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Note: this is the final draft of the article:

**Whittaker JL, Booyesen N, de la Motte S, Dennett L, Lewis CL, Wilson D, McKay C,
Warner M, Padua D, Emery CA, Stokes M.**

**Predicting Sport and Occupational Lower Extremity Injury Risk through
Movement Quality Screening: A Systematic Review**

Br J Sports Med 2016; In Press

Accepted: 3rd November 2016 for publication in the *British Journal of Sports Medicine*

The final, fully proofed and peer-reviewed journal article will be found online via the
following link:

<http://bjsm.bmj.com/>

1 **Predicting Sport and Occupational Lower Extremity Injury Risk through Movement**
2 **Quality Screening: A Systematic Review**

3

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24 **Key Words:** Athletic Injuries, Lower Extremity, Movement Screening, Occupational Injuries,

25 Risk Factors

26

1 **ABSTRACT** (Word count 247)

2 **Background:** Identification of risk factors for lower extremity (LE) injury in sport and
3 military/first-responder occupations is required to inform injury prevention strategies.

4 **Objective:** To determine if poor movement quality is associated with LE injury in sport and
5 military/first-responder occupations.

6 **Material and methods:** Five electronic databases were systematically searched. Studies
7 selected included: original data; analytic design; movement quality outcome (qualitative rating of
8 functional compensation, asymmetry, impairment or efficiency of movement control); LE injury
9 sustained with sport or military/first-responder occupation. The PRISMA guidelines were
10 followed. Two independent authors assessed the quality [Downs and Black (DB) criteria] and
11 level of evidence (Oxford Centre of Evidence-Based Medicine model).

12 **Results:** Of 4361 potential studies, 17 were included. The majority were low quality cohort
13 studies (level 4 evidence). Median DB score was 11/33 (range 3-15). Heterogeneity in
14 methodology and injury definition precluded meta-analyses. The Functional Movement Screen
15 was the most common outcome investigated (15/17 studies). Four studies considered
16 interrelationships between risk factors, seven reported diagnostic accuracy and none tested an
17 intervention program targeting individuals identified as high-risk. There is inconsistent evidence
18 that poor movement quality is associated with increased risk of LE injury in sport and
19 military/first-responder occupations.

20 **Conclusions:** Future research should focus on high quality cohort studies to identify the most
21 relevant movement quality outcomes for predicting injury risk followed by developing and
22 evaluating pre-participation screening and LE injury prevention programs through high quality
23 randomized controlled trials targeting individuals at greater risk of injury based upon screening
24 tests with validated test properties.

1 **BACKGROUND**

2 Due to the increasing prevalence and cost of treating chronic musculoskeletal (MSK) conditions
3 such as hip, knee and ankle osteoarthritis (OA) there has been a call for scientific inquiry
4 focused on shifting the approach taken to manage these conditions away from treatment and
5 toward prevention.¹ From an epidemiological perspective prevention of chronic MSK conditions
6 may include strategies aimed at reducing MSK injuries in susceptible populations (primary
7 prevention) and/or strategies aimed at slowing down or halting the onset of the chronic MSK
8 disorder after a MSK injury has occurred (secondary prevention). Susceptible populations for
9 MSK injury include those that participate in sport and recreation, or have a service related
10 occupation (e.g., military and first responders such as police officers, fire fighters and
11 paramedics).^{2,3} For example epidemiological surveys have shown that the risk of injury is 1.5 to
12 2.0 times greater amongst individuals that participate in a variety of sporting and physical
13 activities,² and that MSK injury is the leading cause of disability in the military.⁴ In both of these
14 at risk populations the most common MSK injuries are those that involve the lower extremities
15 (LE).³

16

17 Van Mechelen⁵ proposed a 4-step model for injury prevention. This model involves establishing
18 the extent of the specific injury burden of interest, followed by identifying injury risk factors and
19 causal mechanisms through prospective analysis. The first two steps inform the development
20 and introduction of preventative strategies (step four), which should then be evaluated to
21 determine their impact on injury burden (step five). Finch et al⁶ expanded upon this model
22 emphasizing the importance of evaluating the effectiveness of preventative strategies in real-
23 world implementation contexts and Meeuwisse et al⁷ emphasized the importance of
24 acknowledging that injury is a consequence of complex interactions of multiple risk factors and
25 inciting events. Consequently, studies aimed at identifying risk factors for LE injuries and

