0.551	–
Heel off (s)	0.094	0.020	0.103	0.020	0.086	–
First contact T1 (%)	31.06	9.76	32.23	8.99	0.618	–
First contact M1 (%)	17.83	5.37	15.27	5.12	0.050[a]	0.055
First contact M2 (%)	15.04	3.58	13.42	4.64	0.088	0.092
First contact M3 (%)	12.48	3.66	10.91	4.25	0.094	0.098
First contact M4 (%)	9.85	3.91	8.40	4.18	0.138	–
First contact M5 (%)	8.34	4.17	8.46	5.08	0.915	–
First contact H1 (%)	0.02	0.06	0.00	0.00	0.265	–
First contact H2 (%)	0.01	0.05	0.00	0.00	0.439	–
End contact T1 (%)	97.67	4.36	98.25	2.33	0.553	–
End contact M1 (%)	90.17	4.49	90.69	3.35	0.616	–
End contact M2 (%)	93.31	3.99	94.05	3.33	0.436	–
End contact M3 (%)	90.97	4.23	91.15	4.74	0.868	–
End contact M4 (%)	84.38	4.52	83.79	5.60	0.609	–
End contact M5 (%)	74.97	4.63	73.56	5.55	0.237	–
End contact H1 (%)	42.96	7.82	44.41	7.79	0.451	–
End contact H2 (%)	39.62	8.73	41.50	8.47	0.378	–

Significance level for *t*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

[a] Significant difference between the two groups ($P \leq 0.05$).

Table 3

Mean and standard deviation of the medio-lateral ratios at the five instants (first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO) and last foot contact (LFC)) and in the four phases of the stance phase (initial contact phase (ICP), forefoot contact phase (FFCP), foot flat phase (FFP) and forefoot push off phase (FFPOP)

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
Ratio 1 FFC	−0.141	0.378	−0.113	0.377	0.770	–
Ratio 1 FMC	−0.007	0.226	−0.010	0.233	0.961	–
Ratio 1 FFF	−0.212	0.210	−0.096	0.250	0.033[a]	0.038[a]
Ratio 1 HO	0.068	0.211	0.173	0.169	0.036[a]	0.040[a]
Ratio 2 FMC	−0.776	0.267	−0.538	0.384	0.011[a]	0.004[a]
Ratio 2 FFF	−0.318	0.141	−0.220	0.212	0.013[a]	0.022[a]
Ratio 2 HO	0.026	0.160	0.103	0.137	0.043[a]	0.049[a]
Ratio 1 ICP	0.135	0.197	0.104	0.193	0.522	–
Ratio 1 FFCP	−0.205	0.202	−0.086	0.236	0.022[a]	0.027[a]
Ratio 1 FFP	0.280	0.197	0.268	0.225	0.821	–
Ratio 1 FFPOP	−0.016	0.288	−0.159	0.177	0.030[a]	0.035[a]
Ratio 2 ICP	−0.769	0.268	−0.514	0.400	0.009[a]	0.002[a]
Ratio 2 FFCP	0.457	0.227	0.318	0.251	0.016[a]	0.020[a]
Ratio 2 FFP	0.344	0.172	0.323	0.131	0.602	–
Ratio 2 FFPOP	−0.026	0.160	−0.103	0.137	0.043[a]	0.049[a]

Significance level for *t*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis. Ratio $1 = [(\mathrm{H1} + \mathrm{M1} + \mathrm{M2}) - (\mathrm{H2} + \mathrm{M4} + \mathrm{M5})]/\mathrm{sum}$ of the pressure underneath all areas; Ratio $2 = (\mathrm{M1} - \mathrm{M5})/\mathrm{sum}$ of pressure underneath all metatarsal heads. A positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution.

[a] Significant difference between the two groups ($P \leq 0.05$).

in the inversion sprain group. Furthermore, medio-lateral ratios showed less displacement of the pressure from lateral to medial in the initial contact phase (ratio 2, $P = 0.002$) and forefoot contact phase (ratio 1, $P = 0.027$; ratio 2, $P = 0.020$). In the forefoot push off phase, there was significantly more pressure displacement from medial to lateral (ratio 1, $P = 0.035$; ratio 2, $P = 0.049$).

