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Gender specific risk factor profiles for patellofemoral pain

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Abstract

Objective: Determine the association between select biomechanical variables and risk of PFP in males and females.

Design: Prospective cohort.

Setting: United States Service Academies.

Participants: 4543 cadets (1727 females and 2816 males).

Assessment of risk factors: Three-dimensional biomechanics during a jump-landing task, lower extremity strength, Q-angle and navicular drop.

Main outcome measures: Cadets were monitored for diagnosis of PFP during their enrollment in a service academy. Three-dimensional hip and knee kinematic data were determined at initial contact (IC) and at 50% of the stance phase of the jump-landing task. Logistic regression analyses were performed for each risk factor variable in males and females ($P<0.05$).

Results: Less than 10° of hip abduction at IC (OR=1.86, $P=0.03$) and greater than 10° of knee internal rotation at 50% of the stance phase (OR=1.71, $P=0.02$) increased the risk of PFP in females. Greater than 20° of knee flexion at IC (OR=0.47, $P<0.01$) and between 0 and 5° of hip external rotation at 50% of the stance phase (OR=0.52, $P=0.04$) decreased the risk of PFP in males. No other variables were associated with risk of developing PFP ($P>0.05$).

Conclusion: The results suggest males and females have differing kinematic risk factor profiles for the development of PFP.

Clinical relevance: In order to most effectively reduce the risk of developing PFP, the risk factor variables specific to males (decreased knee flexion and increased hip external rotation) and females (decreased hip abduction and increased knee internal rotation) should be addressed in injury prevention programs.

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Keywords

risk factors; chronic knee pain; biomechanics; strength

INTRODUCTION

Patellofemoral pain (PFP) is one of the most common chronic knee conditions affecting physically active individuals[1] with females being two times more likely to develop PFP compared to males[2]. The frequent recurrence of symptoms and long-term pain reported by individuals with PFP[3], in addition to the proposed association between PFP and the development of patellofemoral osteoarthritis[4–6], highlights the need for prospective research investigations to identify the risk factors for PFP. Although there are numerous prospective studies investigating risk factors for PFP[7–18], it still remains unclear if males and females present with differing risk factor profiles.

The development of PFP is thought to be multifactorial with theorized biomechanical risk factors including altered lower extremity kinematics, muscle weakness, structural malalignment, and decreased flexibility.[19] Two recent systematic reviews have summarized the current evidence for the biomechanical risk factors for the development of PFP.[20,21] Based on pooled analyses, decreased knee extension strength was the only factor associated with an increased risk of developing PFP.[20,21] Although additional biomechanical risk factors have been investigated, many variables have only been investigated in a single cohort [7–11,13–18], the results from the studies provide conflicting evidence[7–18], and/or the cohort size was small[7–11,15,16,18]. Additional research is needed in order for more data on large cohorts to be included in the pooled analyses to make conclusive statements regarding the risk factors for PFP.

In addition to the need for more prospective risk factor studies, there is also a need to better understand gender differences in the risk factors for the development of PFP. There is evidence to support gender differences in the theorized risk factors for PFP[22–27], however, no studies have been performed to determine if the risk factor profiles differ between males and females. If the risk factor profiles differ between males and females, more effective injury prevention strategies can be developed that target the risk factors specific to each gender. Therefore, the purpose of this investigation was to determine the biomechanical risk factors for PFP that are specific to males and females.

METHODS

Study Design & Participants

The cohort consisted of 4543 cadets (1727 females: 18.6±0.9yrs, 165.7±6.6cm, 63.0±7.9kg; 2816 males: 18.9±0.8yrs, 178.1±7.2cm, 77.5±12.3kg) from three United States Service Academies (United States Air Force Academy, United States Military Academy, United States Naval Academy). Inclusion criteria for enrollment into the cohort included the following: 1) freshman at time of enrollment into the investigation and 2) no injury limiting participation in a jump-landing task and/or lower extremity strength tests. Institutional

Review Board approval was obtained from each Service Academy prior to the start of the investigation. Each participant underwent a baseline biomechanical assessment during his/her first summer of enrollment at the respective Service Academy. All participants in this investigation were followed prospectively for the diagnosis of PFP during their time as a cadet at one of the academies (maximum of four years).

