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Original Research

Active pelvic tilt is reduced in athletes with groin injury; a case-controlled study

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ABSTRACT

Objective: To study if athletes with groin injury had less active pelvic tilt (APT) than non-injured controls.
Design: Case-control.
Setting: Sports physiotherapy clinics and sports clubs.
Participants: 17 athletes (Tegner>5, age 25.1(5.2) with groin injury and 27 healthy controls (Tenger>5, age 24.4(3.6)).
Main outcome measures: Active pelvic tilt, defining the ability of an individual to actively tilt the pelvis anteriorly and posteriorly over a frontal axis, and hip range of motion (HROM) parameters.
Results: Linear regression model associations with generalized estimated equations revealed that APT was lower on injured sides compared to non-injured for total (21.1(7.1) vs. 27.2(8.0), P = .003, effect size (ES) = 0.8) and anterior (10.2(5.9) vs. 13.7(4.8), P = .004, ES = 0.65) APT. Posterior APT (−10.9(3.6) vs. −13.4(5.2), P = .06, ES = 0.56) showed a trend towards being lower in those with groin injury. HROM parameters were not found associated.
Conclusions: Total active and anterior pelvic tilt were lower on the injured side in athletes with groin injury when compared to non-injured sides and healthy controls. This may be a relevant factor to consider in rehabilitation. Whether this is a cause or effect cannot be ascertained due to the cross sectional study design.

1. Introduction

Groin injury is common in sports that include agility and is problematic due to the high incidence and risk of recurrence and chronicity.(Haroy et al., 2017; Ryan, DeBurca, & Mc Creesh, 2014; Schache, Bennell, Blanch, & Wrigley, 1999). The within-season prevalence of groin injury in professional football ranges between 4 and 19% leading to reduced performance, time-loss or sometimes even the end of career.(Waldén, Hägglund, & Ekstrand, 2015; Whittaker, Smal, Maffey, & Emery, 2015). Previous injury, reduced adductor strength, lower levels of sport-specific training and lower total range of motion (ROM) of both hips are considered risk factors for subsequent groin injury.(Langhout et al., 2018; Tak et al., 2017; Whittaker et al., 2015). A previous injury resulting in a higher risk to sustain a new injury may imply that we neither understand the re-injury mechanism, nor that we are aware of the most important factors that need targeted interventions.(Bittencourt et al., 2016; Gokeler, Verhagen, & Hirschmann, 2018).

Pelvic movement is essential during sprinting and kicking in football. (Langhout, Weber, Tak, & Lenssen, 2015; Schache, Blanch, & Murphy, 2000). In sprinting the pelvis tilts posteriorly during early stance as a result of ground reaction forces (GRF) and then quickly reverses to anterior tilt (Fig. 1).(Schache et al., 2000; Sun et al., 2015) In kicking, spinal flexion and pelvic posterior tilt are coupled movements occurring prior to ball impact.(Langhout et al., 2015). When changing from submaximal to maximal kicking, ROM of spinal flexion and pelvic posterior tilt showed the greatest relative increase.(Langhout, Tak, Westen, & Lenssen, 2017). The GRF induces pelvis posterior tilt, thus hip extension and results in energy transfer to the ipsilateral kicking leg assisting in the proximal-to-distal kinematic sequence of the forward swing.(Inoue, Nunome,

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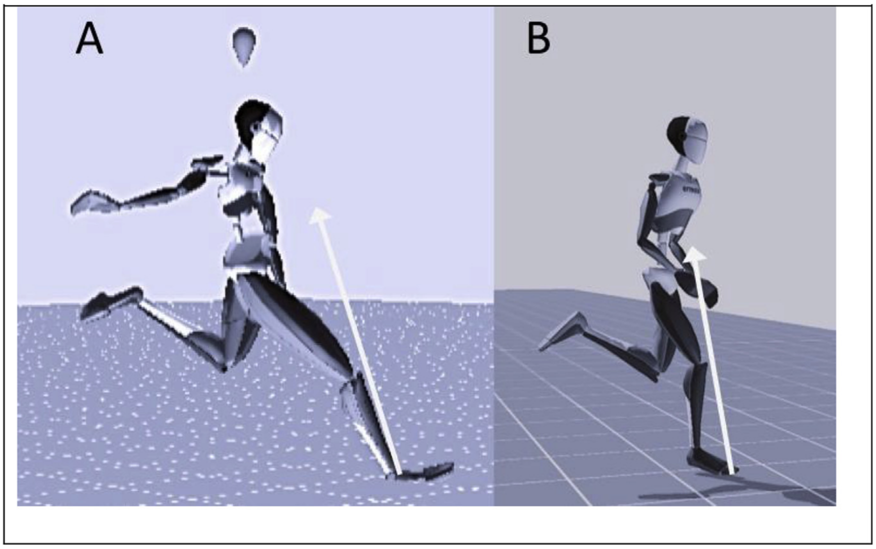

