Higher vertical jumping asymmetries and lower physical performance are indicators of increased injury incidence in youth team-sport athletes

ABSTRACT

To date, the literature looking at the association between injury-risk factors and actual injury incidence in young elite team-sports athletes is scarce. The main objective of the present study was to examine how modifiable factors may affect injury incidence. Eighty-one young elite team-sports athletes (age: u-14 to u-18) performed the countermovement jump (CMJ), a single leg CMJ (SLCMJ), the one-legged hop test (OLHT), a 30 m sprint test, the v-cut test, a repeated sprint ability and the 30-15 intermittent fitness test during the pre-season period. Inter-limb asymmetries were calculated for SLCMJ and OLHT. Injuries were recorded prospectively for the entirety of the 2017-2018 season. Comparison of injury and non-injury data was carried out using a two-way analysis of variance (ANOVA). Results of the ANOVA according to injury showed significant differences in CMJ ($p = 0.01$), SLCMJ on the lowest performing limb ($p = 0.03$) and SLCMJ asymmetry (< 0.001). Sex*injury interaction was significant from CMJ (p = 0.018) and 30-15 IFT (p = < 0.001). In conclusion, the current study indicated that athletes with greater inter-limb asymmetries, less vertical jump capacity and lower intermittent aerobic fitness had a greater predisposition to injury. Therefore, monitoring CMJ, aerobic performance and inter-limb asymmetries is recommended given their sensitivity to detect significant differences between injured and healthy youth athletes.

Key Words: Aerobic fitness; countermovement jump; inter-limb differences; risk factors.

INTRODUCTION

Injury incidence in high performing youth athlete populations is known to be high (16). Previous research has shown that a weekly training time of > 16 h per week among 14-18 year old team sport athletes is associated with increased injury risk (49). With this in mind, sports injuries during childhood and adolescence represent a considerable social and economic burden (9). Consequently, it is important to develop strategies to reduce the risk of injury in youth athlete populations (20).

In team sports, the majority of injuries are a result of the complex interaction from a multitude of reasons (e.g. sex, age, strength deficits) (21,44). However, athletes continually repeat high-risk injury situations without injury occurring. Despite this, when the interaction of personal (e.g. psychological, neuromuscular, hormonal aspects), environmental (e.g. playing surface, opponents, score) and task (e.g. changes in direction with decision-making, fatigue and high intensity) risk factors align, the risk of injury is likely to increase (44). Although we know that the etiology of sports injuries is multifactorial, and according to the classical approach to injury prevention proposed by Van Mechelen (41), it is necessary to understand the risk factors and injury mechanisms in order to propose an optimal prevention program. Currently, there are few prospective studies that relate physical performance with sports injuries (26).

Team sports are characterized by repetitive high intensity, unilateral skills such as jumping and changes of direction (51). These repetitive movement patterns lead team sport athletes to developing asymmetric neuromuscular adaptations of the lower limbs (4,40). For example, Ross et al. (50) found that the kicking leg had superior thigh strength (isokinetic peak torques), better proprioception, and greater knee-flexion ROM than the stance limb in physically active individuals. Despite being a somewhat controversial topic (4), previous research has suggested a 10-15% threshold of inter-limb asymmetry in strength and power to be considered as ‘normal physiological variability’ in team sports (18,19,30,35). Therefore, monitoring and quantification neuromuscular deficits between legs has been a common line of investigation in order to identify individuals who may be at risk of injury or establish when an athlete can return to sport following injury (3). Despite this, there are only a few studies that have investigated the association between inter-limb asymmetry and future injury in sports team athletes (13,29,32). Hewett et al. (28) observed significant between-limb differences in knee abduction moment in nine youth sport-team players, who injured their anterior cruciate ligament (ACL) compared to uninjured limb. In addition, Chalmers et al. (13) found that junior Australian football players with greater asymmetrical movement during pre-season testing (from the Functional Movement Screen) were more likely to sustain an injury during the regular season. Moreover, Brumitt et al. (32) observed that collegiate volleyball players had a greater risk of non-contact time-loss lower quadrant injury, when starting the season with asymmetries > 10% from the single leg hop for distance test.

Enhanced athletic development has been suggested as a vital component of injury prevention strategies (14,34). Additionally, well-developed physical capacities such as lower-body strength, repeated sprint ability, speed and aerobic fitness have also been associated with better tolerance to higher workloads and reduced risk of injury in team-sport athletes (37,39). However, there is limiting scientific literature that associate a better physical performance with less injury incidence (27). Malone et al. (38) found that elite soccer players with poor aerobic fitness as indicated by a lower 30–15 IFT(intermittent fitness test) had a greater risk of injury than players with superior aerobic fitness levels.

Additionally, Case et al. (11) examined that pre-season relative 1RM back squat strength was significantly higher in the uninjured male and female collegiate athletes compared with the injured groups.

