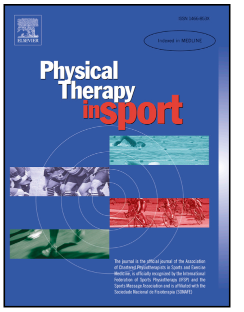

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ABSTRACT

Objectives: To explore whether homogeneous subgroups could be discriminated within a population of recreational runners with a running-related injury based on running kinematics evaluated with marker-based two-dimensional video analysis.

Design: Cross-sectional

Setting: Research laboratory

Participants: Fifty-three recreational runners (15 males, 38 females) with a running-related injury.

Main outcome measures: Foot and tibia inclination at initial contact, and hip adduction and knee flexion at midstance were measured in the frontal and sagittal plane with marker-based two-dimensional video analysis during shod running on a treadmill at preferred speed. The four outcome measures were clustered using K-means cluster analysis (n=2-10). Silhouette coefficients were used to detect optimal clustering.

Results: The cluster analysis led to the classification of two distinct subgroups (mean silhouette coefficient=0.53). Subgroup 1 (n=39) was characterized by significantly greater foot inclination and tibia inclination at initial contact compared to subgroup 2 (n=14).

Conclusion: The existence of different subgroups demonstrate that the same running-related injury can be represented by different kinematic presentations. A subclassification based on the kinematic presentation may help clinicians in their clinical reasoning process when evaluating runners with a running-related injury and could inform targeted intervention strategy development.

KEYWORDS

Running injury, kinematics, two-dimensional video analysis, subclassification

HIGHLIGHTS

Two homogeneous subgroups were identified in runners with running-related injuries.

Foot and tibia inclination were significantly different between subgroups.

The same injury can be represented by different kinematic presentations.

Similar kinematic presentations can be related to different injuries.

Marker-based 2D video analysis can be used to assist clinical reasoning.

INTRODUCTION

Running is an increasingly popular form of physical activity with associated general health benefits.[54] The incidence of running-related injuries remains high, ranging from 3 to 85%,[30, 55] creating a major barrier for continuing running.[20] Running-related injuries are hypothesized to occur from a combination of multiple interacting risk factors.[5, 43] Within this multifactorial etiologic framework, running kinematics may be related to running-related injury by contributing to structure-specific loading.[5, 43]

Interestingly, different studies have associated similar kinematics with different running-related injuries. For example, greater hip adduction has been associated with patellofemoral pain,[42] iliotibial band syndrome,[1] tibial stress fractures[40, 48] and gluteal tendinopathy.[23] Bramah et al[8] reported greater peak contralateral pelvic drop, forward trunk lean, and a more extended knee and dorsiflexed ankle at initial contact in runners with a variety of running-related injuries, compared to non-injured controls. Within these studies, injured and non-injured runners have been considered as two homogeneous groups. However, it is unclear whether group-based average results of isolated angular measurements are applicable to the individual with a highly specific clinical biomechanical presentation.[14, 22] Creating two distinct groups based on pre-defined injury status fails to acknowledge the existence of inter-individual variance within kinematic patterns.[46] It is likely that specific subgroups with particular kinematic presentations are present within a group of runners with running-related injuries, even when the medical diagnosis is the same.[14, 29, 56]

The existence of distinct subgroups has been reported in non-injured runners,[46] as well as in runners with patellofemoral pain[12, 44, 56] and a variety of running-related injuries[29] based on three-dimensional motion analysis. Different methods have been used to identify these subgroups. Unsupervised machine learning data analysis techniques have the advantage to identify subgroups within a population by discovering patterns or associations in data without a priori information or bias by a researcher, aside from the set of variables being measured.[29]

Although three-dimensional motion analysis has been considered the gold standard approach for a detailed running analysis,[37] this method is rarely implemented in clinical settings as it requires expensive equipment and time. Recent research, including our own work, has reported excellent intra- and interrater reliability,[11, 17, 18, 37] test-retest reliability[13] as well as validity[18, 37] of marker-based two-dimensional video analysis compared to three-dimensional motion analysis. In addition, marker-based two-dimensional video analysis has been shown to discriminate kinematics between runners with and without running-related knee injury.[17] However, it remains unknown whether specific subgroups can be classified with this methodology. The identification of distinct subgroups of runners with running-related injuries based on their kinematic presentation measured with marker-based two-dimensional video analysis may assist clinicians in their clinical reasoning and decision-making processes to optimize targeted intervention strategies.

