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Literature Review

The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review

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Abstract

Objective

To systematically review literature investigating the relationship between hip muscle strength and dynamic lower extremity valgus during movement tasks in asymptomatic females.

Methods

Four databases (CINAHL, SPORTDiscus, Embase and Ovid MEDLINE) were searched in February 2017. Studies investigating the relationship between hip muscle strength and dynamic knee or lower extremity valgus during movement tasks among asymptomatic females over 18 years old were included. Meta-analyses were performed where two or more studies used similar tasks.

Results

Five studies reported no relationship between hip strength and dynamic lower extremity valgus. Greater peak lower extremity valgus was associated with reduced hip strength in eight studies, and greater hip strength in three studies. In the meta-analysis, a relationship between weaker hip strength and greater dynamic lower extremity valgus was found for ballistic single leg landing, but not double leg landing or single leg squat tasks.

Conclusions

Although the relationship between hip strength and dynamic lower extremity valgus is conflicting, meta-analysis revealed lower extremity dynamic valgus was consistently associated with hip strength in single leg ballistic tasks, but not double leg ballistic or single leg squat tasks. The relationship between hip strength and dynamic lower extremity valgus may be conditional to task demand.

Keywords: Biomechanics; D~~d~~ynamic knee valgus; H~~h~~ip strength; D~~d~~ynamic lower extremity valgus

1 Introduction

Lower extremity valgus, also referred to as knee valgus in other literature, is a combination of hip adduction and internal rotation, knee abduction and internal rotation of the tibia (Krosshaug et al., 2007). Excessive lower extremity valgus during dynamic activities (e.g. landing, running) has been linked with the development of lower extremity injuries such as patellofemoral pain (Myer et al., 2010; Noehren, Pohl, Sanchez, Cunningham, & Lattermann, 2012; Stefanyshyn, Stergiou, Lun, Meeuwisse, & Worobets, 2006) and anterior cruciate ligament (ACL) injuries (Hewett et al., 2005).

The hip provides bony stability as the proximal articulation for the lower extremity, but it is dependent on a complex interaction of muscles to provide dynamic stability during motion. In the loading phase of walking, running or landing, external moments acting on the hip create flexion, adduction, and internal rotation moments that is recognized as lower extremity valgus (Powers, 2010). These moments are resisted by internal moments created by the eccentric actions of the hip extensors, abductors, and external rotators (Simoneau, 2002). Impaired force production of these muscles may increase the range of hip adduction and internal rotation during weight bearing motion, potentially affecting the kinematics of the entire lower extremity (Powers, 2010).

A substantial body of research has investigated the relationship between hip muscle strength, lower limb kinematics and how this relates to injury. Some studies have concluded that decreased hip abductor and external rotator strength is a risk factor for patellofemoral pain (Chumanov, Wall-Scheffler, & Heiderscheit, 2008) and ACL injury (Ramskov, Barton, Nielsen, & Rasmussen, 2015). Others have argued that hip muscle weakness is more likely to follow rather than to precede injury (Khayambashi, Ghoddosi, Straub, & Powers, 2016). It also is possible that reduced hip muscle strength may be a risk factor for lower limb injury independent of kinematics (Rathleff, Rathleff, Crossley, & Barton, 2014).

A prior systematic review by Cashman, (2012) (Crossley et al., 2016) has investigated the relationship between hip muscle strength and dynamic lower extremity valgus. The authors reported limited evidence for a relationship between weaker hip strength and dynamic lower extremity valgus. However, there has not been a review that focuses on females. Based on the higher propensity for greater dynamic lower extremity valgus in females (Cashman, 2012), and a higher occurrence of ACL (Joseph et al., 2011) and other lower extremity injuries (Agel, Rockwood, & Klossner, 2016; Franettovich-Smith, Honeywill, Wyndow, Crossley, & Creaby, 2014) than males, further analysis specific to females is justified. Further, the review of Cashman et al. (2012) did not investigate whether the task or strength measures investigated influenced the relationship between hip strength and dynamic lower extremity valgus. The higher the demand of the activity performed, the greater the eccentric forces required to control peak frontal and transverse plane angles and joint excursions (Grimaldi et al., 2015). This potentially affects the validity of comparison between the findings of research that uses different kinematic assessment tasks. Finally, new studies have been published since the Cashman, (2012) review.

The aim of this systematic review was to synthesize current evidence investigating the relationship between hip strength (extensor, abductor or external rotator) and lower extremity valgus during dynamic tasks among asymptomatic females. A secondary aim was to investigate whether the strength measures or tasks assessed influenced the relationship between hip strength and dynamic lower extremity valgus.

2 Methods

2.1 Eligibility criteria

Peer-reviewed studies were included if they investigated the relationship between hip strength and dynamic knee or lower extremity valgus in healthy females over 18 years old. Studies including men were considered if the outcomes of interest were reported for the females separately. Studies were excluded if they were not written in English, included only injured participants, made comparison of specific athletic populations and non-athletic groups or used artificial means to bring about muscle fatigue and inhibit muscles prior to testing (e.g. saline injection).

2.2 Types of outcome measures

All included studies were required to report measures of hip strength and dynamic lower extremity valgus. Hip strength was defined as isometric, isokinetic or isotonic strength measured using reliable methods (reported reliability or a reference to a reliability study). Biomechanical measures included kinematics (peak angles) related to dynamic lower extremity valgus (i.e. any combination of hip adduction/internal rotation, knee abduction and tibial internal rotation) measured using 3D video analysis.

2.3 Search methods for identification of studies

2.3.1 Electronic search

CINAHL (1981–2017); SPORTDiscus (1985–2017); Embase (1974–2017 Week 07); Ovid MEDLINE (1946–February Week 1 2017) and reference lists of articles and relevant related systematic reviews were searched (Fig. 1). The search was updated August 2017. Comprehensive search terms based on a PICO strategy were defined, incorporating appropriate Boolean Operators and relevant database specific subject headings. The MEDLINE search strategy example is shown in Appendix 1.