Fig. 1. Visual representation of ground reaction force passing in front of knee and hip joint during early stance phase in kicking (A) and sprinting (B), resulting in an extension moment in the support hip inducing posterior tilt of the pelvis.

Sterzing, Shinkai, & Ikegami, 2014; Nunome, Asai, Ikegami, & Sakurai, 2002). A deficit in the ability to tilt the pelvis is likely to negatively affect energy transfer, resulting in compensating movement strategies of adjacent segments with concomitant increased muscle load.(Naito, Fukui, & Maruyama, 2010). It was recently found that football players with a history of groin injury had decreased pelvic tilt during a kicking task compared to those without.(Severin, Mellifont, & Sayers, 2017).

Little has been documented on the relationship between pelvic movement in sport specific tasks and groin injury in athletes.(Severin et al., 2017). Hip ROM, which on itself was found to be reduced in athletes with groin injury, was not reported.(Mosler, Agricola, Weir, Hölmich, & Crossley, 2015). Hip ROM is related to pelvic position (Ross et al., 2014) and movement.(Birmingham, Kelly, Jacobs, McGrady, & Wang, 2012; Schache et al., 1999; Williams, 1978). Insight in this relationship could establish criteria for pelvic function as part of rehabilitation programs. The main aim of this study was to examine whether differences in active pelvic tilt exist between athletes with groin injury compared to those without. We hypothesize that active pelvic tilt would be reduced in athletes with groin injury. The secondary aim was to study hip ROM parameters in athletes with and without groin injury.

2. Materials and methods

2.1. Design

Our study was a case-control study. All participants gave their written consent prior to participating, based on the requirements of the Declaration of Helsinki.(World Medical Association, 2017). The Dutch Central Committee on Research Involving Human Subjects (CCMO) confirmed exemption from full ethical approval prior to the study as stated in the Dutch Medical Research Involving Human Subjects Act (https://wetten.overheid.nl/BWBR0036864/2018-08-01). Reporting the study findings was performed according to the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) guideline.(von Elm et al., 2014).

2.2. Participants

Participants were athletes (male or female), aged between 18 and 35 years and competing in track and/or field based sports (Tegner>5) (Briggs et al., 2009).

2.3. Inclusion criteria

Non-injured athletes had no current groin injury neither had they suffered a groin injury over the past 2 years. This was asked to them specifically on the day of measurement. Injured athletes had a current groin injury, classified as a clinical entity according to the Doha agreement(Weir et al., 2015), on the day of measurements with symptoms for at least 5 days. The injury could be either with or without time loss.

2.4. Exclusion criteria

Athletes were considered non-eligible in case of:

- History of fractures, dislocation and/or surgery of lower back, pelvis and/or upper leg (including knee);
- Chronic (>6 months) lower back pain;
- Hamstring injury in the past 12 months;
- Clinical suspicion of specific hip pathologies, nerve entrapment, referred pain, intra-abdominal abnormality (e.g. prostatitis or urinary tract infections), spondylarthropathy or tumors.

All athletes were recruited in two sports physiotherapy clinics and the collaborating sport clubs that these clinics provide health services for. They were invited by email through their trainers and treating therapists, enrolled consecutively and divided between two groups.

Athletes' characteristics and information about current or previous injuries were obtained by paper questionnaires on the day of measurement (Appendix 1). Data collection was between March–August 2018 and either on the sport club site (non-injured athletes) or in the clinic (injured athletes).

2.5. Injury

An injury can be either 'non-time loss' or 'time loss'. A 'time loss'-injury was defined as: the athlete is not able to particpate in training or matches due to groin injury.(Fuller et al., 2006). 'Non-time loss' injury was defined as: pain in the groin region while the athlete is still participating in training and matches. The duration of groin injury present was registered in weeks. Participants were instructed to report any pain or discomfort during the test protocol.