The primary objective of this study was to explore whether homogeneous subgroups could be discriminated within a group of recreational runners with a running-related injury based on running kinematics evaluated with marker-based two-dimensional video analysis. We hypothesized that robust and clinically relevant subgroups are present within the population of runners with a variety of running-related injuries. The secondary objective was to explore the distribution of different running-related injuries within the subgroups.

METHODS

Participants

Inclusion criteria for the injured group were (i) recreational runners: runners that run for enjoyment,[26] with a running volume of at least 10 km per week before injury; (ii) aged 18-45 years, in order to avoid a heterogeneous age group;[45] (iii) individuals with a current running-related injury, which was defined as any running-related (training or competition) musculoskeletal pain that caused a restriction of or cessation of running (distance, speed, duration, or training) for at least seven days or three consecutive scheduled training sessions, or that required the runner to consult a physician or other health professional.[60] Injured runners were recruited by referrals from physicians. All injured runners were medically diagnosed by a physician with a running-related injury. The Lower Extremity Functional Scale (LEFS),[6, 61] a clinical measure containing 20 questions about a person's ability to perform various daily tasks and activities, was also administered to assess overall function. A zero indicates maximum limitation in all items and 80 indicates no limitations in any of the items.

Exclusion criteria were (i) individuals with a lower extremity injury resulting from an acute trauma (e.g. car accident) or activities other than running (e.g. playing volleyball); (ii) sprinters: runners who participate in running distances of 400 meters or less;[30] (iii) ultra-marathon runners: runners competing in races longer than a marathon,[30] in order to reach a more homogeneous running volume; (iv) elite athletes: professional runners or runners selected as an elite runner by the Flemish Athletic League; (v) runners who compete in sports other than running for more than six hours per week; (vi) individuals who are not able to run for 10 minutes anymore as a result of the injury,[8] as we aim to assess running; (vii) individuals with a history of major trauma and/or major orthopaedic surgery of the lumbopelvic region or lower extremity (e.g. anterior cruciate ligament reconstruction); and (viii) the presence of the following conditions or constitutions: neurological or vestibular impairments, pregnancy.

Appropriate ethical approval was granted by the local ethical committee prior to the commencement of the study (S60108 B322201731705). Before participating in the study, all participants read and signed the informed consent form.

<u>Procedures</u>

The procedures of this study were the same as described by Dingenen et al.[13, 17] All participants wore tight-fitting running pants, their own running shoes, and a sports bra for the female participants. Male participants were asked to undress their upper body. Reflective markers (diameter 14 mm) were placed on the manubrium sterni and bilateral on the anterior superior iliac spine (ASIS), greater trochanter, lateral femoral epicondyle, fibular head and lateral malleolus. All participants were instructed to run naturally on a motorised treadmill (h/p/cosmos pulsar®, h/p/cosmos® sports & medical gmbh, Nusseldorf-Traunstein, Germany) at their preferred running speed. A treadmill familiarization period of six minutes was used at preferred running speed before running kinematics were measured.[31] After this acclimatisation period, digital videos were captured during 30s with two tablets (iPad Air ®) sampling at 120 frames per second.

The frontal plane iPad was placed on a portable tripod perpendicular to the frontal plane at a height of 1.05 m and a distance of 2.0 m from the treadmill.[13] The sagittal plane iPad was also placed on a portable tripod, perpendicular to the sagittal plane at a height of 0.80 m and a distance of 1.40 m from the treadmill.[13] The video recordings were analyzed using a freely available software package (Kinovea® version 0.8.15, available at http://www.kinovea.org). Seven consecutive steps in the beginning of the video capture were analyzed of the injured leg.[13] The rater drawing the angles was blinded for the type of injury. The test-retest reliability, intra- and interrater reliability of this methodology have been proven to be excellent in previous studies.[13, 17, 18]

In the frontal plane, the deepest landing position (near midstance) was determined visually by slowly advancing the video frame by frame.[13, 18, 37] We defined this deepest landing position as the time point where there was maximal foot contact and no downward or upward movement occurred at the hip, knee and ankle.[13, 18, 37] We defined four different angles in the frontal plane, based on previously published methodologies.[13, 16-18] The lateral trunk position angle was the angle between the vertical line starting at the ASIS of the stance leg, and a second line connecting the ASIS of the stance leg and the manubrium sterni.[13, 16] The smaller this angle, the more the trunk is positioned in the direction of the stance leg. The contralateral pelvic drop angle was the angle between the horizontal line starting at the ASIS of the stance leg and a second line connecting the ASIS of the stance and swing leg.[13, 18]