Therefore, the main objective of this study was to investigate the association between inter-limb asymmetries and non-contact lower limb sport injuries among youth elite team sports players. A secondary objective was to investigate the association between physical performance measurements and non-contact lower limb sport injuries. Our primary hypothesis was that athletes who exhibit greater inter-limb asymmetries and worse physical performance in the pre-season, will have a greater risk of suffering non-contact injuries than the other athletes.

METHODS

Experimental Approach to the Problem

The current study employed a prospective cohort design with the aim of finding the association between inter-limb asymmetries, physical performance and injury rate, in elite youth team-sports players. Countermovement jump (CMJ), single leg CMJ (SLCMJ), one-legged hop test (OLHT), 30-m sprint, change of direction (v-cut test), repeated sprint ability and intermittent aerobic fitness were assessed during the pre-season period. In addition, inter-limb asymmetries were subsequently calculated from both unilateral jump tests. Injuries were recorded prospectively for the entirety of the 2017-2018 season (September to May), in accordance with the recommendations provided by Fuller et al. (2006).

Subjects

A total of 81 participants (29 males, 52 females) volunteered to participate in the present study consisting of: 30 handball players (14 males, 16 females), 28 volleyball players (15 males, 13 females) and 23 basketball players (23 females). Subjects were eligible for inclusion if they were high performance team-sports players between 14-18 years old. Subjects were excluded if they presented any injury at the time of testing. Table 1 provides subject characteristics. All the athletes train and study in the same high-performance sports center, in Esplugues de Llobregat (Joaquim Blume Residence). Routine training did not differ between groups and consisted of 8-10 sessions (90-120 minutes per week), of which 2 were dedicated towards structured strength and conditioning training. In addition, they played a weekend match, totaling approximately 16-20 hours of combined training and competition per week. Prior to the commencement of the study, subjects and their parents received detailed written and verbal information about the possible risks and benefits associated with testing. Written informed consent and assent were obtained from both parents/tutors and participants, respectively. This study was approved by [deleted for peer review] and conformed to the recommendations of the Declaration of Helsinki.

** PLEASE INSERT TABLE 1 ABOUT HERE **

Procedures

One week before data collection, each subject was familiarized with performance test procedures. During testing days, all participants completed the same standardized warm-up in groups of 3-4 athletes consisting of 7-minutes of light multidirectional displacements, 3-minutes of dynamic stretching exercises (e.g. walking lunges, high knee lifts, side steps) and 3-minutes of maximal and progressive intensity displacements including changes of direction, jumps, and acceleration/deceleration movements. Following the warm-up, three practice trials were provided for each test where participants were instructed to perform them at 75, 90, and 100% of their perceived maximal effort. The warm-up was supervised by a qualified strength and conditioning coach and consistent feedback was provided throughout all tests to ensure proper technique. Each participant completed a baseline field-based assessment at the starting (between week 2 and 4) pre-season (September-October 2017). These evaluations were carried out on three separate days over one week in pre-season, with a minimum of 48 hours of rest and a maximum of 96 hours between testing days. Day 1 consisted of the CMJ, SLCMJ, OLHT and 30 m-sprint in that order. On day 2, test order was: v-cut-test and RSA test (10*(15+15m), r:3'sec). Finally, on day 3, athletes performed the 30-15 intermittent fitness test (30-15 IFT). The athletes performed their usual field training during the testing period; however, the strength and conditioning sessions were used to perform the different tests reported in this study.

Countermovement jump test (CMJ)

The CMJ test was performed on a contact mat with hands on hips (Chronojump Boscosystem, Barcelona, Spain) (6). Flight time was recorded using Chronojump software to calculate the vertical jump height obtained (5). Each trial was validated by a visual inspection to ensure that each landing was without any leg flexion at contact time and players were instructed to maintain their hands on their hips throughout the duration of the jump. The depth of the CMJ was self-selected and each trial was separated by a rest period of 60-s. The highest vertical jump height of three trials was used for further analysis.

Single leg countermovement jump (SLCMJ)

Subjects were instructed to stand on one leg with hands on hips, descend into a countermovement of self-selected depth, and then rapidly extend the stance leg to jump as high as possible in the vertical direction (42). The swing of the opposite leg prior to the jump was not allowed; however, they were also instructed to land on both feet simultaneously. A trial was considered successful if the hands remained on the hips throughout the movement. The SLCMJ height was calculated from flight time (6) with the same contact mat system as used for the bilateral CMJ. For the three trials of each jump, participants started with their preferred leg and the order of the right and left legs was alternated thereafter. Each trial was separated by a 30 s recovery period. The highest trial of the three jumps was used for further analysis.