Baseline Assessment - Instrumentation

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL) was used to assess lower extremity kinematics at a sampling rate of 144Hz. A non-conductive force plate (Bertec Corporation, Columbus, OH, Model 4060-NC) collected ground reaction forces to allow for the determination of specific time points during a jump-landing task. Force plate data were collected synchronously with the kinematic data at a sampling rate of 1440 Hz. A hand-held dynamometer (Chatillon MSC-500, AMETEK, Inc, Largo, FL) was used to collect mean isometric strength values for lower extremity musculature and a standard goniometer was used to measure Q-angle.

Baseline Assessment Testing Procedures

Prior to the start of baseline data collection, all participants provided informed consent in accordance with the respective Service Academy’s Institutional Review Board. Additionally, participants completed a baseline questionnaire, which included questions on age, gender, and lower extremity injury history.

The jump-landing task required participants to jump forward from a 30-cm high box to a force platform set at a distance of 50% of their height from the box, complete a double-leg landing, with the dominant foot on a force plate and non-dominant foot on the floor. Once participants landed on the force platform, they jumped vertically for maximum height. Following task instruction, each participant was given as many practice trials as needed to perform the task successfully. A successful jump was characterized by landing with the entire foot of the dominant lower extremity on the force plate, landing with the entire foot of the non-dominant lower extremity off the force plate, and completing the task in a fluid motion.

Following task instruction and practice, electromagnetic tracking sensors were attached to the dominant lower extremity (leg used to kick a ball for maximum distance). Electromagnetic sensors were placed on the participants’ skin over the superior sacrum, lateral aspect of the distal 1/3 of the thigh over the IT band, and anteromedial aspect of the proximal 1/3 of the tibia. Six bony landmarks (medial and lateral epicondyles of the femur, medial and lateral malleoli of the ankle, and left and right anterior superior iliac spine (ASIS) of the pelvis) were digitized with the endpoint of a stylus on which a fourth receiver was mounted. Medial and lateral malleoli and femoral epicondyles were digitized to determine the ankle joint center and knee joint center, respectively. Left and right ASIS were digitized to determine the hip joint center of rotation using the Bell method[28]. Participants performed three successful trials of the jump-landing task.

Lower extremity isometric muscle strength tests were performed in the following order: knee extension (quadriceps), hip external rotation (hip external rotators), hip internal rotation (hip internal rotators), knee flexion (hamstrings), hip extension (gluteus maximus), and hip abduction (gluteus medius). During each test, participants were instructed to push as hard as they can, holding the contraction for five second. Specific testing procedures for each strength test are provided in Table 1. Mean isometric strength values for two separate trials were collected. All strength data were normalized to the mass of the participant and averaged over the two trials. Intra-rater reliability ($ICC_{2,k}$) calculated from pilot data collected on twenty participants during two separate sessions for the strength tests ranged from 0.73–0.98 [standard error of measurement (SEM) range= 13.99–98.95N].

The structural alignment measures assessed included Q-angle and navicular drop. Q-angle was measured with participants in a standing position using a standard goniometer. The angle between a line from the center of the patella to the tibial tuberosity and a line from the center of the patella to the ASIS was recorded in degrees for three separate trials. All landmarks were exposed except for the ASIS. Navicular drop was measured using a standard ruler as the difference in centimeters between the navicular tuberosity height in a non-weight bearing subtalar joint neutral position (seated) and a weight bearing position (standing). Intra-rater reliability from pilot data collected on twenty participants during two separate sessions showed good reliability for Q-angle ($ICC_{2,k}$= 0.83, SEM=2.85°) and navicular drop ($ICC_{2,k}$= 0.79, SEM=1.14cm). The average of the three trials for Q-angle and navicular drop were used for data analysis.

Biomechanical Data Reduction

All kinematic data were filtered using a 4^{th} order low pass Butterworth filter at 14.5 Hz. A global reference system was defined using the right hand rule, in which the x-axis was positive in the anterior direction, the y-axis was positive to the left of each participant, and the z-axis was positive in the superior direction. Lower extremity joint rotations were calculated using the Euler rotation method in the following order: Y, X, Z. The y-axis corresponded to the flexion-extension axis, the x-axis corresponded to the abduction-adduction axis, and the z-axis corresponded to the internal-external rotation axis. Hip joint motion is defined as femur relative to pelvis and knee joint motion is defined as tibia relative to femur.

