Does lower-limb asymmetry increase injury risk in sport? A systematic review.

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ABSTRACT

Objective

The aim of this review was to synthesize the current understanding relating to the risks of lower body functional asymmetry with injury in athletic populations.

Methods:

An iterative data mining and sampling approach was used to construct a search phrase from key words, which were used to identify studies within SPORTdiscus, Medline and Academic Search Complete databases. Additional references were sourced from the reference lists of these articles

Results:

After screening, 31 papers were reviewed, from an initial search identifying 302 possible studies. A total of 6228 participants were involved in the studies, of which soccer players were the most observed sporting demographic (n =2171). Of the 31 studies reviewed eight found no statistical association between lower limb asymmetry and injury risk, 10 studies provided partial statistically significant evidence and a further 10 provided statistically significant statistical links.

Conclusion:

Overall moderate to lower quality evidence for functional asymmetry as a risk factor for injury in sport was observed. While the possibility of a relationship between lower limb functional asymmetry and injury risk cannot be ruled out, further higher quality investigations, adopting standardised methodologies, is required.

Highlights

- Research evidence suggests there is low to moderate level evidence for association between asymmetry and injury
- Within the literature methodological approaches are inconsistent, specifically to the way in which asymmetry data is collected and analyzed
- Methods of analysis do not reflect contemporary understanding of injury aetiology, failing to account for differences in exposure, changes in levels of asymmetry during the observation period, and the presence of and interaction with other injury risk factors. Future studies require improved methodology and statistical analysis to account for these factors.

Keywords

Strength, speed, power, coordination, injury prevention, injury reduction

1. INTRODUCTION

Injuries create a physical, financial and psychological cost to athletes, coaches and sporting organisations. Between limb imbalances, or asymmetry, have been described as one possible internal injury risk factor [1]. Motor control theory [2] suggests that the presence of an asymmetry represents a potential constraint that limits an athletes movement strategies. As a result, athletes may adopt motor behaviours that increase injury risk. Potential mechanisms, for injury, may include athletes performing tasks in an inefficient or dysfunctional manner, causing fatigue or micro-trauma to accumulate. Additionally, the physical constraints may cause the athlete to adopt postures, during performance, that compromise muscle and/or joint health increasing the probability of an injury.

Functional asymmetry can be considered fluctuating [3] in response to environmental stressors and is therefore modifiable. An appealing concept for sports science and medicine practitioners is that modifiable factors can demonstrate prognostic value for the determination of injury risk. In this way, the reduction of injury costs may be achieved through the identification of risk factors, specific to the demands of the sport, and subsequent integration of strategies to mitigate these risks. For these reasons the examination of lower-limb functional asymmetries, in relation to injury risks, is one possible way in which research activity can support the decision-making practices of coaches and sports medicine professionals. To allow for this evidence-informed practice the research evidence should allow practitioners to determine whether the level of risk associated with a particular attribute is acceptable, or requires intervention in order to mitigate that risk [4].

Asymmetry has been investigated both for its effect on injury risk [5, 6] and returning to play from an injury [7, 8]. The presence of asymmetries in participants post injury

has frequently been reported [7, 9-11], leading to the assumption that asymmetry and injury occurrence are causally linked. However, post-injury research designs cannot establish if the observed asymmetry was present prior to injury or played any causative role in the occurrence or severity. A number of prospective research studies have attempted to answer this question, but no comprehensive assessment of the research evidence for functional asymmetry measurements, as indicators of injury risk, has been completed. As such, there is a gap in the research evidence, making it difficult for practitioners to make fully informed decisions regarding interventions to restore functional symmetry. The aim of this review, therefore, is to synthesize the current literature, pertaining to lower limb asymmetries and the risk of lower limb injuries in sporting populations, to aide practitioners in evaluating their athletes.

2. METHODS

2.1 Search Strategy

A literature search, for original articles, was undertaken using SPORTdiscus, Medline and Academic Search Complete databases. An iterative data mining and sampling approach was used to construct a search phrase from key words. The search terms and inclusion and exclusion criteria applied are detailed in Table 1. Articles were screened firstly by title, followed by the abstract and finally the full manuscript. The date of the final search was 12th December 2019. A further search of the reference lists, of the studies found, was conducted and any additional references where added.

Table 1: Summary of the search strategy used with inclusion and exclusion criteria

Search terms	
Asymmetry (“asymmetr*” OR “symmetr*” OR imbalance) AND injury (“Injur*”) AND lower limb (leg OR lower limb OR lower extremity) AND sport (“sport*” OR “athlet*”) AND risk factor or predictor (risk OR factors OR “predict*” OR effect) NOT retrospective (after OR post OR following).	
Inclusion criteria	**Exclusion criteira**
• Included participants who participated in structured, competitive sport. • Participants were between the ages of 13 and 44. • Analysed the risk of injury to the presence and/or magnitude of asymmetry. • Analysed a kinetic, kinematic or task competence asymmetry between limbs, • Full-text in a peer reviewed journal, in English	• Analysed anatomical asymmetries, not a specific task performance. • Analysed limb dominance and/or preference, without measuring the performance of said limbs • If the study was a systematic review or meta-analysis • If the study used participants who were either currently injured or undergoing rehabilitation from a previous injury. • Used a non-sporting sample such as those participants from tactical populations • Did not directly measure the incidence of injury.

