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Literature Review

# A systematic review of the discriminating biomechanical parameters during the single leg squat

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ABSTRACT

*Objective:* To determine whether there are common biomechanical parameters when analysing the single leg squat movement to compare pathological and non-pathological groups and whether these parameters are able to effectively distinguish between groups.
*Methods:* Five electronic databases were searched using MESH terms, keywords and phrases across four constructs: squat, biomechanical measures, region of interest, study design. Studies were selected based on inclusion of a quantitative biomechanical measure, compared between a pathological and a non-pathological group, and participants performed a single leg squat movement.
*Results:* Fifteen studies were included and reviewed, where the majority of studies investigated patellofemoral pain. There was considerable variation in the biomechanical outcome measure used to compare between groups. The frontal plane projection angle was the most commonly reported measure. There was considerable variation in the manner in which the single leg squat was performed.
*Conclusion:* Due to variation in how the single leg squat was performed, it was not possible to determine specific biomechanical parameters that distinguish between pathological and non-pathological groups. Frontal plane projection angle appeared to be a parameter that could be effectively utilised. Standardisation of the single leg squat movement is needed to allow comparison between studies of pathological and non-pathological groups.



## 1. Introduction

The single leg squat (SLS) is a movement task regularly used in clinical practice as it simulates common everyday tasks, such as stair ascent and descent, as well as sporting activities (Zeller et al., 2003) and is often pain provoking. This task is part of the growing field of observational movement screening tests, which have become an increasingly used tool to identify individuals who might be at risk of musculoskeletal injury enabling targeted interventions to reduce the potential risk. A variety of methods are currently used to assess movement during a single leg squat, ranging from visual qualitative assessments (Whatman, Hume, & Hing, 2015), to assessment involving 3D motion capture using inertial sensors (Ageberg et al, 2010a). Visual observational movement screening tests offer a cost-effective, time-efficient method of assessing movement ability in both a clinical or field setting for a large number of participants and provide instant results. Qualitative type assessment of the SLS grade an individual's ability to perform the task against benchmarked criteria (Crossley et al., 2011). The qualitative based criteria within the tests are often based on the ability to perform gross movements and could be subject to rater bias through a subjective interpretation of whether the movement meets the required criteria. Additionally, the ability of movement screening tests to predict musculoskeletal injuries is low (Hegedus et al., 2015a, 2015b; Whittaker et al., 2017).

The use of objective biomechanical measures provides the

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researcher or clinician with the ability to quantitatively assess movement during a given task and provide greater fidelity in understanding the movement and potentially removes subjective interpretation. Biomechanical measures, such as kinematic and kinetics parameters, have also been used to validate movement screen tasks (Ageberg et al., 2010b; Dingenen et al., 2014; Whatman, Hume, & Hing, 2013). In addition to providing objective measures, a further use of biomechanical measures is the ability to understand the mechanisms and, therefore, the potential causes of injury to the musculoskeletal system. The range of biomechanical methods and outcome measures, however, is vast and can encompass the use of marker based motion capture systems or inertial measurement units through to dynamic medical imaging such as video fluoroscopy to obtain a kinematic analysis of movement. Force platforms, pressure plates, in-shoe pressure systems and inverse dynamic analyses are commonly employed for kinetic analysis of movement. Identifying the biomechanical parameters and methods that have been used previously to analyse these tasks would help researchers and clinicians to develop standardised methods. This would enable the quantification of parameters associated with injury, potentially facilitating the development of training interventions. However, it is not currently known which potential parameters characterise and discriminate between pathological groups. The aim of this systematic review, therefore, was to determine whether there are common biomechanical parameters utilised when analysing the single leg squat movement comparing pathological and non-pathological groups and whether these parameters are able to effectively distinguish between pathological and non-pathological groups providing some insight in to the mechanisms and causes of joint injury.

## 2. Method

### 2.1. Search strategy

A systematic search of PUBMED, CINAHL, SCOPUS, EMBASE and DELPHIS databases was performed; the latest search was completed in February 2018. A combination of Medical Subject Headings (MeSH) terms, keywords and phrases were derived in consultation with the author group to search for relevant articles (Table 1). Search terms were truncated and wildcard operators used where appropriate to reduce the number of required key words. Near operators were used in order to identify different combinations of phrases. The search terms were divided into four constructs: squat related, biomechanical measures, region of interest, and study design. The Boolean operator 'AND' was used between constructs, with the exception of study design where the 'NOT' operator was used. Inclusion criteria consisted of: study performed a comparison between two groups, participants performed squat-based manoeuvre, and biomechanical related measures were used to quantify differences between groups.

Following the search in each database the results were imported into an Endnote (version X7) library (Clavariate Analytics, Philadelphia, USA). Duplicates were identified and removed from the list using the built-in function within Endnote. Remaining references were then exported as a text file. A custom written MATLAB (MathWorks, Massachusetts, USA) Graphical User Interface (GUI) function was created to assist with the screening of the study titles and abstracts. The GUI imported the text file from Endnote, parsed the author name, year of publication, article title and abstract, and displayed this information for each article in turn. The tool automatically excluded articles that were not full text articles based on the Endnote text export format that places inverted commas around the title of the article for journal articles (i.e. articles that did not have inverted commas around their title were excluded). A pool

**Table 1**
MeSH terms, key words and phrases used in the systematic search of databases. A Boolean operator used between each character presented in parenthesis after each category heading. Inverted commas represent phrase, asterix represents truncated term with wildcard operator, 'n' represents near operator with the number of words within which the term should appear.

| Category | MeSH terms | Key words and phrases |
|---|---|---|
| Squat related (AND) | | Squat<br>"Step down"<br>"Small knee bend" |
| Biomechanical measures (AND) | Biomechanics<br>Kinematics<br>Kinetics<br>Torque<br>Motion<br>Pressure<br>Accelerometry | Kinematic*<br>Kinetic*<br>Kinesio*<br>Force*<br>"Centre of pressure" n3<br>Angle*<br>Moment*<br>Torque*<br>Jerk<br>Velocit*<br>"Angular velocity"<br>Acceleration*<br>Impulse*<br>"Angular impulse"<br>"Vector coding"<br>"Coupling angles"<br>Stereophotogrammetr*<br>"Computed tomography"<br>MRI<br>"Magnetic resonance imag*"<br>Motion<br>"Motion analysis"<br>Mechanics<br>Fluroscop*<br>IMU<br>"Inertial measurement unit"<br>Distance*<br>Displacement*<br>"2D video"<br>Load<br>Sway |
| Region of interest (AND) | Lower extremity<br>Hip Joint<br>Knee joint<br>Foot joint | "Lower Extremity"<br>"Lower Extremities"<br>"Lower Limb"<br>Hip<br>Knee<br>Ankle<br>Foot<br>Feet<br>Leg<br>Shank<br>Thigh<br>Femur<br>Tibia<br>Pelvis |
| Study design (NOT) | Surgical procedures<br>Case reports<br>Consensus<br>Meta-analysis<br>Clinical conference<br>Scientific integrity review | |

