Original Paper

Biomedical Human Kinetics, 18, 1–10, 2026
DOI: 10.2478/bhk-2026-0001

Unveiling injury risks: The impact of fatigue on functional movement screen performance in youth hockey players

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Abstract

Study aim: This study aimed to identify factors associated with injury risk before and during fatigue among youth hockey players.
Materials and methods: One hundred and twenty male and female (age: 14.44 ± 1.17 years, BMI: 19.29 ± 3.43) youth hockey players were recruited for this study from hockey talent high schools. The potential associated factors or determinants for injury risk were musculoskeletal screening tools: pelvic kinematics (single leg vertical drop jump), core stability (plank test), trunk extensor endurance (Sorensen test), dynamic balance (Y-Balance Test) and a pain scale (VAS). Data for all outcome measures were taken for PRE (before fatigue simulation), POST0 (immediately after fatigue simulation) and POST15 (15 minutes after fatigue simulation). Repeated sprint ability (RSA) was used as a fatigue simulation. Simple linear regression was performed to analyse the data statistically.
Results: Right-side pelvic kinematics was found to be significantly associated with FMS at PRE, POST0 and POST15 among youth hockey players ($P < 0.001$).
Conclusion: Right-side pelvic kinematics may be associated with injury risk.

Keywords: Balance – Endurance – Core Stability – Pelvic Kinematics – Athletes

Introduction

Field hockey is the world's second most well-known team sport, after soccer (Murtaugh, 2009). The International Hockey Federation is made up of five continental associations and 119 member associations. Even with the apparent popularity of the sport, data on rates of injury among hockey players are scarce (Holmes et al., 2022). According to Murtaugh (2009), lower extremity sprains and bruises are the most common hockey injuries, and it is also frequently suspected that hockey has a higher number of upper extremity injuries than other sports. Additionally, field hockey players are considerably more likely to experience hand or phalangeal injuries (Hassan and Gaballah, 2024). Furthermore, the lower leg was the most frequently injured site due to stick impact, tackling and deflections, and the most common injury types were contusions and muscle strains. Contact injuries were more prevalent in studies based on competitions, but non-contact injuries were more prevalent in studies over a whole season (Rees et al., 2021).

According to Shanmugam and Maffulli (2008), youths are more vulnerable to injury due to a variety of factors, including the growth of cartilage, which has less resilience to constant microinjury than mature adult counterparts, skeletal immaturity, rough training, reduced flexibility due to a pronounced growth spurt, a proclivity to try new things and take risks during sports, and finally, differences in how the body reacts to exercise in adolescents. Bone's biomechanical qualities alter significantly during growth. As bone stiffness and impact resistance decrease in youth athletes, abrupt loading can cause bones to bow or buckle. Fractures that were previously associated with a deformity can fully heal and appear normal later in life (Shanmugam and Maffulli, 2008).

Caine et al. (2008) found that individuals with a larger body mass are more likely to sustain injuries due to increased stress on joints and soft tissue. Stuart et al. (2002) found that athletes with a greater body mass index (BMI) have a higher risk of injury. Ellapen et al. (2014) revealed that female adolescent field hockey players with larger body mass, stature, and BMI had higher injury rates.

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Research indicates that athletes are more likely to sustain injuries during competitions than during practice sessions. Murphy et al. (2003) found that athletes may exhibit increased levels of aggression and risk-taking during competitions, increasing the chance of injury. Poor aerobic fitness can increase muscular fatigue, affecting biomechanics and putting additional strain on supporting systems including ligaments and tendons (Murphy et al., 2003).

Fatigue can impair motor function (Kahlaee et al., 2012) by altering muscular co-contraction and recruitment patterns (Gregory et al., 2008). Furthermore, weariness can impair an individual's capacity to maintain spinal stability and coordinate upper and lower limb joint movement (Granata and Gottipati, 2008). According to Asgari et al. (2017), weariness may increase the risk of spine and hip injury, and fatigability is also associated with spinal and lower limb injury.