The greater this angle, the greater the contralateral pelvic drop. The femoral adduction angle was the angle between the horizontal line starting at the ASIS of the stance leg and a second line connecting the ASIS of the stance leg with the midpoint of the tibiofemoral joint (knee joint centre).[13, 18] The hip adduction angle was calculated as the difference between the femoral adduction angle and the contralateral pelvic drop angle.[13, 18] To facilitate data interpretation, we normalized the femoral and hip adduction angles to 90°. For example, a femoral adduction angle of 80° and a hip adduction angle of 75° represent 10° femoral adduction and 15° hip adduction respectively. All frontal plane angles were drawn at the same digital picture, at the same time frame (midstance).

In the sagittal plane, we defined two angles at initial contact and two angles at midstance. Initial contact was determined visually by slowly advancing the video frame by frame, and was defined as the first time that the foot touched the ground.[47] The foot inclination angle was defined as the angle between the horizontal and the sole of the foot.[2, 13, 47, 52, 57] Greater foot inclination angles represent greater foot inclination (a foot that is less parallel to the floor with the toes inclined upwards). The foot inclination angle was negative when a forefoot strike was used. The tibia inclination angle was defined as the angle between a vertical line starting at the lateral malleolus and a second line connecting the lateral malleolus and the fibular head.[13, 47, 52] Greater tibia inclination angles represent greater tibia inclination, with the proximal end of the tibia in the posterior direction. The foot and tibia inclination angles were drawn on the same digital picture at initial contact. Midstance in the sagittal plane was defined visually in the same way as in the frontal plane, and was typically the point where the swing leg crossed the stance leg.[13, 47] The ankle dorsiflexion angle at midstance was defined as the angle between the vertical line starting at the lateral malleolus and a second line connecting the lateral malleolus and the fibular head.[13] Greater ankle dorsiflexion angles represent greater ankle dorsiflexion. The knee flexion angle at midstance was defined as the angle between the line formed by the greater trochanter and the lateral femoral epicondyle, and a second line connecting the lateral femoral epicondyle and the lateral malleolus.[11, 13, 15]

To facilitate data interpretation, we normalized the knee flexion angle to 180°. For example, a knee flexion angle of 140° represents 40° knee flexion. The ankle dorsiflexion and knee flexion angles were drawn on the same digital picture.

As a secondary outcome measure, step rate was determined for each runner by counting the number of steps over a 30-s interval and multiplying by two.[7, 17]

<u>Statistical analysis</u>

Clustering analysis

Prior to the application of the clustering analysis, the mean values were calculated for each of the eight outcome measures based on the seven consecutive steps.[13] All data were normally distributed (Shapiro-Wilk), except for foot inclination. Subsequently, Pearson correlation coefficients were calculated between all angles. Foot inclination was correlated with all other angles with Spearman's correlations. Outcome measures which were correlated with at least large correlation coefficients ($r>0.5$)[27] were considered for data reduction. As a consequence, the following outcome measures were excluded: contralateral pelvic drop, femoral adduction and ankle dorsiflexion at midstance. The former two measures were strongly correlated with hip adduction (respectively 0.75 and 0.64; $P<.001$) and the latter was strongly correlated with knee flexion (0.54; $P<.001$). Finally, lateral trunk position angle was also excluded since literature indicated its poor discriminative value with respect to running-related injury using the current methodology.[17]

To identify whether different subgroups with homogeneous kinematic patterns were present within the 53 injured runners, a K-means clustering analysis was performed.[49] Input for this analysis included the remaining four outcome measures: hip adduction and knee flexion at midstance and foot inclination and tibia inclination at initial contact. A K-means function (Matlab 2014a; The Mathworks, Natick, US) was applied together with a standard Euclidean distance setting for the partitioning into subgroups.[49] K-means clustering is commonly performed in 2 to 10 groups (K=2 to 10). Since the iterative K-means algorithm uses randomly determined starting points, all K-means calculations were repeated 10 times. The best outcome was taken as the position of the cluster centres (K=2 to 10). Decision about the optimal classification system was done by calculating the average silhouette coefficient (SC) for each chosen number of subgroups (K=2 to 10). The SC expresses the extent to which the identified subgroups represent distinguished patterns between subgroups and consistency within subgroups. It ranges from -1 to +1, where a high value indicates that the participant is well matched to its own subgroup and poorly matched to neighbouring subgroups. The SC calculation was repeated for each k clustering, and the highest SC was considered as the most representative classification. A benchmark of 0.5 was put forward as the minimal threshold to define the presence of relevant homogeneity for a classification system.[49]