The kinematic data were reduced using custom Matlab software (Mathworks, Natick, MA). Three-dimensional knee and hip joint angles were determined at initial contact (IC) and at 50% of the stance phase. Initial contact was defined as the time point when vertical ground reaction force (VGRF) exceeded 10 N as the participant landed on the force plate from the 30-cm high platform. The stance phase was defined as the time period between IC until takeoff for the rebound jump (VGRF>10 N). The average of the values across the 3-trials for IC and 50% of the stance phase were calculated for each of the kinematic variables. Tables 2 and 3 provide a list of all biomechanical variables assessed in this investigation.

Follow-up Procedures

Physicians at each academy diagnosed cases of PFP and the diagnosis code was entered into an electronic medical record database, the Armed Forces Health Longitudinal Technology Application (AHLTA). The Defense Medical Surveillance System (DMSS) was used in order to search for diagnosis codes (ICD-9: 726.69 [Unspecified knee enthesopathy], 726.64 [patellar tendonitis], 717.7 [patella chondromalacia], and 719.46 [patellofemoral syndrome] in AHLTA across all academies.

All medical records with one of the above ICD-9 codes and date of diagnosis during the study follow-up period were evaluated by one of the study investigators to determine whether the medical record documentation qualified the individual for inclusion into the PFP group. To be included in the PFP group, the following criteria had to be documented in the medical record.

Must Demonstrate Both During Evaluation:

1. Retropatellar knee pain during at least 2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting.
2. Negative findings on examination of knee ligament, menisci, bursa, tendon, and synovial plica.

Must Demonstrate One of the Following During Evaluation:

1. Pain on palpation of medial or lateral patellar facets
2. Pain on palpation of the anterior portion of the medial or lateral femoral condyles

When reviewing medical records, if the mechanism of injury stated a traumatic blow to the knee/patella and the medical record matched the above listed inclusion criteria, the individual case was not included in the injured cohort. Based on this, an attempt was made to only include individuals who developed PFP insidiously and not due to an acute traumatic injury. Additionally, if an individual developed bilateral PFP, this counted as a single case. Once an individual became a case, they were no longer followed for the diagnosis of PFP.

Injuries sustained by varsity athletes were commonly evaluated and treated by athletic trainers at the Service Academies. At each academy, athletic trainers utilized a separate medical record database to record athletic injuries. These databases were searched at each academy to determine varsity athletes who may have developed PFP but were not evaluated by a military physician. The keywords utilized to search for potential cases of PFP included patellofemoral pain, chondromalacia, and patella malalignment. If a varsity athlete in the cohort was highlighted by the keyword search, one of the study investigators was provided access to documentation of the injury evaluation to confirm the development of PFP using the same injury criteria described above.

Statistical Analysis

Means, standard deviation, and 95% confidence intervals (CIs) were computed for the PFP group and the non-injured group. Logistic regression analyses adjusting for cohort, service academy and varsity sport status were performed for each risk factor variable in males and females, separately. Prior to performing the logistical regression procedures, each variable was divided into tertiles to allow for grouping of participants into a range of values. Values for the tertiles are presented with each variable in Tables 4 and 5. We chose to group individuals into tertiles so that we could assess odds ratios across a range of values for each risk factor variable instead of assessing odds ratios for a one-unit change in each risk factor variable. All statistical analyses were performed using SAS 9.4 (SAS Institute, Inc., Cary, NC). An a priori alpha level for all analyses was set at 0.05.

RESULTS

Cohort Selection

Of the 4543 participants who initially enrolled in this investigation, 607 participants (13.4%) reported a prior history of PFP on the baseline questionnaire and were removed from the cohort used in the final analyses. The final cohort included 3893 cadets (2448 males and 1445 females). A total of 188 participants (94 males, 94 females) developed PFP during the follow-up period (PFP group) and 3,705 (2,354 males, 1,350 females) did not develop PFP during the follow-up period (non-injured group). The incidence proportion for PFP among males was 4% and the incidence proportion among females was 7%. Means, standard deviations, and 95% CIs for all dependent variables are provided in Tables 2 and 3.