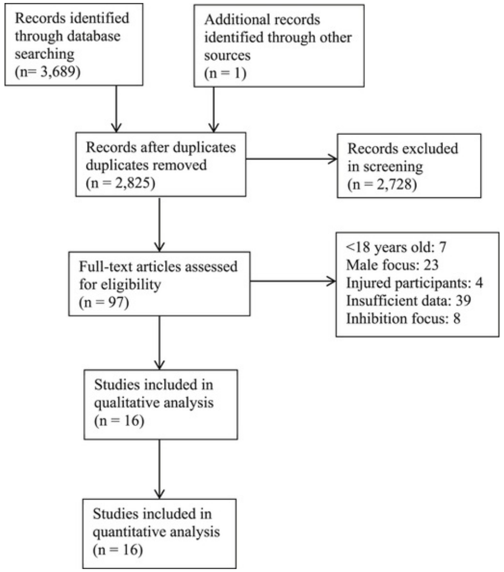

Fig. 1 Flow chart describing search yield (Moher, Liberati, Tetzlaff, & Altman, 2009).

alt-text: Fig. 1

2.4 Data collection process

2.4.1 Selection of studies

One author (SM) screened titles and abstracts of the final yield and excluded those obviously not appropriate for inclusion. Two authors (JD, SM) then independently reviewed the titles, abstracts, and full texts of each of the remaining articles, screening for inclusion. Any disagreement was resolved by discussion and a third reviewer (PM) was available when consensus could not be reached(see Table 1).

Table 1 Quality ratings of included studies using modified version of the Joanna Briggs Institute checklist for cohort studies (Joanna Briggs Institute., 2015) (Appendix 2).

alt-text: Table 1

Quality Rating (0–7)	No. of studies (total = 16)	Studies
5	6	Malloy, Morgan, Meinerz, Geiser, and Kipp (2016), Nilstad, Krosshaug, Mok, Bahr, and Andersen (2015), McCurdy, Walker, Armstrong, and Langford (2014), Bandholm et al. (2011), Lawrence, Kernozek, Miller, Torry, and Reuteman (2008), Jacobs and Mattacola (2005)
4	4	Baggaley et al. (2015), Suzuki, Omori, Uematsu, Nishino, and Endo (2015), Hollman, Hohl, Kraft, Strauss, and Traver (2013), Baldon et al. (2011)
3	4	Stickler, Finley, and Gulgin (2015), Hollman, Galardi, Lin, Voth, and Whitmarsh (2014), Munkh-Erdene, Sakamoto, Nakazawa, Aoyagi, and Kasuyama (2011), Heinert et al. (2008)
2	1	Hollman et al. (2009)
1	1	Smith et al. (2014)

2.4.2 Data extraction

Two authors (JD, SM) extracted relevant data in relation to trial characteristics (including first author name, year of publication and type of trial), participant characteristics (including age, gender and current level of sport or athletic participation), the kinematic variables of interest, and the strength measures of interest using a pre-determined data extraction form (Appendix 3). Review authors were not blinded to author(s), institution or title of the studies (see Table 2).

Table 2 Sources of possible increased risk of bias within included studies according to modified version of the Joanna Briggs Institute checklist for cohort studies (Joanna Briggs Institute., 2015) (Appendix 2).

alt-text: Table 2

Study deficiency increasing risk of bias	No. of included studies with deficiency (out of 16)	% of included studies with deficiency
Similar subjects	7	44%
Exposure measured	0	0
Valid exposure measured	14	89%
Confounders identified	4	25%
Confounders minimized	16	100%
Valid outcome measure	8	50%
Statistics analyzed	2	12.5%

2.4.3 Assessment of risk of bias in included studies

Quality of included studies was assessed using the Joanna Briggs Institute checklist for cohort studies (Joanna Briggs Institute., 2015) (Appendix 2). Each of the 11 items was scored as "Yes", "No", "Not applicable" or "Unclear". As the included studies were all a cross-sectional, four questions relating to prospective study designs (rules 6, 8, 9 and 10) were removed. A quality score out of seven was generated by assigning a score of one for each 'yes' received. Two of the authors (JD, SM) independently assessed study quality (Table 3). Disagreements were resolved by discussion and consultation of a third reviewer (PM) if required.

Table 3 Study characteristics.

alt-text: Table 3

Author, year	Study design	Population (age, weight, athletic level)	Strength measure (Hand held dynamometry & isometric testing unless otherwise stated)	Kinematic measure
Malloy et al., 2016	Cohort Quality score: 5/7	19 (18–22), 61 kg (Heinert et al., 2008), collegiate soccer players	Abduction; Side-lying with hip in neutral in both planes. Dynamometer placed 1 inch proximal to lateral epicondyle of the femur. External Rotation; Sitting with hip and knee in 90° flexion. Dynamometer placed 1 inch proximal to the ankle medial malleolus.	3D kinematics of frontal plane movement during unanticipated single leg landing & cutting tasks.
Baggaley et al., 2015	Cohort Quality score: 4/7	29 (23–35), 62 kg (McCurdy et al., 2014), recreational runners	Abduction; Side-lying with hip in neutral in both planes. Dynamometer 5 cm above the knee joint.	3D kinematic analysis of treadmill running (6.2 km/h).
Nilstad et al., 2015	Cross sectional laboratory study Quality score: 5/7	21 (Heinert et al., 2008), 63 kg (Hollman et al., 2009), elite soccer players	Abduction; Supine with hip in neutral in both planes. Dynamometer proximal to the ankle lateral malleolus.	3D kinematic analysis of double leg drop jump (30 cm) into double leg max vertical jump.
Stickler et al., 2015	Cross sectional laboratory study Quality score: 3/7	18-30, 60 kg (Baldon et al., 2011), unspecified athletic experience	Abduction; Side-lying with hip in neutral in both planes. Belt restrained dynamometer 5 cm proximal to ankle lateral malleolus. External Rotation; Sitting with hip and knee in 90° flexion. Belt restrained dynamometer 5 cm proximal to ankle medial malleolus. Extension; Prone with hip neutral. Belt restrained dynamometer 5 cm proximal to knee joint line.	3D kinematic analysis of frontal plane movement on single leg squat to 60°.
Suzuki et al., 2015	Cohort Quality score: 4/7	20, (0.8), 58 kg (Hollman et al., 2009), intercollegiate basketball players	Extension; Prone with hip in neutral. Dynamometer placed 5 cm proximal to knee joint line. Abduction; Side-lying with hip in neutral in both planes. Dynamometer placed 5 cm proximal to ankle lateral malleolus. External rotation (sitting); Sitting with hip and knee in 90° flexion. External rotation (prone); Prone with hip in neutral. Dynamometer placed 5 cm proximal to ankle medial malleolus for both External rotation tests.	3D kinematic analysis of single leg drop landing from 20 cm.

