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Frontal plane projection angle predicts patellofemoral pain: Prospective study in male military cadets☆

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ABSTRACT

Background: Patellofemoral pain (PFP) is a major source of knee pain. Identifying who may develop PFP is of paramount importance.
Purpose: To assess whether Frontal plane projection angles (FPPA) and hand held dynamometry (HHD) strength measures can predict development of PFP.
Study design: Prospective evaluation of individuals undertaking a military training programme.
Methods: Male military recruits were enrolled and prospectively followed up from enrolment to completion of 12-weeks training. Lower limb kinematics (FPPA, Q-angle, hip adduction angle, knee flexion, ankle dorsiflexion, and rearfoot eversion angle) measured during running, single leg squatting (SLS), and single leg landing (SLL) and isometric muscle strength of hip abductors and knee extensors.
Results: Body mass, hip abductor muscle strength, Q-angle during SLS and SLL, FPPA during SLL all significantly different between the PFP and non-injured groups and predicted PFP, highest predictor variable was FPPA during SLL (Odds Ratio = 1.13, P = 0.01). A FPPA$\geq$5.2° during SLL predicting PFP with a sensitivity of 70% and a specificity of 70%.
Conclusion: Participants who developed PFP had a number of physical factors significantly different than the non-injured group, most predictive was a larger FPPA during SLL, with angles greater than 5.2° associated with a 2.2x greater risk.
Clinical relevance: Assessing FPPA during SLL could be used to determine who was predisposed to PFP.

What is known about the subject?

Knee valgus angles and decreased muscle strength are regarded as risk factors for patellofemoral pain. However, prospectively designed studies with large sample sizes have not been performed up to the time this study started nor assessed a range of tasks.

What this study adds to existing knowledge

This study was the first study to employ 2-dimensional video analysis to a large prospective cohort of individuals to identify risk factors in the predisposition of patellofemoral pain during different tasks. This is the first study to identify the task which has the best predictive value for identifying the incidence of patellofemoral pain. To the authors knowledge, no other study has been conducted in this way and this study identified that simple measures could be used in screening populations to identify 'at risk' individuals. This would then allow individuals to be stratified to corresponding rehabilitative treatments.

1. Introduction

Patellofemoral pain (PFP) is a major problem among physically active populations, such as adolescents, young adults, and military recruits (Glaviano et al., 2015; Smith et al., 2018). It is one of the main sources of chronic knee pain in young athletes (Brody & Thein, 1998; Piva et al., 2006), accounting for 25%–40% of all knee joint problems examined in sports medicine clinics (Bizzini et al., 2003). Commonly, the pain is aggravated during loaded knee flexion, such as ascending and descending stairs, squatting, prolonged sitting or running (Crossley et al., 2016; Nunes et al., 2013).

☆ All participants gave written consent to participate, and the study was approved by the University and Military research and ethics committees.

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Previously, biomechanical factors which could predispose an individual to PFP, have been identified through retrospective study designs whereby an increase in hip adduction and internal rotation angles, an increase of knee valgus, Q-angle, rearfoot eversion angle, a decrease of knee extensors (KEXT) and hip abductor (HABD) and external rotator strength has been shown to be a factor (Crossley et al., 2016). However, within retrospective designs, it is difficult to determine if the risk factor is the cause or the consequence of PFP. Therefore, prospective studies are needed to improve our understanding of the potential biomechanical risk factors for PFP.

Three previous systematic reviews and meta-analysis investigated the prospective studies of risk factors of PFP (Lankhorst et al., 2012; Neal et al., 2019; Pappas & Wong-Tom, 2012). These reviews identified lower knee extensors muscle strength as a possible predictor for PFP development. There was a lack of agreement among studies as to any other factors, which may be due to differences in the variables considered and measurement methods used, and a limited number of variables were possible to be pooled in a meta-analysis and several risk factors being described individually, each in a single study.