The Copenhagen Hip And Groin Outcome Score (HAGOS) was used to quantify the levels of hip and groin problems experienced. The HAGOS is a valid (R = 0.55 to 0.78) and reliable (ICC = 0.63–0.86) patient reported outcome measure to assess levels of hip and groin related problems in young and active individuals and available in Dutch language.(Tak, Tijssen, Schamp, Sierevelt, & Thorborg, 2018; Thorborg et al., 2011). Standard error of measurement (SEM) for the subscales range from 6.5 to 11.6.(Tak et al., 2018).

2.6. Clinical examination

Groin injury was assessed along the clinical entities approach as per the Doha agreement on terminology and definitions in athletes with hip and groin pain.(Weir et al., 2015). These clinical data were collected on a standardized form with entity scoring instructions as used in a previous study (Appendix 2) (Langhout et al., 2018; Tak et al., 2018).

2.7. Outcome measures

2.7.1. Active pelvic tilt (APT)

Active pelvic tilt was defined by the degree of rotation around a medial-lateral axis through the spina iliaca anterior superior in the sagittal plan. The degree of APT was measured with the CoreX Therapy application (Perfect Practise, Ohio, USA) on a smart phone (iPhone type 5c, Apple Inc., California, USA) using the inclinometer properties of the device. This application was found valid ($R^2 = 0.89$ and $R = 0.76$, $p \leq .001$) for the study of pelvic movement when compared to an optical motion capture system (Vicon, MX-F40, Vicon Peak, Oxford), with an acceptable intra-class reliability of $\alpha = 0.89–0.93$.(Chaudhari et al., 2013; Chaudhari, McKenzie, Pan, & Oñate, 2014).

A pilot study to assess the intra- and interrater reliability of the APT measurement was performed in 9 non-injured individuals (18 legs). The SEM and MDC were calculated, based on data obtained by both researchers on the same day. They were blinded for each other's results during testing.

Maximum anterior and posterior APT were measured and combined for total APT. Results of measurements were saved in the application and exported to a cloud database.

Active pelvic tilt was measured according a standardized protocol for both legs separately. The telephone was connected to an elastic band and placed directly under the anterior and posterior iliac spines on a fixed position on the sacrum of the participant (Fig. 2-A).(Chaudhari et al., 2013; Chaudhari et al., 2014) The starting position was based on the "golden position" described by Mann: standing upright with one leg in a midstance position and with the trailing swing leg in high knee position.(Mann, 2011). To prevent rectus femoris muscle length affecting pelvic tilt, excessive knee flexion was avoided. The toe of the swing leg was placed on the ground in line with the heel of the standing leg with both knees parallel. The front leg carries the body weight with the knee slightly flexed. The shoulder of the swing leg was placed against the wall for support to avoid lateral tilt. The maximal lateral tilt allowed was limited in the app settings (+5°/0/-5°). When these were exceeded a warning signal was produced and the test was stopped. Data from the trials with excessive lateral tilt were deleted.

Prior to measurement a maximum of three trial repetitions on each leg were completed to avoid learning effects during measurement. The participants were instructed to stand in a neutral relaxed position while no instructions were given about anterior or posterior tilt. From this starting position the participant maximally tilted their pelvis anteriorly and posteriorly (Fig. 2C and 2D), both three times following a standard verbal instruction: "Tilt your pelvis maximally forward to create a hollow lower back. Keep both knees parallel and your shoulder against the wall while the front leg carries body weight. Now tilt the lower back maximally backward to create a flat back, while keeping your shoulder against the wall and body weight on the front leg".

2.7.2. Bent knee fall-out (BKFO)

Hip flexibility towards combined flexion, abduction and external rotation was assessed using the BKFO test. The participant was in a supine position with the knees 90° flexed, as confirmed with a goniometer, and the soles of both feet against each other. Both hips were rotated outwards to end range and the examiner gave gentle overpressure.(Tak et al., 2017). The distance between the fibular head and the top of the table was measured in centimetres (cm) with a rigid tape measure. The BKFO has excellent intrarater and interrater reliability with ICC's of 0.89 and ICC 0.91 respectively. The SEM for this protocol is 1.0 cm(Malliaras, Hogan, Nawrocki, Crossley, & Schache, 2009).