2.2 Grouping of findings

Papers were organised based on three main methodological approaches: movement competency, dynamic force production and isolated muscular assessments. Movement competence studies were operationally defined as those methods which required the assessment of range and/or quality of movement, by a trained observer. These tests were not related to physiological parameters such as force and power or constrained by time, for example the functional movement screen (FMS). Studies included within the dynamic force production category, were measures of lower body force production, using multi-joint closed kinetic chain, discrete tasks, which required maximal physical output, for example, single leg jump tasks. The final category, isolated muscular assessments, were studies which used open kinetic chain tasks, such as knee flexion and extension to measure force output of isolated muscle groups in, using such methods as isokinetic dynamometry (IKD).

2.3 Methodological approaches

Studies identified for inclusion in this review adopted one of two methodological approaches:

1. Observational cohort designs - asymmetry levels are determined prior to sports participation, whereafter the occurrence of sports related injury is then observed. Asymmetry levels are then compared between injured and uninjured groups.
2. Clinical prediction rule (CPR) designs – asymmetry levels are determined prior to sports participation, whereafter the occurrence of sports related injury is then observed. Data are used to establish a CPR through receiver operated characteristic (ROC) analysis. This approach provides information on the sensitivity (proportion of true positives correctly identified) and specificity (proportion of true negatives correctly identified) of the prediction rule.

2.4 Statistical significance of asymmetry effects

Studies that demonstrated univariate statistically significant evidence ($p < 0.05$) of an asymmetry effect, in any of the measured variables, as an independent risk factor were designated as 'statistically significant evidence'. Studies where statistical evidence of an asymmetry effect was only demonstrated as part of a multivariate model or only part of the sample investigated, for example in females only, were designated as 'partial statistically significant evidence'. Studies that failed to demonstrate any level statistical significance were designated 'no statistically significant evidence'.

2.5 Practical significance of asymmetry effects

Estimated risk magnitudes resulting from asymmetry are reported for all studies. Researchers have adopted a range of methods for estimating risk magnitudes

including odds ratios (OR), risk ratios (RR), hazard ratios (HR) and positive likelihood ratios (LR+). In order to compare these effects, for studies that reported OR, RR or HR data, relative effect sizes (RES) were classified as small (1.22 < 1.86), moderate (1.86 < 3), large (≥3), according to the guidelines by Olivier et al., [12]. The representation of OR may be misleading dependent on the rarity of an event occurring, typically defined as <10% of the sample suffering and injury [13]. Where the injury incidence (no. of injuries/sample size) is greater than 10% across the studies reviewed, the average OR RES proposed by Olivier et al., [12] will be applied: small (1.32 < 2.38), moderate (2.38 < 4.70), large (≥4.70). All OR, HR or RR values less than 1.22, were classified as trivial.

For studies reporting sensitivity (Sn) and Specificity (Sp) data, without further analysis, these were be converted into LR+ and probability odds, using the estimations reported by McGee [14]. Further to the probability of injury projection, from LR's, small, (<2), moderate, (2 < 5) and large (5<10), adapted from thresholds reported by Dauty, Menu [15] and terminology used by Cohen [16] were applied.

2.6 Assessment of methodological quality

The methodological quality of these studies was assessed using tools designed by the critical appraisal skills program (CASP). The CASP-Cohort checklist and CASP CPR checklist were used for studies using observational cohort or CPR designs respectively. Each criterion within the CASP-Cohort or CASP-CPR checklists were scored in a binary system, indicating where there was clear evidence of a criteria being met (1) or if the evidence was either lacking or ambiguous (0). All studies were independently scored by both MH and JT and consensus regarding each criteria for all studies was agreed. Based on the number of criteria achieved, each study was awarded a percentage score, and classified accordingly: lower quality, <50%,

moderate quality, 50-75%, higher quality >75%. Where studies included elements that met both the cohort and CPR descriptors, they were assessed twice using both checklists. The checklist criteria are stated in supplementary tables 1 (CASP-Cohort) and 2 (CASP-CPR).

3. RESULTS

3.1 Description of study data

Figure 1 depicts the search strategy used within this review. In total 31 studies, investigating 6397 participants, were included for review.