Values for the X-component of the COP are shown in Table 4. The X-component of the COP is situated significantly more laterally at last foot contact ($P = 0.012$) and COP displaces more laterally in the forefoot push off phase ($P = 0.004$) in the inversion sprain group. No significant differences are found for the Y-component of the COP.

Table 5 shows the mean values and standard deviations for the kinematic data of the rearfoot with respect to the laboratory frame in the frontal plane. Kinematic data show that the instant of maximal inversion velocity occurred significantly later in the inversion sprain group ($P = 0.050$). The timing of maximal knee flexion was significantly delayed ($P = 0.032$), and the mean knee flexion velocity was significantly lower ($P = 0.002$) (Table 6).

Alignment measurements showed that subjects in the inversion sprain group, had a significantly higher MTPJ I extension range of motion ($P = 0.021$; 78.25° ± 13.71° versus 67.33° ± 16.52° for the control group).

A Bonferroni correction was not applicable as all the variables that were evaluated in this study were strongly correlated. Altman et al. [22] have recommended that unadjusted *P*-values should be reported.

Table 4

Mean and standard deviation for the scaled X-component (medio-lateral) of the center of pressure in percentage of foot width at the five instants (first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO) and last foot contact (LFC)) and in the four phases (initial contact phase (ICP), forefoot contact phase (FFCP), foot flat phase (FFP) and forefoot push off phase (FFPOP)

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
X-comp FFC	−1.95	1.86	−2.75	2.84	0.062	0.138
X-comp FMC	−1.14	3.20	−2.00	3.65	0.286	–
X-comp FFF	−9.24	6.88	−7.84	6.06	0.392	–
X-comp HO	−10.21	6.65	−8.30	5.59	0.225	–
X-comp LFC	8.37	7.59	2.99	9.77	0.008[a]	0.012[a]
X-comp ICP	0.81	2.11	0.75	1.99	0.907	–
X-comp FFCP	−8.11	5.93	−5.83	5.97	0.120	–
X-comp FFP	−0.97	5.04	−0.46	5.08	0.682	–
X-comp FFPOP	18.55	8.85	11.29	11.03	0.002[a]	0.004[a]

The X-component is positive when it is positioned medially of the heel-M2 axis and negative when it is positioned laterally (Fig. 3). Significance level for *t*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

[a] Significant difference between the two groups ($P \leq 0.05$).

Table 5

Mean and standard deviation for kinematic data of the rearfoot with respect to the laboratory frame for the sagittal axis (inversion–eversion) (RelTime: relative time to total foot contact, Vel: velocity)

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
Initial eversion position (°)	−8.78	4.04	−8.90	3.31	0.913	–
Maximum eversion (°)	−0.87	4.34	0.56	4.25	0.117	–
Excursion eversion (°)	8.56	3.82	10.23	4.17	0.063	0.129
Pushoff eversion (°)	−10.68	3.97	−10.96	6.11	0.822	–
RelTime maximum eversion (%)	44.73	14.72	51.52	16.17	0.054	0.110
Maximum eversion Vel (°/sec)	240.34	110.71	301.19	152.94	0.105	–
Maximum inversionVel (°/sec)	−236.44	82.31	−264.67	120.69	0.265	–
RelTime maximum eversion Vel (%)	18.19	10.68	23.14	18.04	0.153	–
RelTime maximum inversion Vel (%)	81.90	18.73	91.99	6.13	0.000[a]	0.050[a]
Mean eversion Vel (°/sec)	72.06	43.11	75.07	37.62	0.797	–
Mean inversion Vel (°/sec)	−83.19	39.25	−100.83	53.62	0.137	–

Significance level for *t*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

[a] Significant difference between the two groups ($P \leq 0.05$).