2.7.3. Hip range of motion (HROM)

Internal and external rotation of the hip were measured with a goniometer (in a supine position with knee and hip flexed to 90°) and added to give the total ROM score per hip. One arm of the goniometer was placed on the apex of the patella through the tuberositas tibiae and the other in line with both spina iliaca anterior (SIAS). The observer then performed rotation until the earliest visible lateral rotation of the pelvis. Further hip rotation can be achieved by lumbar spine lateral flexion resulting in an overestimation of hip rotation.(Tak et al., 2017). This HROM assessment method has a high intrarater (ICC 0.95) and interrater (ICC 0.91) reliability. The SEM is 2.4° for internal and 2.5° for external rotation with a MDC of 7° each.(Tak et al., 2016, 2017).

2.8. Statistical analysis

Data analyses were completed with the Statistical Package Social Sciences (SPSS, v. 20, IBM, Armonk, USA).

Intra- and interrater reliability for the measurement protocol was assessed calculating intraclass correlations (two way mixed for absolute agreement) for single measures with 95% confidence intervals (CI). Standard error of measurement (SEM) was calculated as: standard deviation (SD) x $\sqrt{(1\text{-ICC})}$ and minimal detectable change (MDC) as $1.96 \times$ SEM x $\sqrt{2}$.

A statistical power analysis was performed a priori for sample size estimation. It was expected that differences in the primary outcome between groups (APT) would be at least moderate in size. At least 17 injured (considering presence of unilateral injury (17 hips)) and 17 non-injured athletes would be required (alpha = 0.05 and power = 0.80) to detect an effect of d = 0.5.

The Shapiro-Wilk test was used to test for normal distribution of all parameters. Normally distributed data were presented by mean (SD). When data were not normally distributed it was presented as median and 25–75% interquartile range (IQR).

Comparisons between groups for descriptive data were performed with independent samples T-tests (age, weight, height, BMI) or Mann Whitney U tests (HAGOS). Differences for APT and HROM variables (BKFO, internal, external and total rotations) between non-dominant and dominant sides in the No-GI group were tested with a paired sample T-test. Linear regression model associations between APT and HROM (as dependent) variables and the presence/absence of GI per side (non-injured and injured) were