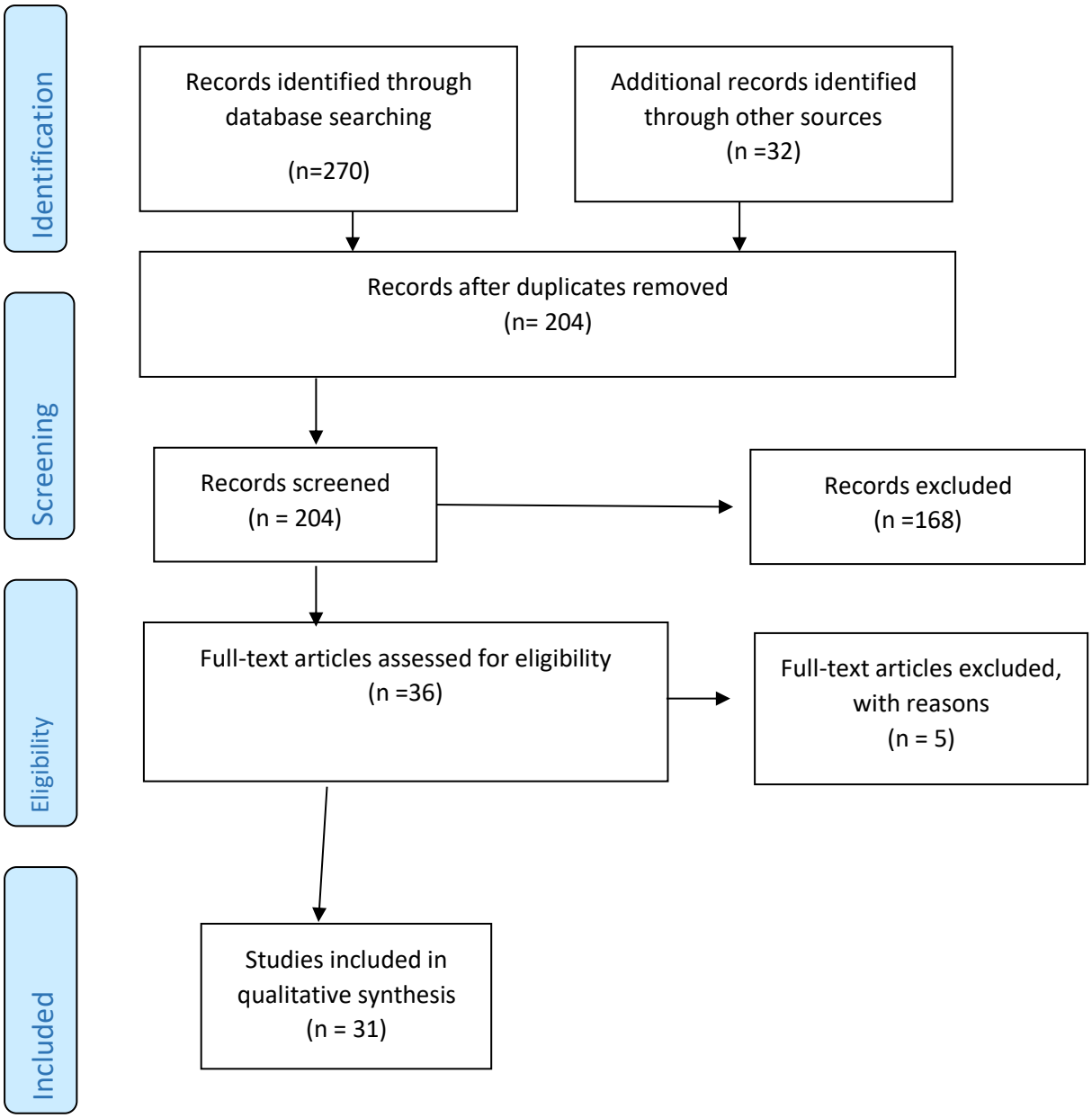

Figure 1: PRISMA flow diagram of the literature search results

3.2 Summary of research evidence quality

A summary of the papers reviewed, including assessments of their statistical and practical significance and methodological quality are presented in tables two and three. Of the 31 studies reviewed, 28 were analysed as cohort studies, from which eight found no evidence, six found partial statistically significant evidence and 14 found

statistically significant evidence of association between lower limb asymmetry and injury risk. Table three displays the 14 papers reviewed as CPR studies, of which seven found statistically significant evidence and the remaining seven showed no statistically significant evidence. The mean quality score was 51.46 ±19 % and 48.50±25 %, for cohort and CPR studies, representing moderate and low-quality research respectively.

In all studies the injury incidence was greater than 10% and therefore not considered a rare event. The application of the average OR classification was applied accordingly.

