Original Research

Two-dimensional video analysis can discriminate differences in running kinematics between recreational runners with and without running-related knee injury

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ABSTRACT

Objectives: To determine whether two-dimensional video analysis could discriminate running kinematics between recreational runners with and without a running-related knee injury.
Design: Case-control.
Setting: Research laboratory.
Participants: Forty-two recreational runners (5 male-13 female injured; 7 male-17 female non-injured). Running-related knee injury was defined as the presence of anterior or lateral knee pain, resulting in altered running activity for at least one week.
Main outcome measures: Foot and tibia inclination at initial contact, and lateral trunk position, contralateral pelvic drop, femoral adduction, hip adduction, knee flexion and ankle dorsiflexion at midstance were measured with two-dimensional video analysis during running. Participant characteristics (sex, age, body weight, body length, body mass index, running volume before injury, running speed) and two-dimensional measured angles were compared between groups.
Results: No significant differences in participant characteristics between groups were identified ($P > .05$). The injured group ran with greater contralateral pelvic drop ($P = .035$), femoral adduction ($P = .021$) and hip adduction ($P = .001$) at midstance, and significantly smaller foot inclination at initial contact ($P = .031$).
Conclusion: Two-dimensional video analysis can discriminate kinematics between runners with and without running-related knee injury. Greater contralateral pelvic drop, femoral adduction and hip adduction at midstance may provide running retraining targets for runners with running-related knee injury.

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1. Introduction

Running-related injury incidence ranges from 3 to 85% (van Gent et al., 2007; Yamato, Saragiotto, Hespanhol Junior, Yeung, & Lopes, 2015), depending on the definition of the running injury (Kluitenberg et al., 2016; Yamato et al., 2015a), method of injury assessment (Videbaek, Bueno, Nielsen, & Rasmussen, 2015) and population being studied (Kluitenberg, van Middelkoop, Diercks, & van der Worp, 2015). Considering the associated health benefits of running (van der Worp et al., 2015) and the fact that running-related injuries are the most common reason reported for discontinuing running (Fokkema et al., 2019), addressing this high incidence is imperative.

The knee is one of the most commonly injured anatomical sites in recreational runners (Lopes, Hespanhol Junior, Yeung, & Costa, 2012; Mulvad, Nielsen, Lind, & Ramskov, 2018; Taunton et al.,

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2002; van Gent et al., 2007). Patellofemoral pain and iliotibial band syndrome are the most frequently diagnosed running-related knee injuries (Mulvad et al., 2018; Taunton et al., 2002). The etiology of these injuries is complex and multifactorial (Bertelsen et al., 2017; Saragiotto et al., 2014), but increasing evidence supports the theory that altered lower extremity biomechanics may play a role (Aderem & Louw, 2015; Neal, Barton, Gallie, O'Halloran, & Morrissey, 2016). For example, increased hip adduction has been associated prospectively and retrospectively with patellofemoral pain (Neal et al., 2016) and iliotibial band syndrome (Ferber, Noehren, Hamill, & Davis, 2010; Noehren, Davis, & Hamill, 2007).

All published research to date reporting evaluation of kinematics in runners with current or previous running-related knee injury (Aderem & Louw, 2015; Neal et al., 2016), or non-injured runners who developed a running-related knee injury in the future (Noehren et al., 2007, 2013), have used three-dimensional motion analysis systems, which have been considered the gold standard approach for a detailed running analysis (Maykut, Taylor-Haas, Paterno, DiCesare, & Ford, 2015). However, based on recent technology and digital innovations, including inexpensive high speed cameras and freely available software, two-dimensional video analysis might now offer a less resource intensive and more clinically applicable approach to evaluate running kinematics. Recent research, including our own work, has reported excellent intra- and interrater reliability (Damsted, Nielsen, & Larsen, 2015; Dingenen, Staes, & Santermans, 2018; Maykut et al., 2015), test-retest reliability (Dingenen, Barton, Janssen, Benoit, & Malliaras, 2018a) as well as validity (Dingenen et al., 2018a; Maykut et al., 2015) of two-dimensional video analysis compared to three-dimensional motion analysis. However, it remains unclear whether two-dimensional video analysis can be used to discriminate differences in running kinematics between runners with and without a running-related knee injury, as has been the case when using three-dimensional motion analysis (Aderem & Louw, 2015; Neal et al., 2016).