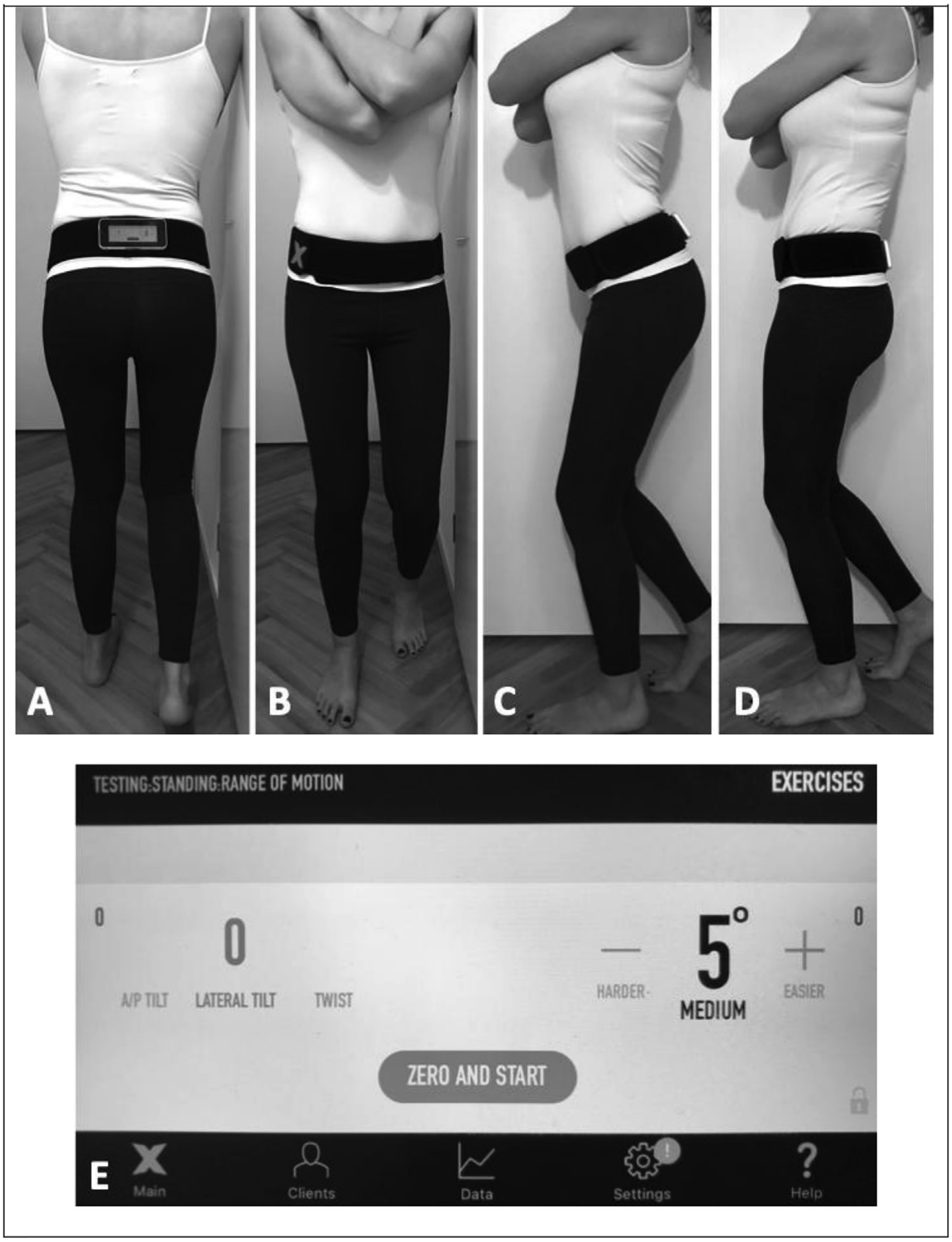

Fig. 2. A: Positioning of the elastic band with iPhone just below the spina iliaca posterior on the sacrum with the athlete in the test position (rear view). B: Athlete position in standing (frontal view). C: Maximum anteriorly tilted position. CD: Maximum posteriorly tilted position. E: Print screen of CoreX Therapy application. Maximum tilt allowed can be set and the tilting position is displayed in degrees.

calculated per hip using univariate linear regression with generalized estimating equations (GEE). By using GEE the interdependency between dominant and non-dominant hips could be modelled. The alpha level for statistical significance was set at $P \leq 0.05$. Effect sizes were calculated using Cohen's d to guide on the relevance of significant findings. Effects sizes were rated as weak ($\geq$0.2), average ($\geq$0.5) or strong ($\geq$0.8).(Cohen, 1992). As HROM relates to pelvic position, HROM variables were entered as co-variate in the regression model in case univariate testing revealed $P < .2$.

3. Results

3.1. Reliability of the APT measurement protocol

Both intra-rater and inter-rater reliability testing in 9 non-injured athletes (5 female and 4 male, age 24.8(1.5) yrs, length 1.80(0.1) m, weight 70.5(8.6) kg and BMI 21.8(1.2) kg/m^2) revealed that the APT measurements were reliable. Reliability data (ICC, SEM and MDC) are presented in Table 1.

3.2. Participants

In total 44 athletes were included. Characteristics for both non-injured ($n = 27$) and injured ($n = 17$) groups are presented in Table 2 as well as the results for testing differences between groups. No significant differences between groups were found for age, height, weight and BMI. All HAGOS subscale scores were significantly lower (all $P \leq .001$) for the injured group when compared to the non-injured group (see Table 2) confirming correct group allocation. No participant reported any pain or discomfort during

Table 1
Results for intra- and inter reliability testing of the APT measures, presented as intra-class correlation coefficient and 95% CI, including SEM and MDC.

	Posterior APT	Anterior APT	Total APT
Intra-rater	0.87 (0.69–0.95)	0.89 (0.74–0.96)	0.97 (0.93–0.99)
Inter-rater	0.57 (0.30–0.75)	0.83 (0.69–0.91)	0.94 (0.88–0.97)
SEM (°)	2	2	1
MDC (°)	5	4	4

Abbreviations: APT = active pelvic tilt; CI = confidence interval; ICC = intraclass correlation; SEM = standard error of measurement, MDC = minimal detectable change.

testing of APT or hip ROM.