Currently, there are limited studies investigating the determinants of injury risks in the fatigue stage among youth athletes. Previous studies have been conducted to investigate determinants of injury risk but not in the fatigue stage (Rossi et al., 2020; Yabe et al., 2020). Therefore, the aim of this study is to identify factors associated with injury risk in youth hockey players under fatigue conditions.

Material and methods

Study design

A non-probability convenience sampling technique was used. The researcher obtained consent from the respective head coaches, parents and players of the youth hockey team to participate in the study. A sample group of youth hockey players, consisting of male and female players, was recruited. The study employed a single-group design, and participants completed the familiarisation protocol of fatigue simulation and experimental trial before the experiment was conducted.

The study was conducted in the halls of several schools. Permission was obtained from the school principal before the research was conducted. The reason for using a hall was due to the requirement for ample size to conduct the research.

The following inclusion criteria needed to be fulfilled by the players to be eligible to participate in this study.

1. Male or female, aged 13–17 years
2. Actively involved in training
3. Field hockey players with no history of upper extremity, lower extremity or spinal injury in the past 3 months (Gonzalez et al., 2018)

Exclusion criteria

1. A history of recent concussion < 2 weeks or persisting symptoms > 1 month (Rees et al., 2021)
2. Previous back, upper extremity or lower extremity surgery
3. Currently using assisted walking devices

This study was approved by the Research Ethics Committee of the university and adhered to the Declaration of Helsinki. The ethics application included information about the study's purpose, confidentiality, privacy, safety, benefits and risks, and participants. All study protocol documents, information sheets, permission forms, parental consent forms, and recording forms were also included.

To involve secondary school students, authorisation from the Ministry of Education was obtained, followed by approval from the state education department, and finally from the school principals. Before the study began, participants were given both verbal and written explanations to make sure that they comprehended the concepts, procedures, and consent, and their confidentiality was protected.

Instrument

1) Demographic data

Before the study began, the demographic data of the participants were obtained such as age, gender, dominant leg, family history of musculoskeletal disorders, and training and playing history over the past 12 months.

2) Fatigue protocol (repeated sprint ability)

Participants performed three sets of a five-minute modified team sport simulation circuit (RSA), with a two-minute rest period in between (Figure 1) (Bishop et al., 2001). The mean heart rate (HR) was measured after each set. HR was measured using a Polar Heart Rate device. The session rating of perceived exertion (sRPE) was recorded at the end of the simulation circuit (Weir et al., 2017). The fatigue protocol starts with a 15 m sprint, followed by 12 m agility run and a 10 m walk. Then, participants performed a 10 m jog, followed by a 10 m sprint and a 10 m walk. After that, they performed a 30 m stride walk, followed by a 10 m sprint and a 5 m jog. Lastly, they completed a 5 m walk.

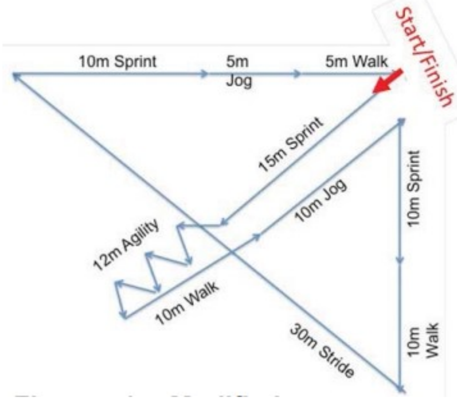

Figure 1. Fatigue protocol (repeated sprint ability)

3) Standardized Nordic Musculoskeletal Questionnaire (NMQ)

Musculoskeletal pain was screened using the Standardized Nordic Questionnaire (ICC=0.88) (Kuorinka et al., 1987). The NMQ includes a back-view human body map with nine anatomical body areas where musculoskeletal issues often appear. It is a self-administered questionnaire, and participants must select "yes" if they have musculoskeletal issues and "no" if they do not. Participants were asked if they had experienced any trouble (pain, ache, discomfort, or numbness) in any of the body parts listed in the questionnaire (neck, shoulder, elbow, wrist and hand, upper back, lower back, hip/thigh, knee, ankle, and foot) over the past 12 months. Those who responded positively were asked if they had ever experienced any trouble that had prevented them from performing their normal jobs over the course of the past 12 months and the past 7 days.