Hollman et al., 2014	Cohort Quality score: 3/7	Weak Group: 23.4 (3.5), 61.3 kg (8.2), unspecified athletic experience Strong Group: 24.4, 61.3 kg (9.6), unspecified athletic experience	Extension; Prone with hip in neutral. Abduction; Side-lying with hip in neutral in both planes. Dynamometer stabilized above knee with a strapping belt for both tests.	3D kinematic analysis of single leg squats down off 20 cm box (5 repetitions); EMG of Gluteus Maximus & Gluteus Medius to measure recruitment stated as peak activation and noted as a percentage of maximal voluntary isometric contraction.
McCurdy et al., 2014	Cohort Quality score: 5/7	20.9 (0.7), 6.9 kg (7.1), previous high school athletics	Extension; Prone with hip in neutral. Dynamometer 2 cm proximal to popliteal crease. Abduction; Side-lying with hip in neutral in both planes. Dynamometer on proximal thigh. External rotation; Sitting with hip and knee flexed to 90°. Dynamometer at ankle medial malleolus.	3D kinematic analysis of double leg (60 cm) & single leg (30 cm) drop jumps into a maximum vertical jump (3 repetitions).
Smith et al., 2014	Cross sectional laboratory study Quality score: 1/7	Weak Group: 23.4 (3.5), 61.2 kg (6.5), unspecified athletic experience Strong Group: 24.1 (3.3), 58.6 kg (5.3), unspecified athletic experience	Abduction; Side-lying with hip in neutral in both planes. Dynamometer placement not stated. Extension; Prone with hip flexed to 30° Dynamometer placement not stated.	3D kinematic analysis of walking at self-selected speed & hopping at 100 hops/minute.
Hollman et al., 2013	Exploratory Quality score: 4/7	18-36, 63 kg (8.5), physically active at any level	Extension; Prone with hip in neutral in both planes. Dynamometer at distal thigh.	3D kinematic analysis of 3 repetitions of a max vertical jump; EMG of gluteus maximus to measure corticospinal excitability.
Baldon et al., 2011	Correlation study Quality score: 4/7	20.5 (1.7), 57.8 kg (10.1), recreationally active	Abduction; Eccentric testing in side-lying with hip in sagittal plane neutral and measured from 30° abduction to neutral. Isokinetic dynamometer used with lever arm attached to lateral thigh 5 cm above base of the patella. Angular speed 30°/sec. External rotation; Eccentric testing in sitting with hips and knees flexed to 90° and measured from 10° Internal rotation to 20° External rotation. Isokinetic dynamometer used with lever arm attached 5 cm above the ankle lateral malleolus. Angular speed 30°/sec.	3D kinematic analysis of single leg squat to 75° of knee flexion.
Bandholm et al., 2011	Cross sectional correlation study Quality score: 5/7	22.4 (2.5), 63 kg (7.7), recreationally active	Abduction; Supine with hip neutral in both planes. Dynamometer at ankle lateral malleolus. External rotation; Sitting with hip and knee flexed to 90°. Dynamometer at ankle medial malleolus.	3D kinematic analysis of double leg drop from 45 cm platform onto force plate then double leg maximum vertical jump.
Munkh-Erdene et al., 2011	Cohort Quality score: 3/7	20.9 (0.7), 54.4 kg (6.7), unspecified athletic experience	Abduction; Supine with no details on joint positioning. Dynamometer with no details on placement. External rotation; Sitting with no details on joint position. Dynamometry with no details on placement.	3D kinematic analysis of single leg squat to 60° knee flexion & a drop landing from 30 cm.
Hollman et al., 2009	Exploratory Quality score: 2/7	24 (2.6), 66.4 kg (Lawrence et al., 2008), recreationally active	Abduction; Side-lying with hip in “slight extension” and 30° Abduction. Dynamometer held just proximal to greater trochanter of femur. External rotation; Sitting with hip and knee in flexion and hip externally rotated to 30°. Dynamometer held just proximal to ankle medial malleolus.	3D kinematic analysis of single leg steps down off a small step (2 s descent).
Heinert et al., 2008	Observational prospective Quality score: 3/7	Weak Group: 23.4 (Bandholm et al., 2011), 69 kg (Munkh-Erdene et al., 2011), recreational athletes Strong Group: 25.8 (Hollman et al., 2009), 59.2 kg (Hollman et al., 2013), recreational athletes	Abduction; Side-lying with hip in 20° Abduction and neutral in sagittal plane. Dynamometer placed 5 cm proximal to the knee joint line.	3D kinematic analysis of treadmill running at 6.5–11.5 km/h.
Lawrence et al., 2008	Observational perspective Quality score: 5/7	Weak Group: 20.4 (2.1), 61.7 kg (11.7), unspecified athletic experience Strong Group: 22.9 (2.6),	Abduction; no details stated on positioning of subject, joints or dynamometer. External Rotation; no details stated on positioning of subject, joints or dynamometer.	3D kinematic analysis of single leg drop landings from 40 cm.

		63.9 kg (Jacobs & Mattacola, 2005), unspecified athletic experience		
Jacobs & Mattacola 2005	Cross sectional study Quality score: 5/7	2.1 (2.3), 64.0 kg (8.6), recreationally active	Abduction; Eccentric testing in standing with hip in sagittal plane neutral and measured from 30° abduction to 5° adduction. Isokinetic dynamometer used with lever arm attached to lateral thigh 5 cm above base of the patella. Angular speed 120°/sec. Isokinetic dynamometer used. No position of pad stated but appears to be mid-thigh in photograph.	3D kinematic analysis of hopping horizontal distance (45% of subject's height) over a 10 cm high wooden obstacle & holding the horizontal landing.

2.4.4 Measures of a relationship between strength and peak lower extremity valgus

Correlation coefficients for the relationship between strength and dynamic lower extremity valgus were extracted where possible. Study authors were contacted (twice over four weeks) via email in any instances of missing data. If they did not respond, we imputed standardized Beta coefficients were available (Peterson & Brown, 2005), otherwise study findings were synthesized qualitatively(see Table 4).