One leg hop for distance (OLHT)

All participants were asked to hop as far as possible with hands on hips, taking off and landing on the same foot and keeping their balance on this foot for 2 seconds upon landing. To facilitate body balance, participants performed the OLHT with free arms. For the two trials of each jump, participants started with their preferred leg and the order of the right and left legs was alternated thereafter. Each trial was separated by a 30-s recovery period. The greatest distance for each leg was recorded using a measuring tape and from the heel of the tested foot and used for further analysis.

30-m sprint

Maximum sprint time was assessed by 30-m sprint. The start and finish lines were clearly marked with cones. Each player completed two sprints with a three-minute rest time between each sprint. The time was recorded using an iPhone 6 (iOS 11.2.5) at 60 fps and MySprint smartphone app (Apple Inc., Cupertino, CA, USA). The reliability and validity of this method has been reported to be excellent (48). The fastest time of the two sprints was used for analysis.

V-cut test

In the change of direction test, players performed a 25-m sprint with four change directions of 45º 5 m each. The front foot was placed 0.5 m before the first timing gate. For the trial to be valid, players had to pass the line, clearly marked on the floor, with the turning foot. The distance between each pair of cones was 0.7 m. If the trial was considered a failed attempt, a new trial was allowed. Two trials were completed with a three-minute rest time between each trial. The fastest time was used for analysis. Time to completion was measured using photocell beam connected to a computer (Chronojump BoscoSystem, Barcelona, Spain) (5). This test has previously demonstrated good reliability and validity (23).

Repeated sprint ability (RSA)

A repeated sprint ability protocol consisting of ten shuttle run sprints of 30 m (designed as a 15m out and back course) interspersed with 30 seconds of passive recovery was conducted (12). Players used a standing start 0.3 m behind the timing lights. Players were given verbal encouragement to run as quickly as possible for each of the ten sprints. Sprint performance during the test was assessed with a photocell beam connected to a computer (Chronojump BoscoSystem, Barcelona, Spain) (5). Athletes were encouraged to decelerate as soon as possible after crossing the finish line and to walk slowly back to the start line to wait for the next sprint. We calculated the mean of the ten sprints time.

30-15 intermittent fitness test

The 30-15 intermittent fitness test is a field evaluation used to assess aerobic fitness, that also includes an athlete’s anaerobic capacity, neuromuscular and change of direction qualities, and their ability to recovery during intermittent exercise (7). In the present study, the modified version of 30-15 intermittent fitness test special for small courts (25) was conducted on a 28m long basketball court. This consists of 30-second shuttle runs interspersed with 15-second walking recovery periods. The test starting speed is 8 km/h (i.e. first 30-second shuttle run), and this speed increases by 0.5 km/h for every 30-second stage thereafter. The speed of the last stage the athlete completes is recorded as their test score. This test has been shown to have good test-retest reliability with a typical error of measurement to be of 0.3 km/h (ICC = 0.96), suggesting a potential difference of about 1 stage (i.e. 0.5 km/h) (8).

Injury data collection

All sports injuries sustained during matches and training sessions were recorded and monitored following the Osics coding (45) after the baseline assessment during the 2017-18 season. Injury was defined as any physical complaint sustained by a player resulting from a match or training session that resulted in time loss. However, only non-contact injuries were included for analysis because contact injuries are dependent on interaction with other team collaborators or opponents. An electronic version of the injury data recording form presented by Fuller et al. (19) was used to register injuries characteristics (severity, injury type, side, previous injury, re-injury level, injury cause and circumstance) (21). Injury severity was classified based on the number of days missed and interpreted as follows: slight (0-1 days), minimal (2-3 days), mild (4-7 days), moderate (8-28 days) and severe (> 28 days) (19). An electronic injury form was completed by the physiotherapy staff and was reviewed by the lead researcher every week. In addition, the lead researcher met once a week with the strength and conditioning coach of each team to ensure that every injury was recorded.

Statistical Analyses

Data are presented as means and standard deviation (SDs) for quantitative variables and absolute frequency and percent (%) for qualitative variables. Assessment of normality for these variables employed the Kolmogorov-Smirnov along with the QQ-Plot distribution graphics. In addition, within-session reliability of test measures were analyzed using two way random intraclass correlation coefficient (ICC) with absolute agreement (95% confidence intervals) and coefficient of variation (CV). For interpretation, intraclass correlation coefficient (ICC) values were > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor (33) and CV values were considered acceptable if < 10% (15).

For the purpose of identifying inter-limb asymmetry between limbs, we also calculated the asymmetry index using a previously recommended formula (10,31,46) in the unilateral jump tests: (Highest performing limb–Lowest performing limb/Highest performing limb) ×100. The highest performing was defined as the side with the highest value in each jump. The mean of the two (OLHT) or three (SLCMJ) trials was used to index asymmetry analyses .

Kappa coefficient (κ) was calculated to determine the levels of agreement for how consistently an asymmetry favored the same side (direction of asymmetry) when comparing SLCMJ and OLHT asymmetries. Kappa values were interpreted in line with suggestions from Viera & Garrett (52) where ≤ 0 = poor, 0.01-0.20 = slight, 0.21- 0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-0.99 = almost perfect.