The objective of this study was to determine whether two-dimensional video analysis could discriminate differences in running kinematics between recreational runners with and without a running-related knee injury.

2. Methods

2.1. Participants

Forty-two (18 injured and 24 non-injured) recreational runners participated (Table 1). Inclusion criteria for the injured group were (i) recreational runners: runners that run for enjoyment (Hespanhol Junior, De Carvalho, Costa, & Lopes, 2016), 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 (Phinyomark, Hettinga, Osis, & Ferber, 2014); (iii) individuals with a current running-related knee injury, which was defined as any running-related (training or competition) musculoskeletal knee 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, and that required the runner to consult a physician or other health professional (Yamato et al., 2015b). Injured runners were recruited by referrals from physicians. All injured runners had anterior ($n = 5$) or lateral ($n = 13$) knee pain, and were medically diagnosed by a physician with patellofemoral pain or iliotibial band syndrome. Based on the patellofemoral consensus statement (Crossley et al., 2016), patellofemoral pain was defined as pain around or behind the patella, which was aggravated by at least one activity that loads the patellofemoral joint during weight bearing on a flexed knee, in this case running. Iliotibial band syndrome was defined as pain over the lateral femoral epicondyle, induced and exacerbating with running (Fairclough et al., 2007; Grau et al., 2011). Symptom duration ranged between 2 and 60 months (14.3 ± 19.3 months). The score on the Lower Extremity Functional Scale (LEFS) (Binkley, Stratford, Lott, & Riddle, 1999; Yeung, Wessel, Stratford, & Macdermid, 2009), a clinical measure containing 20 questions about a person's ability to perform various daily tasks and activities, was 72.3 ± 5.6, where 0 indicates maximum limitation in all items and 80 indicates no limitations in any of the items.

Exclusion criteria were (i) individuals with a knee 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 m or less (Kluitenberg et al., 2015); (iii) ultra-marathon runners: runners competing in races longer than a marathon (Kluitenberg et al., 2015), 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 other sports than running more than 6 h per week; (vi) individuals who are not able to run for 10 min anymore as a result of the injury (Bramah, Preece, Gill, & Herrington, 2018), 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.

The inclusion and exclusion criteria for the non-injured group were the same, except for the fact that individuals with a current running-related injury, a running-related injury over the past 24 months, or a running volume lower than 20 km per week were

Table 1
Participant and running characteristics.

	Non-injured group	Injured group	*P*-value
Participants (n)	24	18	
Sex			.924
Men (n)	7	5	
Women (n)	17	13	
Age (years) (M ± SD)	29.6 ± 8.2	31.3 ± 6.8	.446
Body height (cm) (M ± SD)	172.1 ± 9.2	170.5 ± 8.4	.446
Body weight (kg) (M ± SD)	66.0 ± 12.0	66.1 ± 10.5	.978
Body mass index (kg/m²) (M ± SD)	22.1 ± 1.9	22.7 ± 2.5	.401
Running volume before injury (km/week) (M ± SD)	37.4 ± 16.6	35.8 ± 16.4	.711
Current running volume (km/week) (M ± SD)	37.4 ± 16.6	11.6 ± 12.4	<.001*
Running speed (km/h) (M ± SD)	10.2 ± 0.9	9.8 ± 1.1	.211

Abbreviations: n, number of participants; M, mean; SD, standard deviation.
* Significant ($P < .05$).

excluded. This 20 km threshold was chosen to avoid including runners in the non-injured group who were not injured based on the current definition of a running-related injury, because of lowering their running volume to avoid injury (Yamato et al., 2015b). This rationale has previously also been applied by Bramah et al. (Bramah et al., 2018). Non-injured runners were recruited by online advertisements across local running clubs and students of Hasselt University. The non-injured group was matched with the injured group for age and sex.