Table 6

Mean and standard deviation for kinematic data of the lower leg with respect to the upper leg for the medio-lateral axis (flexion–extension in the knee) (RelTime: relative time to total foot contact, Vel: velocity)

	Mean control group	S.D. control group	Mean inversion sprain group	S.D. inversion sprain group	Significance *t*-test, MW *U*-test	Significance logistic regression
Initial flexion position (°)	12.64	6.34	11.62	7.39	0.586	–
Max flexion (°)	43.64	6.22	42.50	6.09	0.507	–
Excursion flexion (°)	31.00	4.43	30.42	4.97	0.652	–
Pushoff flexion(°)	20.17	6.55	17.46	7.14	0.146	–
RelTime maximum flexion (%)	44.20	4.75	47.54	6.51	0.021[a]	0.032[a]
Maximum flexion Vel (°/sec)	617.70	147.56	600.93	166.84	0.699	–
RelTime maximum flexion Vel (%)	18.02	6.39	16.63	7.49	0.450	–
Mean flexion Vel (°/sec)	285.01	39.01	245.69	27.64	0.000[a]	0.002[a]

Significance level for *T*-test or Mann–Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

[a] Significant difference between the two groups ($P \leq 0.05$).

4. Discussion

To date, no investigations for gait related variables as possible risk factors for ankle sprains have been performed. There have been some prospective studies on other intrinsic risk factors of ankle sprains e.g. generalized joint laxity, isokinetic muscle strength, ankle proprioception, anatomic alignment of the foot and ankle and muscle reaction time [2,4]. However, in overuse injuries of the leg, foot biomechanics are an important intrinsic risk factor [23,24]. We suggest that the mechanisms for the unrolling foot during stance phase could be important in the development of ankle sprains as well.

Our results demonstrate that the gait of subjects who will sustain an inversion sprain has typical characteristics. These can be summarised as follows: (1) a longer total foot contact time, (2) a higher loading underneath the medial and less loading underneath the lateral border of the foot, (3) a medially directed pressure distribution at first metatarsal contact, forefoot flat and heel off and less pressure displacements in the intervening phases, (4) a delayed knee flexion, (5) a more laterally directed pressure displacement in the forefoot push off phase and a laterally situated COP at last foot contact, and finally (6) a greater extension range of motion at the MTPJ I.

In contrast to our hypothesis of an increased inversion or plantar flexed foot position at initial contact, the results of this study show no kinematic differences at initial contact between the controls and the inversion sprain group. However, muscle model driven computer simulations have shown an increased touchdown plantar flexion which may cause an increased likelihood of an ankle sprain [10]. Spaulding et al. [25] observed in a retrospective study that chronically unstable ankles were more plantar flexed at foot contact compared to stable control ankles. In the plantar flexed position, the ankle is less stable than in the neutral or dorsiflexed position (close packed position) because of the anteriorly wedge-shaped structure of the talus. A frequent question in retrospective studies is whether the findings are the result or the cause of the injury. We did not find a limited dorsiflexion range or an increased touchdown plantar flexion in our subjects and hypothesize that after an ankle sprain there is a limited dorsiflexion range. This concurs with Spaulding et al. [25] and it seems that this lack of dorsiflexion contributes to a more plantar flexed position at initial contact. We suggest that an increased touchdown plantar flexion could therefore be considered as a consequence of an ankle sprain rather than a cause.

Many investigations have indicated that proprioception is disturbed after an ankle sprain [26–29]. An inappropriate positioning of the ankle may also be due to the loss of proprioceptive input from mechanoreceptors.

As hypothesized, the results of this study show a trend toward a laterally situated COP at first foot contact in the inversion sprain group. This implies that the thrust needed to invert the ankle is smaller in these subjects. It is possible that, while walking or running on uneven ground, ankles at risk of a sprain are less able to accommodate changes in the surface as well as controls can. Becker et al. [30] measured plantar pressure distribution during gait in subjects with functional and mechanical ankle instability. They found a significantly higher impulse underneath the lateral side of the heel in subjects with functionally unstable ankles. In mechanically unstable ankles, they did not find any differences in the heel region. When considering peak pressures and impulses at the heel in the current study, no significant differences between controls and the inversion sprain group were found even though the medio-lateral component of the COP is situated more laterally at first heel contact. These findings are probably due to methodological differences. In the study of Beckers et al. [30], the heel region was divided into three areas in contrast to the present study, where only two areas were defined.