Differences between subgroups

Depending on the number of clusters associated to the optimal classification system and the normality of the outcome measures (Shapiro-Wilk), non-parametric (Mann-Whitney U test) or parametric (independent t-test) inferential analysis, together with effect sizes (ES) were calculated for participant characteristics (age, body height, body weight, body mass index, symptom duration, LEFS scores), running characteristics (running experience, running volume before injury, current running volume, running speed, step rate) and two-dimensional angles. Gender was compared between clusters with the Chi-square test. Given the exploratory nature of these group comparisons, significance was set at $P<.05$. Effect sizes (Hedges' g) were established by calculating the difference between the means of both groups, divided by the pooled standard deviation, multiplied by a correction factor.[53] A modified version of Cohen's classification was used to classify ES: very small ES: <0.2, small ES: 0.2-0.49; medium ES: 0.5-0.79; large ES: 0.8-1.19, very large ES: 1.20-1.99 and huge ES: ≥ 2.0.[10, 50] All statistical analyses were performed using SPSS (SPSS Science, version 24 for Windows, USA).

Injuries within subgroups

To explore whether the proportion of runners with a running-related injury of a specific body region (hip, knee, lower leg, foot) would differ between subgroups, the proportion of runners (%) with a running-related injury of a specific body region was calculated within both subgroups. To explore whether the proportion of runners with a specific running-related injury (categorized by pathology) would differ between subgroups, the proportion of runners (%) with a specific running-related injury was calculated within both subgroups.

RESULTS

Fifty-three recreational runners with a running-related injury participated in the study (TABLE 1).

Clustering analysis

Mean SC values associated to the repeated clustering (K2 to 10) ranged between 0.26 and 0.53. Clustering runners into two subgroups encompassed the most optimal and robust classification (SC=0.53). The first subgroup consisted of 39 runners, the second of 14 runners.

Differences between subgroups

Participant characteristics (gender, age, body height, body weight, body mass index, symptom duration, LEFS scores) and running characteristics (running experience, running volume before injury, current running volume and running speed) were not significantly different between clusters. Only step rate was significantly lower in subgroup 1 compared to subgroup 2 (*P*=.036; medium ES=.615) (TABLE 1).

Subgroup 1 (n=39) was characterized by greater foot inclination and tibia inclination at initial contact, greater knee flexion at midstance, and smaller hip adduction at midstance compared to subgroup 2 (n=14). Independent t-tests showed a significant difference between subgroups for foot inclination (*P*<.001; huge ES=2.747) and tibia inclination (*P*=.001; large ES=1.082), but not for hip adduction and knee flexion (*P*>.05; medium ES) (TABLE 2). A graphical illustration of the typical running kinematics of both subgroups is presented in Figure 1.

Injuries within subgroups

The distribution of runners within subgroups with a running-related injury categorized by body region is presented in Figure 2. The distribution of runners within subgroups based on the specific running-related injury is presented in Figure 3.

DISCUSSION

Our findings indicate that two homogeneous subgroups could be discriminated within a group of recreational runners with a running-related injury based on running kinematics evaluated with marker-based two-dimensional video analysis. The same running-related injury can be represented by different kinematic presentations, and similar kinematic presentations can be related to different running-related injuries. Nevertheless, a tendency towards more shin and less hip injuries could be observed in subgroup 1, who displayed a kinematic presentation with significantly greater tibia and foot inclination at initial contact, and a trend towards smaller hip adduction and greater knee flexion at midstance compared to subgroup 2. Statistical comparison between subgroups showed that only tibia and foot inclination were significantly different between subgroups with large to huge effect sizes. In addition, the magnitude of these differences were larger than the previously published smallest detectable differences.[13] Although medium effect sizes were found for hip adduction and knee flexion, differences were not statistically significant, and smaller than the smallest detectable differences.[13] Therefore, the subclassification within this study appears to be dominated by tibia and foot inclination.