of eight reviewers screened the titles and abstracts of the articles. The articles were equally divided into four groups of articles which were then assigned to pairs of authors for title and abstract screening, where each reviewer of the pair screened all assigned articles. Articles were screened and excluded based on the following criteria: no single leg squat task, no quantitative biomechanical measures, not lower limb, no human participants, strength measures only, electromyography only, simulation study, cadaver study, surgical intervention, not original article, no comparison between pathological and non-pathological groups, reliability study only and validity study only. The results between the reviewers of each pair were compared and where disagreement over the inclusion or exclusion of an article occurred, the lead author reviewed the article and made the final decision for inclusion or exclusion. As the purpose of the review was to investigate squat movements that are conducted without outside influence that could affect the performance of the movement the full text records of the selected articles were then reviewed and excluded based on the following criteria: increased load during the squat movement, concerned with resistance training, included vibration, included a fatiguing protocol, squat movements that involved isometric contractions and studies that included movements with eyes closed. In addition, studies including participants with neurological impairments were excluded in order to focus on musculoskeletal conditions.

Articles that were included in the final review were then assessed for methodological quality using a modified version of the STROBE checklist (Vandenbroucke et al., 2007). The STROBE checklist is a reporting standard, however, due to the lack of an appropriate tool to assess the methodological quality of observational studies, the STROBE checklist was deemed a reasonable tool to adopt as it is generally expected that observational studies should include all items within the checklist. The articles were assessed against each item of the STROBE checklist and given a score of 1 where the article met the criteria and 0 where it did not. An additional two items were added to the STROBE checklist: “Did the article report or provide reference to appropriate evidence of the validity of the outcome measure?” and “Did the article report or provide reference to appropriate evidence of the reliability of the outcome measure” in order to score the article based on the robustness of the outcome measures. As some items of the STROBE checklist were not applicable to all articles, the final score was normalised with respect to the number of applicable answers and expressed as a percentage. A pool of eight reviewers scored the included articles that were equally divided across four groups of reviewers, where each reviewer scored each article that was allocated to their group. The scores from the pairs of reviewers were assessed for agreement; disagreements were then assessed and settled by the lead author.

## 3. Results

### 3.1. Identification of studies

The initial search resulted in a total of 6162 articles: 2628 duplicates were removed and a further 272 articles were removed as they were not journal articles, resulting in 3262 articles that were screened (Fig. 1). Following the screening of the titles and abstracts according to the initial exclusion criteria, 392 articles remained.

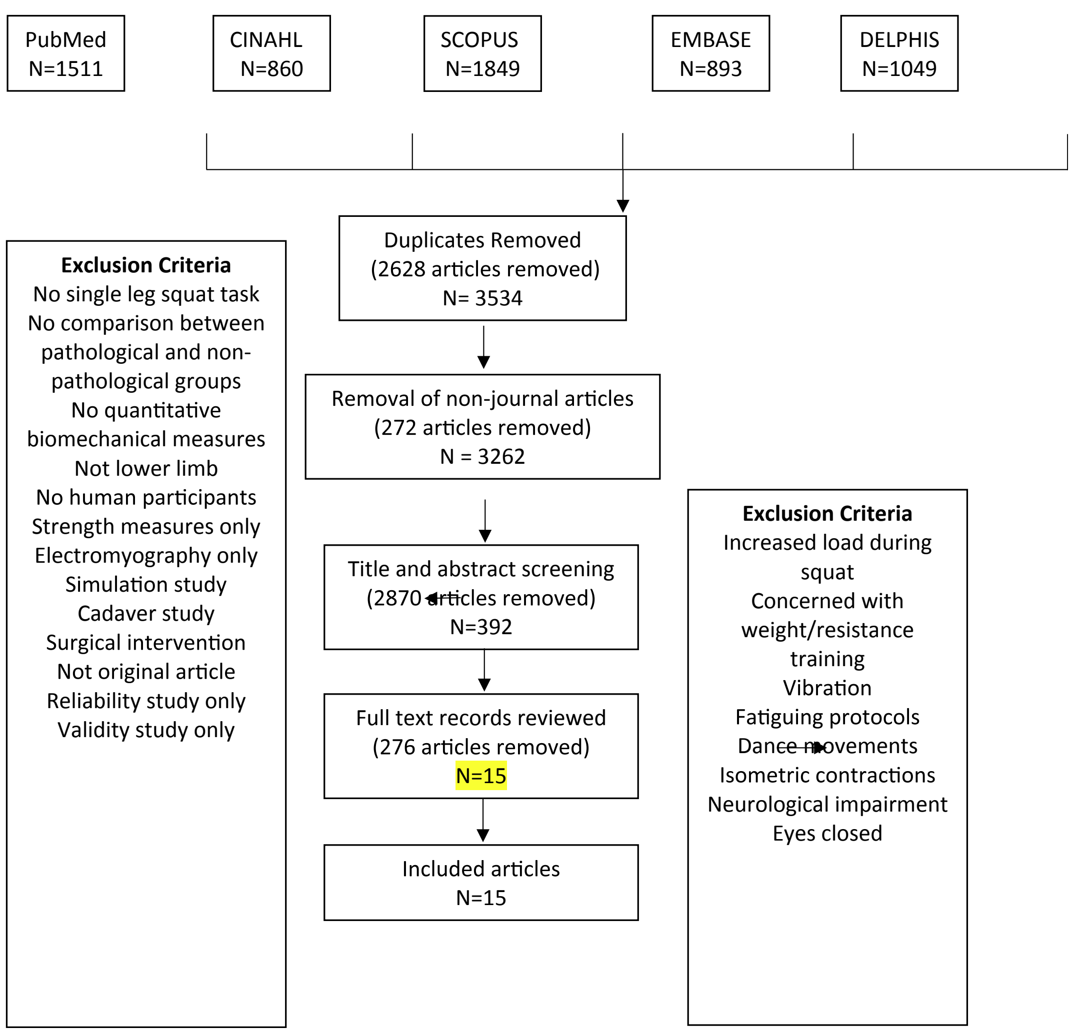


**Fig. 1.** Flow diagram of study selection process.

After reviewing the full text articles, 15 articles were included in the review.