Data from injured individuals was compared to non-injured using a two-way analysis of variance (ANOVA). Magnitude of difference between groups was also computed via eta squared (η^2) effect sizes. Chi square statistical tests were carried out to assess if severity, type, side cause and circumstance of injury were uniformly distributed according to athletes' sex. Statistical significance was set at $p < 0.05$. All statistical analyses were conducted using SPSS for windows version 24 (IBM Co. Armonk, NY, USA).

RESULTS

A total of 72 injuries were recorded (76.4% lower limbs, 11.1% trunk, 11.1% upper limbs and 1.4 % head and neck) across 51 athletes in the studied season. A high percentage of injuries (63.88%) were reported as contact related. Specifically, there were a total of 46 reported non-contact injuries affecting the lower extremities (Table 2). When comparing by sports, 42.2 % of total injuries occurred in handball, 30.9% in basketball and 26.76% in volleyball players. During the registration period, 43.5% (n = 20) of the non-contact lower extremities injuries were estimated as a moderate injury (8 to 28 days) while 28.3% (n = 13) was considered as severe injury (> 28 days). Of all these injuries, only 6.5% (n = 3) were estimated as slight. No sex difference was observed ($p = 0.756$; $d = 0.14$). According to type on injury, the most common type was joint (non-bone) and ligament injury (45.7%, n = 21) and muscle and tendon injury (43.5, n = 20) respectively. Main injury cause was trauma (52.2%, n = 24) while overuse was 47.8% (n = 22). Recurrent injuries in the same location accounted for 30.4% (n = 14), and these injuries occurred during the next 2 to 12 months (late recurrence) in 63.6% of cases (n = 7). Higher rate of injuries was produced during training (78.3%, n = 36) versus injuries produce during match (21.7%, n = 10). A total of 31% of women injuries occurred during match versus 5.9% of men injuries (p = 0.045).

** PLEASE INSERT TABLE 2 ABOUT HERE **

Mean and standard deviation for all the variables are shown in Table 3. Almost all the tests showed excellent within-session ICC values (≥ 0.9) and each test had acceptable consistency with all CV values < 10%.

Kappa coefficient for the direction of asymmetry between the SLCMJ and OLHT tests was only slight (κ = 0.19) during pre-season.

Non-injured athletes exhibited significant superior performances in CMJ (p = 0.01; η^2 = 0.06) and SLCMJ-LPL (p = 0.03; η^2 = 0.04) tests but no differences were reported in the OLHT, 30m-sprint, V-Cut test, RSA or 30-15 IFT tests. Moreover, non-injured athletes presented lower asymmetries in the SLCMJ (p = 0.00; η^2 = 0.08), but not in the OLHT (p = 0.17; η^2 = 0.03) (Table 3). Related to this result, 68.25% of injuries occurred on LPL, 26.9 on HPL and 4.76 on both limbs. Sex*injury interaction was significant from CMJ (p = 0.018; η^2 = 0.05) and 30-15 IFT (p = 0.00; η^2 = 0.06) (Figure 1 and Figure 2). In addition, and according to sex significant differences were observed in all variables except for interlimb asymmetries variables (Table 3).

** PLEASE INSERT TABLE 3 ABOUT HERE **

** PLEASE INSERT FIGURE 1 AND 2 ABOUT HERE **

DISCUSSION

The first aim of this study was to investigate the relationship between inter-limb asymmetries and non-contact low limb sport injuries among youth elite team sports players. A secondary objective was to investigate the association between physical performance measurements and non-contact lower limb sport injuries. Results showed that athletes who sustained an injury had greater pre-season vertical jump asymmetries and lower performance in the bilateral CMJ and lowest performing limb during the SLCMJ. However, when considering the sex of the participants, only males that sustained an injury had both lower vertical jump performance and intermittent aerobic fitness values at pre-season.

To the authors' knowledge this is the first prospective study that has observed an association between jump height asymmetry in the SLCMJ ($p < 0.001$) and non-contact low limb injury risk in young healthy athletes. Specifically, non-injured athletes (n = 30) recorded an average asymmetry of 9.7 ± 8.3 and 7.7 ± 5.6 % in males and females, respectively. In contrast, for injured athletes (n = 51), values were 17.1 ± 13.3 and 12.8 ± 6.2 % for males and females, respectively. These results are in agreement with the 10-15% 'physiologically normal' asymmetry threshold suggested by several authors (4,40). Despite the limited evidence in this area, some research has linked major side-to-side differences in knee abduction moment, mobility and hop tests with future injury in sport team athletes (13,29,32). In accordance with our results, Read et al. (47) observer that greater SLCMJ peak ground reaction force asymmetry was a potential risk factor for injury in healthy elite male, although the strength of these relationships were moderate. Contrary to our study, these authors measured asymmetry in SLCMJ ground reaction force (and not jump height), as in our study. However, body mass did not change between left or right jumps; thus, it can probably be suggested that similar changes in height asymmetry would be found. Therefore, our study shows that between-limb differences in vertical jump performance could be a potential risk factor for non-contact low limb injuries in youth team-sports. This fact could be explained because the reduced physical capacity of the weaker limb to both produce and absorb force is likely to increase the risk of injury, given it will exceed its "tolerance capacity" sooner than the stronger limb when repeated high intensity actions occur, as characterized by team sports athletes.