Female Risk Factors

In females, less than 10° of hip abduction at IC (OR=1.86; 95% CI=1.06, 3.26; $P=0.03$) and greater than 10° of knee internal rotation at 50% of the stance phase (OR=1.71; 95% CI=1.08, 2.73; $P=0.02$) increased the risk of developing PFP. No additional kinematic, isometric strength, or structural alignment variables were associated with an increased risk of developing PFP in females ($P>0.05$) (Tables 4 and 5).

Male Risk Factors

In males, greater than 20° of knee flexion at IC (OR=0.47; 95% CI=0.29, 0.77; $P<0.01$) and between 0 and 5° of hip external rotation at 50% of the stance phase (OR=0.52; 95% CI=0.27, 0.99, $P=0.04$) decreased the risk of developing PFP. No additional kinematic, isometric strength, or structural alignment variables were associated with an increased risk of developing PFP in males ($P>0.05$) (Tables 4 and 5).

DISCUSSION

The purpose of this investigation was to provide an understanding of the risk factors for the development of PFP that are specific to males and females. To our knowledge, this is the largest cohort to date in which risk factors were assessed in males and females. Additionally, this is the first study to elucidate gender specific risk factors profiles for PFP.

Kinematic Risk Factors

Females—Previously reported kinematic risk factors for the development of PFP in females include altered frontal plane hip kinematics[13]. The findings of this study provide additional support for altered frontal plane hip kinematics during a dynamic task increasing

the risk for the development of PFP. Increased hip adduction (12.1±2.8°) during the stance phase of running was reported in female runners who later developed PFP[13]. Although a hip adducted position was not directly associated with PFP during the jump-landing task in this study, a less hip abducted position was associated with an increased risk for developing PFP in females. Females who landed with 10° or less of hip abduction at IC were almost twice (OR=1.86) as likely to develop PFP compared to those who landed with greater than 10° of hip abduction.

Transverse plane knee kinematics have yet to be reported as a risk factor for the development of PFP in a physically active female population. In the current study, females landing with 10° or more of knee internal rotation were approximately twice (OR=1.71) as likely to develop PFP compared to those who landed with less than 10° of knee internal rotation. It is possible that in this cohort the combination of a less hip abducted position and increased knee internal rotation lead to a change in contact area between the patella and femoral trochlea and an increase in contact stress at the patellofemoral joint[29,30].

Males—Only two previous prospective investigations have assessed risk factors for PFP in a male only cohort and neither investigation evaluated kinematic risk factors[17,31]. In the current investigation, males landing with less than 20° of knee flexion at IC were more than twice ($OR=0.47^{-1}=2.13$) as likely to develop PFP compared to those landing with 20° or more of knee flexion. Also, males who displayed hip ER greater than 5° at 50% of the stance phase were almost twice ($OR=0.52^{-1}=1.92$) as likely to develop PFP compared to males landing with 0–5° of hip external rotation. We speculate that decreased knee flexion at IC and the increased rotation of the femur could lead to altered patellofemoral contact stress and eventually the development of PFP in males.

Strength Risk Factors

Females—Previous prospective studies have provided inconsistent results regarding an association between strength of the hip musculature and the risk of developing PFP in females[9,14]. Herbst et al.[14] reported increased isokinetic concentric strength of the hip abductors as a risk factor for the development of PFP in adolescent female basketball athletes, while Thijs et al.[9] reported no association between isometric measures of hip strength and the risk of developing PFP in novice female recreational runners. The results of our investigation are in agreement with Thijs et al.[9], however, it is important to note the differences in methods for assessing strength (isokinetic[14] vs. isometric[9]) and variation in participant populations (adolescent female[14] vs. novice runners[9] vs. female cadets) between these studies. Only one previous prospective investigation has assessed strength of the quadriceps and hamstring musculature specifically in females[18]. Duvigneaud et al.[18] reported decreased isokinetic concentric peak torque of the quadriceps in female military recruits. These finding are in contrast to the findings of this investigation; however, different methods for strength assessment (isokinetic vs. isometric) may also explain the differences in findings.