The studies reported in the reviews showed several potential limitations in relation to exploration of findings in larger scale prospective studies. Some studies used expensive and complex technology (Boling et al., 2009; Myer et al., 2010; Stefanyshyn et al., 2006), and some achieved results that were not generalizable to dynamic tasks (Myer et al., 2010) as they were based on static measurements (Rauh et al., 2010; Thijs et al., 2011; Witvrouw et al., 2000), or have looked at a single factor or observed a single task (Boling et al., 2009; Thijs et al., 2011; Van Tiggelen et al., 2009). There also was a relatively low incidence rate of PFP in some of the studies (Boling et al., 2009). The most important limitations of sampling biomechanical data in large populations is the time taken and use of advanced technology which may not be suitable for these applications. Therefore, speed, simplicity and portability are essential factors and utilising two-dimensional (2D) video and handheld dynamometry offer quicker assessments allowing large populations to be sampled. Previously, two studies have utilised 2D video to assess knee valgus displacement in adolescent females (Holden et al., 2017) and utilising the Frontal Plane Knee Projection Angle (FPPA) (Willson & Davis, 2008) in a military training cohort (Nakagawa et al., 2020). Military training is an intensive task where individuals suffer increased lower limb injuries (Sharma et al., 2015) and offers an improved homogeneity of individuals especially in relation to their load exposure. Previous studies have shown that PFP was one of the most prevalent injuries during military training (Cutbill et al., 1997) and has demonstrated that FPPA greater than 4.8° during a single leg squat was a significant predictor for the development of PFP (Nakagawa et al., 2020). Only one study to date has assessed multiple athletic tasks to determine if any of these common tasks has superior ability to identify individuals at risk of patellofemoral pain (Boling et al., 2021) and they found no factors which predicted development of PFP in military recruits.

The purpose of this study was to prospectively assess the lower limb kinematic variables and measures for strength and identify their relationship to PFP development and other lower limb injuries in Saudi Arabian Military recruits during a 12-week cadet training course. A secondary aim was to identify the incidence of PFP during training of these recruits.

2. Methods

Individuals from the Royal Saudi Land Forces were invited to take part in this prospective study at the beginning of their basic 12-week military training. This training entails approximately 12–15 h of daily training programmes, consisting mainly of extensive physical training, marching with backpacks, military tactical exercises, and shooting, in addition to theoretical classes. Ethical approval was attained from local University and Saudi Arabian Military Ethical Committees and each individual signed an informed consent form.

2.1. Baseline assessment

It was required that all participants were free from any recent (in the last 12 months) lower limb injury or lower back pain and were clinically screened by the principal investigator for signs of knee meniscal abnormalities, ligamentous instability, effusion and tenderness. Any individuals with such injuries were referred to the unit's physician and were excluded from the study. Following successful eligibility, all recruits were fitted with the standard training shoes for basic military training, and they wore standard shorts and training shirts. Mass, height and dominant leg (referred to as the one which they would kick a ball with) were recorded.

Three reflective markers (anterior superior iliac spine (ASIS), mid-point of the femoral condyles and the tibial tubercle) were placed on anatomical landmarks for the measurement of the Q-angle (Herrington, 2013). For the FPPA, markers were placed on the midpoint between the medial and lateral malleoli, (marker depicting midpoint between condyles above) and on the proximal thigh along a line from the ASIS to the knee marker (Munro et al., 2012). Markers were also placed on the greater trochanter, lateral epicondyle, lateral malleolus, head of the fibula, and the head of the fifth metatarsal, (which was approximated outside the standard shoes) to determine the anatomical landmarks for knee flexion angle and ankle dorsiflexion angle. Finally, for the rearfoot eversion angle, four markers were placed, in descending order, on the midpoint of the calf muscle, the top of the Achilles tendon, the top of the calcaneus, and the bottom of the calcaneus. The lower two markers were glued onto the standard training shoes that were worn by all individuals. Markers were placed bilaterally.

Four commercial video cameras on tripods (Casio Exilim F1) with a sampling rate of 30Hz were located around the capture area at 10m in front of the centre of the capture area at a height of 50 cm to capture the markers and to determine the Q-angle, FPPA, and HADD angles during the designated movements. The second and third cameras were placed 3m to the left and right of the centre of the capturing area, at a height of 50 cm to film the lower limb sagittal plane movement (maximum knee flexion and foot dorsiflexion). The fourth camera was placed 10m behind the centre of the capturing area, at a height of 50 cm to capture the posterior markers (used to determine the rearfoot eversion angle) during the tasks.