### 3.2. Study characteristics

The included studies all investigated a group comparison between an injured and a non-injured cohort (Table 2). The most common condition that was investigated was patellofemoral pain (n = 11) (Herrington, 2014; Levinger, Gilleard, & Coleman, 2007; Nakagawa et al., 2012, 2015; Rathleff et al., 2014; Song et al., 2015; Souza et al., 2010; Willson and Davis, 2008a, 2008b; Scholtes & Salsich, 2017; Carry et al., 2017), followed by anterior cruciate ligament injury (n = 3) (Kvist, 2005; St-Onge et al., 2004; Yamazaki et al., 2010) and one study on hip chondropathy (Hatton et al., 2014). Of the studies that investigated patellofemoral pain eight included female participants only, (Herrington, 2014; Levinger et al., 2007; Song et al., 2015; Souza et al., 2010; Willson and Davis, 2008a,b; Scholtes and Salsich, 2017; Carry et al., 2017) while three studies investigated both females and males (Nakagawa et al., 2012, 2015; Rathleff et al., 2014). Of the studies that investigated anterior cruciate ligament injury two had both male and female participants (Kvist, 2005; Yamazaki et al., 2010) and one had male participants only (St-Onge et al., 2004). The study on hip chondropathy included both male and female participants (Hatton et al., 2014). The average ages of participants were generally between 20 and 30 years old (Table 2); one study examined adolescent females (Carry et al., 2017) and one study had average ages of 37 and 35 years for their pathological and control groups respectively (Hatton et al., 2014).

### 3.3. Squat characteristics

There were large variations in the manner in which the SLS was performed and wide spread omissions in the description of the methods (Table 3). When asking participants to perform the squat movement all studies except for one required a natural movement, i.e. participants were not instructed to maintain prescribed orientations for the supporting leg, pelvis or trunk. The study of Scholtes and co-workers (Scholtes & Salsich, 2017) asked participants to perform a single leg squat under natural and cued conditions. The cued condition required participants to maintain their knee over the middle of the foot. The depth of squat required of participants varied across the included studies and ranged from 45° of knee flexion to maximal depth achievable (Table 3). The studies also varied in the method used to standardise the depth of the squat ranging from using a goniometer (Song et al., 2015; Souza et al., 2010), an electrogoniometer (Levinger et al., 2007), or an external target (i.e. buttocks touching a plinth) (Hatton et al., 2014). The majority of studies (n = 11), however, did not standardise the depth of squat during the data collection, although some studies did provide feedback during practice trials prior to data collection and some provided feedback as to the speed of the squat using a metronome (Table 3). Only two studies explicitly stated the position of the unsupported leg during the squat movement where the leg was placed behind the participant (Rathleff et al., 2014; Yamazaki et al., 2010) or kept the toes in contact with the ground with the heel raised (Levinger et al., 2007). The most common position for the arms during the movement was across the chest (n = 5), with one study placing them on the pelvis (Herrington, 2014), two studies placing them by their sides (Levinger et al., 2007; Scholtes & Salsich, 2017) and one behind their backs (St-Onge et al., 2004). The remaining studies (n = 6) did not specify where the arm were placed or were self-selected by the participants (Table 3). None of the studies included a qualitative measure of the movement.

### 3.4. Biomechanical measures

The biomechanical outcome parameters reported by the studies primarily consisted of 3D kinematic parameters; some studies reported 2D projection angles and two studies reported pressure-related outcome variables (Table 4). With regards to the 3D kinematics the outcome measures included trunk lean, contralateral pelvis drop, peak hip adduction, hip internal rotation, peak knee abduction, knee flexion, patellar flexion/extension, patellar mediolateral rotation, patellar displacement and ankle flexion (Table 4). Studies utilising 2D projection angles reported knee valgus angle or femoral angle in the frontal plane (Herrington, 2014; Levinger et al., 2007; Scholtes & Salsich, 2017; Willson & Davis, 2008b). All cases which used the frontal plane projection angle compared participants with patellofemoral pain to control participants. One study utilised open MRI to determine patella displacement in 2D (Souza et al., 2010). The majority of studies reported single indices extracted from the measured data (e.g. maximum angle) with exception of one study which additionally utilised Principal Component Analysis on the 3D kinematic waveforms (St-Onge et al., 2004). Five studies provided evidence for the validity and reliability of the outcome measures (Kvist, 2005; Rathleff et al., 2014; Scholtes & Salsich, 2017; Willson & Davis, 2008b; Yamazaki et al., 2010), one study reported evidence of validity only (Song et al., 2015), six studies reported evidence of reliability only (Hatton et al., 2014; Herrington, 2014; Levinger et al., 2007; Nakagawa et al., 2012; Souza et al., 2010) and four studies reported no evidence for either validity or reliability (Carry et al., 2017; St-Onge et al., 2004; Willson and Davis, 2008a, 2008b).

### 3.5. Comparisons between pathological and non-pathological groups - summary of results

A range of biomechanical parameters were used to compare various pathological groups. The most commonly used parameter was the frontal plane projection angle, which was used to compare patellofemoral pain with control participants. The frontal plane projection angle, however, was not used to compare other conditions, such as anterior cruciate ligament injury.

Patellofemoral pain participants had a greater knee frontal plane projection angle compared to controls, ranging from 4° to 8° (Herrington, 2014; Levinger et al., 2007; Willson & Davis, 2008b; Scholtes & Salsich, 2017). Patellofemoral pain participants also demonstrated a 2.6° greater ipsilateral trunk lean (Nakagawa et al., 2012, 2015), a 2.9° greater pelvis drop (Nakagawa et al., 2012), greater hip adduction (24°±6.5 *vs.* 19.2°±6) and knee abduction (10.5°±6.4 vs. 6.8°±5.3) (Nakagawa et al., 2015), and greater frontal plane hip adduction (19.7°± 7.7 *vs.* 14.2°±6.5) (Scholtes and Salsich, 2017) compared to control participants (Table 4). A 'Dynamic Valgus Index', defined as the sum of the hip and knee angles and intended to provide a more comprehensive representation of movement than a single angle, demonstrated that patellofemoral pain participants had greater movement both in 2D (31.1°±13.4 *vs.* 18.3°±18.0) and 3D (12.4°±9.8 *vs.* 1.81°±13.4) than control participants (Scholtes & Salsich, 2017). Patellofemoral pain participants also demonstrated greater lateral displacement and tilt of the patella compared to control participants during the squat movement when the supporting knee was flexed to 15° and 30°. However, the largest difference was observed at 0° of knee flexion (75% ± 8 *vs.* 58% ± 7; lateral patella displacement, 13.1°± 5.8 *vs.* 8.1°±4.1; lateral patella tilt) (Souza et al., 2010). In terms of kinetics related parameters, patellofemoral pain participants had a 32% relative group difference in force compared to controls (Rathleff et al., 2014). Control participants demonstrated a higher centre of pressure range (7.72 cm mean difference), a higher peak power absorption