4) Physical Readiness Questionnaire (PAR-Q +)

Prior to the fatigue simulation being conducted, the Physical Activity Readiness Questionnaire (Par-Q+) was answered by the participant. According to Warburton et al. (2011), the reliability of Par-Q + was high (r=0.99). PAR-Q+ is a questionnaire that consists of 7 steps that can be used by people of all ages. It investigates the family history and severity of the condition, and identifies potential risk factors during moderate physical activity. Individuals who intend to receive a fitness evaluation need to complete the PAR-Q.

5) Obstacle Single Leg Forward Step Test (OSFS)

Before the fatigue simulation, the OSFS was conducted. Shin and Demura (2007) stated that the step test has high reliability (ICC = 0.90). The OSFS investigates fall risk and fall-related physical fitness. In the Single Leg Forward Step (SFS) test, participants advanced one leg 25 cm forward and returned it to its original place as fast as possible five times. The Obstacle-SFS added an obstacle to the above condition in the SFS test. The obstacle height was 10 cm. The OSFS was used as a physical examination to assess fall risk.

6) Functional Movement Screen (FMS)

A low FMS score is a potential indicator of injury risk during the athletic season, according to the literature (Cook et al., 2014). The cut-off score of 14 points is considered indicative of a high risk of sports injuries. The FMS assesses injury risk using seven fundamental movement patterns: squatting, stepping, lunging, shoulder reaching, active leg raising, push-ups, and rotary stability. Five of the seven sub-tests are bilateral, and the average score is taken. Cook et al. (2006) described the 7 FMS tasks. Each pattern of movement is scored on a scale of 0 to 3: 3 indicates no movement dysfunction as defined for each test, 2 indicates little movement compensation, 1 indicates an inability to perform the pattern of movement, and 0 indicates the presence of pain during the test. The total FMS score ranges from 0 to 21 points (21 = no movement change; movements performed exactly as described). The examiner demonstrated each task at the station before the participant performed it. The FMS is a valid outcome measure for both inter-rater and intra-rater reliability (ICC = 0.74–1.00) (Shultz et al., 2013).

7) Single leg vertical drop jump (SLVDJ)

Rossi et al. (2020) noted an increased injury rate in players with lower femur-pelvic angle (FPA) during SLVDJ landing, indicating a link between hip-pelvic biomechanics and injury risk. The normal range of FPA is 85 degrees. When Stensrud et al. (2011) evaluated lower limb biomechanics during the SLVDJ, they found moderate to excellent reliability (ICC range = 0.58–0.89). Small pieces of sports tape were applied on the left and right sides of the upper anterior iliac tubercle (ASIS) and tibia tuberosity for this examination. The video was recorded with a high-definition digital camera. During the test, the player stood on a 10-cm box in front of the video camera. The participant landed on one leg after dropping from the box with one leg. The participant immediately after landing completed a maximal straight-up jump with the same leg (the test was repeated three times). Trials involving jumping, a leg contacting the ground, or falling were deemed invalid. Two valid trials were considered sufficient.

The frontal plane knee and pelvic angles were estimated by a physiotherapist by marking the knee joint centre and ASIS in a still image obtained from a video using the program Kinovea. The angles of the joints were measured at the time of maximal knee flexion during the initial landing. The FPA describes the angle between the femur and the pelvic and is obtained from the intersection of an ASIS-created line and the knee joint centre. A narrower angle suggests more femoral adduction and/or pelvic drop.