1 accompanying preventative strategies should engage end-users, utilize a prospective design
2 and ensure an adequate sample size to facilitate biostatistical methods that consider the
3 interrelationships between various risk factors.⁸ Further, to establish the value of injury risk
4 screening on injury burden it is crucial that there is an accumulation of high quality evidence
5 indicating that an intervention program targeting those at high risk of injury based on a
6 screening program is more beneficial than a non-targeted intervention.⁹

7
8 Concomitant to injury prevention models is the development of approaches to identify 'high-risk'
9 individuals. Identification of these individuals enables prevention programs to be individually
10 targeted, improving their effectiveness and public health impact (e.g., health care cost
11 reduction). One method that is widely used to identify individuals at high-risk of injury are
12 movement screening tests. The value of these tests is that they can be administered on-field or
13 in clinical settings and are less costly than tests that require specialized equipment or highly
14 trained personnel (e.g., laboratory tools such as 3D motion analysis). Additional advantages of
15 movement screening tests are that they can be administered to a large number of individuals,
16 are easily adapted to various sporting or occupation environments and provide almost
17 immediate results. Further, as movement is modifiable, these tests provide information that can
18 directly inform a prevention strategy and possibly assist in return to activity decisions.

19
20 Movement screening can involve the assessment of a single movement task or a composite
21 battery of movement tasks. Further, participants can be assessed on their physical performance
22 and/or the quality with which they move. Assessment of physical performance would consider a
23 quantifiable outcome(s) of sport or occupational strength, power, balance, agility etc., often
24 through multi-joint movements (e.g., Triple Single Leg Hop, Y Balance Test).^{10 11} Conversely,
25 assessment of movement quality involves qualitative identification and rating of functional
26 compensations, asymmetries, impairments or efficiency of movement control through

1 transitional (e.g. squats, sit to stand, lunge) or dynamic movement (e.g. hopping, walking,
2 running, landing, cutting) tasks. Both physical performance and movement quality assessments
3 would ideally align with the sport or occupation specific context. Although there is consensus
4 and several recent high-quality summaries of the clinimetric properties (e.g., validity, reliability
5 and diagnostic accuracy) and evidence related to predicting injury risk and successful return to
6 sport for physical performance outcomes,^{10 11} the same cannot be said for movement quality
7 outcomes.

8
9 As identification of risk factors and casual mechanisms are precursors to the development of
10 effective prevention strategies, the lack of consensus related to movement quality risk factors
11 for LE injury in sport and service occupations has likely hindered the process of developing and
12 evaluating injury prevention strategies. The primary objective of this systematic review is to
13 determine whether screening movement quality (a qualitative rating of functional compensation,
14 asymmetry, impairment or efficiency of movement control either with individual movements
15 tasks or a composite battery of movement tasks) can predict LE injury in sport and/or
16 occupational (e.g., military, first responders) populations of all ages. A secondary objective is to
17 summarize the clinimetric properties of the movement quality screening tests in the identified
18 literature to inform clinicians and future research aimed at the development and use of
19 movement quality screening.

20

21 **METHODS**

22 This review was registered in the PROSPERO database (CRD42015026958) and conducted
23 according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses
24 (PRISMA) guidelines.¹²

25

1 **Data Sources and Search**

2 Relevant studies were identified by searching five online databases, selected based on their
3 relevance to the research topics, from inception to January 2016. These databases included:
4 Medline, EMBASE (Excerpta medical databases), CINAHL (Cumulative Index to Nursing and
5 Allied Health Literature), Sport Discus, and SCOPUS. The combination of medical subject
6 headings (MeSH) and text words that were used to execute each search was developed in
7 consultation with a health sciences librarian scientist (LD). Appendix 1 outlines the search terms
8 used for population, injury type, screening type, screening quality, measurement as well as
9 limits and exclusions, along with combinations of search terms that formed the final search
10 strategy. The search strategy (specifically filters 3 and 4) from Kroman et al¹³ was heavily used
11 as a source of search terms for screening quality and measurement concepts. Limits included:
12 English language; human and MSK condition studies published in peer-reviewed journal.
13 Articles were organized using the reference management software package, EndNote version
14 7.1 (Thomson Reuters, 2013). The number of references obtained from each search strategy for
15 each database was recorded and a running total constructed. After accounting for duplication,
16 the titles and corresponding abstracts of all returned records were independently reviewed by
17 two of the authors blinded to record author(s) and journal title using a Microsoft Excel workbook
18 designed specifically for screening.¹⁴ Data were compiled and consensus (first between the two
19 reviewers and if required by the lead author) regarding potentially relevant studies was reached
20 on items in which there was disagreement. Prior to title and abstract review all authors
21 independently screened a random sample of 120 titles and abstracts in which they were blinded
22 to authors and journal title and reached strong agreement with the lead author (agreement
23 ranging from 81-97%, Kappa ranging from 0.13-0.49) using an Excel workbook designed
24 specifically for this purpose.^{14 15} Finally, two authors independently reviewed the full text of all
25 potentially relevant studies to determine final study selection.