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.

2.2. Procedures

The procedures of this study were the same as described by Dingenen et al. (Dingenen, Batron et al., 2018b). 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 acclimatisation period of 6 min was used before running kinematics were measured (Lavcanska, Taylor, & Schache, 2005). After this acclimatisation period, digital videos were captured during 30 s with 2 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 (Dingenen, Batron et al., 2018b). The sagittal plane tablet 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 (Dingenen, Batron et al., 2018b). 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 were analyzed (Dingenen, Batron et al., 2018b). The injured leg was analyzed for the injured runners, and the right or left leg was analyzed at random from the non-injured group to match the distribution of the right and left legs in the injured group, in order to avoid any perspective error (Bramah et al., 2018).

In the frontal plane, the deepest landing position (near midstance) was determined visually by slowly advancing the video frame by frame (Dingenen et al., 2018a, Dingenen, Barton et al., 2018b; Maykut et al., 2015). 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 (Dingenen et al., 2018a, Dingenen, Barton et al., 2018b; Maykut et al., 2015). We defined three different angles in the frontal plane, based on previously published methodologies (Dingenen et al., 2014, 2018a, Dingenen, Barton et al., 2018b). 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 (Dingenen et al., 2014, Dingenen, Barton et al., 2018b). 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 (Dingenen et al., 2018, Dingenen, Barton et al., 2018b). The greater this
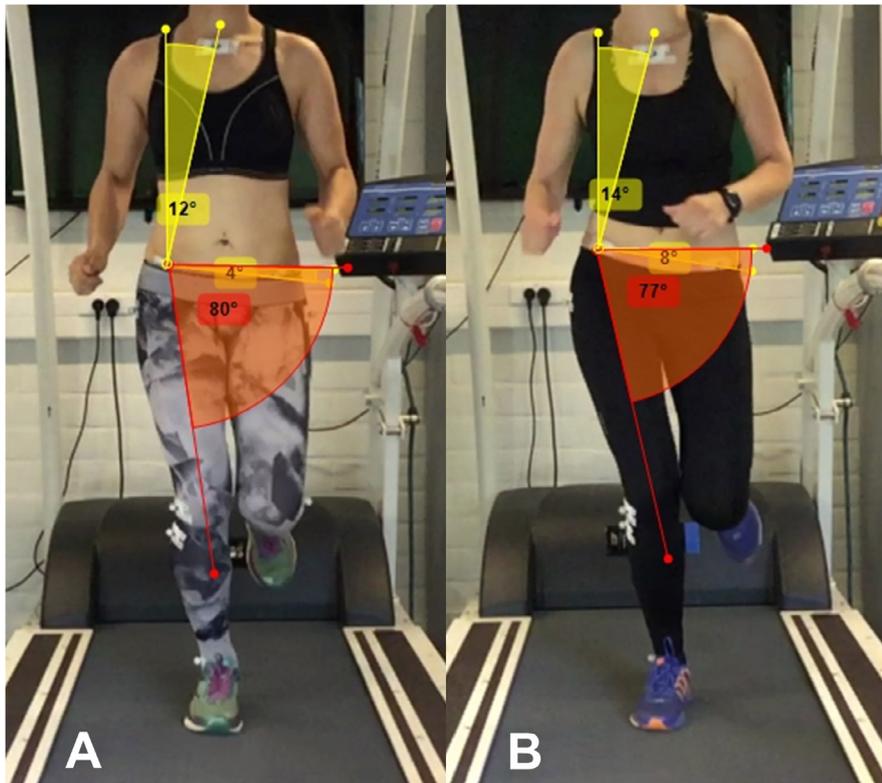
angle, the greater the contralateral pelvic drop. The femoral adduction angle was the angle between the horizontal line starting at the ASIS of the stance leg and a second line connecting the ASIS of the stance leg with the midpoint of the tibiofemoral joint (knee joint centre) (Dingenen et al., 2018a, Dingenen, Barton et al., 2018b). Smaller femoral adduction angles represent more femoral adduction. The hip adduction angle was calculated as the difference between the femoral adduction angle and the contralateral pelvic drop angle (Dingenen et al., 2018a, Dingenen, Barton et al., 2018b). Smaller hip adduction angles represent greater hip adduction. All frontal plane angles were drawn at the same digital picture, at the same time frame (midstance) (Fig. 1).