Greater tibia and foot inclination angles are often associated with “overstriding” mechanics. Even though there is no consensus on what constitutes overstriding,[41] this running pattern is mostly characterized by a landing of the foot further in front of the person’s center of mass.[34,

[52] In a clinical context, increased tibia and foot inclination angles are believed to be measures of overstriding.[41] Napier et al[41] reported significant correlations between the tibia inclination, step length and horizontal distance between the heel and center of mass on the one hand, and between foot inclination angle and horizontal distance between the heel and center of mass on the other hand. This lower extremity posture at initial contact has been reported to influence subsequent loading patterns during the stance phase.[34, 41, 57] In contrast with the greater body of literature evaluating the relationship between a variety of "proxies" of overstriding (step rate, step length or horizontal distance between the foot and the center of mass) and kinetic outcomes,[25, 34, 41, 51, 58] the direct relationship between tibia and foot inclination and kinetics has only been studied to a limited extent. In a study of Wille et al,[57] foot inclination was the most common predictive factor to estimate kinetic outcomes during running. Greater foot inclination at initial contact can be used to estimate peak knee extensor moment, mechanical energy absorbed about the knee during loading response, peak vertical ground reaction force and braking impulse.[57] Napier et al[41] also found that increased foot inclination at initial contact was associated with greater vertical loading rates.

Greater tibia and foot inclination are typically associated with a lower step rate for a given running speed.[51] Our results support this finding, indicating a significantly lower step rate in subgroup 1 compared to subgroup 2, while no differences between groups were found for running speed. Lower step rate has been related to higher vertical ground reaction forces, braking impulse, vertical displacement of the body's center of mass, vertical loading rates,[51, 59] patellofemoral joint stress,[32] Achilles tendon stress[36] and shin injury risk.[35]

Although hip adduction was not significantly different compared to subgroup 1, it can be stated that subgroup 2 ran with relatively large hip adduction at midstance (16.8°) based on previous studies using the same methodology for injured (18.0°) and non-injured runners (14.6°) with similar sex and age distribution.[13, 17] The lack of significant differences between both subgroups for hip adduction might therefore also be related to a ceiling effect, since only injured runners were included in the current study. Therefore, clinically, subgroup 1 could be classified as a "sagittal plane dominant" running pattern, while subgroup 2 could be classified as a "frontal plane dominant" running pattern. This frontal plane dominant pattern has been related to increased tensile and compressive loading of the gluteal tendons,[23] patellofemoral joint stress,[28, 33] iliotibial band strain and strain rate[38] and tibial bone stress.[39] A running pattern characterized with greater contralateral pelvic drop, femoral adduction and hip adduction, and smaller foot inclination was previously observed by Dingenen et al[17] in a group of runners with running-related knee injury, compared to non-injured runners, using the same marker-based two-dimensional video analysis methodology.

Our findings related to the second objective of our study indicate that the same running-related injury can be represented by different kinematic presentations. In addition, we found that similar kinematic presentations can be related to different running-related injuries. These outcomes support the results of Jauhiainen et al,[29] who concluded that the traditional method of creating a cluster of runners based on a pre-defined injury and considering these runners as one homogeneous group does not consider the variance of kinematic patterns that exists independent of the injury location. Nevertheless, our results also indicate a tendency towards a higher proportion of lower leg injuries and a lower proportion of hip injuries in subgroup 1 compared to subgroup 2, while this discrepancy was not found for knee and foot injuries. The additional injury-specific analysis indicated that the higher proportion of lower leg injuries in subgroup 1 was mainly dominated by shin injuries, while the hip injuries in subgroup 2 were dominated by gluteal tendinopathy and nonspecific hip pain. The higher proportion of shin injuries in subgroup 1 may be related to the more "sagittal plane dominant" kinematic pattern within this subgroup, which might contribute to increased structure-specific loading of the anterior and posterior compartment of the lower leg.[19, 21] The higher proportion of hip injuries in subgroup 2 can be supported by previous studies reinforcing the relationship between a more "frontal plane dominant" movement pattern including hip adduction, chronic hip joint pain[24] and gluteal tendinopathy.[3, 23] Despite the fact that caution is warranted to make strong conclusions based on the small number of specific injuries within each body region, these data tend to point out that the relationship between movement patterns and pathology can differ between body regions and specific running-related injuries.