26

1 **Study Selection**

2 Studies were included if they investigated the prospective association between a movement
3 quality outcome (defined as a qualitative rating of functional compensation, asymmetry,
4 impairment or efficiency of movement control during either an individual movement task or
5 battery of movement tasks) and MSK LE injury (defined as an injury involving the hip joint or
6 distal). Additional inclusion criteria included: primary research with original data, analytic or
7 intervention design, an outcome measure of LE injury sustained during sport or military/first-
8 responder occupation participation and an objective exposure measure of one or more potential
9 movement quality risk factor for LE injury. Studies were excluded if they were not written in
10 English or involved animal models or cadavers. Further, conference proceedings or abstracts,
11 editorials, commentaries, opinion-based papers review articles (systematic and narrative), case
12 series, case studies, or studies in which screening did not take place prior to injury onset (e.g.,
13 cross-sectional) were excluded.

14

15 **Data extraction and study rating process**

16 Data extracted from each study included: study year; design; study location and population (e.g.,
17 sport, military/first-responder occupation, age, sample size); injury outcome (e.g., definition) and
18 how it was ascertained; injury estimates (e.g., incidence proportion, incidence rate, prevalence);
19 risk factors, and results (e.g., significant and non-significant) including measures of reliability,
20 measures of risk [e.g., difference in means, correlations, odds ratio (OR), incidence rate ratios;
21 IRR and risk ratio (RR)] and diagnostic accuracy (e.g., sensitivity, specificity, negative predictive
22 value, positive predictive value, positive or negative likelihood ratios). Two authors
23 independently assessed the quality and level of evidence of each study. Quality of evidence
24 was evaluated based on criteria for internal validity (study design, quality of reporting, presence
25 of selection and misclassification bias, potential confounding) and external validity
26 (generalizability) using the Downs and Black (DB) quality assessment tool which assigns an

1 individual score calculated out of 32 total points for each study (11 points for reporting, 3 points
2 for external validity, 7 points for bias, 6 points for confounding and 5 for power: Appendix 2)¹⁶.
3 The level of evidence represented by each study was categorized based upon the Oxford
4 Centre of Evidence Based Medicine (OCEBM) 2009 model (Appendix 3).¹⁷ As per study
5 exclusion criteria, levels 1a, 2a, 3a (systematic reviews), 4 (case series) and 5 (opinion-based
6 papers) were not included. Discrepancies in DB scoring or OCEBM categorization were
7 resolved first by consensus between the two reviewers who rated the study and if required, by
8 the lead author (JW).

9

10 **Data synthesis**

11 Extracted data, quality and level of evidence were summarized for each study. The quantity,
12 quality and level of evidence for the most commonly investigated movement quality risk factors
13 for LE injury in sport military/first-responder occupation were collated.

14

15 **RESULTS**

16 **Identification of studies**

17 An overview of the study identification process is provided in Figure 1. The initial search yielded
18 8219 articles, 3858 duplicates were removed leaving 4361 potentially relevant articles.

19 Following the removal of studies not meeting inclusion criteria based on abstract review (e.g.,
20 not human studies, ineligible study design, not sport or military/first-responder occupation, no
21 LE injury, no movement quality risk factor, no association between a movement quality risk
22 factor and LE injury) this was reduced to 119. Subsequent to full article evaluation by the two
23 independent reviewers, 102 were excluded leaving 17 studies deemed appropriate for inclusion
24 to the systematic review. Due to inconsistent methodology and injury definition, and
25 heterogeneity of the risk factors examined, meta-analyses was precluded (see Table 1).