3.3. Main outcome variables

The results of testing for differences between non-injured and injured sides for the outcome variables of APT are presented in Table 3. Total APT (Cohens' d = 0.80, OR = 1.1(95%CI:1.04–1.27)) and anterior APT (Cohens' d = 0.65, OR = 1.2(95%CI:1.06–1.36)) were found to be significantly lower at the injured sides when compared to non-injured sides. Pelvic posterior tilt showed a trend towards being reduced (Cohens' d = 0.56, OR = 0.9(0.80–1.01)).

The results of statistical analysis between non-injured and injured sides for the outcome variables for HROM are presented in Table 4. None of these were found to be different between injured and non-injured sides.

BKFO showed a trend (P = .074) towards being 2.2 cm higher (indicating less flexibility) at the non-injured side (see Table 4). When entered as co-variate in the regression model, BKFO did not affect the association found between APT and presence or absence of groin injury. No significant differences were found between dominant and non-dominant sides in the non-injured group for APT and all HROM parameters (see Table 5).

Table 3
Main outcome measures for APT in non-injured and injured sides presented as mean (SD) and P-values (presented after correction for dominance. P-values<.05 presented in bold).

	Non-injured side (n = 68)	Injured Side (n = 20)	P
Posterior APT (°)	−13.4 (5.2)	−10.9 (3.6)	P = .061
Anterior APT (°)	13.7 (4.8)	10.2 (5.9)	**P = .004**
Total APT (°)	27.2 (8.0)	21.1 (7.1)	**P = .003**

Abbreviations: APT = active pelvic tilt; SD = standard deviation; n = number; P = p-value.

Table 4
Main outcome measures for HROM in non-injured and injured sides presented as mean (SD) and P-values (presented after correction for dominance).

	Non-injured side (n = 68)	Injured side (n = 20)	P
BKFO (cm)	21.3 (4.5)	19.1 (5.1)	P = .074
HROM Internal (°)	20.1 (7.0)	18.0 (5.7)	P = .209
HROM External (°)	36.3 (8.7)	36.8 (8.5)	P = .793
HROM Total (°)	56.5 (13.3)	54.8 (12.7)	P = .626

Abbreviations: HROM = hip range of motion; SD = standard deviation; n = number; P = p-value; BKFO = bent knee fall out.

Table 2
Athletes' characteristics presented as mean (SD) or median (25%–75% inter quartile range) or absolute numbers (n) and percentages (%).

	Non-injured (n = 27/100%)	Injured (n = 17/100%)	P
Sex (n,%)			
Male	11 (41%)	9 (53%)	
Female	16 (59%)	8 (47%)	
Age (y)	24.4 (3.6)	25.1 (5.2)	P = .565
Height (m)	1.78 (0.08)	1.75 (0.11)	P = .513
Weight (kg)	71.9 (7.2)	72.2 (13.6)	P = .928
BMI (kg/m^2)	22.8 (1.6)	23.2 (2.8)	P = .501
Sporting level (Tegner)	7 (7–8)	7 (7–9)	P = .229
Sport type (n)			
Football	0 (0%)	7 (41%)	
Hockey	11 (41%)	1 (6%)	
Athletics	0 (0.0%)	8 (47%)	
Korfball	0 (0.0%)	1 (6%)	
Handball	16 (59%)	0 (0%)	
Dominant side (n,%)			
Left	5 (19%)	4 (23%)	
Right	22 (81%)	13 (77%)	
Injured side (n,%)			
Non-dominant	NA	7 (41%)	
Dominant	NA	7 (41%)	
Both	NA	3 (18%)	
Doha classification (n,%)			
Adductor-related	NA	10 (60%)	
Iliopsoas-related	NA	7 (40%)	
Type of injury (n,%)			
Non-timeloss	NA	3 (18%)	
Timeloss	NA	14 (82%)	
Duration of symptoms (wks)	NA	4 (2–7)	
HAGOS			
Symptoms	96 (93–100)	57 (36–66)	P ≤ .001
Pain	100 (100–100)	73 (65–79)	P ≤ .001
ADL	100 (100–100)	80 (63–90)	P ≤ .001
Sport	100 (100–100)	56 (33–66)	P ≤ .001
Physical activities	100 (100–100)	38 (25–63)	P ≤ .001
QOL	100 (95–100)	45 (40–60)	P ≤ .001

Abbreviations: SD = standard deviation; n = number; P = p-value; NA = not applicable; BMI = body mass index; HAGOS = hip and groin outcome score; wks = weeks; ADL = activities daily living; QOL = Quality of Life.