Table 4 Relationship between strength and kinematics.

alt-text: Table 4

Author, year	Population (n)	Strength measure	Kinematic measure	Relationship
Malloy et al., 2016	23	Abduction External rotation	Unanticipated single leg landing and cutting tasks	Statistically insignificant correlation ($r = 0.04$, $p = 0.85$) Statistically insignificant correlation ($r = 0.15$, $p = 0.32$)
Baggaley et al., 2015	25	Abduction	Treadmill running (6.2 km/h)	Statistically insignificant correlation ($r = -0.16$, $p = 0.44$)
Nilstad et al., 2015	279	Abduction	Drop jump (30 cm) into double leg max vertical jump	Statistically insignificant correlation ($\beta = -14.59$, p - 0.9)
Stickler et al., 2015	40	Abduction External rotation Extension	Single leg squat to 60°	Moderate positive correlation ($r = 0.47$, $p = 0.002$) Moderate positive correlation ($r = 0.46$, $p = 0.003$) Moderate positive correlation ($r = 0.40$, $p = 0.01$)
Suzuki et al., 2015	36	Abduction External rotation Extension	Single leg drop landing from 20 cm	Moderate negative correlation ($r = -0.46$, $p = 0.03$) Statistically insignificant correlation ($r = -0.27$, $p = 0.21$) Moderate negative correlation ($r = -0.48$, $p = 0.02$)
Hollman et al., 2014	Weak Group: 20 Strong Group: 21	Abduction Extension	Single leg squats (5 repetitions) down from a 20 cm box	Statistically insignificant correlation ($r = -0.17$, $p = 0.10$) Statistically insignificant correlation ($r = -0.01$, $p = 0.32$)
McCurdy et al., 2014	26	Abduction External rotation Extension	Double leg (60 cm) & single leg (30 cm) drop jumps into max vertical jump	Double leg drop jump: Moderate negative correlation ($r = -0.42$, $p \leq 0.05$) Single leg drop jump: Statistically insignificant correlation ($r = -0.32$, $p > 0.05$) Double leg drop jump: Strong negative correlation ($r = -0.61$, $p = 0.05$) Single leg drop jump: Strong negative correlation ($r = -0.58$, $p \leq 0.05$) Double leg drop jump: Statistically insignificant correlation ($r = -0.38$, $p > 0.05$) Single leg drop jump: Statistically insignificant correlation ($r = -0.25$, $p > 0.05$)
Smith et al., 2014	Weak Group: 9 Strong Group: 10	Abduction Extension	Walking at self-selected & hopping at speed of 100 hops/minute	No significant correlation (no r value provided)
Hollman et al., 2013	40	Extension	3 repetitions of a max vertical jump	Weak positive correlation ($r = 0.22$, $p = 0.001$)
Baldon et al., 2011	16	Abduction	Single leg squat to 75° knee flexion	Strong positive correlation ($r = 0.61$, $p = 0.01$)

		External rotation		Statistically insignificant correlation (r = —-0.07, p = 0.78)
Bandholm et al., 2011	33	Abduction External rotation	Double leg drop from 45 cm platform into double leg max vertical jump	Statistically insignificant correlation (r = 0.18, p = 0.31) Moderate positive correlation (r = 0.48, p = 0.005)
Munkh-Erdene et al., 2011	12	Abduction External rotation	Single leg squat to 60° knee flexion & drop landing from 30 cm	Single leg squatting: Statistically insignificant correlation (r = —-0.6, p = 0.85) Drop landing: Statistically insignificant correlation (r = 0.1, p = 0.75) Single leg squat: Strong negative correlation (r = —-0.69, p = 0.013) Drop landing: Moderate negative correlation (r = —-0.59, p = 0.04)
Hollman et al., 2009	20	Abduction External rotation	Single leg step down off a small step	Moderate positive correlation (r = 0.46, p = 0.05) Very weak positive correlation (r = 0.12, p = 0.05)
Heinert et al., 2008	Weak Group: 15 Strong Group: 15	Abduction	Treadmill running at 6.5–11.5 km/h	Statistically significant correlation in favor of a negative relationship (p = 0.03)
Lawrence et al., 2008	Weak Group: 16 Strong Group: 16	Abduction External rotation	Single leg drop landings from 40 cm	Statistically insignificant correlation (p = 0.82) Moderate negative correlation (r = —-0.47, p = 0.005)
Jacobs & Mattacola, 2005	10	Abduction	Hopping horizontally over 10 cm high wooden obstacle & holding the landing	Strong negative correlation (r = —-0.61, p = 0.03)

2.4.5 Data synthesis

Meta-analysis was performed with Cochrane Collaboration statistical software, Review Manager 5.3, (RevMan, 2014). We only pooled data among studies with similar characteristics. This included very similar tasks (e.g. single leg squat tasks). Only strength outcomes from the same planes (hip abduction, extension or external rotation were pooled). Two studies used treadmill running to assess kinematics. We decided against a meta-analysis of these studies as very slow running pace was used in one study (6.2 kph) (Baggaley, Noehren, Clasey, Shapiro, & Pohl, 2015) and self-selected running pace that varied (6.5–11.5 kph) between subjects was used in the other (Heinert, Kernozek, Greany, & Fater, 2008). As kinematics change with speed (Brughelli, Cronin, & Chaouachi, 2011), these studies were not considered sufficiently homogeneous.

A random effects model was chosen a priori for all analyses given clinical and methodological heterogeneity are likely to exist and may impact model findings. Where data could not be pooled we reported effect estimates and 95% confidence intervals and summarized study findings descriptively. Effect sizes calculated from correlation coefficients were classified 0.1 as being small, 0.3 as medium and 0.5 as large (Cohen, 1988).

Assessment of statistical heterogeneity was based on Chi-square statistic and the I2 statistic (Higgins & Thompson, 2002). For the I2 statistic, we interpreted statistical heterogeneity as not important (<50%), moderate (50–75%) and high (>75%) (Higgins & Thompson, 2002).

3 Results

3.1 Results of the search

A total of 3689 records were retrieved through individual searches of CINAHL (1,319), SportDiscus (788), MEDLINE (655) and EMBASE (927). After duplicates were removed, 2824 results remained, of which titles and abstracts were screened. A further study was identified by searching the reference lists of relevant studies of which the authors had knowledge, bringing the total number of studies to 2825. After screening titles and abstracts, the full text of 98 papers was assessed and 18 studies were included in the final yield (Fig. 1).

3.2 Risk of bias in individual studies

Additionally, most studies used hand held dynamometry (HHD) to measure strength used a support strap to help resist the participant's force, but one study (Suzuki et al., 2015) did not. While probably not a source of bias, not using a strap affects control of the device and potentially affects the accuracy of results (Katoh & Yamasaki, 2009).

3.3 Characteristics of included studies

Appendix 3 provides the characteristics of the included studies. All studies used a cross sectional design. All studies measured hip strength (abduction, external rotation and/or extension), assessed hip and knee kinematics and then statistically analyzed the relationship between lower extremity valgus kinematics during a dynamic task and hip strength. All studies included in this review used isokinetic or HHD to assess muscle strength, both of which have high reliability in testing hip strength (Gerodimos et al., 2015; Thorborg, Petersen, Magnusson, & Hölmich, 2010). All studies used 3-dimensional (3D) motion analysis systems to record task performance and used kinematic analysis software to measure kinematics, which have been shown to be reliable methods of recording frontal plane and knee valgus movement in double leg (Malfait et al., 2014; McLean et al., 2005) and single leg (Sorenson, Kernozek, Willson, Ragan, & Hove, 2015) landings.