1 INSERT FIGURE 1 ABOUT HERE

2

3 **Study characteristics**

4 Characteristics of the 17 included studies are summarized in Appendix 4. Sixteen of the 17
5 studies were cohort studies, representing four countries (13 from the United States,¹⁸⁻³⁰ 1 each
6 from Canada³¹, Iran³² and Japan³³) published between 2007 and 2015. Thirteen^{18 19 22-25 28-34} of
7 the studies investigated the value of movement quality screening for athletes (including three¹⁸
8 ^{24 25} involving professional athletes and four^{22 23 29 30} involving National Collegiate Athletic
9 Association athletes^{22 23 29 30}; 2128 total participants; 1159 males and 817 females), two^{20 27} in
10 the military (total male participants 3350) and two^{21 26} in first responder trainees (total
11 participants 1153; unable to distinguish by sex). Fourteen^{18-20 24-34} of the studies are believed to
12 have included male participants, while seven^{19 22 26 28 29 32 34} of the studies included female
13 participants. Five^{21 23-25 30} of the studies did not specify participant sex however based on the
14 sport or military group investigated in three^{24 25 30} of these it is likely the participants were male.
15 The age range of the athletes was 11-25 years, military members 18-57 years and first
16 responder trainees 11-22 years. One of the studies involving first responder trainees²¹ and
17 three^{18 24 25} with athletes did not report age range. Amongst the 17 studies, three^{20 26 27} had a
18 sample size greater than 500, five^{20 23 25 29 30} had at least 50 injury cases (range 7-916 with three
19 not reporting the number of injured participants) and four^{20 27 29 33} utilized a multivariable
20 statistical approach to identify if movement quality outcomes could identify injury risk. Five^{22 24 25}
21 ^{28 31} of the 17 studies included a metric of diagnostic accuracy and no studies were identified
22 that assessed the value of screening for movement quality on reducing the burden of LE injury.

23

24 **Clinimetric Properties**

25 Fifteen^{18-27 29-33} of the 17 studies (88%) employed the Functional Movement Screen (FMS) to
26 assess movement quality, while two^{28 34} used the Lower Extremity Scoring System (LESS). Of

1 those using the FMS only three^{22 23 33} investigated the reliability of their measurement system
2 while one³⁴ of the investigations employing the LESS embedded an assessment of reliability
3 into the study design. The most common reliability statistic estimated was an intraclass
4 correlation coefficient with two^{29 33} of the 17 studies including 95% confidence intervals (CI).
5 One³³ study reported estimates of measurement precision.

6

7 **Injury estimates**

8 Descriptions of injury estimates (incidence proportion, incidence rate, prevalence), effect
9 estimates (IRR, RR, OR) and significant and non-significant movement quality outcomes are
10 presented in Appendix 4.

11

12 **Quality and level of evidence**

13 The highest level of evidence demonstrated by all reviewed studies was level 2b (cohort study)
14 with the majority (13/17) of studies classified as level 4 which corresponds to low quality cohort
15 study (n < 500, injury sample < 50, lack of multivariable analyses).

16

17 The median methodological quality for all 21 studies, based on the DB criteria, was 11/33
18 (range 3-15) with only 9/17 scoring greater than 10. The aim of the DB criteria is to assess
19 scientific study methodological quality (inclusive of randomized and non-randomized
20 intervention as well as observational studies). As all of the included studies were observational
21 in nature, 7 items (4, 8, 14, 19, 23, 24, and 27; totaling 10 points) on the DB checklist were not
22 applicable. Areas in which the included studies were consistently limited included: incomplete
23 description of how the sample was representative of the population of interest (e.g., insufficient
24 description of participant characteristics such as sex, history of previous injury, training
25 exposure); limited description of the characteristics of those lost to follow-up; insufficient
26 reporting of how participants were lost to follow-up and differing length of follow-up were

1 accounted for in statistical analyses; inadequate sample size; and lack of adjustment for
2 potential modification and confounding by factors, such as exposure and previous injury. Of
3 further note is the fact that two of the studies reported significant findings even though the
4 95%CI of the statistical estimate included a null value and that 11/17 studies were published in
5 non-indexed journals or in journals with an impact factor less than 2.