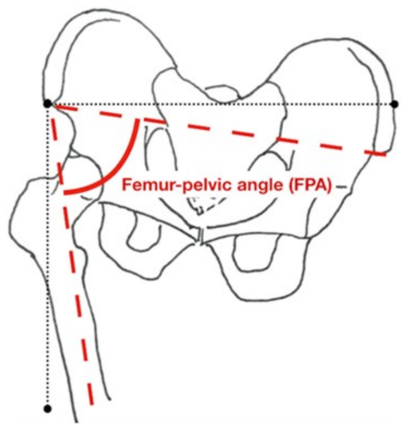

Figure 2. Femur-pelvic angle measured in SLVDJ

8) Plank test

The plank test was performed in stages, as reported by Tong et al. (2014). First, the participants underwent one practice trial. They were given a one-minute break before beginning the test. The participant began the test in a prone plank position, stabilizing the body with the forearms and feet (1). From head to heels, the body should be parallel to the floor. After 60 seconds in this plank position, the participant (2) lifted the right arm off the ground and held this position for 15 seconds, (3) returned the right arm to the ground and lifted the left arm for 15 seconds, (4) returned the left arm to the ground and lifted the right leg for 15 seconds, and (5) returned the right leg to the ground and lifted the left leg for 15 seconds, (6) lifted and held the left leg and right arm for 15 seconds, followed by (7) right leg and left arm, (8) returned to the basic plank position for 30 seconds, and (9) repeated stages 1 to 9 until unable to hold the prone plank any longer. These phases were carried out without stopping. The examiner recorded each participant's overall time as well as the maximum number of phases completed. This test has proven to be reliable for assessing global core endurance (ICC = 0.96–0.99) (Tong et al., 2014).

9) Sorensen test

For the Sorensen test, participants lay face down on a table with their iliac crest margins parallel to the edge of the table, as described by Demoulin et al. (2016). Straps secured the lower body to the table. Participants were advised to keep their upper bodies straight and horizontal while folding their arms across their chests. The participant's entire time in this posture was recorded. The Sorensen test is used to determine back muscle endurance. McGill et al. (1999) reported a high test-retest reliability of 0.98 to 0.99.

Y-Balance Test

The Y Balance Test (YBT) is a dynamic balance test that has been shown to be a feasible and efficient risk assessment tool for extremity injury as well as sport injuries (Smith et al., 2015). A Y-Balance Test Kit is needed to carry out the YBT. Participants extend their free leg as far as they can in the anterior, posteromedial, and posterolateral planes, then repeat this procedure with the opposite leg. A trial is deemed invalid if the participant touches down with the reaching foot, fails to maintain a unilateral stance, fails to return to the starting position, such as by taking their hands off their hips, or accelerates the indicator by pushing to increase distance. The best three tests were noted. In order to normalize the result, limb length was measured, and the distance achieved was divided by limb length and multiplied by one hundred (Smith et al., 2015). Dominant limbs were determined by demographic data, and limb length was determined by measuring from the ASIS to the medial malleolus.

Procedure

This study employed a single-group design. Before the study started, players who volunteered were given a consent form to be completed by their parent/guardian. Participants were instructed to refrain from vigorous exercise within 48 hours before the test, avoid caffeine within two hours before the test, and complete a familiarization session for the fatigue simulation and all tests before undergoing the actual data collection. The testing protocol was conducted over two separate visits, with a minimum of two days of rest between sessions. On the first visit, the SLVDJ and FMS were conducted, while on the second visit, the plank test, Sorensen test and YBT were conducted. VAS scores were also taken on both visits. The demographic data of the participants were obtained, such as age, gender, dominant leg, family history of musculoskeletal disorders, and training and playing history during the previous 12 months. Then the NMQ, PAR Q+ and OSFS were conducted. Before fatigue simulation (PRE), participants underwent a 5-minute dynamic warm-up followed by blood pressure and heart rate measurement as precautions as well as the rate of perceived exertion, VAS, SLVDJ and FMS testing for baseline data. This procedure was performed twice, with a two-minute rest in between, and the average of the two measurements was used as the baseline value. After that, participants completed three sets of a five-minute modified team sport simulation circuit (RSA), with 2 minutes of rest between sets (Bishop et al., 2001). Following each set, heart rate (HR) was recorded. At the completion of the simulation circuit, the rating of perceived exertion (sRPE) was determined (Weir et al., 2017). To prevent a reduction of the effect of fatigue, the SLVDJ and FMS were performed immediately upon completion of fatigue simulation (POST0). VAS scores were taken, and the SLVDJ and FMS were repeated after a 15 min rest (POST15). On the next visit, all the procedures were repeated with different musculoskeletal screening tools or outcome measures, which were the plank test, Sorensen test and YBT, and VAS scores were again recorded. The two-visit design was implemented due to the time constraints of performing all tests in a single day, as the effects of fatigue diminish after 15 minutes (Bossuyt et al., 2015), and the gap between 2 visits must be at least 2 days to prevent delayed onset muscle soreness (DOMS) (Nosaka, 2008). All tests were randomly conducted without a standard sequence to prevent bias, and the warm-up protocol for the first and second visits was the same.