3.4 Participant characteristics

Most studies included asymptomatic, active females between 18 and 36 years old. Four of 18 studies grouped participants based on ‘strong’ or ‘weak’ hip strength (Heinert et al., 2008; Hollman et al., 2014; Lawrence et al., 2008; Smith et al., 2014). Most studies included recreationally active females whereas three studies investigated elite level athletes (Malloy et al., 2016; Nilstad et al., 2015; Suzuki et al., 2015). Sample sizes varied from small underpowered samples such as n = 10 (Jacobs & Mattacola, 2005) to larger cohort studies such as n = 279 (Nilstad et al., 2015).

3.5 Relationship between hip strength and dynamic lower extremity valgus

Of the 16 studies reviewed, 5 studies (Baggaley et al., 2015; Hollman et al., 2014; Malloy et al., 2016; Nilstad et al., 2015; Smith et al., 2014) found no relationship between any hip strength measurement and dynamic peak lower extremity valgus. The remaining 11 studies found some relationship.

3.5.1 Hip abduction strength and dynamic peak lower extremity valgus

There was conflicting evidence from fifteen studies that investigated the relationship between hip abductor strength and dynamic lower extremity valgus. Six studies found weaker hip abduction strength was associated with greater dynamic lower extremity valgus (Baldon et al., 2011; Heinert et al., 2008; Jacobs & Mattacola, 2005; McCurdy et al., 2014; Stickler et al., 2015; Suzuki et al., 2015). Two studies assessed eccentric strength (Baldon et al., 2011; Jacobs & Mattacola, 2005), four assessed kinematics with single leg ballistic loading tasks and two used double leg squats. One study reported greater hip strength was associated with greater dynamic lower extremity valgus (Hollman et al., 2009). This study (Hollman et al., 2009) investigated kinematics during a task with a relatively low level of demand (single leg step down from 15 cm step). Eight studies reported no significant correlation between the two variables (Baggaley et al., 2015; Bandholm et al., 2011; Hollman et al., 2014; Lawrence et al., 2008; Malloy et al., 2016; Munkh-Erdene et al., 2011; Nilstad et al., 2015; Smith et al., 2014), including one that did not report a statistical relationship (Smith et al., 2014). Three of these studies used single leg ballistic tasks to measure kinematics, one used double leg drop into vertical jump, one used single leg squat, one used slow jogging and one used both walking at self-selected speed and rapid hopping (100 hops per minute).

3.5.2 Hip external rotation strength and dynamic peak lower extremity valgus

There was conflicting evidence from nine studies that investigated the relationship between hip external rotation strength and peak lower extremity valgus. Four studies found weaker hip strength was associated with greater dynamic lower extremity valgus (Lawrence et al., 2008; McCurdy et al., 2014; Munkh-Erdene et al., 2011; Stickler et al., 2015). Three of these studies (Lawrence et al., 2008; McCurdy et al., 2014; Munkh-Erdene et al., 2011) investigated ballistic hop tasks and one investigated single leg squatting (Stickler et al., 2015). Two studies reported greater hip external rotation strength was associated with dynamic lower extremity valgus during double leg drop landing into maximal vertical jump (Bandholm et al., 2011) and single leg step down from 15 cm step (Hollman et al., 2009). Three studies found no relationship between hip external rotation strength and dynamic lower extremity valgus. These studies used a range of tasks, including a high-level hop task (Malloy et al., 2016), single leg drop jump (Suzuki et al., 2015), and single leg squat (Baldon et al., 2011). Most studies (8 out of 9) tested external rotation in sitting with the hip in 90° flexion. Only Suzuki et al. (2015) tested in both sitting and prone. They reported a weak negative correlation between hip external rotation strength with the hip in neutral and lower extremity valgus range.

3.5.3 Hip extension strength and dynamic peak lower extremity valgus

There was conflicting evidence from six studies that investigated the relationship between hip extension and peak lower extremity valgus. Three studies reported weaker hip extension strength was associated with greater dynamic lower extremity valgus during a diverse range of tasks including single leg drop landing (Suzuki et al., 2015), single leg squat (Stickler et al., 2015) and double leg maximum vertical jump (Hollman et al., 2013). Three studies reported no relationship, including one study that did not report a statistical relationship (Smith et al., 2014). Studies finding no relationship investigated single leg and double leg drop landings (McCurdy et al., 2014), single leg squats (Hollman et al., 2014) and walking at self-selected speed and rapid hopping (100 hops per minute). All studies tested hip extension strength in prone and most studies (6 out of 8) tested hip extension strength in sagittal plane neutral. McCurdy et al. (2014) and Smith et al. (2014) tested in 30 degrees of hip flexion. Only McCurdy et al. (2014) found a relationship (negative).

3.6 Relationship between hip strength and dynamic lower extremity valgus for the various tasks

Lower extremity dynamic valgus was associated with reduced hip abduction strength (OR 95% CI, 3 studies), extension strength (OR 95% CI, 2 studies) and external rotation strength (OR 95% CI, 3 studies) during single leg drop jump landings (Fig. 2). In a single study, there was a trend towards a relationship between lower extremity dynamic valgus and reduced hip abduction strength (OR 95% CI) during forward hop landing (Fig. 2). When considering all studies investigating single leg ballistic tasks, there were 5 studies (3 included in this meta-analysis) showing a negative relationship (one for both abduction and external rotation (McCurdy et al., 2014), two for external rotation only (Lawrence et al., 2008; Munkh-Erdene et al., 2011), and two for abduction only (Heinert et al., 2008; Jacobs & Mattacola, 2005)), one study showing a positive relationship (abduction and external rotation strength (Hollman et al., 2009)), and 3 studies (1 included in this meta-analysis) showing no relationship at all (Baggaley et al., 2015; Malloy et al., 2016; Smith et al., 2014).