**Table 2**
Study characteristics.

| Author | Year | Title | Participant Groups | Number in each group | Age (mean ± standard deviation or range) | Activity level | How sex was treated in analysis |
|---|---|---|---|---|---|---|---|
| Carry et al. | 2017 | Postural Stability and kinetic change in subjects with patellofemoral pain after a nine-week hip and core strengthening intervention | Females with patellofemoral pain<br>Control | 7<br>7 | 14.20 ± 0.75<br>14.12 ± 0.86 | | Single-sex study |
| Hatton et al. | 2004 | Impairment of Dynamic Single-Leg Balance Performance in Individuals With Hip Chondropathy | Hip chondropathy<br>Healthy controls matched for age, sex and physical activity level | 63 (41 females)<br>60 (36 females) | 37.36 ± 11.6<br>35.7 ± 9.7 | | Considered as a covariate for correlations |
| Herrington | 2014 | Knee valgus angle during single leg squat and landing in patellofemoral pain patients and controls | Females with unilateral patellofemoral pain<br>Asymptomatic controls | 12<br>30 | 24 ± 3.2<br>20.4 ± 1.4 | Participants completed at least 3 h of sport training per week | Single-sex study |
| Kvist | 2005 | Sagittal tibial translation during exercises in the anterior cruciate ligament-deficient knee | Unilateral non-operated anterior cruciate ligament injury<br>Non-injured controls | 12 (4 females)<br>17 (nine females) | 28<br>29 | All participants took part in competitive sports | Not considered |
| Levinger et al. | 2007 | Femoral medial deviation angle during a one-leg squat test in individuals with patellofemoral pain syndrome | Females with patellofemoral pain syndrome<br>Female controls | 12 females<br>13 females | 37.4 ± 9.41<br>23.9 ± 7.84 | Physically active; 3 h per week for pain group, 4.1 h per week for control group | Single-sex study |
| Nakagawa et al. | 2012 | Frontal plane biomechanics in males and females with and without patellofemoral pain | Females with patellofemoral pain syndrome<br>Female controls<br>Males with patellofemoral pain syndrome<br>Male controls | 20 females<br>20 females<br>20 males<br>20 males | 22.3 ± 3.1<br>21.8 ± 2.6<br>24.2 ± 4.4<br>23.5 ± 3.8 | | Main effect and interaction included |
| Nakagawa et al. | 2015 | Trunk biomechanics and its association with hip and knee kinematics in patients with and without patellofemoral pain | Patellofemoral pain<br>Control | 30 (10 females)<br>30 (10 females) | 22.7 ± 3.4<br>22.3 ± 3.0 | | Not considered |
| Rathleff et al. | 2014 | Increased medial foot loading during drop jump in subjects with patellofemoral pain | Patellofemoral pain<br>Control | 23 (10 females)<br>20 (10 females) | 25.8 ± 7.4<br>26.6 ± 3.1 | | Not considered |
| Scholtes and Salsich | 2017 | A dynamic valgus index that combines hip and knee angles: assessment of utility in females with patellofemoral pain | Females with patellofemoral pain<br>Controls | 20 females<br>16 females | 22.4 ± 4.3<br>21.6 ± 3.0 | | Single-sex study |
| Song et al. | 2015 | Effects of femoral rotational taping on pain, lower extremity kinematics and muscle activation in female patients with patellofemoral pain | Patellofemoral pain<br>Controls | 16 females<br>8 females | 25.7 ± 6.1<br>28.6 ± 5.7 | | Single-sex study |
| Souza et al. | 2010 | Femur rotation and patellofemoral kinematics: a weight-bearing magnetic resonance imaging analysis | Patellofemoral pain<br>Pain free | 15 females<br>15 females | 30.8 ± 8.9<br>29.1 ± 4.2 | 198 ± 188 min per week<br>175 ± 141 min per week | Single-sex study |
| St-Ogne et al. | 2004 | Interjoint coordination in lower limbs in patients with a rupture of the anterior cruciate ligament of the knee joint | Injured (ruptured anterior cruciate ligament)<br>Control | 6 males<br>9 males | 27.7 ± 7.5<br>25.3 ± 7.4 | | Single-sex study |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Willson and Davis | 2008a | Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands | Injured (patellofemoral pain) | 20 females | 23.3 ± 3.1 | Tegner activity rating = 6.3 ± 1.4 | Single-sex study |
| | | | Control | 20 females | 23.7 ± 3.6 | Tegner activity rating = 6.9 ± 1.3 | |
| Willson and Davis | 2008b | Utility of the frontal plane projection angle in females with patellofemoral pain | Injured (patellofemoral pain) | 20 females | 23.3 ± 3.1 | Tegner activity rating = 6.3 ± 1.4 | Single-sex study |
| | | | Control | 20 females | 23.7 ± 3.6 | Tegner activity rating = 6.9 ± 1.3 | |
| Yamazaki et al. | 2010 | Differences in kinematics of single leg squatting between anterior cruciate ligament-injured patients and healthy controls. | Injured (anterior cruciate ligament) | 63 (31 females) | male: 26.4; 16–51<br>female: 25.5; 14-47 | | Tested difference between sexes in ACL group |
| | | | Control | 26 (12 females) | male: 26.2; 22-35<br>female: 23.2; 19-33 | | |

(0.92 W/Kg mean difference) and a higher peak power generation (0.87 W/Kg) compared to patellofemoral pain participants (Carry et al., 2017). One study found no significant group differences between patellofemoral pain and control participants (Song et al., 2015).

Participants with anterior cruciate ligament injury demonstrated greater knee translation (9.1 mm ± 2.5 *vs.* 6.7 mm ± 2.4) (Kvist, 2005), knee external rotation (18.9°±34.3 *vs.* 38.8°±12.2; males only) (Yamazaki et al., 2010), hip rotation (9.1°±8 *vs.* 1.7°±6.1; females only) (Yamazaki et al., 2010), knee flexion (73.9°±13.3 *vs.* 66.2°±9.9; females only) (Yamazaki et al., 2010) and hip flexion (29.9°±18.4 *vs.* 48°±11.3; females only) (Yamazaki et al., 2010) compared to control participants (Table 4). One study found no group differences between anterior cruciate ligament injury and control participants (St-Onge et al., 2004).

The study on hip chondropathy participants showed a greater range of medial/lateral and anterior/posterior centre of pressure compared to control participants (Table 4).

### 3.6. Quality of studies

The normalised scores for the STROBE assessment of the articles ranged from 50% to 93.1% (Table 5). None of the studies reported the dates of recruitment, exposure, data collection or follow-up. Other items that had few studies (<6) scoring points were “Describing efforts to address potential sources of bias”, “Explaining how the study size was arrived at”, “Reporting of evidence for the validity of the outcome measure” and “Discussed the generalizability (external validity) of the study results”.

## 4. Discussion

The aim of this systematic review was to identify the biomechanical parameters used when performing a biomechanical analysis of the single-leg squat (SLS) and determine which parameters detected differences between pathological and non-pathological groups. The frontal plane knee projection angle was the most commonly used parameter, but was limited to studies of individuals with patellofemoral pain. Therefore, the ability of biomechanical parameters to distinguish between pathological and non-pathological groups is likely condition-specific.