Males—Previous prospective investigations assessing strength as a risk factor for PFP in males have only reported results for quadriceps and hamstring strength[17,31]. Similar to the results from this investigation, Van Tiggelen et al.[31] did not report an association between hamstring strength and the risk of developing PFP in males. The previous prospective studies specific to males have reported conflicting results for quadriceps strength as a risk factor for the development of PFP in males[17,31]. One study reported male infantry recruits with decreased isokinetic strength (absolute and normalized) of the quadriceps were more prone to developing PFP while another investigation reported increased absolute isometric strength of the quadriceps in male military recruits as a risk factor for the development of PFP[17,31]. These previous findings are in contrast to the current investigation in which isometric quadriceps strength was not a risk factor for the development of PFP in male cadets. Differences in methodologies to assess strength (isometric vs. isokinetic) and the use of normalized vs. absolute strength in the analyses likely influenced the contrasting results between studies.

Structural Alignment Risk Factors

Only a few previous studies have investigated Q-angle and foot alignment as risk factors for the development of PFP and none have assessed these factors specific to males or females[7,8,12]. Based on previous studies and the current investigation, Q-angle in males or in females is not associated with the risk of developing PFP[7,12]. With regards to foot posture, previous prospective investigations have assessed navicular drop[12], foot posture index[8], lower leg-heel frontal plane alignment[7], and heel-to-forefoot frontal plane alignment[7] as risk factors for the development of PFP in males and females. An increased navicular drop was the only foot posture measure that was significantly associated with the risk of developing PFP but this finding was not specific to gender[12]. The results from the current study do not support an association between navicular drop and the risk of developing PFP when analyzed in males and females separately. Based on the findings from this study and previous prospective investigations, Q-angle does not appear to be a risk factor for the development of PFP and there is not conclusive evidence to support measures of foot posture as risk factors for the development of PFP in males or females.

Limitations

A few limitations should be mentioned in our investigation. First, the study population was limited to military cadets, which is not representative of the general population. Military cadets were selected for this study due to their high levels of physical activity, higher levels of baseline fitness than the general population and other military recruits, and the military's closed medical record system, which allowed for long term follow up and increased capture of cases. Another limitation of this study was the assessment of kinematics at specific time points during the jump-landing task. We chose the time points of IC and 50% of the stance phase because we wanted to understand if an individual's landing strategy at initial contact or at a time where PF joint compressive forces are higher (50% of stance phase) may play a role in the development of PFP.

Conclusions

In conclusion, differing profiles of altered kinematics that are specific to gender appear to increase the risk of PFP. Specifically in males, landing with decreased knee flexion and increased hip external rotation increase the risk for the development of PFP. In females, landing with less hip abduction and increased knee internal rotation increase the risk for the development of PFP. These findings may be directly utilized by clinicians when developing injury prevention programs with male and female physically active individuals. As motion analysis equipment is not readily available in the clinical setting, clinicians may utilize validated movement assessment tools, such as the Landing Error Scoring System[32], to identify individuals who display these faulty movement patterns placing them at risk for the development of PFP. Additional prospective risk factor studies are warranted in order to gain a better understanding of the biomechanical variables that are associated with the risk of developing PFP specific to males and females.

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Table 1.

Strength testing procedures

Muscle group	Procedures
Hamstrings	Participant was placed in a prone lying position with his/her test leg in 90° of knee flexion. The dynamometer was placed over the posterior aspect of the participant’s shank, just proximal to the ankle joint. The participant was instructed to flex his/her knee with maximal effort.
Quadriceps	Participant was placed in a seated position with his/her test leg in 90° of knee flexion. The dynamometer was placed over the anterior aspect of the participant’s shank, just proximal to the ankle joint. The participant was instructed to extend his/her knee with maximal effort.
Hip Extensors	Participant was placed in a prone lying position with his/her test leg in 90° of knee flexion. The dynamometer was placed over the posterior aspect of the participant’s thigh, just proximal to the knee joint line. The participant was instructed to extend his/her hip with maximal effort while keeping his/her knee in the flexed position.
Hip Abductors	Participant was placed in a side lying position with his/her test leg in neutral hip extension and aligned parallel with his/her torso. The dynamometer was placed over the lateral aspect of the participant’s thigh, just proximal to the knee joint line. The participant was instructed to abduct his/her hip with maximal effort.
Hip External Rotators	Participant was placed in a prone lying position with his/her test leg in 90° of knee flexion and neutral hip rotation. The dynamometer was placed over the medial aspect of the participant’s shank, just proximal to the ankle joint. The participant was instructed to externally rotate his/her hip with maximal effort.
Hip Internal Rotators	Participant was placed in a prone lying position with his/her test leg in 90° of knee flexion and neutral hip rotation. The dynamometer was placed over the lateral aspect of the participant’s shank, just proximal to the ankle joint. The participant was instructed to internally rotate his/her hip with maximal effort.