Contrary to SLCMJ asymmetry, OLHT asymmetry had no relationship with injured or non-injured athletes. This fact agrees with the slight consistency (κ = 0.19) showed between these two inter-limb asymmetry values, that means low agreement for how consistently an asymmetry favored the same side (direction of asymmetry) when comparing the two tests. This low agreement between tests has been demonstrated in previous research (1,2) and indicates that limb dominance is rarely the same between tasks. As a result, strength and conditioning and rehabilitation programs should focus on the assessment of inter-limb asymmetries on a test-by-test basis, and not assume that limb differences will exhibit any common patterns between tasks. This will give a comprehensive evaluation of the athlete, especially when returning to sport. Moreover, strength and conditioning coaches and physiotherapists may use asymmetry values (and the direction of asymmetry) to make decisions in the identification of healthy athletes who may be at risk for future injury and guide injury prevention programs.

In addition, the present study is also the first study that have demonstrated a relationship between vertical jump capacity (CMJ, p = 0.01; SLCMJ-LPL, p = 0.03) and non-contact low limb injury risk in healthy sport-team athletes. Regarding the bilateral CMJ, the athletes who were not injured scored higher values (males 0.38 m; females 0.25 m) than those who experienced an injury (males 0.3 m; females 0.25 m). Based on these results, enhanced neuromuscular capacity (in this case higher jumping capacity), could protect athletes from a greater joint load and therefore could help reduce non-contact low limb injuries. Additionally, healthy athletes also had higher values in the lowest performing limb (LPL) of the SLCMJ (males 0.17 m; females 0.13 m) than those who were injured (males 0.15 m; females 0.12 m). This last finding was in accordance with Read et al. (47) who found that lower right leg relative SLCMJ landing forces were associated with an increased injury risk, in the U15-U16s soccer players. Although the present study did not measure landing forces, reduced landing forces can be inferred for the injured population, given they did not jump as high on the LPL. In addition, given only the LPL had an association with injury occurrence, it seems prudent to suggest that improved capacity should be seen as an important consideration for the weaker limb and is in line with recent suggestions from Maloney (40) who showed that weaker limbs have a greater "window of opportunity" for enhanced capacity. Related to this, in our study we found that most part of injuries occurred on LPL (68.25%) vs. HPL (26.9%). As mentioned previously, it is likely that the weaker limb likely exceeds its tolerance capacity sooner than the stronger side; thus, these findings can be somewhat expected.

When analyzing the interaction between sex and injury, CMJ (*p* value = 0.02; $\eta^2 = 0.05$) and 30-15 IFT (*p* value =0.001; $\eta^2 = 0.06$) were significant. In females, the average CMJ and 30-15 IFT between non-injured (0.25 m and 17.4 Km/h, respectively) and injured athletes (0.25 m and 17.63 Km/h, respectively) was very similar. However, in males, the average CMJ and 30-15 IFT were greater in non-injured (0.38 m and 19.33 Km/h, respectively) compared to injured athletes (0.30 m and 18.0 Km/h, respectively). These findings indicate that adolescent male athletes with a higher jump capacity and a greater capacity to repeat high-intensity efforts, were less likely to obtain a non-contact injury in the lower extremities. Practically, our data suggest that well-developed physical qualities, such as jump capacity and aerobic fitness, could protect against injury and are in line with previous research relating to enhanced physical qualities (14).These results are related to those obtained by Malone et al. (39) which showed that male Gaelic football players with greater aerobic capacity could protect against spikes in workload. Moreover, Malone et al. (37) demonstrated that well-developed RSA was associated with better tolerance to higher workloads and reduced risk of injury in amateur hurling players.

Although the usefulness of these findings, we recognize some limitations that should be considered relative to the interpretation of the current study results. The etiology of most sports injuries is multifactorial, so there are many risk factors that we have not controlled in this study (i.e. previous injury), not only physical or physiological but also psychological factors. Consequently, multi-variate models be likely more powerful as 'predictors' (17). However physical capacity appears to be a major determinant, which is positive since it is modifiable through well-designed strength and conditioning programs (43). In addition, asymmetries and physical performance are highly variable during the season, therefore longitudinal monitoring should be essential to determine consistency in data (2). Moreover, the use of only adolescents' basketball, volleyball and handball players is a limitation to the generalizability of the findings. Finally, and probably one of the most important limitations of this study, exposure time and training/competition load were not recorded. Current evidence has shown how excessive and rapid increases in training or competition loads can result in a major injury incidence (22). Despite the sample of this study lives, train and study in the same high-performance center (Joaquim Blume Residence), differences in exposure time between injured and uninjured groups may have contributed to the findings.