To the best of our knowledge, this is the first study to explore the presence of subgroups within a group of runners with variety of running-related injuries, using marker-based two-dimensional video analysis. Our results support the existence of distinct subgroups previously reported in runners with patellofemoral pain[12, 44, 56] and a variety of running-related injuries,[29] evaluated with three-dimensional motion analysis. This implies that it might be useful to subclassify runners with a running-related injury based on their kinematic presentation in order to further unravel the complex relationship between biomechanics and injury in future studies. Clinically, the results of this study suggest that clinicians should not directly relate a specific running-related injury to one “typical” biomechanical presentation, or vice versa. One could even argue that the individual clinical presentation plays a larger role than attempting to determine whether a runner exhibits a “typical” running pattern associated with a specific injury.[29] Indeed, it should be clear that the observation of two distinct kinematic presentations in this study does not implicate that combinations of both patterns cannot exist within an individual presentation. Furthermore, observing a certain biomechanical presentation in an injured runner does not imply that the presentation equals causation. Running-related injuries occur due to multiple, varying and interacting factors.[5, 9] Individual clinical assessment with comprehensive multifactorial clinical reasoning is therefore warranted when evaluating an injured runner in clinical practice and planning potential intervention strategies.[4, 17]

Some limitations of this study need to be addressed. It is not possible to conclude whether the current findings were the cause or the result of the injury based on the cross-sectional design of the study. The current sample size was relatively small to make strong conclusions on the relationship between the subgroups and the injury location. Therefore, the descriptive analysis should be interpreted with caution and further studied in future studies with larger sample sizes. Finally, only injured runners were included in this study. In line with Jauhiainen et al,[29] non-injured runners can be included in future studies to explore the potential differences between injured and non-injured runners across subgroups.

CONCLUSION

Two homogeneous subgroups were identified within of a group of 53 recreational runners with a running-related injury based on running kinematics evaluated with marker-based two-dimensional video analysis. Subgroup 1 was characterized by significantly greater foot inclination and tibia inclination at initial contact compared to subgroup 2. The same running-related injury can be represented by different kinematic presentations, and similar kinematic presentations can be related to different running-related injuries. A subclassification based on the kinematic presentation may help clinicians in their clinical reasoning process when evaluating runners with a running-related injury and could inform targeted intervention strategy development.

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FIGURE CAPTIONS

Figure 1:

Two runners representing the main differences in running kinematics between both subgroups. Runners in subgroup 1 (ABC) demonstrated smaller hip adduction at midstance (A), greater foot and tibia inclination at initial contact (B) and greater knee flexion at midstance (C) compared to runners in subgroup 2 (DEF).

Figure 2:

The distribution of the location of running-related injuries (RRI) within subgroups by body region. The percentages represent the proportion of runners with a specific injury location within each subgroup.

Figure 3:

The distribution of running-related injuries (RRI) within subgroups. The percentages represent the proportion of runners with a specific running-related injury within each subgroup.

TABLE 1. Participant and running characteristics.

	Total group	Subgroup 1	Subgroup 2	*P*-value	Effect size
Participants (n)	53	39	14		
Gender					
Men (n)	15	12	3	.506	/
Women (n)	38	27	11		
Age, years (M ± SD)	31.3 ± 6.8	30.6 ± 6.9	33.1 ± 6.4	.238	.369
Body height, cm (M ± SD)	169.9 ± 7.8	170.0 ± 7.3	169.4 ± 9.4	.796	.076
Body weight, kg (M ± SD)	65.6 ± 10.1	66.0 ± 10.9	64.5 ± 7.5	.636	.148
Body mass index, kg/m^2 (M ± SD)	22.7 ± 2.6	22.7 ± 2.6	22.6 ± 2.8	.842	.038
Running experience, years (M ± SD)	9.7 ± 8.4	10.1 ± 8.4	8.9 ± 8.8	.419	.141
Symptom duration, years (M ± SD)	3.1 ± 4.9	3.4 ± 5.6	2.1 ± 2.2	.717	.262
LEFS (score/80) (M ± SD)	73.1 ± 5.3	72.8 ± 5.9	74.1 ± 3.4	.413	.242
Running volume before injury, km/week (M ± SD)	34.3 ± 19.9	34.7 ± 20.2	32.9 ± 19.6	.642	.090
Current running volume, km/week (M ± SD)	15.2 ± 14.3	16.1 ± 15.5	12.5 ± 10.3	.649	.251
Running speed, km/h (M ± SD)	9.9 ± 1.3	10.0 ± 1.1	9.7 ± 1.6	.474	.321
Step rate, steps/min (M ± SD)	166.3 ± 8.3	165.0 ± 8.3	170.0 ± 7.6	.036*	.615

Abbreviations: n, number of participants; M, mean; SD, standard deviation; LEFS: Lower Extremity Functional Scale.