Table 2.

Hip and Knee Kinematics (°) [a]

	Males	Mean	SD	95 % CI	Females	Mean	SD	95% CI
Knee flex IC	Non-injured	20.22	7.89	19.89, 20.55	Non-injured	18.41	7.95	17.98, 18.84
	PFP	16.92	7.51	15.35, 18.50	PFP	16.83	7.08	15.36, 18.30
Knee vlg IC	Non-injured	2.15	5.96	1.90, 2.40	Non-injured	−0.28	5.54	−0.58, 0.02
	PFP	1.09	5.36	−0.02, 2.22	PFP	−0.34	4.98	−1.37, 0.69
Knee rot IC	Non-injured	0.11	7.59	−0.21, 0.42	Non-injured	−3.78	7.50	−4.19, −3.38
	PFP	−0.23	7.35	−1.77, 1.31	PFP	−1.82	7.34	−3.34, −0.30
Hip flex IC	Non-injured	−30.47	11.01	−30.93, −30.01	Non-injured	−29.50	10.26	−30.06, −28.94
	PFP	−28.69	11.18	−31.03, −26.34	PFP	−28.24	9.52	−30.21, −26.27
Hip ABD IC	Non-injured	−10.62	6.65	−10.90, −10.34	Non-injured	−9.58	6.77	−9.95, −9.22
	PFP	−9.92	6.87	−11.36, −8.48	PFP	−8.64	6.28	−9.94, −7.33
Hip rot IC	Non-injured	−3.23	8.30	−3.58, −2.89	Non-injured	−3.33	7.61	−3.74, −2.91
	PFP	−5.54	7.63	−7.14, −3.94	PFP	−4.10	8.25	−5.81, −2.39
Knee flex 50%	Non-injured	80.99	15.36	80.35, 81.62	Non−injured	76.68	13.58	75.93, 77.42
	PFP	80.38	12.92	77.67, 83.09	PFP	76.80	13.00	74.10, 79.49
Knee vlg 50%	Non-injured	−2.96	10.13	−3.38, −2.54	Non-injured	−6.83	9.14	−7.33, −6.33
	PFP	−4.18	10.37	−6.35, −2.01	PFP	−6.17	9.84	−8.21, −4.13
Knee rot 50%	Non-injured	6.94	10.69	6.50, 7.39	Non-injured	1.55	9.74	1.02, 2.08
	PFP	5.13	11.95	2.62, 7.63	PFP	3.75	9.67	1.75, 5.76
Hip flex 50%	Non-injured	−65.81	21.00	−66.68, −64.93	Non-injured	−60.61	20.00	−61.70, −59.52
	PFP	−68.35	19.64	−72.46, −64.48	PFP	−61.68	18.79	−65.57, −57.79
Hip ABD 50%	Non-injured	−7.30	9.01	−7.67, −6.92	Non-injured	−5.22	8.38	−5.68, −4.76
	PFP	−7.53	10.19	−9.66, −5.39	PFP	−6.38	8.85	−8.21, −4.54
Hip rot 50%	Non-injured	0.63	10.33	0.19, 1.05	Non-injured	−0.48	8.98	−0.97, 0.01
	PFP	−0.73	10.88	−3.02, 1.54	PFP	−1.25	10.22	−3.37, 0.86

[a] SD, standard deviation,; CI, confidence interval; IC, initial contact; 50%, 50% of stance phase; flex, flexion; vlg, valgus; rot, rotation; ABD, abduction.

Table 3.