Each participant completed three tasks, single leg squatting (SLS), single leg landing (SLL) and running (RUN). Individuals performed a single-leg squat to at least 45 degrees of knee flexion over a period of 5 s. A counter was used whereby the first count initiated the movement, the third indicates the lowest point and the fifth indicates the end. For the single leg land, subjects were asked to stand on one leg on a 30-cm high step and to step down and land onto the opposite leg. Individuals were asked to keep their arms across their chest during the task and had to keep their balance ensuring that the contralateral leg was not in contact with any objects or the ground during the trial (Munro et al., 2012). Subjects ran over a 10-m runway at a velocity of 3 m/s, which was controlled with a Brower Timing Gate System with a±5% tolerance between the trials. To minimise the effect of fatigue, a 1.5-min rest was given to all participants between the trials. Participants could practice each task two or three times until they felt familiarised and comfortable with the trials. Subsequently, three acceptable trials from each participant for both legs were completed and analysed for all tasks.

Handheld dynamometry (HHD) was used to measure knee extensor and hip abductor strength. The HHD (MicroFet F1, Hoggan Industry, USA) was stabilised on a horizontal stake at a height of 20 cm. The subjects were asked to sit on the edge of the treatment bed, with a 90° flexion at the knee and both feet off the ground. The height of the treatment bed was adjusted to place the HHD 5 cm proximal to the ankle joint at the anterior aspect. For the hip abductors, the HHD was stabilised on the wall, and subjects were asked to lie down on their backs with on their none testing limb their knee flexed at 90°, the tested limb was on the edge of the bed, beside the stabilised HHD, which was aligned 4 cm above the tip of the lateral malleolus, to apply maximum force in abducting the hip joint against the fixed HHD. The subjects were asked to apply maximum force against the fixed device for 5 s and to repeat the trial four times, with a 30-s rest in between. The last three trials were recorded, while the first trial was used as practice for familiarisation (Bolgla et al., 2008). The maximum force, in (N), of the knee extensors for each trial was recorded for both sides and the average multiplied by lower leg length in metres (m) (the distance from the head of the fibula to the tip of the lateral malleolus) to calculate the isometric peak torque of knee extensors in (Nm), then divided by body mass to give Nm/kg. The maximum force, in (N), of the hip abductors for each trial was recorded for both sides and the average multiplied by length of femur in (m) (the distance from greater trochanter to the lateral epicondyle) to calculate the isometric peak torque of hip abductors in (Nm) then divided by body mass to give Nm/kg.

2.2. Assessment and registration of injuries

Participants' were followed for the 12 weeks of basic military training to record the occurrence of PFP and other lower limb injuries. Any participant presenting with a suspected injury was reported to the training camp medical unit's physician for assessment and diagnosis. For diagnosis of PFP, participants had to meet the following inclusion criteria (Crossley et al., 2016); exhibit retropatellar pain during at least two of the following activities: jumping/hopping, squatting, stairs, and running (Crossley et al., 2016) and exhibit two of the following clinical criteria (with scores greater than 3/10) (Powers, 2010); i Pain during direct compression of the patella against the femoral condyle while knee is in full extension; ii Tenderness on palpation of the posterior surface of the patella; iii Pain on resisted knee extension from 90° of flexion to the full extension; iv Pain during isometric contraction of the quadriceps against resistance on the suprapatellar resistance with 15° of knee flexion. These issues needed to have been present for two consecutive days. Additionally, negative findings (i.e. no symptoms) in the examination of knee ligaments, bursae, menisci, synovial plica, iliotibial band, Hoffa's fat pad, and the hamstring, quadriceps, and patellar tendons and their insertions were essential for being included in the PFP group.

2.3. Data analysis

2D videos were analysed using the Quintic Biomechanics software package (Version 26) with which the following angles were calculated. The Q angle was calculated with the participant in standing by extending a line through the center of the patella to the anterior superior iliac spine and another line from the tibial tubercle through the center of the patella (Herrington, 2013). The intersection of these two lines is the Q-angle (positive value) (Herrington, 2013), this was captured whilst in standing for the SLS and at point of initial foot contact for SLL, this was not captured during running. The FPPA was calculated by measuring the angle between the line from the marker of the proximal thigh to the marker of the midpoint of the knee joint and the line from the marker of the knee joint to the marker of the ankle. The frontal plane projection angle was measured at the frame corresponding to the maximum knee flexion angle (Willson & Davis, 2008). The Hip adduction angle (HADD) was calculated from the angle formed by two lines. Line one was between the midpoint of the knee joint and the ASIS and line 2 which was formed from a connection to both ASIS points at the frame corresponding to maximum knee flexion.