Statistical analysis

An a-priori calculation for sample size determination was conducted based on previous studies (Armstrong et al., 2018) using G*Power analysis. To achieve 80% statistical power and an effect size of 0.20, a minimum of 80 participants was required for this study. The study increased the study group by 20% to reduce the likelihood of dropout, bringing the target recruitment to 96 participants. However, the researcher was able to recruit 120 participants.

All data were analysed using SPSS version 27.0 (IBM Corp). As the sample size was large ($n \geq 50$), the Kolmogorov-Smirnov test was used to test the null hypothesis that the data were normally distributed. Data were presented as means and standard deviation (SD), with 95% confidence intervals (CI). A p-value of <0.05 was considered statistically significant. Simple linear regression was used to identify the determinants of FMS, including musculoskeletal screening tools before and during fatigue. Model assumptions were met. There was no interaction between independent variables. No multicollinearity was found between the variables. No autocorrelation issue was found in the model. Both linearity and homoscedasticity were met. Regressions were conducted separately for each time point (PRE, POST0, POST15). Fatigue was modelled as a moderator. For PRE, $R^2 = 0.354$ and adjusted $R^2 = 0.348$, for POST0, $R^2 = 0.307$ and adjusted $R^2 = 0.302$, and for POST15, $R^2 = 0.244$ and adjusted $R^2 = 0.238$.

Results

Demographic data

Table 1 shows the demographic data of participants. A total of 120 participants (60 males and 60 females) were included in this study after considering inclusion and exclusion criteria. All of them are of Malay ethnicity, with 109 (90.8%) participants having right leg dominance and 11 (9.2%) having left leg dominance. The mean age, BMI, and years of experience playing field hockey are 14.44 years old (1.17), 19.29 kg/m^2 (3.43), and 4.93 years (2.17), respectively.

Nordic Musculoskeletal Questionnaire, Physical Activity Readiness Questionnaire and Obstacle Single Leg Forward Step Test

For participants' musculoskeletal symptoms (NMQ), all participants reported no upper limb or lower limb symptoms. For risk while engaging in physical activities (PAR Q+), all participants reported no medical history, and for risk of falls (OSFS), no participants were identified to be at risk of falls.

Table 1. Demographic data of the participants

	Frequency (%)	Mean (SD)
Gender		
Male	60 (50.0)	
Female	60 (50.0)	
Ethnicity		
Malay	120 (100.0)	
Dominant leg		
Right	109 (90.8)	88.21 ± 2.90
Left	11 (9.2)	85.21 ± 2.90
Age (years)		14.44 ± 1.17
BMI (kg/m^2)		19.29 ± 3.43
Body height (m)		1.60 ± 1.21
Body mass (kg)		49.40 ± 3.12
Years of participation in hockey		4.93 ± 2.17

Heart rate, rating of perceived exertion and visual analogue scale before and during fatigue

Table 2 shows HR, RPE and VAS before and during fatigue simulation (RSA). VAS before and during fatigue is O. The RPE score throughout the 3 sets of fatigue simulation ranges from 4 (somewhat hard) to 5 (hard). The mean HR and maximum HR increased throughout the fatigue simulation, and the RPE values were high, indicating that the participants were fatigued after the fatigue simulation.