Summarising the data extracted from the studies some general observations can be made. Generally, there was greater frontal plane motion in the injured groups than in the healthy control groups. This was true whether the measure was from a 2D angle (Herrington, 2014; Levinger et al., 2007; Scholtes & Salsich, 2017; Song et al., 2015; Willson & Davis, 2008b), 3D motion capture (Nakagawa et al., 2012, 2015; Scholtes & Salsich, 2017), or medial/lateral range of centre of pressure motion (Hatton et al., 2014). This was also true throughout the kinematic chain with differences being noted in the knee, hip, pelvis and trunk. Peak knee flexion (Yamazaki et al., 2010), peak hip internal rotation and knee internal rotation excursion (Willson & Davis, 2008a) were variables noted to be less in the injured group than in the healthy control group. Overall, though, this review observed substantial variability in methodology when using a biomechanical analysis of the SLS to investigate group differences. The majority of studies (11 out 15) investigated patellofemoral pain meaning there was some consistency in the patient group of interest; however, due to the inconsistencies and omissions in the description of methodology, drawing overall substantiated conclusions was not possible.

The ankle is a crucial part of the lower extremity kinematic chain providing a stabilising role during the closed chain task of the SLS. Despite the ankle's role during the SLS it was only included in one paper (St-Onge et al., 2004). As these data were likely collected

**Table 3**
Description of squat movement.

| Author | Year | Squat method | | | | Natural or cued |
|---|---|---|---|---|---|---|
| | | Unsupported leg position | Arm position | Depth of squat | Depth of squat standardised? | |
| Carry et al. | 2017 | Not stated | Self-selected by participant | Self-selected to the end of range | No | Natural, although stipulated trunk had to remain upright |
| Hatton et al. | 2004 | Not stated | Folded across chest | 60° of knee flexion | Yes, buttocks needed to have touched a plinth positioned behind participant | Natural |
| Herrington | 2014 | Not stated | Hands on pelvis | Knee flexion of at least 45° but no greater than 60° | Not during recorded trials. Depth of squat checked during practice trials. | Natural |
| Kvist | 2005 | Not stated | Not stated | Maximum depth possible with unassisted rise | No | Natural |
| Levinger et al. | 2007 | Toe tips in contact with ground with heel raised | At sides | 45° of knee flexion | Audio cue from electrogonimeter when target knee flexion angle reached | Natural |
| Nakagawa et al. | 2012 | Not stated | Not stated | 60° of knee flexion<br>Participants required to perform squat at a speed of 2 s down, 2 s up. | Depth of squat not checked. Digital metronome used to control speed of squat. | Natural |
| Nakagawa et al. | 2015 | Not stated | Not stated | Knee flexion greater than 60°. Required to perform at a speed of 15 squats per minute | Digital metronome used to control speed of squat. | Natural |
| Rathleff et al. | 2014 | Behind weight bearing leg | Across chest | 90° of knee flexion | Visual observation by investigator | Natural |
| Song et al. | 2015 | Not stated | Across chest | 45° of knee flexion<br>Perform at a speed of 30° per second | Goniometer used initially to check depth. Then visual observation against a marker placed on a wall. | Natural |
| Scholtes et al. | 2017 | Not stated | Arms by side | At least 60° of knee flexion | Visual observation by investigator | Natural and cued<br>Cued condition required participants to maintain their knee over the foot. |
| Souza et al. | 2010 | Not stated | Not stated (required not to touch sides of scanner) | Approximately 50° of knee flexion<br>Participants required to squat to approximately 50° then slowly rise pausing at 45°, 30°, 15° and 0° for image collection | Plastic goniometer attached to side of leg | Natural |
| St-Ogne | 2004 | Not stated | Arms behind back | Not specified | No | Natural |
| Willson and Davis | 2008a | Not stated | Not stated | Beyond 60° of knee flexion. Verbal cadence, 15 squats per minute. | No | Natural |
| Willson and Davis | 2008b | Not explicitly stated. From figure it can be speculated that the knee of unsupported leg flexed to approximately 90° | Arms across the chest | Beyond 60° of knee flexion. Verbal cadence, 15 squats per minute. | Participants given feedback during practice trials. Not monitored during trials. | Natural |
| Yamazaki et al. | 2010 | Unsupported leg behind participant | Arms across the chest | Perform half squat over 10 s on injured, than non-injured leg. | No | Natural |

**Table 4**
Biomechanical outcome parameters.

| Author | Year | Outcome measures | | | | Results |
|---|---|---|---|---|---|---|
| | | Outcome parameters | Hardware and software | Evidence of validity | Evidence of reliability | |
| Carry et al. | 2017 | 3D kinematics and kinetics<br>Peak knee flexion<br>Peak power absorption<br>Peak power generation<br>CoP mean distance<br>Average distance from mean CoP<br>RMS distance<br>RMS distance from mean CoP range<br>Maximum distance between any two CoP location<br>95% CI circle area | Vicon – plug-in gait<br>Bertec force platforms | No | No | Peak power absorption:<br>0.92 W/KG higher in control group ($p = 0.0029$)<br>Peak power generation:<br>0.87 W/Kg higher in control group ($P = 0.0081$)<br>CoP range:<br>7.73 cm higher in control group ($P = 0.0403$) |
| Hatton et al. | 2004 | CoP path length<br>Range of CoP in anterior/posterior and medial/lateral directions<br>Standard deviation of CoP in A/P and M/L directions | Wii Balance Board | No | Yes | Greater Medial/Lateral CoP range in hip chonropathy ($p = 0.023$)<br>Control = 3.14 cm ± 0.45<br>Hip Chon = 3.5 cm ± 0.77<br>Greater Anterior/Posterior SD of CoP in hip chondropathy ($p = 0.043$)<br>Control = 1.19 cm ± 0.31<br>Hip Chon = 1.37 cm ± 0.47 |
| Herrington | 2014 | 2D frontal plane projection angle of knee valgus at lowest point of knee flexion | Digital video camera at 50 Hz. Video digitised using Quintic software | No | Yes | Significant difference between injured limb of PFP group and control (non-dominant side) and injured limb to non-injured limb with PFP group.<br>Control: 8.4°±5.1<br>PFP injured: 16.8°±5.4<br>PFP non-injured: ~10. |
| Kvist | 2005 | Maximum knee flexion angle<br>Maximum tibial translation | Computerised goniometer linkage at 2000 Hz | Yes | Yes | Significantly more knee translation in ACL injured leg compared to control group, and ACL injured leg to non-injured leg within ACL group.<br>ACL injured: 9.1 mm ± 2.5<br>ACL non-injured: 8.1 mm ± 3.7<br>Control: 6.7 mm ± 2.4 |
| Levinger et al. | 2007 | 2D frontal plane kinematics<br>Femoral frontal angle: anterior superior iliac spine to midline of the femoral condyles<br>Foot longitudinal alignment from second toe to midline of the malleioli<br>Femoral deviation: horizontal deviation of the lower marker on the thigh relative to a marker on the second toe.<br>Each parameter calculated as the difference between initial posture and posture at 45° knee flexion | Single video cameras placed perpendicular to the frontal plane at 50 Hz. Marker data digitised using Peak Motus (version 7) | No | Yes | Significant difference in femoral frontal angle between right knee of PFP group (injured knee) and right knee of control group (no indication of limb dominance).<br>PFP: 11.75° ± 3.61<br>Control: 7.79° ± 4.22<br>No significant difference in femoral deviation between right knee of PFP group (injured knee) and right knee of control group (no indication of limb dominance).<br>PFP: 2.54° ± 1.29<br>Control: 2.02° ± 1.11<br>Note: a significant difference was found between ages of groups<br>PFP: 37.4 years ± 9.41<br>Control: 23.9 years ± 7.84 |
| Nakagawa et al. | 2012 | 3D kinematics<br>Maximum excursion of ipsilateral trunk lean<br>Contralateral pelvic drop<br>Hip adduction<br>Hip Internal rotation<br>Knee Abduction | Flock of Birds electromagnetic sensors with MotionMonitor software | No | Yes | No significant difference between groups for knee excursion<br>Female PFP: 64.7° ± 3.8°<br>Male PFP: 66.1° ± 3.5°<br>Female controls: 65.2° ± 2.9°<br>Male controls: 67.4° ± 3.2°<br>Females (with or without PFP) had greater ipsilateral trunk lean than males (with or without PFP)<br>Female PFP: 11.1° ± 4.6°<br>Male PFP: 7.5° ± 3.9°<br>Female controls: 7.5° ± 3.5°<br>Male controls: 6.4° ± 2.3°; |