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 (Pipkin, Kotecki, Hetzel, & Heiderscheit, 2016). The foot inclination angle was defined as the angle between the horizontal and the sole of the foot (Allen, Heisler, Mooney, & Kring, 2016; Dingenen, Batron et al., 2018b; Pipkin et al., 2016; Souza, 2016; Wille, Lenhart, Wang, Thelen, & Heiderscheit, 2014). 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 (Dingenen, Batron et al., 2018b; Pipkin et al., 2016; Souza, 2016). 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 (Fig. 2). 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 (Dingenen, Batron et al., 2018; Pipkin et al., 2016). 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 (Dingenen, Batron et al., 2018b). 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 (Damsted et al., 2015; Dingenen et al., 2015, Dingenen, Batron et al., 2018b). Smaller knee flexion angles represent more knee flexion. The ankle dorsiflexion and knee flexion angles were drawn on the same digital picture.

All angles were drawn independently by two raters to calculate inter-rater reliability. The data of one rater who was blinded to injury status were used to compare the angles of the injured and non-injured runners. 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 (Bowersock, Willy, DeVita, & Willson, 2017).

2.3. Statistical analysis

For the two-dimensional video analysis, the mean of seven consecutive steps was the outcome measure of each angle (Dingenen, Batron et al., 2018b). All data were normally distributed (Shapiro-Wilk), except for foot inclination. To evaluate inter-rater reliability of all angles, the absolute differences between raters and intraclass correlation coefficients ($ICC_{2,2}$) were calculated. The ICC values were interpreted as poor (<0.50), moderate (0.50–0.74), good (0.75–0.89) or excellent (0.90–1.00) (Portney & Watkins, 2000). The standard error of measurement (SEM) and smallest

Fig. 1. Two examples of the two-dimensional measurement of lateral trunk position, contralateral pelvic drop and femoral adduction at midstance. The contralateral pelvic drop and femoral adduction angles of runner B are respectively greater and smaller than runner A.
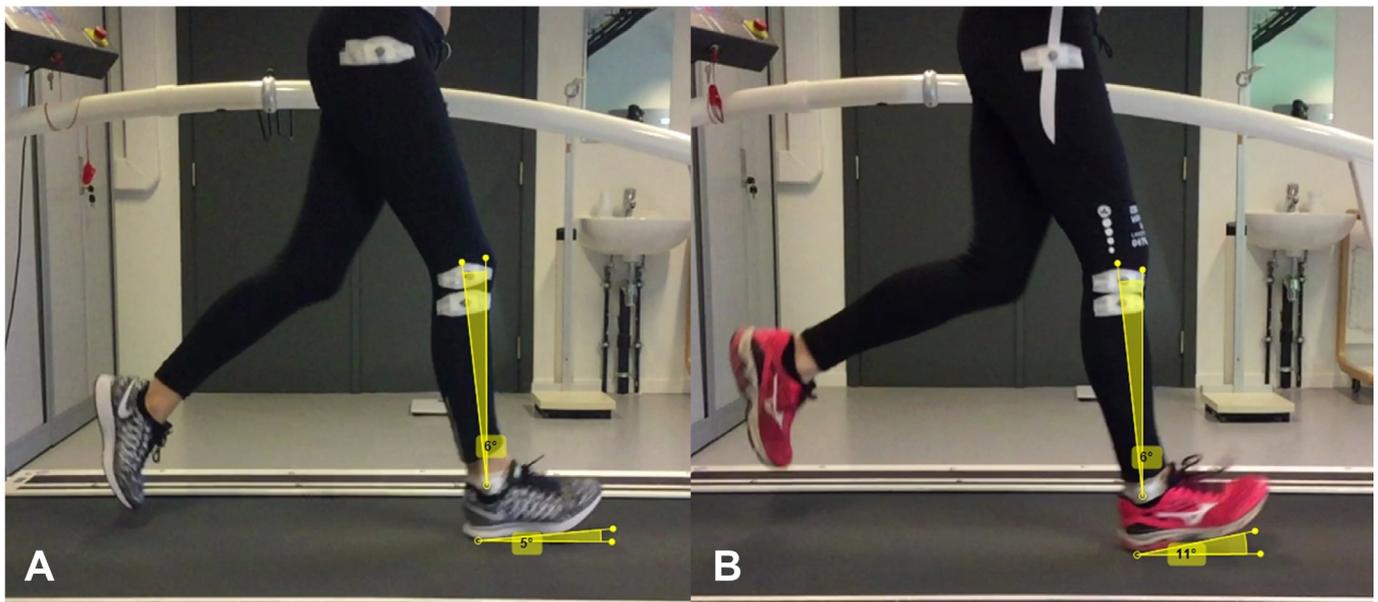
Fig. 2. Two examples of the two-dimensional measurement of tibia and foot inclination at initial contact. The foot inclination of runner A is smaller than runner B, while the tibia inclination is the same.