PRACTICAL APPLICATIONS

The current study reports that injured adolescent team sport players had large vertical jump asymmetries at pre-season in comparison to un-injured players. When time is limited for practitioners, the single leg countermovement vertical jump test may be used to detect asymmetry imbalances (magnitude and direction), with the intention of informing training interventions, in elite youth team-sports players. From a strength perspective, recent research has emphasized that unilateral strength training programs can reduce inter-limb asymmetries (24,36). In addition, the present study shows that jump capacity scores demonstrated a relationship to injury in youth team-sports athletes, indicating that superior physical performance may protect against future injury.

Moreover, a higher intermittent aerobic fitness capacity was associated with less non-contact lower limb injuries in male athletes. These latest findings reaffirm the importance of strength and conditioning programs in reducing injury rate in youth elite team-sports athletes. Practically, our data suggest that well-developed physical qualities, such as jump capacity and aerobic fitness, could protect against injury. However, the etiology of sports injuries is multifactorial, so we should not fall into the error of simplifying it into a single risk factor. Therefore, the interpretation of inter-limb asymmetries and physical performance as injury risk factors should never be done in isolation.

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Table 1. Subject characteristics as total and split by gender.

	Total (*n* = 81)	Males (*n* = 29)	Females (*n* = 52)
Age (years)	15.91 ± 1.12	16.13 ± 1.08	15.78 ± 1.15
Years post-PHV*	2.78 ± 1.76	1.56 ± 2.26	3.48 ± 0.83
Body mass (kg)	69.91 ± 11.71	75.42 ± 13.83	66.84 ± 9.27
Height (m)	1.79 ± 0.20	1.80 ± 0.32	1.78 ± 0.08
BMI ($kg{\cdot}m^{-2}$)	21.26 ± 2.49	21.89 ± 3.03	20.92 ± 2.12
Training experience (years)	6.44 ± 2.70	5.33 ± 3.21	7.02 ± 2.25

* estimation of biological age (Mirwald et al., 2002)

Table 2. Summary of non-contact lower extremity injuries

		Males (*n* = 29)	Females (*n* = 52)	Total (*n* = 81)	p-value
Severity	Slight (0–1 days)	0 (0%)	3 (10.3%)	3 (6.5%)	0.756
	Minimal (2–3 days)	2 (11.8%)	3 (10.3%)	5 (10.9%)	
	Mild (4–7 days)	2 (11.8%)	3 (10.3%)	5 (10.9%)	
	Moderate (8–28 days)	8 (47.1%)	12 (41.4%)	20 (43.5%)	
	Severe (>28 days)	5 (29.4%)	8 (27.6%)	13 (28.3%)	
	Slight (0–1 days)	0 (0%)	3 (10.3%)	3 (6.5%)	
Injury type	Fractures and bone stress	2 (11.8%)	2 (6.9%)	4 (8.7%)	0.332
	Joint (non-bone) and ligament	9 (52.9%)	12(41.4%)	21 (45.7%)	
	Muscle and tendon Muscle	6 (35.3%)	14 (48.3%)	20 (43.5%)	
	Other	0 (0%)	1 (3.4%)	1 (2.2%)	
Side	Bilateral	3 (17.6%)	5 (17.2%)	8 (17.4%)	0.459
	Right	10 (58.8%)	12 (41.3%)	22 (47.9%)	
	Left	4 (23.5%)	12 (41.4%)	16 (34.8%)	
Previous injury (same location)	No	14 (82.4%)	18 (62.1%)	32 (69.6%)	0.149
	Si	3 (17.6%)	11 (37.9%)	14 (30.4%)	
Reinjury level	Delayed recurrence (>12 months)	1 (33.3%)	0 (0%)	1 (9.1%)	0.15
	Early (<2 months)	0 (0%)	3 (37.5%)	3 (27.3%)	
	Late recurrence (2-12 months)	2 (66.7%)	5 (62.5%)	7 (63.6%)	
Injury cause	Overuse	6 (35.3%)	16 (55.2%)	22 (47.8%)	0.195
	Trauma	11 (64.7%)	13 (44.8%)	24 (52.2%)	
Circumstance	Training	16 (94.1%)	20 (69%)	36 (78.3%)	0.046
	Match	1 (5.9%)	9 (31%)	10 (21.7%)	

Table 3. Mean test scores (standard deviations) and within-session reliability data of all test and comparison of injury and non-injury data (ANOVA).