(*continued on next page*)

**Table 4** (*continued* )

| Author | Year | Outcome measures | | | | Results |
|---|---|---|---|---|---|---|
| | | Outcome parameters | Hardware and software | Evidence of validity | Evidence of reliability | |
| | | | | | | PFP groups (males and females) had greater ipsilateral trunk lean than controls<br>Mean difference = 2.6°<br>PFP had greater pelvic drop than controls (mean difference = 2.9°)<br>Female PFP: 11.3° ± 4.3°<br>Male PFP: 9.2° ± 4.6°<br>Female controls: 6.6° ± 2.9°<br>Male controls: 7.1° ± 4.5°<br>Females (with or without PFP) had greater hip adduction than males (with or without PFP) (mean difference = 6.9°). PFP had greater hip adduction than controls (mean difference, 4.0°):<br>Female PFP: 20.4° ± 6.0°<br>Male PFP: 13.9° ± 7.3°<br>Female controls: 14.3° ± 4.6°<br>Male controls: 7.2° ± 3.8°;<br>Females with PFP had greater hip internal rotation than males with PFP (mean difference, 5.8°), control females (mean difference, 5.9°) and control males (mean difference = 6.1°)<br>Female PFP: 15.6° ± 5.8°<br>Male PFP: 9.8° ± 4.8°<br>Female controls: 9.7° ± 5.4°<br>Male controls: 9.5° ± 4.3°;<br>Females (with or without PFP) had greater knee abduction than males (with or without PFP) (mean difference = 3.9°)<br>PFP had greater knee abduction than controls (mean difference, 3.4°)<br>Female PFP: 11.2° ± 4.6°:<br>Male PFP: 7.1° ± 3.5°<br>Female controls: 7.2° ± 3.3°<br>Male controls: 4.2° ± 2.3°; |
| Nakagawa et al. | 2015 | 3D kinematics<br>Peak ipsilateral trunk lean<br>Peak hip adduction<br>Peak knee abduction | Flock of Birds electromagnetic sensors with MotionMonitor software | No | Yes | PFP have greater peak ipsilateral trunk lean compared to controls.<br>PFP: 9.8° ± 5.2<br>Control: 6.9° ± 4.4<br>PFP have greater peak hip adduction compared to controls<br>PFP: 24.0° ± 6.5<br>Control: 19.2° ± 6.0<br>PFP have greater peak knee abduction compared to controls<br>PFP: 10.5° ± 6.4<br>Control: 6.8° ± 5.3 |
| Rathleff et al. | 2014 | In-shoe pressure distribution | Pedar, Novel | Yes | Yes | PFP 9% higher peak absolute force compared to controls (P = 0.01), relative group difference of 32%. |
| Scholtes and Salsich | 2017 | 2D frontal plane projection angle<br>2D dynamic valgus index (DVI)<br>3D kinematics<br>Hip adduction<br>Hip medial rotation<br>Knee abduction<br>Knee lateral rotation<br>3D dynamic valgus index | Dartfish<br>Vicon – Visual3D | Yes | Yes | PFP greater knee FPPA (p = 0.014)<br>PFP: 11.48° ± 7.45<br>Control: 4.14° ± 9.62<br>PFP greater hip FPPA (P = 0.03)<br>PFP: 19.66°± 7.70<br>Control: 14.15°±6.53<br>PFP greater 2D DVI (P = 0.01)<br>PFP: 31.14°±13.36<br>Control: 18.3°± 17.97<br>PFP greater 3D DVI (P = 0.01)<br>PFP: 12.41° ± 9.77<br>Control: 1.81° ± 13.44 |
| Song et al. | 2015 | 3D kinematics<br>Peak excursion in stance leg for:<br>Hip flexion/extension, abduction/adduction, internal/external rotation<br>Patellar flexion/extension, | Fastrak, Polhemus | Yes | No | No group significant group differences for 3D kinematics |

**Table 4** (*continued* )

| Author | Year | Outcome measures | | | | Results |
|---|---|---|---|---|---|---|
| | | Outcome parameters | Hardware and software | Evidence of validity | Evidence of reliability | |
| | | mediolateral rotation, mediolateral tilt<br>Patellar displacement in mediolateral, anteroposterior and proximodistal planes | | | | |
| Souza et al. | 2010 | 2D kinematics<br>Patella displacement, expressed as percentage of total patella width<br>Medial/lateral patella tilt angle<br>Medial/lateral femoral rotation<br>Patella rotation | Vertically open Magnetic Resonance Imaging (0.5T). General Electric Medical Systems | No | Yes | PFP greater lateral patella displacement at 0° knee flexion ($p = 0.011$)<br>PFP: 75% ± 8%<br>Control: 58% ± 7%<br>PFP greater lateral patella tilt at 0° knee flexion ($p = 0.03$).<br>PFP: 13.1° ± 5.8°<br>Control: 8.1° ± 4.1°<br>PFP greater medial femoral rotation at 0° knee flexion ($p < 0.037$).<br>PFP: 12.2° ± 5.0°<br>Control: 6.2° ± 5.2° |
| St-Ogne | 2004 | 3D kinematics<br>Thigh flexion/extension<br>Thigh abduction/adduction<br>Knee flexion/extension<br>Ankle flexion/extension<br>Principle Component Analysis conducted on waveforms | Optotrack | No | No | No differences between groups found during single leg squat movement. |
| Willson and Davis | 2008a | 3D kinematics at 45° of knee flexion | Vicon – Visual3D | No | No | PFP had greater knee external rotation ($P = 0.06$), less internal rotation excursion ($P = 0.05$), greater hip adduction ($P = 0.012$), and greater contralateral pelvic drop (no P value).<br>PFP group had decreased hip internal rotation ($P = 0.01$) and more femoral external rotation (no P value).<br>PFP had less internal rotation excursion ($P = 0.005$).<br>Not possible to determine values as only reported figures and the average difference between groups for all activities. |
| Willson and Davis | 2008b | 3D kinematics of the hip and knee at count of 2 during squat (authors state that knee flexion at the count of 2 is associated to peak knee extension moment during running and jumping)<br>2D Frontal Plane Projection Angle at count of 2 during squat<br>Peak knee extensor moment | Vicon – Visual3D<br>Bertec Fore Platforms<br>FPPA: Digital image (equipment used not stated) and CorelDraw to determine angle. | Yes | Yes | No group difference in knee flexion angle.<br>PFP group greater medial position of the knee during squats (difference between groups = 4.1°; $P = 0.012$). |
| Yamazaki et al. | 2010 | 3D kinematics of hip and knee at maximum knee flexion | Fastrak, Polhemus | Yes | Yes | Uninjured male ACL leg less external knee rotation than dominant leg of male control ($P = 0.0090$)<br>Uninjured leg of male ACL group: 18.9° ± 34.3<br>Dominant leg of male control group: 38.8° ± 12.6<br>Uninjured leg of female ACL group significantly more external hip rotation ($P = 0.001$), knee flexion ($P = 0.0070$) and hip flexion ($P < 0.0001$) than dominant leg of female control.<br>Hip rotation<br>Uninjured leg of female ACL group: 9.1° ± 8.0<br>Dominant leg of female control: 1.7° ± 6.1<br>Knee flexion<br>Uninjured leg of ACL group: 73.9° ± 13.3<br>Control: 66.2° ± 9.9<br>Hip flexion<br>Uninjured leg of ACL group: 29.9° ± 18.4<br>Control: 48.0° ± 11.3 |