Knee flexion angle was the angle formed between the line from the greater trochanter to the lateral epicondyle and the line from the lateral malleolus to the lateral epicondyle (Nunes et al., 2013). Ankle dorsiflexion angle was represented by the angle formed between the lines from the two peripheral markers (fibular head and 5th metatarsal) to the central marker placed on the lateral malleolus (Fong et al., 2011). Finally, the rearfoot angle was represented by the smaller angle formed by the upper two markers, on the leg and the lower two markers on the rearfoot (Powers, 2010).

2.4. Statistical analysis

All statistical analyses were performed using IBM SPSS statistical software (Version 23). Means and standard deviations for all measured variables were obtained. All measured variables were analysed to check the normality of distribution using a Shapiro-Wilk test. In comparing the injured with the non-injured groups, independent t-tests were used for normally distributed variables and Mann-Whitney *U* tests for non-normally distributed variables. Effect sizes were calculated to assess the importance of significant differences found between injured and non-injured groups for each variable. Effect sizes were determined using Cohen's d, which was categorised into three levels: 0.2 represented a small effect size, 0.5 a medium effect size, and 0.8 a large effect size (Thomas et al., 2011). Binary logistic regression analysis was performed for each variable to identify the predictive variables on the development of PFP. Forward stepwise logistic regression analysis was applied to create a predictive model to determine the predicted variable with regards to interaction with other variables. Only the variables that were significantly different between the injured and non-injured groups were included in binary logistic regression and creating the model. A receiver operating characteristic (ROC) curve, with a value of area under the curve and sensitivity and specificity values, was performed to identify the discriminatory capability of each variable. The cut-off point on the ROC curve was chosen with maximised sensitivity and specificity values. Statistical significance was accepted at $a = 0.05$ level.

3. Results

338 male individuals consented to take part in the study. 16 individuals were excluded as they had positive clinical findings or presence of another injury at initial assessment. 3 individuals did not complete training due to another medical condition and 4 individuals withdrew from military training. Therefore, 315 individuals (Age 19.8 [2.9] years; Height 1.72 [0.06] m; Mass 66.43 [3.73] kg; body mass index (BMI) 22.39 [3.88] kg/m^2) completed the 12 weeks of military training.

37 of the 315 participants (11.7%) were diagnosed with PFP in 46 knees and was the highest recorded injury accounting for 44% of all recorded lower limb musculoskeletal injuries. Participants who developed PFP were significantly heavier than the healthy group ($p = 0.039$), with a higher body mass index (BMI) ($p = 0.048$) and normalised body mass (normalised to height) ($p = 0.027$). Effect sizes though were small for body mass-related variables (mass

0.26; BMI 0.22; normalised body mass 0.24) as shown in Table 1.

Individuals who developed PFP had significantly lower muscle strength during the baseline assessment in knee extensors ($p = 0.046$), hip abductors ($p = 0.049$), when compared to those who did not go on to develop PFP. Small effect sizes were found for the strength variables: 0.23 for knee extensors, 0.22 for hip abductors, as shown in Table 2.

The FPPA and Q-angle of participants with PFP were significantly greater than those who did not develop PFP during all of the three screening tasks: $p = 0.003$ and $p = 0.016$ during SLS, $p = 0.001$ and $p = 0.001$ during SLL, and $p = 0.001$ during RUN (FPPA). Participants who developed PFP also had a significantly greater HADD angle ($p = 0.003$) in SLS and in SLL ($p < 0.001$) during the baseline assessment. Effect sizes were moderate only for FPPA during SLL (0.50) and were small for the other kinematic variables that had significant differences (Table 2). No significant differences were detected between the two groups in any of the other kinematic variables.

Results of the binary logistic regression for each individual variable are presented in Table 3. The results show that mass, mass normalised to height, KEXT & HABD muscle strength, FPPA during SLS, SLL, and RUN, HADD and QA during SLL significantly predicted PFP. The odds ratio of each variable ranged between 0.99 for knee extensor muscle strength and 1.12 for FPPA during SLL.