detectable difference (SDD) were calculated using the formulas SD*√(1-ICC) and 1.96*SEM*√2 respectively (Weir, 2005).

Differences between groups for participants and running characteristics, two-dimensional measured angles and step rate were compared between groups with independent t tests. Foot inclination was compared between groups with the Mann-Whitney U test.

Statistical significance was set at $P < .05$. Given the exploratory nature of this study we did not correct the alpha level for multiple comparisons. All statistical analyses were performed using SPSS (SPSS Science, version 24 for Windows, USA). Post-hoc statistical power was calculated for each of the significant results with G^*Power (Faul, Erdfelder, Lang, & Buchner, 2007), based on the

sample sizes, standard deviations and between-group comparison effect sizes within the current study, with $\alpha = .05$.

3. Results

3.1. Participant and running characteristics

No significant differences in participant or running characteristics were identified between groups ($P > .05$), with the exception of current running volume, which was significantly lower in the injured group due to the injury ($P < .001$) (Table 1).

3.2. Two-dimensional measured angles

Inter-rater reliability was excellent for all angles with ICC's ranging from 0.93 to 0.99 (Table 2). The injured group ran with significantly greater contralateral pelvic drop (mean difference = $1.6°$; $P = .035$), femoral adduction (mean difference = $1.8°$; $P = .021$) and hip adduction (mean difference = $3.4°$; $P = .001$) at midstance (Table 3, Fig. 1), and significantly less foot inclination at initial contact (mean difference = $2.9°$; $P = .031$) (Table 3, Fig. 2). If the alpha level would have been adjusted for multiple comparisons ($P = .05/8 = .006$), only hip adduction would remain significantly different between groups. Post-hoc power analysis revealed a statistical power of .96, .73, .71 and .48 for hip adduction, femoral adduction, contralateral pelvic drop and foot inclination respectively.

3.3. Step rate

No significant difference in step rate was found between the injured group (166.2 ± 8.6 steps/min) and the non-injured group (166.8 ± 6.5 steps/min) ($P = .795$), while running speed was not significantly different between groups ($P = .211$).

4. Discussion

Our findings indicate that two-dimensional video analysis can discriminate differences in running kinematics between recreational runners with and without a running-related knee injury. Specifically, we identified significantly greater contralateral pelvic drop, femoral adduction and hip adduction at midstance, and smaller foot inclination at initial contact in the runners with running-related knee injury.