Table 2. Heart rate, rate of perceived exertion and pain (Visual Analogue Scale)

RSA	Set 1	Set 2	Set 3	*p*-value
Mean HR (bpm)	154.00	174.23	177.23	0.004
Max HR (bpm)	177.33	184.23	186.48	0.007
RPE	4.33	5.21	5.45	0.023
VAS	0	0	0	1.000

HR: heart rate, VAS: Visual Analogue Scale, RPE: rate of perceived exertion, bpm: beats per minute

Impact of fatigue on FMS, pelvic kinematics, core stability, trunk extensor endurance and dynamic balance

Normality for all variables was assessed using the Kolmogorov-Smirnov test, as the number of participants was >50. Most variables were found to be significantly non-normal ($p < 0.05$). Therefore, nonparametric statistical analyses were conducted, and the Friedman test was used to analyse all data. Table 3 shows the Friedman test results for FMS, pelvic kinematics, core stability, trunk extensor endurance and dynamic balance among all participants, indicating a significant difference at all time points considered, $p < 0.001$.

Table 3. Friedman test for FMS, pelvic kinematics, core stability, trunk extensor endurance and dynamic balance

	PRE	POST0	POST15	Chi square ($df = 3$)	*p*-value
FMS	16.53 ± 1.80	15.28 ± 1.89	13.83 ± 1.92	368.7	< 0.001
RTSLVDJ	77.87 ± 2.90	76.66 ± 2.78	75.71 ± 2.64	352.6	< 0.001
LTSLVDJ	78.58 ± 2.88	77.50 ± 2.80	76.82 ± 2.47	351.4	< 0.001
Plank test	196.25 ± 173.56	157.18 ± 153.09	126.34 ± 133.16	345.1	< 0.001
Sorensen test	195.76 ± 109.39	170.86 ± 106.58	151.85 ± 106.97	352.1	< 0.001
RTAYB	60.23 ± 5.45	57.57 ± 5.41	56.27 ± 5.41	350.8	< 0.001
LTAYB	59.73 ± 6.35	56.19 ± 6.41	53.71 ± 6.52	352.1	< 0.001
RTPMYB	76.64 ± 9.78	74.78 ± 9.76	73.68 ± 9.75	352.3	< 0.001
LTPMYB	77.02 ± 10.14	75.13 ± 10.20	73.85 ± 10.14	351.9	< 0.001
RTPLYB	77.23 ± 9.50	75.28 ± 9.68	74.08 ± 9.71	353.4	<0.001
LTPLYB	77.32 ± 9.78	75.18 ± 9.77	73.78 ± 9.86	352.4	< 0.001

RT: right, LT: left, SLVDJ: single leg vertical drop jump, A: anterior, PM: posteromedial, PL: posterolateral, YB: Y-Balance

Assumptions for regression analysis

All necessary assumptions for linear regression were met. No significant interaction effects were observed between independent variables, as indicated by non-significant interaction term coefficients (p > 0.05). There was no autocorrelation in the residuals, confirmed by a Durbin-Watson statistic of 1.5, which falls within the acceptable range (< 2.5). No multicollinearity was detected; all variance inflation factor (VIF) values were below 10. The linearity assumption was satisfied, as indicated by a scatter plot showing a linear relationship without curvature. Homoscedasticity (equal variance of residuals) was observed, with residuals evenly distributed around the zero line.