Table 2: A summary of observational cohort design studies assessing the effect of functional asymmetries on injury risk including statistical effect, effect size and quality assessment using the CASP-Cohort checklist

Asymmetry measure	Authors	Participants (n = sample size, mean age ±1sd)	Methods	Finding	Statistical effect	Effect Size (odds ratio/risk ratio/hazard ratio)	CASP Quality review Score
	Attwood et al., [17]	Male community Rugby Union players, n=277, 24.8±4.4 years,	FMS	Severe injury was 2.3 time more likely in the presence of an asymmetry	Statistically significant evidence	Moderate risk (RR = 2.5)	83%
	Chalmers, Fuller [18]	Male junior AFL players, n=237, 16.6±0.8 years,	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Moderate risk (RR = 1.9)	75%
	Chalmers, Debenedictis [5]	Male junior AFL players, n=277, 16.7 ±0.8 years,	FMS	≥ 1 Asymmetry was not associated with increased injury risk	No evidence	Trivial (HR = 0.7)	75%
	Colston, Wilkerson [19]	Male high school football players, n = 61, 15.4 ± 1.2 years,	U-CMJ Y-balance test (YBT) (anterior reach only)	Asymmetry associated with injury as part of a combined model including horizontal trunk hold and Sport Fitness index	Partial statistical evidence	Moderate (OR = 3.8)	42%
	Duke, Martin [20]	Male amateur Rugby Union players, n=76, 22±3 years ,	FMS	No association between asymmetry and injury risk	No statistical evidence	Trivial	50%
	Gonell, Romero [21]	Male soccer players, n = 74	YBT	Only asymmetry in the posteromedial direction was found to be associated with injury (OR = 3.86), no significant risks were found in either the anterior or posterolateral directions	Statistically significant evidence	Moderate (OR = 3.8)	33%

	Hartley, Hoch [22]	Division II collegiate athletes, Females, n=167; Males, n =384	YBT	No association between asymmetry in each direction and ankle sprains in males. Postero-medial asymmetry was smaller in injured females than uninjured females, no OR or RR data reported	No statistical evidence	No risk	50%
	Kiesel, Butler [23]	Male professional Football players, n=238	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Small risk (RR = 1.8)	42%
	Mokha, Sprague [24]	Division II collegiate athletes, Females, n=81; Males, n =20	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Moderate risk (RR= 2.73)	58%
	Moran et al., [25]	Adult CrossFit participants, n=117, males = 66, females = 51. 35 ± 10 years,	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Moderate risk (RR= 2.62)	67%
	O'Connor, McCaffrey [26]	Male Gaelic Football players, n=570, 17.7± 2.3 years,	Active knee extension test	Asymmetries in flexibility are not associated with injury risk	No evidence	Trivial	58%
	Plisky, Rauh [27]	High school Basketball players, n= 235, males = 130, females = 105	SEBT	Anterior reach asymmetry of ≥ 4cm was associated with greater injury risk.	Statistically significant evidence	Moderate risk (OR = 2.4)	83%
	Räisänen et al., [28]	Youth Soccer players, n= 558, males = 445, females = 113.	Single leg squat	Asymmetry of Frontal plane movement in the knee is not associated with injury risk	No evidence	No risk	25%
	Šiupšinskas et al., [29]	Female Basketball players, n=351	YBT, FMS landing error scoring system (LESS).	No significant differences found between injured or uninjured groups, no odds ratio reported.	No evidence	Trivial	42%

	Smith, Chimera [30]	Division I collegiate athletes, N = 184, Females =82, Males =102	YBT	Asymmetry of ≥4cm in anterior reach scores were associated with injury risk	Statistically significant evidence	Small risk (OR 2.33)	58%
	Stiffler, Bell [31]	Division I collegiate athletes, n=147	SEBT	Significantly greater anterior reach asymmetry in the injured groups. No OR given	Statistically significant evidence	Unclear risk	50%
Dynamic force production tests	Brumitt, Heiderscheit [32]	Division III collegiate athletes, Females 19.1 ± 1.1 years, n=110 Males = 19.5 ± 1.5 years n =83	Single leg hop test	An asymmetry of >10% had a risk of injury in females but not males.	Statistically significant evidence	Small risk in female athletes (OR = 2.3) Male athletes (OR =0.8)	33%
	Brumitt, Mattocks [33]	Female collegiate Volleyball players, n=82, 18.9± 1.0 years.	Single leg hop test	An asymmetry of > 10% alone was not associated with injury risk in female VB athletes	Partial evidence	Moderate risk (RR = 2.1)	42%
	Maulder [34]	Female Netball players, n=24, 21.6±3.2 years	Change of direction test	An asymmetry of >10% was probably likely harmful.	Partial evidence	No risk values were given.	17%
	Read, Oliver [35]	Male youth Soccer players, n= 357	U-CMJ Single leg hop test	Inconsistent asymmetries risk between age groups	Partial evidence	Unclear risk	75%
	Steidl-Müller, Hildebrandt [36]	Alpine Ski racers, females, n=125 males, n =160	U-CMJ	Limb symmetry index was significantly greater in the injured groups. No OR given.	Statistically significant evidence	Unclear risk	75%
Isolated muscular actions	Croisier, Ganteaume [37]	Male professional soccer players, n=462, 26 ± 6 years,	Isokinetic testing	No analysis of inter-limb asymmetry as an individual variable.	Partial evidence	Unclear (multivariate significance)	25%
	Fousekis, Tsepis [38]	Male professional soccer players,	Isokinetic testing	Asymmetries of ≥15% in ankle plantarflexion and dorsiflexion are associated with ankle injury risk	Statistically significant evidence	Large risk (OR =8.88)	33%