The magnitude of the differences between groups for femoral adduction ($1.8°$), hip adduction ($3.4°$) and foot inclination ($2.9°$) was greater than the previously reported standard errors of measurement and smallest detectable differences, using this two-dimensional video analysis methodology (Dingenen, Batron et al., 2018b). These findings increase our confidence that the differences between groups of these angles are likely not due to

measurement error or participant variability. Additionally, greater peak hip adduction in runners with running-related knee injury is supported by moderate cross-sectional evidence in runners with patellofemoral pain, evaluated with three-dimensional motion analysis (Neal et al., 2016). For iliotibial band syndrome, greater, smaller as well as no significant differences for hip adduction have been reported in cross-sectional and retrospective studies (Aderem & Louw, 2015). A number of methodological differences could explain these mixed findings, including differences in sex of included participants (male, female or mixed-sex), footwear (shod, barefoot), inclusion of runners with a history of symptoms or current symptoms, and often small sample sizes (Aderem & Louw, 2015). Prospective literature linking hip kinematics to running-related knee injury is limited to two studies in female recreational runners (Noehren et al., 2007, 2013), but the results are consistent with our findings. Specifically, greater peak hip adduction was reported in those who developed patellofemoral pain (Noehren et al., 2013) and iliotibial band syndrome (Noehren et al., 2007) compared to a matched control group who remained uninjured over two years follow-up.

From a biomechanical perspective, current evidence indicates that abnormal hip kinematics may play a role with respect to knee injury mechanisms (Powers, 2010; Reiman, Bolgla, & Lorenz, 2009). Hip adduction during weight-bearing activities is typically coupled with hip internal rotation (Powers, 2010). This kinematic presentation has been reported to affect patellofemoral and tibiofemoral kinematics and kinetics, leading to elevated patellofemoral joint reaction forces, decreased patellofemoral contact area and consequently elevated patellofemoral joint stress (Powers, Witvrouw, Davis, & Crossley, 2017). As the iliotibial band crosses the lateral aspects of the hip and the knee, more hip adduction can affect iliotibial band strain and strain rate (Meardon, Campbell, & Derrick, 2012). This is hypothesized to relate to iliotibial band syndrome due to associated increases in compression between the lateral femoral condyle and the iliotibial band (Fairclough et al., 2007; Hamill, Miller, Noehren, & Davis, 2008). As such, hip adduction could be interpreted as a global contributor to both patellofemoral pain and iliotibial band syndrome.

Hip adduction kinematics are influenced by both adduction of the femur relative to space and contralateral pelvic drop. Our findings indicated both significantly greater femoral adduction and contralateral pelvic drop in the injured group. However, the magnitude of the differences between groups was greater than the previously reported standard errors of measurement and smallest detectable differences for femoral adduction, but not for contralateral pelvic drop. This suggests that femoral adduction was the main contributor of the greater hip adduction. Nevertheless, it is clinically important to acknowledge that the contribution of femoral adduction and contralateral pelvic drop to hip adduction can vary between individuals. A systematic review and meta-analysis reported moderate evidence for increased contralateral

Table 2
Inter-rater reliability of two-dimensional measured angles.

	Absolute difference between raters (°)*	ICC$_{2,2}$ (95% CI)	SEM (°)	SDD (°)
Lateral trunk position	0.3 ± 0.3	0.99 (0.98–1.00)	0.2	0.5
Contralateral pelvic drop	1.1 ± 0.7	0.93 (0.32–0.98)	0.7	1.8
Femoral adduction	0.6 ± 0.4	0.98 (0.95–0.99)	0.4	1.1
Hip adduction	1.1 ± 0.7	0.97 (0.87–0.99)	0.7	1.8
Foot inclination	0.8 ± 1.0	0.99 (0.98–0.99)	0.6	1.7
Tibia inclination	0.6 ± 0.6	0.99 (0.98–0.99)	0.4	1.2
Knee flexion	0.8 ± 0.7	0.98 (0.97–0.99)	0.6	1.5
Ankle dorsiflexion	0.9 ± 0.6	0.98 (0.96–0.99)	0.5	1.4

Abbreviations: ICC, intraclass correlation coefficients; CI, confidence interval; SEM, standard error of measurement; SDD, smallest detectable difference.
* Mean ± standard deviation.