Determinants of FMS at PRE, POST0 and POST15

The determinant of FMS in this study was analysed using simple linear regression. Table 4 shows the factors that determine the FMS of 120 participants at PRE, POST0 and POST15. For PRE, it was found that 12.2% of the variation in the FMS score in our population was explained by right side pelvic kinematics (RTSLVDJ). It was found that RTSLVDJ was a significant determinant for FMS in this study population after adjustment for confounders. For every 1 degree increase in the RTSLVDJ, the FMS score increased by 0.369. In addition, there was a significant positive linear relationship between RTSLVDJ and FMS score. Hence, the linear regression equation model: FMS score = 12.189 + 0.369 (RTSLVDJ). For POST0, it was found that 13.5% of the variation in the FMS score in our population was explained by RTSLVDJ. It was found that RTSLVDJ was a significant determinant for FMS in this study population after adjustment for confounders. For every 1 degree increase in the RTSLVDJ, the FMS score increased by 0.375. In addition, there was a significant positive linear relationship between RTSLVDJ and FMS score. Hence, the linear regression equation model: FMS score = 13.467 + 0.375 (RTSLVDJ). For POST15, it was found that 13.4% of the variation in the FMS score in our population was explained by RTSLVDJ. It was found that RTSLVDJ was a significant determinant for FMS in this study population after adjustment for confounders. For every 1 degree increase in the RTSLVDJ, the FMS score increased by 0.360. In addition, there was a significant positive linear relationship between RTSLVDJ and FMS score.

Discussion

The results show that at PRE, POST0, and POST15, right-side pelvic kinematics (RTSLVDJ) was significantly associated with FMS. This indicates that, both before and after the fatigue simulation, RTSLVDJ was a factor contributing to injury risk. This result aligns with research

Table 4. Determinants of FMS at PRE, POST0 and POST15

Variable	SLR[a] Beta (standardized regression coefficient (95%CI)	*p*-value
RTSLVDJ		
PRE	0.60 (0.280, 0.860)	<0.001
POST0	0.55 (0.270, 0.580)	<0.001
POST15	0.50 (0.250, 0.880)	<0.001
LTSLVDJ		
PRE	0.03(−0.11, 0.120)	0.982
POST0	0.01(−0.120, 0.130)	0.951
POST15	−0.03(−0.160, 0.120)	0.762
PLANK		
PRE	0.01(−0.002, 0.020)	0.804
POST0	0.02(−0.002, 0.040)	0.852
POST15	0.04(−0.002, 0.060)	0.642
SORENSEN		
PRE	−0.12(−0.010, 0.001)	0.214
POST0	−0.08(−0.090, 0.002)	0.382
POST15	−0.07(−0.080, 0.002)	0.444
RTAYB		
PRE	−0.12(−0.100, 0.020)	0.212
POST0	−0.07(−0.090, 0.040)	0.421
POST15	−0.01(−0.070, 0.060)	0.902
RTPMYB		
PRE	0.03(−0.030, 0.040)	0.733
POST0	0.03(−0.020, 0.050)	0.333
POST15	0.01(−0.020, 0.060)	0.251
RTPLYB		
PRE	0.04(−0.030, 0.060)	0.652
POST0	0.11(−0.010, 0.360)	0.252
POST15	0.11(−0.010, 0.320)	0.222
LTAYB		
PRE	-0.02 (−0.090, 0.020)	0.191
POST0	−0.05(−0.070, 0.040)	0.563
POST15	−0.02(−0.060, 0.050)	0.843
LTPMYB		
PRE	−0.02(−0.040, 0.030)	0.841
POST0	0.07(−0.020, 0.090)	0.473
POST15	0.11(−0.010, 0.260)	0.232
LTPLYB		
PRE	0.01(−0.030, 0.040)	0.913
POST0	0.07(−0.020, 0.080)	0.483
POST15	0.06(−0.020, 0.080)	0.502

by Mirzashahi et al. (2023). The study found that pelvic kinematics malalignment is a risk factor for injury. This is in accordance with a study by Rossi et al. (2020), which recruited male and female floorball and basketball athletes. The study found that pelvic kinematics, indicated by femur-pelvic angle (FPA), was associated with future occurrence of spinal and lower extremity injury.