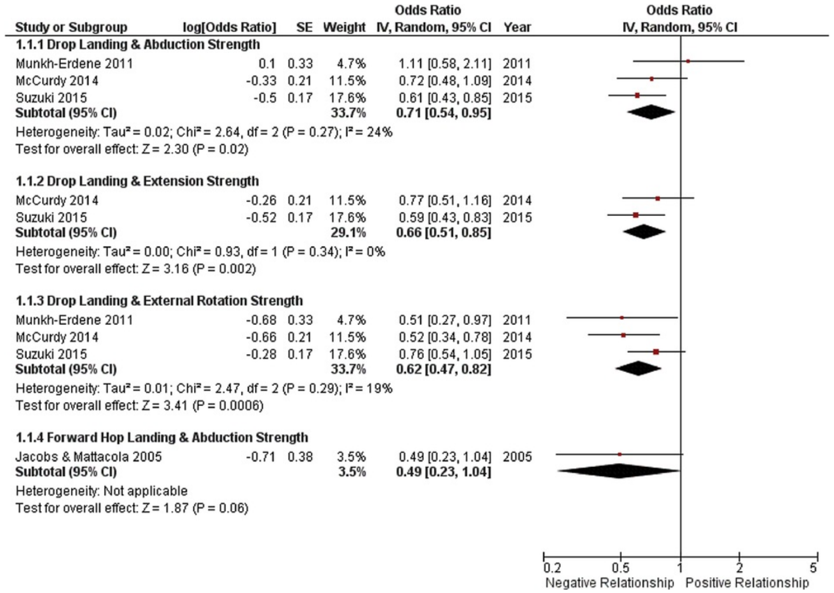

Fig. 2 Pooled effect estimates of the relationship between lower extremity dynamic valgus and hip strength during single leg ballistic 0tasks in recreationally active women.

alt-text: Fig. 2

In contrast to single leg ballistic tasks, there was no significant relationship between lower extremity dynamic valgus and hip abduction strength (OR 95% CI, 2 studies), extension strength (OR 95% CI, 1 studies) and external rotation strength (OR 95% CI, 2 study) during single leg drop jump landings (Fig. 3). In a single study, lower extremity dynamic valgus was also not associated with hip extension (OR 95% CI) strength during maximal vertical double leg jump (Hollman et al., 2013) (Fig. 3). There was high heterogeneity in pooled effect estimates for the relationship between double leg drop landing and abduction and external rotation strength. McCurdy et al. identified a negative relationship between these strength planes and double leg drop landing from 60 cm, whilst Bandolm et al. found no relationship (abduction) and positive relationship (external rotation) with drop landings from 45 cm. McCurdy et al. used younger subjects (Hewett et al., 2005; Myer et al., 2010) who had athletic backgrounds compared with Bandholm et al. who used “physically active” subjects of a wider age range (Chumanov et al., 2008; Hewett et al., 2005; Myer et al., 2010; Powers, 2010; Ramskov et al., 2015; Simoneau, 2002). When considering all 5 studies that used double leg ballistic tasks, there were 2 studies (both used in the meta-analysis) showing a positive relationship (Bandholm et al., 2011; Hollman et al., 2013) and 1 study (1 used in the meta-analysis) showing no relationship (Nilstad et al., 2015).

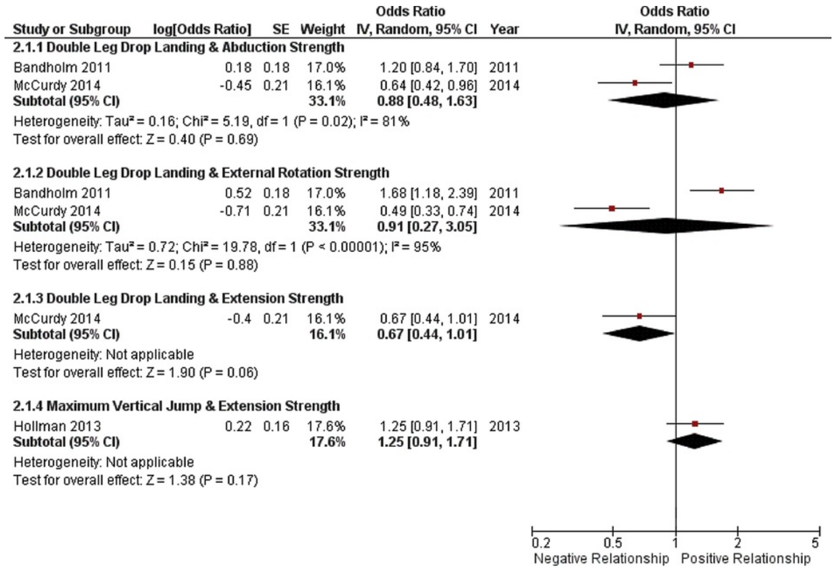

Fig. 3 Pooled effect estimates of the relationship between lower extremity dynamic valgus and hip strength during double leg ballistic tasks in recreationally active women.

alt-text: Fig. 3

Lower extremity valgus was associated with reduced hip abduction strength (OR 95% CI, 4 studies) during single leg squat tasks, but there was no relationship for hip extension (OR 95% CI, 2 studies) and external rotation strength (OR 95% CI, 3 studies) (Fig. 4). There was moderate heterogeneity in pooled effect estimates for the relationship between single leg squat tasks and extension and external rotation strength. Knee flexion may have been greater, and therefore more likely to expose lower extremity valgus issues, in the study by Stickler et al. compared with the study by Hollman et al. (2014), potentially explaining heterogeneity with external rotation strength. In contrast, for external rotation strength, Baldon et al. performed a deeper single leg squat than Munkh-Erdene et al. and Stickler et al. but was the only study not to identify a negative relationship. Baldon et al. and Munkh-Erdene et al. used similar subject numbers and age ranges (20–21 years old) compared to Stickler et al. who used a larger sample of larger age diversity (18–30 years old). No studies showed a negative relationship. All studies that used a single leg squat were included in the meta-analysis (Fig. 4).