		n=100, 23.6±4.2 years					
	Fousekis, Tsepis [39]	Male professional soccer players, n=100, 25.44 ±8.7 years,	Isokinetic testing	Eccentric hamstring strength asymmetry associated with hamstring injury in football	Statistically significant evidence	Moderate risk (OR = 3.8)	58%
	Izovska, Mikic [40]	Male professional soccer players, n=227, 23.6±4.2 years,	Isokinetic testing	No data provided quantifying risk	No evidence	No risk specified	25%
	Knapik, Bauman [41]	Female Collegiate athletes, n=138, 18.9 ±1.2 years,	Isokinetic testing	Players with ≥15% knee flexion asymmetry suffered more injuries	Statistically significant evidence	No risk values were given.	50%
	Opar, Williams [42]	Male AFL players, n=210, 23.3 ±3.7 years,	Nordic exercise	Not associated with hamstring injury risk	No evidence	No risk	75%
	Sugiura, Saito [43]	Male sprinters, 20.2 ±1.3 years, n = 30	Isokinetic testing	Asymmetry not quantified, injuries occurred on the weaker leg, no OR given.	Partial evidence	Unclear risk	42%

Sd = standard deviation, OR = odds ratio, RR = Relative risk, HR = Hazard ratio, FMS = Functional movement screen, U-CMJ = unilateral counter movement jump

Table 3: A summary of observational cohort design studies assessing the effect of functional asymmetries on injury risk including statistical effect, effect size and quality assessment using the CASP-CPR checklist

Asymmetry measure	Authors	Participants	Methods	Injury prediction rule	Statistical effect	Effect Size (Probability)	CASP Quality review Score
[17][17][17]Movement competence tests	Brumitt, Nelson [45]		YBT	Anterior reach asymmetry of ≥ 4cm was associated with greater injury risk.	No evidence	NA	82%
	Butler, Lehr [44]	Female collegiate Volleyball players, 18.9± 1.0 years, n=82.	YBT	Asymmetry was not a predictor of injury	No evidence	NA	18%
	Chalmers, Fuller [18]	Male junior AFL players, 16.6 ±0.8 years, n=237	FMS	≥2 FMS asymmetries	Statistically significant evidence	Moderate probability ≈ 15%, (+ LR = 2.38)	73%
	Chalmers, Debenedictis [5]	Male junior AFL players, 16.7 ±0.8 years, n=277	FMS	≥2 FMS asymmetries	No evidence	Rule not proven	63%
	Colston, Wilkerson [19]	Male high school football players, 15.4 ± 1.2 years, n = 61	Unilateral vertical jump YBT	As individual variables asymmetry in either test was not associated with injury risk	No evidence	Rule not proven	36%
	Duke, Martin [20]	Male amateur Rugby Union players, 22±3 years, n=76.	FMS	No association between asymmetry and injury risk	No evidence	NA	45%
	Kiesel, Butler [23]	Male professional Football players, n=238	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Small probability = <15%, (+ LR = 1.80)	55%
	Mokha, Sprague [24]	Division II collegiate athletes, Females, n=81 Males, n =20	FMS	≥ 1 Asymmetry was associated with increased injury risk	Statistically significant evidence	Small probability = <15%, (+ LR = 1.78)	55%
	O'Connor, McCaffrey [26]	Male Gaelic Football players, 17.7± 2.3 years, n=570	Active knee extension test	Asymmetries in flexibility are not associated with injury risk	No evidence	NA	25%
	Plisky, Rauh [27]	High school Basketball players, n= 235, males = 130, females = 105	SEBT	Anterior reach asymmetry of ≥ 4cm was associated with greater injury risk.	Statistically significant evidence	Probability not given	82%

	Smith, Chimera [30]	Division I collegiate athletes, females, n=82 males, n =102	YBT	Asymmetry of ≥4cm in anterior reach scores were associated with injury risk	Statistically significant evidence	Moderate probability = 15%, (+ LR = 2.05)	73%
	Stiffler, Bell [31]	Division I collegiate athletes, n=147	SEBT	Significantly greater anterior reach asymmetry in the injured groups. No OR given	Statistically significant evidence	Moderate probability = 15%, (+ LR = 2.72)	9%
Dynamic force production tests	Brumitt, Mattocks [33]	Division III collegiate athletes, Females19.1 ± 1.1 years, n=110 Males = 19.5 ± 1.5 years n =83	Single leg hop test	An asymmetry of > 10% alone was not associated with injury risk in female VB athletes	No evidence	NA	18%
Isolated muscular actions	Dauty, Menu [15]	Male professional Soccer players, n=136	Isokinetic testing	≥ 15% asymmetry between hamstring eccentric strength	Statistically significant evidence	Moderate probability ≈ 15%, (+ LR = 2.20)	45%