Table 3
Two-dimensional measured angles (degrees) for both groups.

	Non-injured group	Injured group	P-value	95% CI of the group difference
Lateral trunk position (M ± SD)	13.9 ± 1.8	14.7 ± 2.0	.172	−0.4−2.1
Contralateral pelvic drop (M ± SD)	6.2 ± 2.1	7.8 ± 2.5	.035*	0.1−3.0
Femoral adduction (M ± SD)	81.6 ± 2.3	79.8 ± 2.7	.021*	−3.4−−0.3
Hip adduction (M ± SD)	75.4 ± 3.0	72.0 ± 3.4	.001*	−5.4−−1.4
Foot inclination (M ± SD)	9.7 ± 6.0	6.8 ± 5.1	.031*	−6.4 − 0.7†
Tibia inclination (M ± SD)	6.3 ± 4.4	6.5 ± 3.1	.854	−2.2−2.7
Knee flexion (M ± SD)	137.1 ± 4.8	137.2 ± 3.5	.953	−2.6−2.8
Ankle dorsiflexion (M ± SD)	27.7 ± 3.5	27.7 ± 3.1	.953	−2.2−2.0

Abbreviations: M, mean; SD, standard deviation; CI, confidence interval.
* Significant ($P < .05$).
† Based on parametric testing.

pelvic drop in runners with patellofemoral pain (Neal et al., 2016). However, this same kinematic profile could not be identified in runners with iliotibial band syndrome (Aderem & Louw, 2015). More recently, greater peak contralateral pelvic drop was reported to be the variable most strongly associated with running-related injuries, including patellofemoral pain and iliotibial band syndrome (Bramah et al., 2018). Further work is needed to understand this varying relationship between different cohorts.

Our sagittal plane findings indicate that the typical "overstride" pattern, which is described as a running pattern in which the foot lands further in front of the person's center of mass (Souza, 2016), characterized with higher tibia inclination, lower step rate and longer step length, was not more present in the injured group compared to the non-injured group. Indeed, tibia inclination, step rate and running speed were not different between groups. A greater tibia inclination is typically associated with longer step length and lower step rate when running speed is kept constant (Schubert, Kempf, & Heiderscheit, 2014). Lower step rate and longer step length have been related to higher patellofemoral joint stress (Lenhart, Thelen, Wille, Chumanov, & Heiderscheit, 2014; Willson et al., 2014, 2015), while longer step length has been related to higher iliotibial band strain (Boyer & Derrick, 2015). In addition, no differences were found for knee flexion and ankle dorsiflexion at midstance. Peak knee flexion at midstance has been found to predict patellofemoral force (Lenhart et al., 2014; Wille et al., 2014), while an inverse relationship with step rate has been reported (Lenhart et al., 2014). Numerous cross-sectional studies have linked altered sagittal plane kinematics and step rate/length to knee loading parameters (Lenhart et al., 2014; Schubert et al., 2014; Wille et al., 2014). However, cross-sectional and retrospective studies using three-dimensional motion analysis comparing sagittal plane kinematics and step rate between injured and non-injured runners are sparse and are not consistently related to patellofemoral pain (Dierks, Manal, Hamill, & Davis, 2011; Esculier, Roy, & Bouyer, 2015; Fox, Ferber, Saunders, Osis, & Bonacci, 2018; Neal, Barton, Birn-Jeffrey, & Morrisey, 2019; Wirtz, Willson, Kernozek, & Hong, 2012). No consistent differences could be identified for iliotibial band syndrome (Aderem & Louw, 2015; Louw & Deary, 2014). Prospective studies linking sagittal plane kinematics or step rate/length to running-related knee injury are lacking.

The only sagittal plane difference we identified was a smaller foot inclination angle at initial contact in the injured group. This indicates a potential compensatory running pattern to reduce knee loading, rather than a characteristic likely to be related to knee injury. Foot inclination at initial contact can be used to estimate knee joint loading, with smaller angles associated with lower peak knee extensor moment and mechanical energy absorbed about the knee during loading response (Wille et al., 2014). Therefore, we hypothesize that the sagittal plane kinematics were not the primary pathomechanism of our cohort.