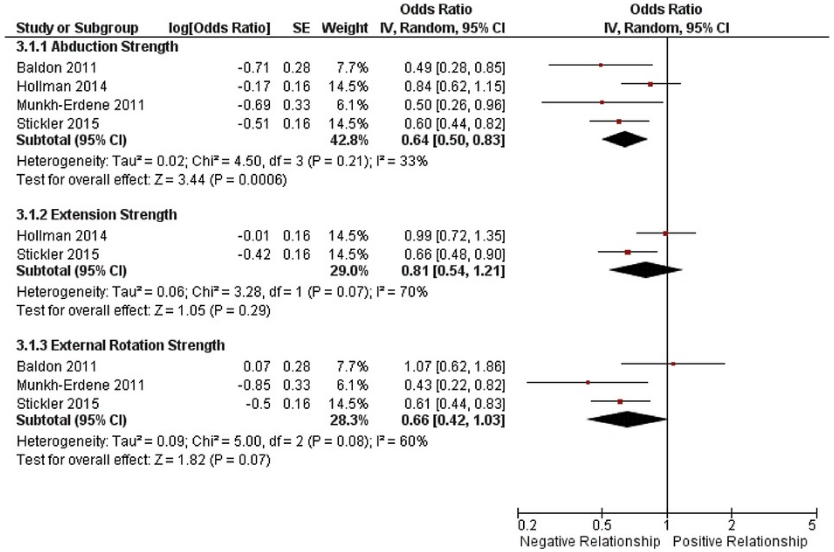

Fig. 4 Pooled effect estimates of the relationship between lower extremity dynamic valgus and hip strength during single leg squat in recreationally active women.

alt-text: Fig. 4

4 Discussion

Female athletes have been reported as having 5.3 times higher relative risk of sustaining injuries relating to dynamic lower extremity valgus than males in equivalent sports (Krosshaug et al., 2007). Physical therapists, coaches and trainers of high level athletes currently devote time and resources to programs that enhance hip and knee control to prevent injury. However, the relationship between hip strength and dynamic lower extremity valgus is more complex than some clinicians may conceive. Human movement patterns are multifactorial and correlation is not the same as causation. Hip strength is a potential factor related to this movement pattern. Clarifying its role will better inform clinicians and improve the efficacy of preventative program delivery.

Many studies have investigated the relationship between hip muscle strength and dynamic lower extremity valgus during tasks such as squatting and landing but to date it is not clear whether a relationship exists. This review demonstrates that there is conflicting evidence for a relationship between hip muscle strength and lower extremity dynamic valgus in female athletes. However, when meta-analyses were performed separating single and double landing and squat tasks, we found weaker hip muscle strength was more likely to be associated with greater dynamic lower extremity valgus for single leg ballistic tasks, and to a lesser extent single leg squat tasks, but not double leg ballistic tasks. This suggests that the relationship between hip muscle strength and dynamic lower extremity valgus may be task specific, with more demanding tasks more likely to challenge lower limb coronal plane biomechanics. There was no clear relationship between hip muscle strength in a particularplane and lower extremity dynamic valgus. Some studies identified a relationship in all three hip muscle planes (Stickler et al., 2015), while some found correlation in a single plane, but not others.

The findings of this review warrant further investigation into the relationship between hip strength and high-demand single leg landing tasks that replicate demands of jumping and cutting sports that have a high incidence of lower extremity injury. In many sporting movement patterns, the hip musculature is active in eccentrically controlling the downward movement of the center of mass during jumping and landing. Therefore, tasks such as jumping vertically and horizontally off high boxes, landing on one foot and performing unanticipated tasks (Malloy et al., 2016) may be more likely to replicate the demands of sport than double leg landing tasks (Cahalan, Johnson, Liu, & Chao, 1989; Dingenen et al., 2015a; Taylor, Ford, Nguyen, & Shultz, 2016). These single leg ballistic movements have also been associated with risk of non-contact knee injuries (Dingenen et al., 2015b; Gianotti, Marshall, Hume, & Bunt, 2009).

There is considerable variation in methods used to evaluate hip muscle strength in the literature and it is questionable whether some measures relate to how hip muscles function in relevant sports tasks. Despite landing requiring eccentric control in weight bearing, 89% of studies (16 of 18) assessed strength isometrically, and in non-weight bearing. Acceptable reliability has been demonstrated with eccentric testing of hip abduction using HHD (Thorborg, Couppé, Petersen, Magnusson, & Hölmich, 2011), yet only two studies in this review tested eccentric hip strength (Baldon et al., 2011; Jacobs & Mattacola, 2005). The positions used to evaluate muscle strength in many studies may also not be optimal for testing key muscles involved in control of hip kinematics during landing. Female athletes typically land in 10–13 degrees of hip abduction (Cronin, Johnson, Chang, Pollard, & Norcross, 2016) and move into hip adduction under eccentric control until they reach peak lower extremity valgus at around 150 msec after initial contact (Lephart, Ferris, Riemann, Myers, & Fu, 2002) during a single-leg landing and forward hop task. Muscles that abduct the hip (particularly gluteus medius) have compromised mechanical advantage to abduct at 20–40 degrees of hip flexion (Cronin et al., 2016) but this may not have been identified by studies in this review that generally tested hip abduction in neutral hip flexion-extension. Additionally, given peak lower extremity valgus is reached in about 150 msec (French, Dunleavy, & Cusack, 2010), whereas the hip abduction synergy takes 250 msec to reach peak torque in a maximum voluntary isometric contraction (Widler et al., 2009), the force produced before peak knee valgus might be more important than a maximum voluntary contraction (MVC) without time constraint (Cronin et al., 2016). Strength tests that consider rate of force development, peak force at the time of peak lower extremity valgus and replicate hip position at peak force absorption may have greater relevance to hip biomechanics in landing.

A further consideration is that testing strength in non-weight bearing positions may not accurately reflect gluteal muscle demand during weight bearing tasks such as landing. Greater gluteus medius EMG magnitude (as % of maximum voluntary isometric contraction) has been shown to be greater in weight bearing versus non-weight bearing tasks (French et al., 2010). Further, one study demonstrated greater maximal hip abductor strength when tested with HHD in side-lying position compared with the standing and supine positions (Widler et al., 2009). Taken together, this may indicate greater hip muscle compromise and demand in weightbearing. Despite this only one study assessed closed kinetic chain strength and they found that weightbearing strength was more strongly correlated to lower extremity dynamic valgus than isometric hip abduction, extension or external rotation strength (McCurdy et al., 2014).

Performing landing tasks in a controlled and predictable laboratory setting is different than landing in a sporting context which is often unpredictable and a response to actions of other players or the movement of the ball. Greater frontal plane peak angles at the hip and the knee during unpredictable landing tasks have been shown (Mornieux, Gehring, Tokuno, Gollhofer, & Taube, 2014). Predictable kinematic assessment tasks used by most studies in this review may not expose the significantly greater hip and knee abduction angles reported in this study during unpredictable landings in lateral cutting tasks. This may limit the ability to identify a potential relationship between hip muscle strength and kinematics. Malloy et al. (2016) was the only study in this review to investigate kinematics during unanticipated landing (Malloy et al., 2016). Replicating similar unanticipated landing tasks experienced by athletes in dynamic ball sports should be a consideration as the relationship between strength demands and kinematics may be different in this context.