Sd = standard deviation, OR = odds ratio, RR = Relative risk, HR = Hazard ratio, FMS = Functional movement screen, U-CMJ = unilateral counter movement jump

3.3 Evidence for different methodological approaches.

3.3.1 Test of Movement Competency

Within this category the FMS was the most frequently adopted method of asymmetry measurement, used by eight studies [5, 17, 18, 20, 24, 25, 29]. Three [5, 20, 29] found no evidence, while five displayed statistically significant evidence [17, 18, 23-25] of risk to injury. The associated injury risk with asymmetry, within the papers that displayed significant evidence, ranged from small to moderate. The best evidence for injury risk from FMS asymmetry was Chalmers et al., [18] which was identified as of moderate quality for as both a cohort (75%) and CPR (73%) study, observing a large HR (3.7) and a moderately useful probability (≈15%, LR+ = 2.38) of predicting injury. However, a replication study in a comparable cohort [5] could not verify this association. Further disagreement is evident, within demographic groups, specifically Rugby Union. Attwood et al., [17] observed a very likely harmful, moderate injury risk for asymmetry in the FMS, yet Duke et al., [20] did not find any risk associated to such an imbalance, in community Rugby Union players.

Seven studies used the Y balance test (YBT) [19, 21, 22, 29, 30, 44, 45] and two adopted the star excursion balance test (SEBT) [27, 31]. These tests share some commonality, in that each measure dynamic balance, of each limb, whilst moving either anteriorly, posteromedially or posterolaterally, using the same movements. Within the context of this review, these movements represent the same lower-limb function, further evidenced by the large significant correlations between SEBT and YBT distances reported by Coughlan et al [46]. However, care must be taken to not consider each test as inter-changeable, as the SEBT distances are typically larger than those in the YBT [46-48].

Two studies found statistically significant, moderate risk from asymmetry of ≥ 4cm in the anterior reach test for both the SEBT [27] and the YBT [30]. As outlined by Coughlan et al., [46] and Fullam et al., [48] these CPR's using absolute distances (4cm) taken from different tests cannot be considered of equal asymmetry, given the differences in test measurement performances. Plisky et al, [27], was the only study found to be of higher quality (>75%), doing so in both cohort (83%) and CPR (82%) elements. This study observed a moderate risk (OR = 2.4) of injury in participants with ≥4cm asymmetry in the anterior reach component of the star balance test. This data was supported by the results reported by Smith et al., [30] who also reported a moderate injury risk (OR = 2.33) and a moderate useful probability of ≈15% (LR+ = 2.05), from a paper assessed to be of moderate quality as both a cohort (58%) and CPR (73%) study. However, five studies [19, 29, 31, 44, 45], did not find any statistical association to injury occurrence from anterior reach asymmetry, in either the YBT or SEBT. Each of these studies were graded as being of lower quality (<50%), with the exception of Brumitt et al [45], which was of good quality (82%). Of the remaining two movement tests, evidence of association in the posteromedial direction was reported in two studies [21, 22] and no studies reported any association in the posterolateral direction. The studies which reported posteromedial associations [21, 22] both applied the YBT and were found to be of low quality (>50%).

Other movement competency assessments, including the single leg squat [28] and the active knee extension test [26], showed no statistical evidence of association with injury risk.

3.3.2 Dynamic force production tests

U-CMJ [19, 35, 36] and single leg hop tests [32, 33, 35] were used in three studies each. Unplanned change of direction test [34] and unilateral leg press [36] were used

in one study each. The results of explosive/ballistic performance tests were variable. Among the three U-CMJ studies, statistically significant [36], partial [35], an no statistical evidence [19] was reported by one study each. Of these, Read et al., [49] found that U-CMJ asymmetry was linked to increased risk of injury in some age groups, but not in others, and the OR's identified only represent a small injury risk. The study by Steidl-Muller et al., [36] found a statistically significant association between U-CMJ asymmetry and injury risk in alpine skiers, but did not report an OR and thus the strength of this association cannot be assessed.

For single leg hop tests, no evidence was found in two [35] [33] out of the three studies. The one study that did display statistically significant evidence [32], did so only for female athletes (OR = 4.4 for a >10% asymmetry in single leg hop distance), but for male athletes or the whole sample collectively. The inconsistent findings within these studies, does not provide clear evidence for association between asymmetries in dynamic force production and injury risk

3.3.3 Isolated muscular assessments

Of the eight studies attributed to this category, seven applied IKD methodologies [15, 37-41, 50], where one study [42] measured the eccentric strength of the hamstrings using the Nordic exercise. Six studies [15, 37, 38, 40, 41, 50] assessed knee flexion and extension peak torque, using both eccentric and concentric muscular actions, across a range of angular velocities (30°/s to 300°/s). Five studies specifically reported risk factor assessment for hamstring strains only [15, 37, 38, 42, 50]. Of the seven studies, within this category, only one [39] did not assess forces acting across the knee joint, instead analysed ankle joint forces in relation to ankle sprain risk.