ACL = anterior cruciate ligament; CoP = Centre of Pressure; SD = standard deviation; FPPA = frontal plane projection angle; PFP = patellofemoral pain.

**Table 5**
Normalised score for STROBE checklist.

| Paper | STROBE score |
|---|---|
| Carry et al., 2017 | 75.9% |
| Hatton et al., 2014 | 75.9% |
| Herrington, 2014 | 72.4% |
| Kvist, 2005 | 58.6% |
| Levinger et al., 2007 | 74.1% |
| Nakagawa et al., 2012 | 83.3% |
| Nakagawa et al., 2015 | 74.1% |
| Rathleff et al., 2014 | 93.1% |
| Scholtes and Salsich, 2017 | 85.7% |
| Song et al., 2015 | 85.7% |
| Souza et al., 2010 | 86.2% |
| St-Ogne et al., 2004 | 50% |
| Willson & Davis, 2008a | 72.4% |
| Willson & Davis, 2008b | 83.3% |
| Yamazaki et al., 2010 | 58.6% |

in all the studies, the omission of such data likely speaks to the challenges of fitting complex, multi-variable analyses within publication constraints. To present a more complete picture, it may be prudent to move toward including full body data where possible or alternatively in an appendix if available.

Force or kinetic data during the SLS were not extensively reported in the studies. Only four papers included these data in any form, and there was no overlap between the variables being analysed. As kinetic data can better represent joint loading and ultimately the causes of joint injuries are often attributed to the loading placed on the musculoskeletal system (Bennell et al., 2011), it would be important to include these in future studies. It must be noted that this review article excluded articles that performed musculoskeletal modelling (i.e. joint reaction force, muscle force analysis, etc) due to the complex nature of the analysis precluding them from being employed in a typical clinical environment.

While the majority of the studies included only a single sex, three of the studies included both males and females and did not report how sex was considered in the analysis (Kvist, 2005; Nakagawa et al., 2015; Rathleff et al., 2014). Sex-specific movement patterns during the single leg squat have been previously noted where females perform the single leg squat with less trunk flexion (Graci, Van Dillen, & Salsich, 2012; Weeks, Carty, & Horan, 2015), and with more pelvic rotation (Graci et al., 2012; Weeks et al., 2015), hip adduction (Graci et al., 2012; Nakagawa et al., 2012; Weeks et al., 2015; Zeller et al., 2003), and knee abduction (Graci et al., 2012; Nakagawa et al., 2012) than males. Females have also been reported to have less ipsilateral trunk flexion (Zeller et al., 2003) than males, although Nakagawa (Nakagawa et al., 2012) found the opposite while others (Graci et al., 2012; Weeks et al., 2015) reported no difference. The observed differences in the dependent measures between males and females could obscure potential group differences if including them within the same group or not accounting for sex differences in the statistical analysis.

As age affects SLS performance, it is important to consider the age of the individual when assessing the SLS. Between childhood and adolescence, SLS performance improves with increasing age (Agresta et al., 2016). In adults, elderly participants have been shown to exhibit alterations in muscle activation during an increased resisted SLS movement, which may be a contributing factor to injury in the elderly (Madhavan et al., 2009). Additionally, the effects of ageing on muscle mass, strength and neuromuscular control are well known (Deschenes, 2004; Hunter, Pereira, & Keenan, 2016; Nikolic et al., 2005). The studies in this review included participants who were young to middle-aged adults with mean ages ranging from 14.1 to 37.3 years old. As a result, this review is unable to suggest if the ability of biomechanical measures to discriminate between pathological groups is affected by age.

Of the studies that reported activity level, participants were generally of recreational level in five studies, (Herrington, 2014; Levinger et al., 2007; Souza et al., 2010; Willson and Davis, 2008a,b) with one study investigating competitive athletes (Kvist, 2005). Physically active participants have been shown to demonstrate greater knee and hip flexion during the SLS, indicating a greater depth of squat, and are likely to be rated as having better performance compared to less physically active participants (Gianola et al., 2017). Level of physical activity of participants should be considered when comparing between groups and between results of different studies. Comparing of studies that used a common biomechanical outcome parameter (frontal plane knee projection angle), two studies investigated physically active participants at a recreational level (Herrington, 2014; Levinger et al., 2007), with one study investigating inactive participants (Scholtes & Salsich, 2017), although an indication of activity level was not mentioned. Frontal plane knee projection angle did not appear to differ between these studies, suggesting that activity level did not affect this biomechanical outcome parameter. However, it is important to consider methodological differences and the omission of activity level in one study makes it difficult to draw a robust conclusion. Future research should examine the effect of activity level on biomechanical parameters during the SLS.

All studies evaluated the SLS without requiring the participants to maintain a specific posture or adopt a specific movement pattern or orientation of body segments during the movement. This approach is often adopted in clinical evaluations to assess the cognitive control of movement (Botha et al., 2014). The analysed movements, therefore, indicate how participants self-select to perform the task. One study also included a cued task to evaluate the participant's ability to correct the movement pattern (Scholtes & Salsich, 2017). The differences noted between the un-cued and cued movement indicated that the self-selected movement pattern does not necessarily evaluate an individual's ability to perform the movement correctly. The goals and methods of cognitive movement control assessment are different compared to a preferred movement pattern assessment (Dingenen et al., 2018), therefore, the movement evaluation model within studies should be carefully considered when interpreting results from studies.