Two studies in this review (Bandholm et al., 2011; Malloy et al., 2016) found that increased hip strength correlates with increased lower extremity valgus movement, finding weak correlations between hip external rotation strength and increased lower extremity valgus. Dynamic lower extremity valgus associated with strong external rotators and abductors may be a protective adaptation to the athlete's high volume loading and impact attenuation requirements (Bandholm et al., 2011; Malloy et al., 2016). While the notion that increased hip strength may mitigate injury risk associated with dynamic lower extremity valgus (e.g. reducing the rate of dynamic knee valgus or associated kinetics) is plausible, this hypothesis needs to be investigated in robust prospective studies.

This review has several limitations that will be outlined here. Excluding studies not written in English potentially biases this review. Despite multiple attempts to contact authors it is important to note that data was not available from all studies for meta-analysis. It is not clear whether the result of the meta-analysis would be different if data from all these studies were included. Two studies (Malloy et al., 2016; Suzuki et al., 2015) used elite athletic populations. These cohorts were more homogeneous (age, height, weight) and were exposed to higher training volumes and were probably more athletically skillful than those used in other included studies. The studies in this review only evaluated peak lower extremity valgus values in landing, reducing a whole landing phase motion to a single value. While this is informative, collecting data in such a way may neglect subtleties across the whole stance phase that potentially mask elements of the relationship between kinematics and muscle strength. While clarifying the contribution of isolated factors to lower extremity valgus in landing is important, it should be viewed within the context that human movement is much more complex than the ability of muscles to generate forces, and our contemplation of lower extremity dynamic valgus must be considered within a complex system potentially being influenced by a myriad of other biomechanical, social, psychological, physiological and training-specific factors (Bittencourt et al., 2016; Thomas, Scott, McLean, & Palmieri-Smith, 2010).

5 Conclusion

The current meta-analysis revealed study designs reflective of the demands of most sports (single leg, ballistic landings and to a lesser extent single leg squat) are more likely to show correlation with hip muscle strength than double leg ballistic tasks. Perhaps a relationship between hip muscle strength and lower extremity valgus kinematics is not evident when considering all the studies in this review because strength testing and kinematic assessment tasks have not challenged the participants capacity to a level reflective of sport. Future studies should increasingly attempt to bridge the gap between the laboratory and the sports field and interpret potential relationship within the complexity of human movement behavior. Perhaps by using more challenging kinematic assessment tasks and strength testing the validity of future studies would be enhanced and give a more realistic indication of whether a correlation exists between hip strength and dynamic lower extremity valgus.

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Conflicts of interest

None declared.

Ethical approval

None declared.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ptsp.2018.05.015.

Appendix 1. Search strategy

1	2	3	4	5
maximum adj1 voluntary adj1 isometric adj1 contraction	Results of Column 1 limited to 'Humans' & 'English'	Biomechanic$	Results of Column 3 limited to 'Humans' & 'English'	Results of Column 2 & Column 4 combined with 'AND'
isokinetic strength		Kinematic$		
isometric adj1 strength		hip moment		
isotonic adj1 strength		knee adj1 moment		
eccentric strength		dynamic valgus		
concentric adj1 strength		knee adj1 valgus		
hip adj1 strength		valgus moment		
glute$ adj1 strength		valgus angle		
hip adj1 abduct$ adj1 strength		frontal plane alignment		
external adj1 rotat$ adj1 strength		frontal plane projection		
Muscle strength (MESH)		knee excursion		
Isometric contraction (MESH)		lower extremity kinematics		
		landing strategy		

Appendix 2. Quality assessment tool (Joanna Briggs Institute – checklist for cohort studies)

		Yes	No	Unclear	Not Applicable
1.	Were the groups similar and recruited from the same population?	☐	☐	☐	☐
2.	Were the exposures measured similarly to assign people to both exposed and unexposed groups?	☐	☐	☐	☐
3.	Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4.	Were confounding factors identified?	☐	☐	☐	☐
5.	Were strategies to deal with confounding factors stated?	☐	☐	☐	☐

6.	Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	☐	☐	☐	☐
7.	Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8.	Was the follow up time reported and sufficient enough for outcomes to occur?	☐	☐	☐	☐
9.	Was follow-up complete, and if not, were the reasons to loss to follow-up described and explored?	☐	☐	☐	☐
10.	Were strategies to address incomplete follow-up utilized?	☐	☐	☐	☐
11.	Was appropriate statistical analysis used?	☐	☐	☐	☐
Overall appraisal:		Include ☐	Exclude ☐	Seek further info	
Comments (including reason for exclusion)					

Appendix 3. Quality assessment of included papers

Author	Similar Subjects	Exposures measured	Valid exposure measure	Confounders identified	Confounders minimized	Valid outcome measure	Stats analyzed	Total
Malloy et al. (2016)	Y	Y	N	Y	N	Y	Y	5/7
Baggaley et al. (2015)	Y	Y	N	Y	N	N	Y	4/7
Nilstad et al. (2015)	Y	Y	N	Y	N	Y	Y	5/7
Stickler et al. (2015)	N	Y	N	Y	N	N	Y	3/7
Suzuki et al. (2015)	Y	Y	N	N	N	Y	Y	4/7
Hollman et al. (2014)	N	Y	N	Y	N	N	Y	3/7
McCurdy et al. (2014)	Y	Y	N	Y	N	Y	Y	5/7
Smith et al. (2014)	N	Y	N	N	N	N	N	1/7
Hollman et al. (2013)	N	Y	N	Y	N	Y	Y	4/7
Baldon et al. (2011)	Y	Y	Y	N	N	N	Y	4/7
Bandholm et al. (2011)	Y	Y	N	Y	N	Y	Y	5/7
Munkh-Erdene (2011)	N	Y	N	Y	N	N	Y	3/7
Hollman et al. (2009)	N	Y	N	N	N	N	Y	2/7
Heinert et al. (2008)	Y	Y	N	Y	N	N	N	3/7
Lawrence et al. (2008)	Y	Y	N	Y	N	Y	Y	5/7
Jacobs et al. (2005)	N	Y	Y	Y	N	Y	Y	5/7

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Appendix A. Supplementary data

The following is the supplementary data related to this article:

Multimedia Component 1

Data Profile

alt-text: Data Profile

Highlights

- Evidence on a link between hip strength and dynamic knee valgus is conflicting.
- Strength testing protocols and movement tasks assessed vary.
- Study designs using single leg, ballistic landings more likely to show correlation.
- The relationship between hip strength and dynamic knee valgus may be task dependent.

Queries and Answers

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