Among the isolated muscular assessment studies, three displayed statistically significant evidence of association with injury risk, two showed partial statistically significant evidence and three showed no evidence. Large risk effects were reported for asymmetry in ankle sprains (OR = 8.88) [39] and moderate risks for hamstring injuries (OR =4.66) [37], (OR =3.88) [38] in adult professional soccer players. The study by Croisier et al., [37], measured seven variables of inter and intra-limb imbalances, whereby an asymmetry in one classified the participant as dysfunctional. However, the specific risks attributed to inter-limb imbalances were not analysed or reported individually. Consequently, it is not possible to deduce, whether between limb asymmetry in knee flexion and/or extension is associated with greater hamstring strain injuries. Fousekis et al., [38] did observe a moderate risk magnitude for asymmetry in knee eccentric strength (OR =3.88) for hamstring injuries. Knapik et al., [41] demonstrated that in female collegiate athletes' asymmetry >15% in knee flexor strength was associated within injury, but estimations of effect size were not provided. The evidence from other studies was inconclusive. the variability in findings and lack of consistent clear evidence does not support a significant association between asymmetry in isolated muscular assessments and injury risk in sporting populations.

DISCUSSION

The aim of this review was to synthesize prior research investigating injury risk in relation to lower-body functional asymmetry to better inform evidence-based practice. The relationship between asymmetry and injury risk could not be conclusively established. However, some studies suggested that this relationship may be present, and thus further investigation of higher quality is required.

Evidence for the association between injury and asymmetry in movement competency tests was equivocal. Ten studies found no statistically significant association to injury

and a further eight did not. Evidence from studies of moderate, or higher quality found significant associations with asymmetries in the FMS and anterior reach in either the YBT or SEBT. These findings showed a moderate to large risk of injury, compared to symmetrical athletes (RR = 1.9 – 3.8). Those papers which did not report a significant association were typically of lower quality (<50%), with the exception of Chalmers et al., [5], which was of moderate quality (75%) and a replication of their previous study [18]. The observation of movement competency asymmetry in the anterior reach test or FMS represents the highest quality evidence for the prediction of lower limb injury among studies included in this review. However, a number of lower quality studies did not replicate these findings, and thus no clear evidence exists relating the measurement of movement competence asymmetry and injury risk.

Analysis of the papers included in both the dynamic force production tests and isolated muscular assessments did not find any consistent themes to support a possible association with injury risk. Only one study [36] of dynamic force production performance asymmetry (unilateral leg press) was able to demonstrate association with traumatic injury in alpine skiers. Of the eight studies to assess the implications of asymmetry in isolated muscular assessments on injury, six demonstrated some evidence of associations between asymmetry and injury. Moderate [38] (OR = 3.8) and large (OR = 8.88) [39] effect sizes were reported for two of these studies, unfortunately the other studies in this category did not report any risk data for comparison. Consequently, of these six studies, three were of considered to be of moderate methodological quality and a further three were of low quality. Based on these mixed results it is difficult to come to a consensus recommendation on the use of any functional asymmetry measures in these categories, to infer injury risk.

Overall, the results of this systematic review provide low to moderate quality evidence for the presence of functional asymmetry as a risk factor for injury in sport. A significant challenge to the interpretation of this body of literature is the broad range of injury definitions, methods of calculating asymmetry and statistical approaches used by researchers in this field. It is unlikely that any level of consensus understanding can be achieved before standardised methodological approaches are adopted and implemented. In the sections below, we review a number of these issues and make recommendations for future studies in this area.

4.1 Definition and quantification of asymmetry

Bishop et al., [51] discussed the varied nature asymmetry calculations within the published research. They demonstrated that using different equations produced variance in the asymmetry values. They further concluded that asymmetry in unilateral and bilateral tests represent different constructs and should be calculated differently. Of the studies examined here, two had adopted the limb symmetry index 1 (LSI-1) [33, 36] and one adopted the percentage difference method (PDM) [35]. The remaining studies either did not state the equation used or reported raw differences in measures. Thus, disagreements in findings, demonstrated by this review, may not be due to a lack of effect, but differences in the way asymmetry was calculated.

4.2 Discretization of asymmetry data

Investigation of athlete asymmetry levels typically leads to categorisation of athletes as either symmetrical or asymmetrical. These categorisations may be helpful for practitioners for planning prehabilitation programs or assessing risk [52] but are unhelpful for the research process of quantifying the effect of asymmetry on injury outcomes. Asymmetry is a continuous variable which ranges in value across athlete populations. Discretizing athletes into groups based on arbitrary asymmetry

categorization points effectively results in a loss of information that may mask the true relationship between variables [53]. A more appropriate method of analysis is to use continuous data to develop injury risk models. Once appropriate models have been developed, thresholds for asymmetry that correspond to different risk levels (e.g., low, moderate, high), based on the continuous model can be provided to coaches and sports medicine practitioners.