Lower Extremity Strength (%BM) and Alignment[a]

	Males	Mean	SD	95 % CI	Females	Mean	SD	95% CI
Knee ext	Non-injured	0.480	0.095	0.476, 0.484	Non-injured	0.394	0.081	0.389, 0.398
	PFP	0.488	0.106	0.466, 0.510	PFP	0.396	0.096	0.376, 0.416
Knee flex	Non-injured	0.237	0.053	0.235, 0.239	Non-injured	0.206	0.048	0.203, 0.209
	PFP	0.236	0.053	0.225, 0.247	PFP	0.208	0.050	0.197, 0.218
Hip ER	Non-injured	0.206	0.041	0.204, 0.207	Non-injured	0.168	0.033	0.166, 0.170
	PFP	0.212	0.036	0.205, 0.220	PFP	0.168	0.036	0.161, 0.176
Hip IR	Non-injured	0.189	0.041	0.187, 0.190	Non-injured	0.180	0.038	0.178, 0.182
	PFP	0.194	0.041	0.185, 0.202	PFP	0.182	0.037	0.174, 0.190
Hip ext	Non-injured	0.254	0.075	0.251, 0.257	Non-injured	0.231	0.065	0.227, 0.234
	PFP	0.266	0.072	0.251, 0.281	PFP	0.244	0.061	0.231, 0.257
Hip ABD	Non-injured	0.330	0.086	0.327, 0.334	Non-injured	0.297	0.078	0.293, 0.301
	PFP	0.350	0.090	0.332–0.369	PFP	0.281	0.070	0.267–0.296
Q-angle (°)	Non-injured	8.512	4.122	8.343–8.681	Non-injured	11.530	4.672	11.279–11.781
	PFP	8.301	3.701	7.538–9.063	PFP	12.029	4.585	11.074–12.984
Navicular Drop (mm)	Non-injured	7.448	2.830	7.332–7.564	Non-injured	7.153	2.640	7.011–7.295
	PFP	8.177	3.474	7.461–8.890	PFP	7.090	2.371	6.605–7.592

[a] SD, standard deviation,; CI, confidence interval; ext, extension; flex, flexion; ER, external rotation; IR, internal rotation; ABD, abduction.

Table 4.

Logistic regression results for kinematic variables[a]

	Males			Females		
	Odds Ratio	**95% CI**	**P-value**	**Odds Ratio**	**95% CI**	**P-value**
Knee Flex IC (°)						
<15(Flx/Ext)	Ref			Ref		
15−<20(Flx)	0.62	0.36, 1.07	0.09	1.34	0.81, 2.22	0.26
≥20(Flx)	0.47	0.29, 0.77	<0.01*	1.05	0.62, 1.78	0.86
Knee Vlg/Var IC (°)						
<0 (Vlg)	Ref			Ref		
0−<5 (Var)	0.95	0.59, 1.53	0.84	1.29	0.83, 2.02	0.26
≥5 (Var)	0.82	0.49, 1.39	0.47	0.79	0.41, 1.51	0.47
Knee IR/ER IC (°)						
<−5 (ER)	Ref			Ref		
−5−<0 (ER)	1.28	0.75, 2.18	0.37	1.06	0.61, 1.84	0.84
≥0 (IR)	0.96	0.58, 1.57	0.86	1.59	0.99, 2.55	0.05
Hip Flex IC (°)						
<−35(Flx)	Ref			Ref		
−35−<−25(Flx)	1.01	0.60, 1.71	0.96	0.88	0.53, 1.47	0.62
≥≥25(Flx)	1.39	0.85, 2.27	0.19	1.05	0.64, 1.74	0.85
Hip Add/Abd IC (°)						
<−15 (Abd)	Ref			Ref		
−15−<−10 (Abd)	1.25	0.70, 2.23	0.44	1.32	0.70, 2.50	0.40
≥−10 (Abd)	1.58	0.94, 2.65	0.09	1.86	1.06, 3.26	0.03*
Hip IR/ER IC (°)						
<−5(ER)	Ref			Ref		
−5−<0 (ER)	0.74	0.44, 1.25	0.26	0.95	0.57, 1.58	0.83
≥0 (IR)	0.62	0.37, 1.02	0.06	0.92	0.56, 1.50	0.74
Knee Flex @ 50% (°)						
<65(Flx)	Ref			Ref		
65−<80(Flx)	0.97	0.52, 1.81	0.92	1.25	0.71, 2.21	0.44