There was considerable variability or omission in the details of how the single leg squat was performed. Twelve of the 15 studies did not report the position of the unsupported leg during the SLS while two reported that it was behind the supporting leg. The position of the unsupported leg affects both kinematic and kinetic outputs measured in the stance leg (Khuu, Foch, & Lewis, 2016), making comparisons between studies that have adopted different positions for the unsupported leg difficult. One study allowed the toes of the unsupported leg to be in contact with the ground (Levinger et al., 2007). This additional point of contact might also affect the measured variables by providing kinaesthetic and proprioceptive feedback as well as an additional base of support. The positions of the arms during the squat also varied across studies, ranging from arms across the chest, to arms by the side, to arm out stretched in front. Although the effect of arm position on SLS kinematics and kinetics has not been investigated, the position of the arms has been shown to influence knee valgus moments during dynamic sports (Chaudhari, Hearn, & Andriacchi, 2005), suggesting arm position will influence performance of a given task. The position of the arms will influence the position of the overall centre of mass and lead to kinematic changes, especially in the trunk, again making comparison between studies difficult if the position of the arms is not standardised or consistent.

The majority of studies did standardise the squat depth with one study not specifying the depth (St-Onge et al., 2004), and two studies going to a maximum depth or self-selected end of range (Carry et al., 2017; Kvist, 2005). The range of depth was extensive, varying from 45 degrees of knee flexion (Levinger et al., 2007; Song et al., 2015) to 90 degrees of knee flexion (Rathleff et al., 2014). Despite this variation between studies, based on an analysis of stepdown from different heights (Lewis et al., 2015), it may be more important to standardise the point at which the variables are measured. In a repeated measures analysis, when the dependent variables were analysed at peak knee flexion, the stepdown from a 16 cm step appears to use a different movement pattern than the stepdown from a 24 cm step. However, when analysed at 60 degrees of knee flexion, only trunk flexion was different between the tasks. Thus, if peak knee flexion may be different between groups, it may also be important to include a standardised angle at which data are analysed. However, depending on the research question, peak angles throughout the movement may also be of interest (Kvist, 2005; Nakagawa et al., 2012; Song et al., 2015). Another consideration is whether a peak angle is used or the change in the angle over a time frame (i.e. excursion). The use of excursion may obscure differences when there is an offset in the initial position that contributes to the difference in peak angles. This situation is noted in Willson et al. (2008a) where differences in peak angles were noted, but not in excursions. In addition, the definition of 'zero' and its relation to a neutral joint position is important to consider. Differences in the definition of the neutral joint angle will influence the absolute angles reported, requiring a clear and consistent definition of the neutral angle to ensure comparisons between groups are valid.

The SLS is often used as a tool to assess movement due to its perceived relationship to functional movement, yet the relationship between the SLS and more dynamic sporting tasks must be considered. The SLS is typically performed in a controlled manner in a bid to simulate activities of daily living, such as walking down stairs. However, it is the more dynamic movements seen in sports, for example, that may be the likely causative factor for joint injury. The velocity of the SLS influences the latency of hip muscle activation (Orozco-Chavez & Mendez-Rebolledo, 2018), and may have subsequent effects on lower limb kinematics and kinetics. Therefore, the slow velocity in which the SLS is performed will not produce the same demands on the musculoskeletal system of the lower limb as a faster dynamic task. Of the studies reported in this review only two standardised the velocity of performing the SLS (Nakagawa et al., 2012, 2015). Although the SLS has been shown to be related to pathology and injury (Kivlan & Martin, 2012), which suggests a relationship between SLS performance and functional movement, evidence on a direct comparison is limited. Movement patterns during the SLS are related to observed patterns during single leg landing (Munro, Herrington, & Comfort, 2017) and bilateral drop jump tasks (Munro et al., 2017; Ugalde et al., 2015), but further research is needed to establish the relationship between SLS and dynamic performance. With the development of inertial measurement units the possibility of establishing kinematic relationships and specific clinical measures such as the SLS can be established.

The current systematic review had a number of limitations. The review was not constrained to a single type of pathology; therefore, it was not possible to combine the results and perform a meta-analysis to determine possible effect sizes for the discriminatory power of the biomechanical outcome parameters. The choice of not constraining the type of pathology was made, as it was not known prior to undertaking the study which pathologies are assessed using a single leg squat movement. The current review was also limited to only including cross-sectional studies that compared a pathological to non-pathological group. To determine the biomechanical measures that are indicative of alterations in movement a review of studies that have examined changes in biomechanical parameters during the single leg squat following an intervention would be needed.

A number of research and clinical recommendations can be stated as a result of this review. Firstly, it is important to standardise and report the position of the unsupported leg and arms during the SLS as differing positions can alter the kinematic profile when performing the movement. Recommendations on the position to adopt include placing the unsupported leg behind with the knee flexed to 90°, and arms across the chest. To account for the differences in depth of squat employed in studies, it would be beneficial to report parameters at different levels of knee flexion during the SLS. This would allow a comparison of studies irrespective of the depth of squat. Many studies only reported kinematics of a single joint, however, the relationship between kinematics and pathology are likely to be multifactorial and therefore it is important to consider the entire kinetic chain. These data should be presented in the paper, or as an appendix or supplementary material as appropriate. In addition, many biomechanics laboratories are equipped with force platforms but very few studies report kinetic findings on the SLS. It is suggested that kinetic data should be considered in future reporting. Due to the known differences in kinematic parameters when performing the SLS the inclusion of sex as a covariate must be considered in future studies. Clinical recommendations must be circumspect, however, the clinician should consider the following points when using the SLS as a tool to assess a patient. Frontal plane motion appears to be the most important factor related to patellofemoral pain in females and should be the focus of the assessment; consistency in the position of the unsupported leg and arms should be employed; and it should be considered that males and females may perform the movement differently irrespective of pathology.

## 5. Conclusion

The SLS provides a controlled means to assess dynamic movement during a simulated movement that occurs in activities of daily living and sporting activities. Through the use of biomechanical measures it is possible to obtain quantitative, and potentially less biased than visual observational measures, measures of movement that will assist in elucidating the mechanisms of joint injuries. This review found large variability in the parameters used to distinguish between pathological and non-pathological groups. Of the biomechanical parameters reported by studies, frontal plane kinematics showed the most differences between pathological and non-pathological groups. This review also found large variability in the way in which the SLS was performed and the dependent variables used to determine groups differences. Based on this review a series of recommendations are suggested for future studies: 1) standardising the position of the unsupported leg during the SLS; 2) standardising arm position during the SLS; 3) reporting kinematic for all joints, included as an appendix if necessary; 4) giving more consideration to kinetic outcome parameters; and 5) considering sex as a covariate.

## Conflicts of interest

Dr Lee Herrington is a co-author of the submitted paper and Editor of Physical Therapy in Sport.

## Ethical approval

Not applicable.

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