One multivariate logistic regression model was created for each task where a maximum of three variables were entered in each model. The variables included in the three models were: (normalised mass to height, combined hip abductor and knee extensor strength, in addition to FPPA during each task). FPPA during the SLL was the most predictive model ($p = 0.001$). The odds ratio shows that the risk of PFP in subjects who had demonstrated greater FPPA in SLL during the baseline assessment was 1.13 times higher than in the healthy group (Table 4).

Receiver operation curve (ROC) analysis demonstrated that the FPPA during SLL task was the highest predictor for PFP (Area = 0.70; $p < 0.001$) with a FPPA$\geq$5.2° during SLL predicting PFP with a sensitivity of 70% and a specificity of 70%. The associated positive likelihood ratio (sensitivity/1-specificity) was 2.2. Therefore, participants with FPPA $\geq$5.2° during SLL had a 2.2 times greater risk of developing PFP compared with those with FPPA <5.2°.

4. Discussion

This study was the first study to investigate the relationship between the development of PFP and FPPA and other lower limb kinematics measured across multiple tasks in a large Saudi military population. The results revealed significant differences (though with small to moderate effect sizes) in the FPPA, Q-angle, and HADD of participants who developed PFP compared with those who did not develop the injury during military training.

Dynamic knee valgus has been cited as a predictor of PFP (Holden et al., 2017; Nakagawa et al., 2020) and the results of this study showed that FPPA measured on military recruits who developed PFP was significantly greater than that of those who did not develop PFP during all three screening tasks, though with small effect sizes apart from when undertaking SLL. It was demonstrated that individuals who had a FPPA greater than 5.2° were over 2.2 times greater risk for developing PFP, identifying that the single leg landing tasks was most predictive in identifying individuals who were at risk of PFP. This infers that this task could be selected for screening of individuals.

The results of the study support those of Holden et al. (Holden et al., 2017), who investigated the development of PFP prospectively in 76 adolescent female athletes using a 2D measurement of knee valgus displacement during bilateral drop vertical jump tasks. Eight participants developed PFP, and knee valgus displacement was increased in the PFP group (10.9 ± 2.2°) in comparison with the control group (3.1 ± 0.64°). Therefore, despite the different gender and tasks it confirms an increase in knee valgus during dynamic tasks appeared to predispose individuals to PFP. Furthermore, a recent study (Nakagawa et al., 2020) also identified a cut off score of 4.8° for FPPA during SLS, although they did find over double the odds 4.65 times versus 2.2 times in the current study. This is likely due to the study assessing a different movement (single leg squat) and having a sample size of a third of this study. Single leg landing is quite different from single leg squat due to its dynamic effect. Although the centre of mass could reach a much lower position in SLS than SLL, the SLS generates much lower ground reaction forces (GRF) and under the active control of the subject while SLL happens rapidly with much higher GRF and less control. The landing leg is subject to large impact forces and responses instinctively to maintain the balance, during which the joint bending moment, joint force and muscle forces would be much higher. As a result of the dynamic impact, higher FPPA angle and higher risk of injury would be inevitability involved.

The incidence of PFP reported in previous military studies ranges from 3% (Boling et al., 2009) to 10.4% in a recent published study (Nakagawa et al., 2020), where this study also found that 11% of individuals who started military training developed PFP. The differences in comparison to previous studies are likely due to differences in population and training related factors (Van Tiggelen et al., 2004).

The finding of significantly decreased isometric quadriceps muscle strength in the PFP group was consistent with previous studies (Boling et al., 2009; Duvigneaud et al., 2008; Van Tiggelen et al., 2004) while contradicting the studies of Milgrom et al. (Milgrom et al., 1991) and Boling et al. (Boling et al., 2021) in patients who developed PFP. A recent systematic review and meta-

Table 1
Mean, standard deviation, 95% confidence interval (CI), and P value of the demographic characteristics of injured and non-injured groups.