Proper pelvic alignment is crucial for maintaining an energy-efficient posture and also a significant risk factor for spinal and lower limb injury (Mirzashahi et al., 2023). Proper pelvic kinematics, which influences posture and lowers mechanical stress on the lumbar region and lower extremity, is essential for avoiding injury risk. Furthermore, pelvic alignment has been shown to be an important aspect in keeping a balanced posture. Pelvic kinematics refers to the link between the morphology and orientation of the pelvic to that of the vertebral spine and line of gravity (Chaléat-Valayer et al., 2011). The anatomical asymmetry of the pelvis, which was similar to that of the lower limbs, was similarly linked to directional biomechanical stress (Kurki, 2017). Research suggests that lateral pelvic tilt, which causes asymmetrical lumbar movement and abnormal mechanical stresses on the body, may contribute to the development of spinal, lower limb and potentially upper limb injury (Al-Eisa et al., 2006). This strain increases on the soft tissues in the lumbar region, affecting the lower limbs, and eventually will affect the upper limbs (Sorensen et al., 2016).

The participants' dominant leg was on the right side, which likely contributed to the greater significance of RTSLVDJ compared to LTSLVDJ. This finding aligns with previous research, which demonstrated an association between injury risk and dominant-side pelvic kinematics (Rahimi et al., 2020). According to Henning et al. (2017), physiological asymmetry typically leads to right dominant motor and postural patterns, resulting in alterations in kinematics and muscle activation of the trunk, pelvis, upper extremities and lower extremities. Research indicates that individuals with spinal and lower extremity conditions exhibit more asymmetric movement of the trunk and limbs, as well as asymmetric spatiotemporal parameters, when walking compared to healthy individuals (Al-Eisa et al., 2006). This suggests that individuals with injury have more asymmetric motor control (muscle activation) than healthy individuals (Leung et al., 2015).

Investigating the involvement of potential sociodemographic risk factors such as marital status and income in relation to LBP is critical, since these variables can have a substantial impact on an individual's physical and psychological health, access to healthcare, and general lifestyle. The impact of neuromuscular training on pelvic kinematics is significant because the pelvis is essential for maintaining postural stability, coordinating lower limb motions, and transmitting forces during dynamic exercises. Abnormal pelvic kinematics, such as excessive tilt or rotation, is frequently associated with musculoskeletal problems such as low back pain or lower limb injuries. Neuromuscular exercise improves motor control, muscle activation patterns, and coordination, perhaps leading to better pelvic alignment and movement efficiency.

The findings of this study show a strong association between RTSLVDJ and the likelihood of injury, especially before and even after fatigue. Disruptions in pelvic kinematics, such as pelvic asymmetry or lateral pelvic tilt, can create aberrant biomechanical stresses on the spine and soft tissues, increasing the risk of injury. This is confirmed by research on degenerative disorders and asymmetrical pelvic movements (Al-Eisa et al., 2006; Kurki, 2017), which emphasizes the significance of keeping appropriate alignment to reduce risk of injury. The dominant side is also associated with risk of injury via altered pelvic kinematics.

Conclusion

This study found a significant association between FMS and musculoskeletal screening tools during and after fatigue simulation among youth hockey players. Among the musculoskeletal screening tools analysed, only right pelvic kinematics emerged as a significant factor. Other variables – core stability, trunk extensor endurance and dynamic balance – did not show significant associations.

This study aimed to address the limitations of previous research, such as a lack of consideration of sociodemographic factors, and give a more comprehensive, accurate, and generalizable understanding of how fatigue affects functional performance and injury risk across populations. Additionally, this study will significantly benefit coaching staff and physiotherapists in order to reduce risk of recurrent LBP among youth hockey players.

One of the key recommendations is that future studies need to incorporate comparative analyses of multiple sports. While the current study provides useful insights into youth hockey players, its focus on a single sport makes it impossible to determine whether the observed patterns are only for hockey or able to reflect a variety of sports. Future research is also recommended to determine whether fatigue patterns, functional limitations, or injury risks differ across various sports. This would allow for a more sophisticated understanding of fatigue effects and injury risk, as well as the development of exercise protocols tailored to the specific needs of different sports.

Conflict of interest: Author state no conflict of interest

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Received 23.01.2025
Accepted 26.11.2025

Acknowledgements

The authors would like to acknowledge the university where the study was started as well as the Ministry of Education for the data collection permission. The authors also thank the university for funding the research through the MYRA research grant [600-RMC/GPM LPHD 5/3 (051/2023)].