	No Injury		Injury		ICC (95% CI)	CV (%)	p-valor Injury (η^2)	p-value sex (η^2)	p-value sex*injury (η^2)
	Males	Females	Males	Females					
CMJ (m)	0.38 (0.11)	0.25 (0.04)	0.3 (0.04)	0.25 (0.04)	0.94 (0.91-0.94)	3.34	**0.01 (0.06)**	**<0.001 (0.43)**	**0.02 (0.05)**
SLCMJ-HPL (m)	0.19 (0.04)	0.14 (0.03)	0.18 (0.03)	0.14 (0.03)	0.96 (0.93-0.97)	2.54	0.38 (0.00)	**<0.001 (0.37)**	0.22 (0.00)
SLCMJ-LPL (m)	0.17 (0.04)	0.13 (0.02)	0.15 (0.03)	0.12 (0.02)	0.95 (0.93-0.96)	2.70	**0.03 (0.04)**	**<0.001 (0.28)**	0.14 (0.01)
SLCMJ ASI (%)	9.73 (8.34)	7.75 (5.63)	16.98 (13.27)	12.81 (6.22)			**<0.001 (0.08)**	0.14 (0.02)	0.60 (0.00)
OLHT-HPL (m)	1.95 (0.19)	1.54 (0.16)	1.94 (0.12)	1.54 (0.14)	0.89 (0.83-0.93)	2.78	0.91 (0.07)	**<0.001 (0.01)**	0.87 (0.00)
OLHT-LPL (m)	1.85 (0.20)	1.47 (0.15)	1.81 (0.14)	1.44 (0.18)	0.94 (0.88-0.97)	2.75	0.31 (0.06)	**<0.001 (0.43)**	0.93 (0.04)
OLHT ASI (%)	5.06 (3.17)	4.05 (3.44)	6.19 (5.33)	6.59 (7.28)			0.17 (0.03)	0.82 (0.03)	0.82 (0.00)
30-m (sec)	4.32 (0.16)	4.85 (0.36)	4.35 (0.16)	4.83 (0.25)	0.94 (0.87-0.96)	6.34	0.87 (0.01)	**<0.001 (0.01)**	0.67 (0.01)
V-Cut test (sec)	6.72 (0.44)	7.52 (0.37)	6.88 (0.25)	7.53 (0.27)	0.96 (0.94-0.97)	5.12	0.30 (0.02)	**<0.001 (0.54)**	0.35 (0.01)
Mean RSA (sec)	6.03 (0.29)	6.84 (0.62)	6.16 (0.18)	6.7 (0.32)			0.94 (0.01)	**<0.001 (0.44)**	0.17 (0.02)
30-15 IFT (Km/h)	19.33 (1.2)	17.4 (1.1)	18 (1.3)	17.67 (1.1)			0.07 (0.03)	**<0.001 (0.23)**	**<0.001 (0.06)**

CMJ = countermovement jump; SLCMJ= Single leg countermovement jump; OLHT= One leg hop for distance; HPL = highest performing limb; LPL = lowest performing limb; ASI = Asymmetry index; 30-m = 30 meters linear sprint; RSA= repeated sprint ability; 30-15 IFT = 30-15 intermittent fitness test; m = meter; ICC = intraclass correlation coefficient; CI = confidence intervals; CV = coefficient of variation; $\eta 2$ = Eta squared effect size.
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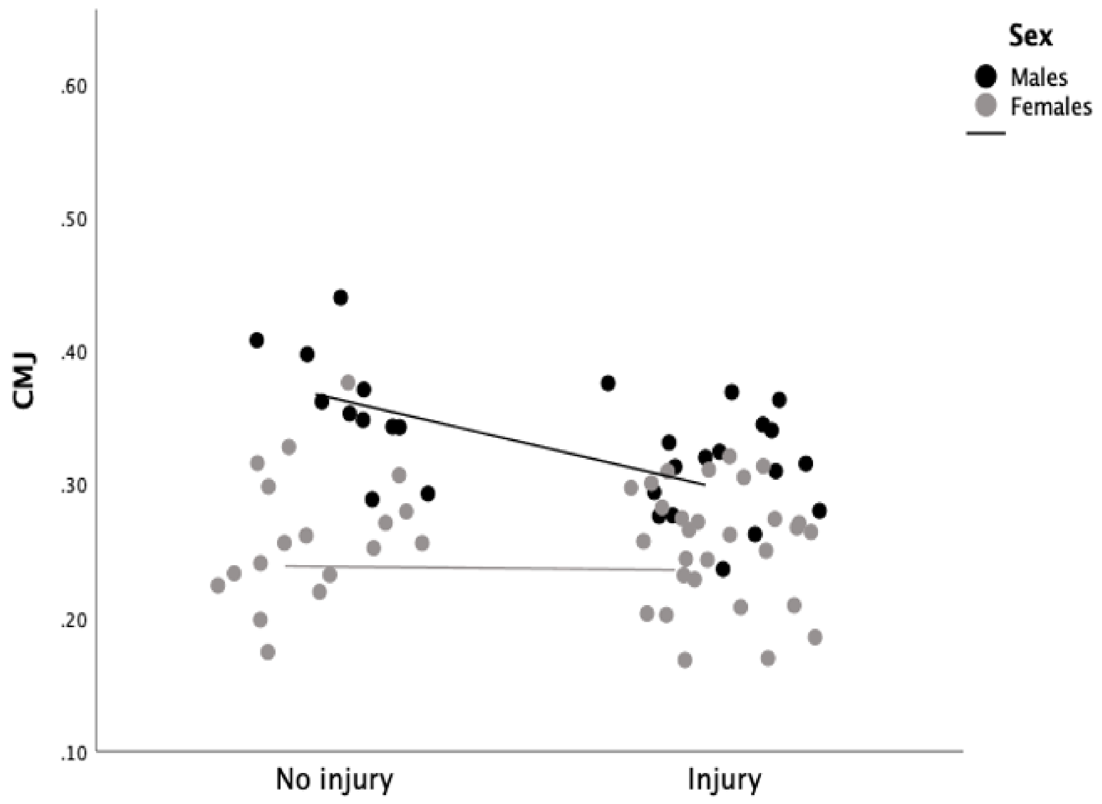