Data from the present study show that loading underneath the medial side of the foot is higher and lower underneath the lateral border in subjects who will sustain an inversion sprain. This can be seen through (1) the absolute impulse underneath M_1, which was significantly higher, (2) the relative impulse underneath M_5, which was significantly lower, (3) the medio-lateral ratios, which indicates that pressure distribution was more medially directed at first metatarsal contact, forefoot flat and heel off and (4) less displacement of the pressure from lateral to medial in the initial contact and the forefoot contact phases. Kinematic data showed that there was a trend of a higher eversion excursion in the rearfoot. There was also a trend toward a delayed maximal eversion of the rearfoot. Biomechanically, there is no direct correlation between inversion sprains and an increase in medial loading. However, there is probably an indirect correlation and we suggest that the inversion sprain group have dynamic mobile feet. Although, no significant differences were found between the two groups for static inversion and eversion range of motion at the subtalar joint as in the study of Beynnon et al. [4], mobility at the midtarsal joints was not investigated. A possible explanation could be that subjects have an unstable feeling due to their mobile feet and try to unroll their feet more medially as a compensation to avoid lateral ankle sprains. This would cause more pressure underneath the medial side of the foot and is accompanied with more eversion.

In addition the relative contact of M_1 was earlier in the inversion sprain group. Even though M_1 was earlier in contact with the ground, peak pressure underneath M_1 occurred later. To explain these findings, it could be possible that the inversion sprain group had a hyper-mobile first ray. However the mobility of the first ray was not measured in this study.

At the knee, maximal flexion occurred significantly later in the inversion sprain group and mean knee flexion velocity was significantly smaller. This delayed knee flexion corresponded to the delayed maximal eversion of the foot. This phenomenon relates to the related timing of movement and coupling mechanism between the knee and the subtalar joint [31].

Kinematic results also showed that maximal resupination velocity was significantly delayed in the rearfoot in the inversion sprain group. This probably occurs because of the prolonged pronation phase and so resupination has to occur in a shorter time. Furthermore, the X-component of the COP was situated significantly more laterally at last foot contact and the COP was more displaced laterally in the forefoot push off phase. Hence medio-lateral ratios also showed more lateral pressure displacement in the forefoot push off phase. This suggests that roll off does not occur across the hallux, but more laterally, across the lesser toes. This is probably caused by the diminished support at the MTPJ I, which had a very mobile extension range of motion compared to the control group.

Ankle sprains are not solely related to running but also occur during lateral cutting and side-shuffle movements and landing from a jump. When landing from a jump, first contact is made with the toes and the same roll off pattern occurs in the opposite direction as in running. Because of the diminished support at the MTPJ I, it could be that the inversion sprain group also makes contact with the ground with the lateral toes instead of the hallux when landing from a jump. This plantar flexed position is very susceptible for inversion sprains [10]. However, this aspect was not investigated in the present study and is an area for future investigation.

Total foot contact time was also longer in the inversion sprain group compared to normal subjects. Therefore, only relative times to the total foot contact time were taken into consideration. A possible explanation for the longer stance phase is the longer time when the foot was everted.

We focused on the movements of the rearfoot, as in most previous biomechanical studies [17,18,32–34] and one of the limitations in our study was the lack of kinematics and alignment measurements of the midfoot and forefoot. However, plantar pressure measurements are very suitable to quantify the interaction between the different foot structures and the ground during stance [35].

The findings of this study suggest that effective prevention and rehabilitation of inversion sprains should include attention to gait patterns and adjustments of foot biomechanics in subjects at risk of a sprain. However, clinical assessment after an ankle sprain does not normally include a gait analysis. Ankle taping and bracing have been shown to reduce the incidence of respraining [36] and may be effective in preventing a first sprain. De Clercq [37] has shown that bracing reduces the range of subtalar eversion while running in normal subjects. Wearing a brace could result in a reduction of the mobility of the foot and a more even distribution of plantar pressures that could give more stability in susceptible subjects. Foot orthotic devices to give better support could also be prescribed to reduce the amount of extension range of motion in the MTPJ I.

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