4.2 Asymmetry variability and reliability

Asymmetries recorded during gross motor tasks, such as unilateral jumping, have been described as fluctuating [3], lacking correlation between different tests [54] and are highly variable [55]. For example, Bishop et al., [56] observed U-CMJ and unilateral drop jump (U-DJ) asymmetry values across one competitive year (July-May) in elite academy soccer players (n=18). During this period the reliability of asymmetry direction ranged from poor to substantial, for both the U-CMJ (-0.06 to 0.77) and U-DJ (-0.10 to 0.78). None of the studies included in this review reported between day reliability for asymmetry measures, making it difficult to interpret the natural variability in this outcome measure. Future research should quantify and report the reliability of asymmetry in the measures adopted to measure lower limb function.

4.3 Quantification of exposure

Many studies included in this review utilised the occurrence of injury as the outcome measure, but this doesn't account for differences in exposure to training and match play. An improved approach is to measure exposure to sport on a per participant level and then calculate injury incidence (injuries per 1000 hours of exposure) as the outcome measure [57]. More recently, it has been proposed that injury burden – a metric that accounts for both the incidence and severity of injuries – is a more

appropriate assessment of risk for injury studies [58]. Within this review, papers with higher methodological quality have adopted these methods [5, 17].

4.4 Definition of injury

The definitions of injury adopted by studies included in this review are highly variable. Fuller at al., [59] defined and differentiated injuries as medical attention injuries and/or time-loss injuries. Medical attention injuries are those which required the athlete to receive treatment from a sports medicine professional, where time-loss injuries are such that the player is absent for more than one day from any sporting activity. Standardising the classification of injuries across studies, such as adopting the Orchard classification system [60], is important for practitioners to translate and interpret the findings between studies. Greater consistency in the classification and definitions of injury is required, to allow practitioners to synthesize this body of evidence and make more efficacious decisions for injury reduction interventions.

4.5 Analysing injury data appropriately

Contemporary understanding of the nature of sports injury suggests that injury aetiology is both multifactorial [61] and complex [4] in nature, and that risk profiles are continually evolving due to the recursive nature of injury [62]. This presents a number of challenges for injury risk researchers. Firstly, measuring asymmetry at a single time point is problematic because asymmetry levels fluctuate as a result of exposure to environmental demands [45]. Secondly, due to the complex interactions that occur between risk factors, it is inappropriate to assess risk factors independently. Instead, as many known risk factors as possible should be included in any analysis, for example, increased age and prior injury are well established injury risk factors [63-65]. Many of the studies included in this systematic review either did not quantify the additional risk factors or failed to account for these in the analysis. Researchers should

choose statistical approaches that allow for multivariate modelling like Cox proportional hazards models, nested frailty models and generalised estimating equations (Poisson and logistic) to analyse asymmetry injury data [46]. Such an approach informs the understanding of whether the associations between asymmetry and injury observed were the result of the asymmetry itself, or the result of other risk factors thereby avoiding spurious findings.

To apply such statistical approaches a requirement exists for greater sample sizes. It has previously been recommended [57] that in order to detect risk factor associations, of the magnitude frequently described in this study, more than 200 injury cases would be required [47,57]. Few of the studies included in this review had samples sizes of this magnitude, suggesting that even in cases where multivariate approaches were used, these models may have been overfitted [66]. Researchers should engage in sample size estimation prior to data collection in order to ensure that sufficient events are likely to support the type of analysis they intend to use.

A number of studies included in this review attempted to establish whether asymmetry measures could be used to forecast injuries through the establishment of clinical prediction rules (CPR). A requirement for predictive modelling is that once a CPR has been established the utility of that rule should be tested on an unseen data set to establish its prognostic ability [67] .Unfortunately, of the 14 CPR studies examined in this systematic review, only three attempted to validate newly established CPR's in an unseen population [5, 27, 45], As such, there can be very little confidence that these unvalidated 'predictors' are applicable in populations other than the one in which they were originally derived.

5. CONCLUSIONS

The evidence substantiating lower limb functional asymmetry as a risk factor for sporting injuries is moderate to low quality. Of this evidence, measures were consistently found to be statistically associated with injury risk, across different sporting populations. This field of research is constrained by a high degree of variance in methodological approaches and quality. Practitioners should be mindful of these observations before implementing athletic interventions. It has been identified that further research is required that adopts key recommendations specifically addressing key points: standardised definitions of injury, quantification of asymmetry and adoption of a multivariate approach, encapsulating exposure among other variables, within a sufficient sample size. Without such research no clear outcome is apparent to accept or reject functional lower limb asymmetry as a risk to sporting participation.

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