Figure 1. Countermovement jump performance (CMJ) (mean ± standard deviation) according to injury and sex.

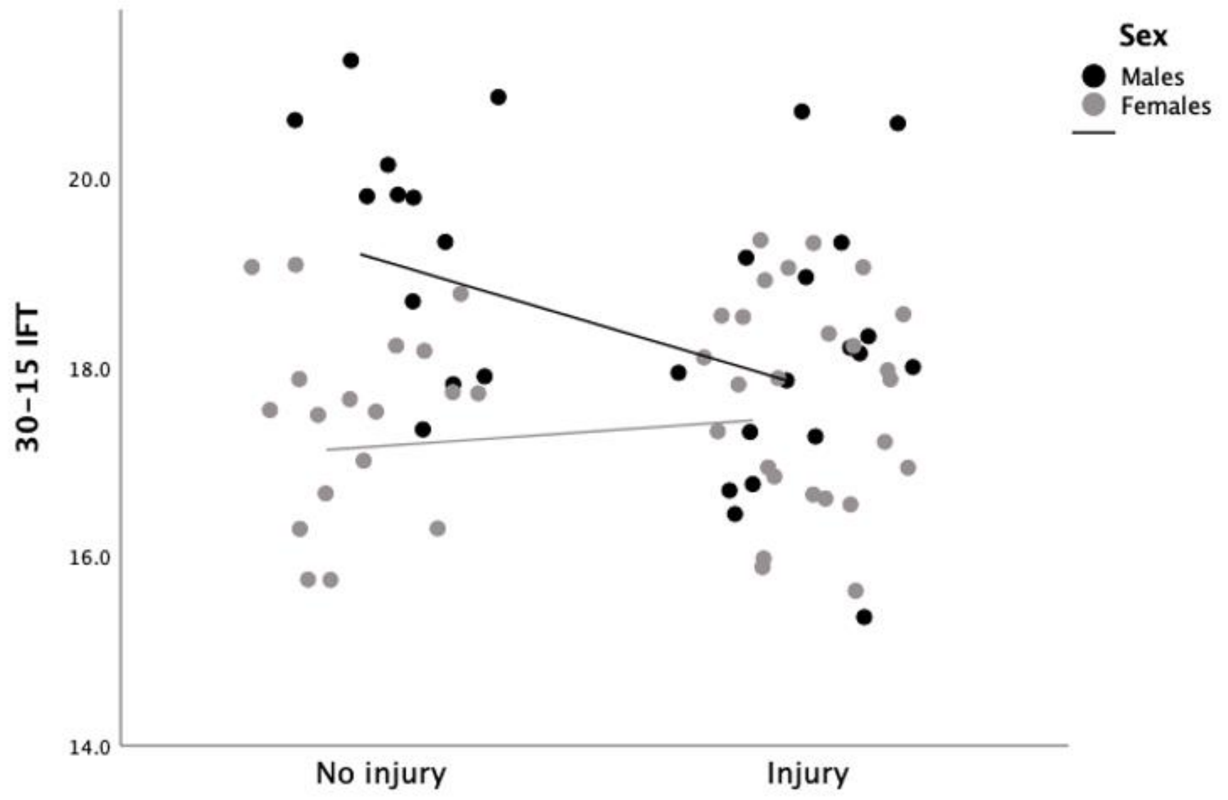

Figure 2. 30-15 intermittent fitness test performance (mean ± standard deviation) according to injury and sex.