	Males			Females		
	Odds Ratio	**95% CI**	**P-value**	**Odds Ratio**	**95% CI**	**P-value**
≥80(Flx)	1.18	0.67, 2.07	0.56	1.34	0.77, 2.44	0.28
Knee Vlg/Var @ 50% (°)						
<−10 (Vlg)	Ref			Ref		
−10−<0 (Vlg)	0.80	0.48, 1.33	0.39	1.41	0.88, 2.27	0.15
≥0 (Var)	0.78	0.47, 1.29	0.33	1.37	0.78, 2.40	0.27
Knee IR/ER @ 50% (°)						
<5 (IR)	Ref			Ref		
5−<10 (IR)	0.71	0.40, 1.25	0.24	0.90	0.48, 1.69	0.75
≥10 (IR)	0.63	0.39, 1.02	0.06	1.71	1.08, 2.73	0.02*
Hip Flex @ 50% (°)						
<−65(Flx)	Ref			Ref		
−65−<−55(Flx)	1.04	0.58, 1.85	0.90	1.35	0.80, 2.27	0.26
≥−55(Flx)	1.02	0.63, 1.64	0.93	0.89	0.56, 1.43	0.64
Hip Add/Abd @ 50% (°)						
<−10 (Abd)	Ref			Ref		
−10−<−5 (Abd)	1.23	0.71, 2.12	0.46	0.88	0.51, 1.53	0.66
≥−5 (Abd)	1.25	0.78, 1.99	0.36	0.80	0.50, 1.26	0.33
Hip IR/ER @ 50% (°)						
<−5 (ER)	Ref			Ref		
−5−<0 (ER)	0.52	0.27, 0.99	0.04*	0.80	0.44, 1.43	0.45
≥0 (IR)	0.66	0.42, 1.04	0.07	0.93	0.58, 1.49	0.77

[a] IC, initial contact; 50%, 50% of stance phase; Flex, flexion; Vlg, valgus; Var, varus; IR, internal rotation; ER, external rotation; ADD, adduction; ABD, abduction.

Table 5.

Logistic regression results for strength and alignment variables[a]

	Males			Females		
	Odds Ratio	**95% CI**	**P-value**	**Odds Ratio**	**95% CI**	**P-value**
Knee Flex (%BM)						
<0.2	Ref			Ref		
0.2–<0.25	1.26	0.76, 2.09	0.37	0.96	0.61, 1.50	0.85
≥0.25	0.90	0.52, 1.56	0.71	1.13	0.62, 2.08	0.69
Knee Ext (%BM)						
<0.35	Ref			Ref		
0.35–<0.45	1.46	0.67, 3.18	0.34	0.87	0.55, 1.38	0.55
≥0.45	1.20	0.57, 2.55	0.63	0.72	0.40, 1.31	0.29
Hip Ext (%BM)						
<0.2	Ref			Ref		
0.2–<0.25	1.16	0.62, 2.17	0.64	1.35	0.77, 2.36	0.29
≥0.25	1.49	0.86, 2.56	0.15	1.60	0.95, 2.68	0.07
Hip Abd (%BM)						
<0.25	Ref			Ref		
0.25–<0.35	1.37	0.71, 2.66	0.34	0.69	0.44, 1.09	0.11
≥0.35	1.77	0.91, 3.43	0.09	0.56	0.30, 1.05	0.07
Hip ER (%BM)						
<0.175	Ref			Ref		
0.175–<0.225	1.32	0.75, 2.34	0.34	0.90	0.58, 1.40	0.76
≥0.225	1.72	0.94, 3.16	0.08	0.91	0.36, 2.30	0.85
Hip IR (%BM)						
<0.15	Ref			Ref		
0.15–0.175	0.74	0.37, 1.49	0.39	1.14	0.61, 2.11	0.68
≥0.175	1.08	0.63, 1.84	0.77	1.29	0.75, 2.23	0.35
Q-angle (°)						
<7.5	Ref			Ref		
7.5–12.5	0.92	0.59, 1.43	0.70	0.94	0.54, 1.65	0.83

	Males			Females		
	Odds Ratio	**95% CI**	**P-value**	**Odds Ratio**	**95% CI**	**P-value**
≥12.5	0.75	0.40, 1.39	0.36	1.10	0.64, 1.91	0.72
Navicular Drop (mm)						
<6.0	Ref			Ref		
6.0–9.0	1.01	0.60, 1.70	0.97	0.99	0.62, 1.60	0.98
>9.0	1.56	0.93, 2.62	0.09	1.33	0.79, 2.26	0.28

[a] Flex, flexion; Ext, extension; ABD, abduction; ER, external rotation; IR, internal rotation.