The main clinical implication of this study is that two-dimensional video analysis can be used in clinical settings to discriminate kinematics of runners with and without running-related knee injury. Although significant differences were reported in the current study, clinical reasoning must consider these findings within a multifactorial decision-making process to decide whether an individual clinical biomechanical presentation needs to be addressed with running retraining. Running-related injuries occur due to multiple, varying and interacting risk factors. Of particular importance when considering biomechanical influences on pain and injury is training load (running), and whether the structure-specific load capacity is exceeded by the structure-specific cumulative load (Bertelsen et al., 2017; Nielsen et al., 2018). Based on the results of this study, the key targets for any running retraining intervention in runners with running-related knee injury could be a reduction in contralateral pelvic drop, femoral and hip adduction. Real-time kinematic feedback (Noehren, Scholz, & Davis, 2011; Willy, Manal, Witvrouw, & Davis, 2012) in runners with excessive hip adduction and cues to increase step rate (Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011; Neal, Barton, Birn-Jeffrey, Daley, & Morrissey, 2018; Willy et al., 2016) can significantly decrease hip adduction and improve pain and function in runners with patellofemoral pain (Neal et al., 2018; Noehren et al., 2011; Willy et al., 2012b). Running retraining for iliotibial band syndrome is limited to case studies including step rate manipulation (Allen, 2014) and real-time kinematic feedback of the pelvis (Hunter, Louw, & van Niekerk, 2014), but may be considered in clinical practice (Barton et al., 2016).

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 similarity between our results for hip adduction and the prospective, cross-sectional and retrospective literature, could lead to the assumption that altered hip adduction kinematics could already exist before injury and remain present after injury. However, this remains speculative based on the current study design. Further, it could be questioned whether group-based average results focusing on angles in isolation can be translated to the individual with a highly specific clinical presentation (Dingenen, Blandford et al., 2018c; Greenhalgh, Howick, & Maskrey, 2014). It is possible that specific subgroups with specific kinematic presentations are present within a group of individuals with the same medical diagnosis (Dingenen, Blandford et al., 2018c; Watari, Kobsar, Phinyomark, Osis, & Ferber, 2016). Future studies should explore the value of subclassifying runners with running-related knee injury based on their kinematic presentation measured with two-dimensional video analysis to assist clinicians in their clinical reasoning and decision-making processes. We did not correct for multiple comparisons given the exploratory nature of this study. However, if we would correct, hip adduction would still remain

significantly different between groups. We included a mixed-sex population, while running mechanics can differ between male and females with patellofemoral pain (Neal et al., 2019; Willy et al., 2012a) or iliotibial band syndrome (Phinyomark, Osis, Hettinga, Leigh, & Ferber, 2015). Therefore, the male/female distribution was kept similar between groups. Although we expect similar kinematics between patellofemoral pain and iliotibial band syndrome, we need larger data sets to evaluate if this is the case. An a priori power calculation was not performed, as we were the first comparing runners with and without running-related knee injury using two-dimensional video analysis. However, previous studies comparing runners with and without running-related knee injury using three-dimensional motion analysis included similar sample sizes (Aderem & Louw, 2015; Neal et al., 2016). The post-hoc power analysis revealed our between-group differences were powered at >.70 for three out of four significant findings (hip adduction = .96; femoral adduction = 0.73; contralateral pelvic drop = .71), while the statistical power of foot inclination (0.48) was only moderate, indicating less confidence in this significant finding. Lastly, only kinematics were measured. Future studies might combine kinematic measurements using the current methodology with wearables such as accelerometers to assess kinetics as well.

5. Conclusion

Two-dimensional video analysis can discriminate kinematic differences between runners with and without running-related knee injury. Greater contralateral pelvic drop, femoral adduction and hip adduction at midstance may provide running retraining targets when treating runners with running-related knee injury.

Conflicts of interest

None.

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.

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