Group	Subject Number	Variable	Mean	SD	95% CI		p	Effect size
					Lower	**Upper**		
Non-Injured	278	Age (year)	19.84	2.11	19.59	20.09	0.954	0.02
PFP	37		19.78	1.89	19.15	20.41		
Non-Injured	278	Height (m)	1.72	0.06	1.71	1.73	0.133	0.22
PFP	37		1.74	0.06	1.72	1.76		
Non-Injured	278	Mass (kg)	65.82	12.23	64.38	67.27	**0.039***	0.26
PFP	37		71.05	15.38	65.92	76.18		
Non-Injured	278	BMI (kg/m2)	22.23	3.73	21.80	22.67	**0.048***	0.22
PFP	37		23.56	4.80	21.96	25.16		
Non-Injured	278	Mass normalised to Height (kg/m)	38.23	6.60	37.45	39	**0.027***	0.24
PFP	37		40.88	8.44	38.07	43.69		

Table 2
Mean, standard deviation, 95% confidence interval (CI), and P value of the strength and kinematic variables of PFP and non-injured groups.

Variable	Group	Mean (Nm/kg)	SD (Nm/kg)	95% CI		p	Effect size
				Lower (Nm/kg)	**Upper** (Nm/kg)		
KEXT	Non-Injured	137.62	47.02	132.07	143.17	**0.046***	0.23
	PFP	122.02	42.81	107.75	136.29		
HABD	Non-Injured	74.86	21.10	72.37	77.35	**0.049***	0.22
	PFP	67.92	20.71	61.02	74.83		
FPPA in SLS	Non-Injured	3.78	9.20	2.68	4.88	**0.003***	**0.26**
	PFP	7.36	8.78	4.39	10.33		
HADD in SLS	Non-Injured	9.58	4.75	9.01	10.14	**0.003***	0.21
	PFP	11.16	5.27	9.37	12.94		
QA	Non-Injured	10.75	8.65	9.71	11.78	**0.016***	0.24
	.PFP	13.77	8.34	10.95	16.59		
FPPA in SLL	Non-Injured	2.46	7.81	1.53	3.39	**0.0001***	0.50
	PFP	7.48	8.20	4.71	10.26		
HADD in SLL	Non-Injured	3.93	5.00	3.34	4.52	**0.0001***	0.37
	PFP	6.74	5.11	5.01	8.47		
FPPA in RUN	Non-Injured	−3.22	5.41	−3.86	−2.57	**0.001***	0.36
	PFP	−0.41	4.64	−2.01	1.18		
HADD in RUN	Non-Injured	8.76	3.96	8.28	9.23	0.258	0.12
	PFP	9.41	2.95	8.40	10.42		
KFA in RUN	Non-Injured	46.12	4.24	45.52	46.72	0.148	0.12
	PFP	45.41	3.33	44.15	46.68		
DFA in RUN	Non-Injured	81.82	4.69	81.16	82.48	0.121	0.13
	PFP	82.73	5.06	80.81	84.65		
RFA in RUN	Non-Injured	14.82	4.46	14.19	15.45	0.156	0.18
	PFP	13.61	4.64	11.84	15.37		

KEXT: *Knee extensors,* ***HABD:*** *Hip abductors,* ***FPPA:*** *Frontal plane projection angle,* ***HADD:*** *Hip adduction,* ***QA:*** *Q-angle,* ***SLS:*** *Single leg squatting,* ***SLL:*** *Single leg landing,* ***RUN:*** *Running,* ***KFA:*** *Knee flexion angle,* ***DFA:*** *Ankle Dorsiflexion angle,* ***RFA:*** *Rearfoot angle.*

Table 3
Odds ratio with P value and 95% confidence intervals (CI) of odds ratio for each variable.

	OR	*P*	95% CI for OR	
			Lower	Upper
Mass	1.031	.021	1.005	1.058
BMI	1.090	.054	.999	1.189
Mass norm to Height	1.006	.029	1.001	1.010
KEXT MS (Nm/Kg)	.992	.057	.984	1.000
HABD MS (Nm/kg)	.983	.061	.965	1.001
FPPA in SLS (°)	1.045	.030	1.004	1.088
HADD in SLS (°)	1.067	.067	.995	1.145
QA (°)	1.044	.051	1.000	1.091
FPPA in SLL (°)	1.120	.001	1.037	1.140
HADD in SLL (°)	1.087	.002	1.042	1.204
FPPA in RUN (°)	1.110	.004	1.034	1.191

KEXT: *Knee extensors,* ***HABD:*** *Hip abductors,* ***FPPA:*** *Frontal plane projection angle,* ***HADD:*** *Hip adduction,* ***QA:*** *Q-angle,* ***SLS:*** *Single leg squatting,* ***LL:*** *Single leg landing,* ***RUN:*** *Running,* ***KFA:*** *Knee flexion angle,* ***DFA:*** *Ankle Dorsiflexion anglevs,* ***RFA:*** *Rearfoot angle.*

Table 4
Odds ratio with P value and 95% confidence intervals (CI) of odds ratio for regression model.