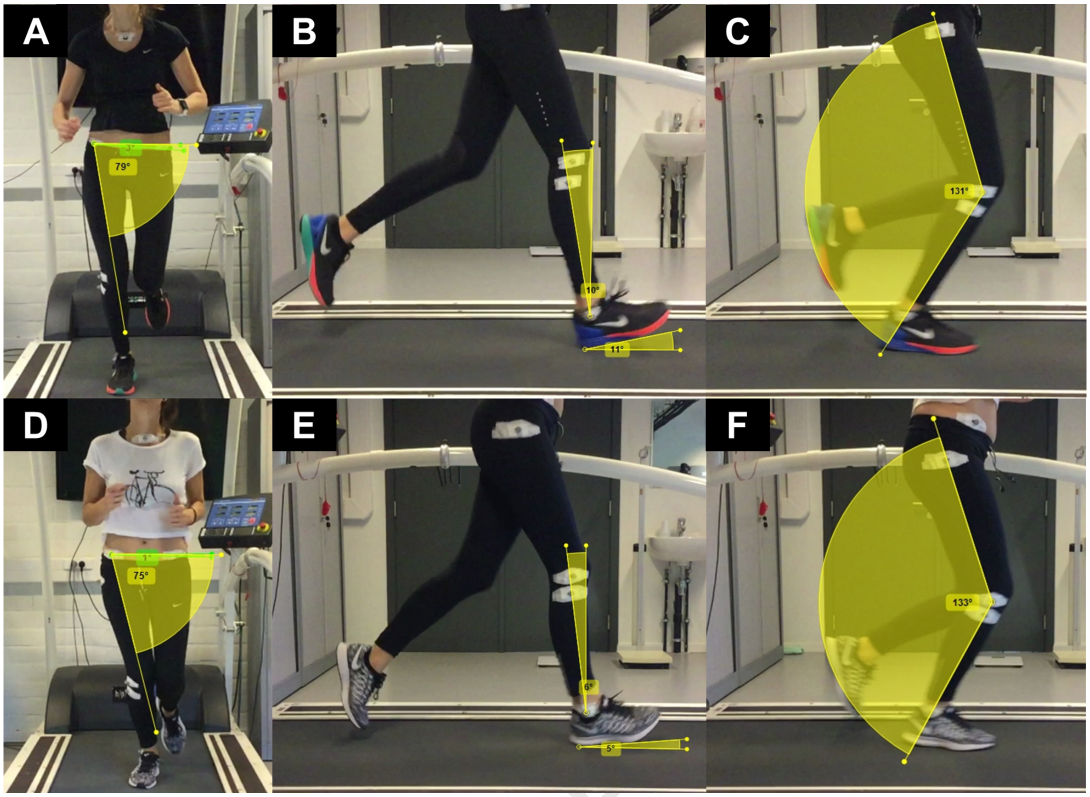
* Significant ($P < .05$).

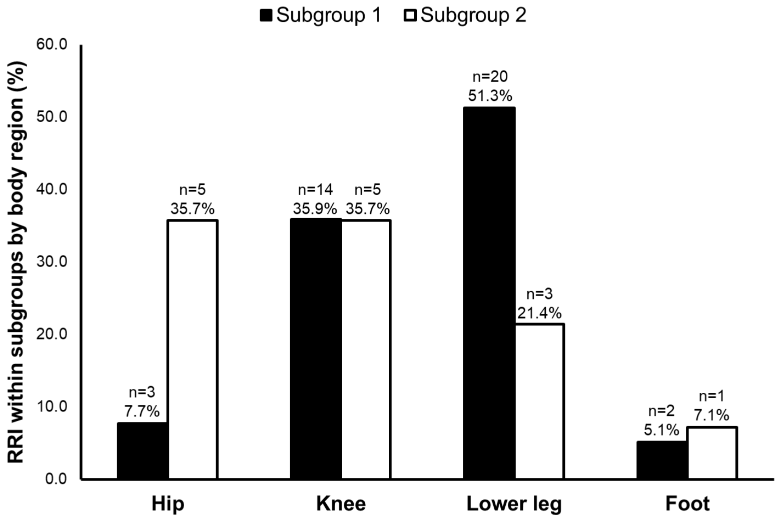
TABLE 2. Two-dimensional measured angles (degrees).