Table 5
HROM and APT for dominant and non-dominant sides in athletes without groin injury presented as mean (SD). P-values are provided for testing on differences between sides.

	Non-dominant side (n = 27)	Dominant side (n = 27)	P
HROM BKFO (cm)	21.9 (4.2)	21.6 (4.4)	P = .399
HROM IR (°)	21.3 (6.3)	19.6 (7.2)	P = .071
HROM ER (°)	36.7 (8.3)	36.5 (9.5)	P = .876
HROM Total (IR + ER) (°)	58.0 (13.0)	56.1 (13.7)	P = .252
APT Anterior (°)	13.7 (4.5)	12.8 (4.3)	P = .244
APT Posterior (°)	−13.8 (5.6)	−13.9 (5.9)	P = .835
APT Total (°)	27.5 (8.3)	26.7 (8.7)	P = .368

Abbreviations: HROM = hip range of motion; APT = active pelvic tilt; d = degree; n = number; cm = centimetre; SD = standard deviation; BKFO = bent knee fall out; IR = internal rotation; ER = external rotation.

4. Discussion

In this study we found active anterior and total pelvic tilt to be reduced on injured sides in athletes with groin injury when compared to athletes without. We did not identify any of the hip range of motion (HROM) variables for bent knee fall out, internal, external or total rotations to be different. No differences between dominant and non-dominant sides were found in non-injured controls.

4.1. Active pelvic tilt

Kinematics of the hip and pelvis during sport specific tasks like kicking(Severin et al., 2017), a single leg drop landing(Janse van Rensburg et al., 2017) and a change of direction task(-FranklynMiller et al., 2016) are different in athletes with groin injury when compared to athletes without. It is not explained however, why this might be of importance from a biomechanical point of view, nor does this assist the clinician in further determination of relevant parameters to be targeted during rehabilitation. Our current study demonstrates significantly decreased active total and anterior pelvic tilt on the injured sides of athletes with groin injury. Posterior APT was found to be slightly lower on the injured side, yet this did not reach statistical significance. All differences found exceeded the standard error of measurement (SEM). The difference in total APT exceeded the minimal detectable change (MDC) threshold but this was not true for single anterior and posterior APT measures. The effect sizes were strong for total APT and average for anterior and posterior APT. We suggest targeting APT in rehabilitation programs for athletes with groin pain. Improvements on this task can be assessed reliably according the presented measurement for total APT.

APT was measured starting from a predefined midrange body position. Ideally the midrange pelvic position (more or less pronounced anterior or posteriorly oriented pelvis) is determined and controlled in 3D space in relation to a fixed raster of coordinates along the X-, Y- and Z-axes. This was not possible with the mobile device used and may have influenced measurement outcome for single posterior and anterior APT yet not for total APT. Using a similar type of mobile device increases the generalizability of this type of assessments. It is easily accessible, cheap and quickly applied in clinical settings. Studies should thus report if pelvis motion was captured relative to fixed 3D coordinates of the testing area, or relative to the pelvis itself, upper leg or lumbar spine. Transparency on definitions and measurement techniques to assess pelvic ROM is thus warranted in future studies.

Total range of APT in relation to trunk and both legs as tested in this study was found impaired. We deem these findings clinically relevant for sports performance and injury prevention. Pelvis, spine and hip kinematics are coupled movements during sporting tasks like sprinting and running.(Schache et al., 1999, 2000). It was observed in football kicking and baseball pitching that knee extension of the support leg attributes to increased ball speed and that the pelvis plays an important role in processing GRF's by transferring mechanical energy to the kicking or throwing extremity.(Huang et al., 2013; Inoue et al., 2014; Sun et al., 2015; Trigt, Schallig, & Graaff, 2018; Zajac, 2002). The pelvis is considered one of the central segments assisting in proximo-to-distal sequencing of high speed body movements.(Shan & Westerhoff, 2005; Zajac, 2002). Impaired pelvic movement may negatively affect the athlete's performance and as such induce a higher risk of recurrence and chronicity of groin injury.(Waldén et al., 2015).