	OR	*P*	95% CI for OR	
			Lower	Upper
Mass norm to Height	1.008	.002	1.003	1.014
FPPA in SLL	1.133	.001	1.051	1.222
Constant	.006	.000		

FPPA: *Frontal plane projection angle,* ***SLL:*** *Single leg landing.*

analysis further confirmed the result of this study (Neal et al., 2019), though this study's results should be viewed with some caution as the effect size was small.

The findings of the current study indicate that the isometric hip abductor muscle strength of participants with PFP was also significantly lower than non-injured individuals, which contrasts with previously reported studies (Finnoff et al., 2011; Herbst et al., 2015) who found similar levels of strength. Finnoff et al. (Finnoff et al., 2011) measured hip abductors with a HHD stabilised by the examiner's hand (i.e. not fixed or stabilised with a belt), whereas Herbest et al. (Herbst et al., 2015) assessed hip isokinetic muscle strength from a standing position, the score of which might have been affected by the ability of the contralateral limb to stabilise the position, which might partially explain the differences. In agreement with the current study, three prospective studies assessed isometric hip abductor muscle strength with a HHD, and neither found any significant differences between the injured and non-injured groups (Boling et al., 2009, 2021; Thijs et al., 2011). In the systematic review and meta-analysis by Neal et al. (Neal et al., 2019), there was moderate evidence that decreased hip abduction strength was not a risk factor for future PFP which is in contrast with the current study, this could relate to different methods of assessing hip abduction strength or the population involved. However, the effect size seen in this study is small and thus these findings need to be confirmed.

A major strength of this paper is that all the participants benefited from the same training programme, environmental conditions, equipment, food, and daily schedules, whereby extrinsic contributing factors which may affect PFP incidence were mostly under control within the current study. However, all studies are not without limitations, we need to be mindful of potential under-recording of injuries sustained as this cohort are motivated to finish their training. Though previous injury history was captured previous training history was not this could have influenced the ability of these individuals to cope with the stresses of military training. This may have impacted on the overall number of injuries seen in the study. As only male participants were included, it is not known whether the results and cut-offs would apply to female military recruits or female sporting individuals. A relatively large number of variables were used in the regression analysis which could have led to bias. A novel testing technique was used for measuring hip abduction isometric force, this was chosen because of increased stability (lying supine versus the more common side lying test), better fixation of the HHD (against a wall rather than reliant on tester strength), ability to maintain a neutral (0°) hip position and speed of test application, the participant merely lied down and pushed. But the technique has not been validated elsewhere so should be viewed with caution until further testing has been undertaken.

5. Conclusion

The results of the current study identified the differences between those who did and did not develop PFP in kinematic variables and muscle strength, at the same time as noting differences between mass-related variables. We found that participants who developed PFP had a greater mass, BMI, mass normalised to height, FPPA, and -angle during the three tasks, as well as greater HADD during SLS and SLL and lower hip abductor and knee extensor muscle strength during baseline measurements. We found that the baseline measures of FPPAs $\geq$5.2° during SLL tasks, were the most predictive of PFP. These findings will help to identify those who are at risk of PFP development with simple, portable, and lower cost measurement tools, leading to the development of injury risk mitigation programmes.

5.1. New findings and contribution of the work

- **Male military cadets who developed PFP had greater mass, BMI, and mass normalised to height during baseline assessment.**
- **Male military cadets who developed PFP had greater Q-angle, FPPA during SLS, SLL, RUN, and HADD during SLS and SLL during baseline assessments.**
- **Male military cadets who developed PFP had lower hip abductor and knee extensor muscle strength during baseline assessment.**
- **Male military cadets with FPPA during SLL $\geq$ 5.2° had 2.2 times risk of development of PFP compared to those who were with FPPA during < 5.2°. The SLL task was the most predictive.**

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Declaration of competing interest

All authors declare no conflicts of interest relating to undertaking or producing this work.

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