	Total group	Subgroup 1	Subgroup 2	*P*-value	Effect size
Hip adduction at midstance (M ± SD)	15.4 ± 3.5	14.9 ± 3.1	16.8 ± 4.1	.086	.562
Foot inclination at initial contact (M ± SD)	7.1 ± 5.9	9.8 ± 3.5	-0.5 ± 4.4	<.001*	2.747
Tibia inclination at initial contact (M ± SD)	5.6 ± 3.4	6.5 ± 3.1	3.2 ± 2.9	.001*	1.082
Knee flexion at midstance (M ± SD)	42.4 ± 3.4	42.9 ± 3.2	41.1 ± 3.5	.085	.549

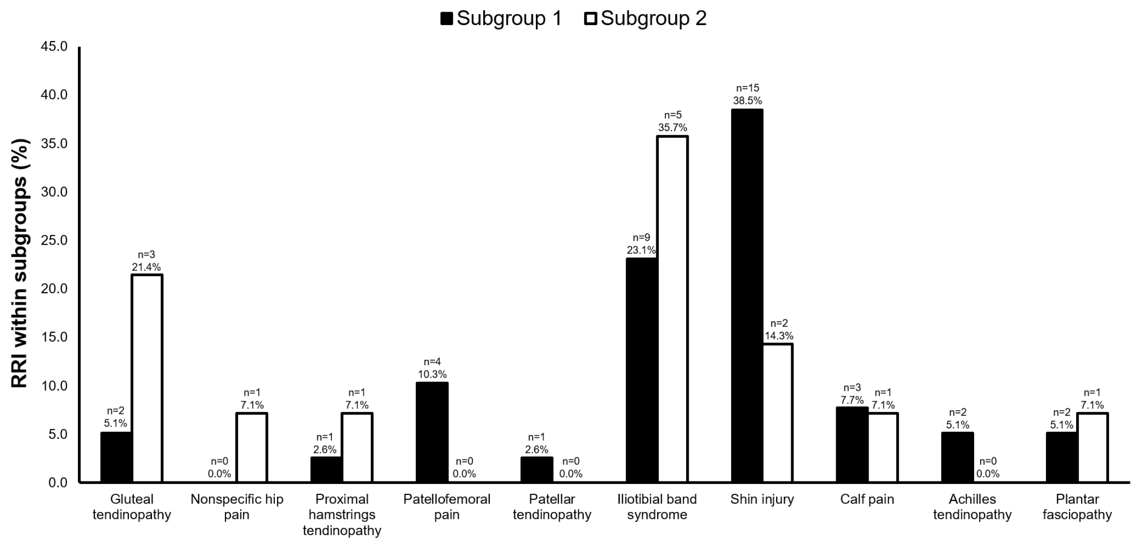
Abbreviations: M, mean; SD, standard deviation.

* Significant (*P* < .05).


A
B
C
D
E
F
79°
11°
10°
131°
75°
5°
6°
133°



Subgroup 1
Subgroup 2
RRI within subgroups by body region (%)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
n=3
7.7%
n=5
35.7%
n=14
35.9%
n=5
35.7%
n=20
51.3%
n=3
21.4%
n=2
5.1%
n=1
7.1%
Hip
Knee
Lower leg
Foot



■ Subgroup 1 □ Subgroup 2
RRI within subgroups (%)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
n=2 5.1%
n=3 21.4%
n=0 0.0%
n=1 7.1%
n=1 2.6%
n=1 7.1%
n=4 10.3%
n=0 0.0%
n=1 2.6%
n=0 0.0%
n=9 23.1%
n=5 35.7%
n=15 38.5%
n=2 14.3%
n=3 7.7%
n=1 7.1%
n=2 5.1%
n=0 0.0%
n=2 5.1%
n=1 7.1%
Gluteal tendinopathy
Nonspecific hip pain
Proximal hamstrings tendinopathy
Patellofemoral pain
Patellar tendinopathy
Iliotibial band syndrome
Shin injury
Calf pain
Achilles tendinopathy
Plantar fasciopathy

HIGHLIGHTS

Two homogeneous subgroups were identified in runners with running-related injuries.

Foot and tibia inclination were significantly different between subgroups.

The same injury can be represented by different kinematic presentations.

Similar kinematic presentations can be related to different injuries.

Marker-based 2D video analysis can be used to assist clinical reasoning.

ETHICAL APPROVAL

The work has been approved by the appropriate ethical committees related to the institution in which it was performed (S60108 BE322201731705). Participants gave informed consent to the work.

CONFLICT OF INTEREST STATEMENT

None.