We propose restoring APT should be considered part of rehabilitation regimes for injured athletes as it allows mechanical energy transfer during sports actions.(Naito, Fukui, & Maruyama, 2012). Physical therapists should consider core mobility apart from core stability strategies.

4.2. Hip range of motion parameters

We found BKFO to be slightly increased on the injured side when compared to the non-injured side yet this did not reach statistical significance. In contrast, previous studies on Australian and Gaelic football players with groin pain found lower BKFO on both sides when compared to non-injured controls.(Malliaras et al., 2009; Nevin & Delahunt, 2014). Both studies however did not correct for the interdependency of BKFO of the left and right hip within one person.(Tak et al., 2017). One study in professional footballers that controlled for this interdependency did not found painful hips to be less flexible at BKFO but established that lower BKFO was found to be associated with the presence of cam type morphology.(Tak et al., 2016).

At the time of these studies the Doha agreement to categorise injured athletes in any of the clinical entities was not yet incorporated. One study was on athletes with (a combination) of adductor-related and/or symphysis related groin pain.(Nevin & Delahunt, 2014). The other studies did not categorise injured athletes into any of the entities.(Malliaras et al., 2009; Tak et al., 2016).

The findings on hip internal rotation not being significantly lower on the injured side, contributes to the little available existing literature. We found a difference of 2.1° after correction for dominance as recently suggested.(Tak et al., 2017). When group size is increased this may reach significance but its value should then be questioned as this difference would not exceed the MDC value and thus can be deemed non-relevant.(Tak et al., 2017). The HROM variables studied did not affect the observed association of lower APT and groin pain in our cohort.

The absence of differences on hip rotations and BKFO between dominant and non-dominant sides in non-injured athletes agrees with previous findings.(Malliaras et al., 2009; Nevin & Delahunt, 2014).

4.3. Meaning of the study

Lumbopelvic motion is important in sprinting as it is highly coordinated with hip movement and pelvic anterior tilt is related to swing hip flexion and high contraction forces of the adductor longus.(Hamner, Seth, & Delp, 2010; Sun et al., 2015). In maximal kicking it showed the greatest relative ROM increase and acts as a safety mechanism due to elongation of the adductors at ball impact.(Langhout et al., 2015). Results of this study are of importance for performance and prevention.

4.4. Strengths

This is the first study on active pelvic tilt that adds new information to the field of groin injury research. Many studies on groin injury have been performed in football, as its prevalence in this sport is high. The differences we found in a homogenous group regarding age and athletic levels adds to the body of knowledge on groin injuries in athletes besides football. The use of a wearable, low cost and generally available app is new and suits the technological advances in health care to assess more complex dynamic parameters. Rehabilitation programs focussing on adductor related groin pain mainly contain strengthening exercises of the adductor and abdominal muscles.(Hölmich et al., 1999; Weir et al., 2011). A multimodality approach, combining these exercise regimes with manual therapy of the adductor muscles found equally good results but reported a faster return to sport.(Weir et al., 2009). None of the exercise regimes had specific elements aiming to improve active pelvic tilting actions.(King, Ward, Small, Falvey, & Franklyn-Miller, 2015). Future research is needed to establish whether restoring normal APT adds to further improvement of any of the clinical outcome measures of athletes with groin injury.

4.5. Limitations

The case-control design prohibits drawing conclusions on whether the lower APT is the cause or effect of groin injury. As this is the first study to evaluate APT as outcome measure no strict comparisons can be made with other studies on this variable. Although this is a case-controlled design and we had homogenous groups for activity levels (Tegner score, track and/or field based), the individual matching was not performed for the type of sport. If and how this may have affected the outcome measures remains unknown. As per our power analysis there were enough participants/injured legs in this study but having 2 clinical entities of groin pain may raise the question whether or not APT relates more to one entity than another. This may have affected measurement outcome.

4.6. Unanswered questions and needs for future research

It remains unclear if restoration of APT in both directions may assist in a quicker or more robust recovery per entity of groin injury. It is also unknown if addressing the APT deficit may prevent from recurrent groin injury and lower the groin injury burden in football teams.

5. Conclusion

This is the first study to use a novel mobile phone based device to measure APT in athletes with and without groin injury. Total and anterior active pelvic tilt was lower on the injured side in athletes with groin injury. APT is a newly identified variable and its role in the rehabilitation and prevention of groin injury should be explored in future studies.

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Conflict of interest

None

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2018.12.011.

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