6

7 **Synthesis of results**

8 The quantity, quality and level of evidence for the most commonly investigated movement
9 quality outcomes are summarized in Table 1. The most common risk factors investigated
10 included age, FMS total score, FMS total score ≤ 14 , FMS total score ≤ 12 , FMS hurdle step,
11 FMS in-line lunge, FMS deep squat, LESS total score and LESS total score ≥ 5 . Based on this
12 synthesis there is inconsistent evidence that poor movement quality is associated with
13 increased risk of LE injury in sport and military/first-responder occupation.

1 Table 1. Summary of significant and non-significant movement quality outcomes by quantity, quality and level of evidence.
 2

Level of Evidence [^]	1			2					3		4		5	Total Studies	
	a	b: RCT	c	a	b: True/Quasi Experimental	b: Cohort		b: Historical Cohort		c	a	b: Case Control	Pilot cohort Cross-sectional		
Risk Factor						SIG	NOT	SIG	NOT			SIG	NOT		
FMS total score												4 3-12)	1 (10)		5
FMS ≤14						1 (15)						5 (7-12)	4 (9-14)		10
FMS ≤12												1* (9)	3 (10-12)		4
FMS HS												2 (9-12)	4 (8-12)		6
FMS ILL												2 (12)	4 (8-14)		6
FMS DS												3 (8-14)	3 (9-11)		6
LESS total score						1 (11)							1 (14)		2
LESS ≥5						1 (11)							1 (14)		2

3 Cell values represent number of studies (range of Downs and Black quality assessment tool scores). As per exclusion criteria,
 4 systematic reviews (1a, 2a, 3a), case series (4) and opinion-based papers (5) were not included (shown in dark grey). [^]Level of
 5 evidence is based on the modified Oxford Centre for Evidence-Based Medicine Model. * = female participants only, DS = deep squat,
 6 FMS = Functional Movement Screen, HS = hurdle step, ILL = in-line lunge, LESS = Landing Error Scoring System.

1 **DISCUSSION**

2 To our knowledge, this is the first systematic review examining movement quality risk factors for
3 LE injury in sport and military/first responder occupations that incorporates both a formal
4 evaluation of study quality and level of evidence. Overall there is inconsistent low-level evidence
5 that poor movement quality is a risk factor for LE injury or to support widespread adoption of
6 movement quality screening programs for predicting LE injury in sport and military/first-
7 responder occupation populations. Further, as the identification of risk factors is the first step in
8 the injury prevention process, it remains unknown if movement quality screening has a role in
9 reducing the burden of LE injury in these populations.

10

11 It is important to highlight that the findings of this review are based upon a synthesis and
12 evaluation of existing literature, and as such they are limited by the inadequacies of studies
13 included. Overall there was a lack of consistent high quality evidence to support nominating any
14 particular movement quality outcome as a LE injury risk factor due to inadequate reporting of
15 concepts essential to establishing internal (how well an experiment was done) and external (can
16 the results be applied to people and situations beyond the experiment) validity. The biggest
17 threats to internal validity were related to the possibility of selection bias, and the reporting of,
18 and adjustment for, potential influence of factors such as sex, injury history and training
19 exposure. Specifically, due to the lack of participant characteristic reporting it was often difficult
20 to determine if the individuals selected for a study differed systematically from those in the
21 source population (selection bias). Equally important was the consistent omission of the
22 characteristics of those lost to follow-up, which made it impossible to determine if participants
23 lost to follow-up were systematically different from those retained in a study. The inability to
24 determine selection bias not only questions the internal validity of several included studies, it
25 impacts the degree to which the findings of these studies can be generalized to the larger
26 population from which the samples were drawn (external validity).

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As indicated earlier, it is highly unlikely that a LE injury is a result of a single risk factor or aberrant movement pattern, but rather the consequence of complex interactions between multiple risk factors and inciting events.⁷ Multivariable biostatistical techniques can explore these complex interactions given an adequate sample size. Bahr and Holme⁸ estimated that 50 injury cases are needed to detect a moderate to strong association between a risk factor and injury. Of the 17 studies included in this review only four^{20 27 29 33} employed multivariable biostatistical techniques, of which only two^{20 29} had 50 or more injury cases (with one²⁷ not reporting the number of injury cases) and were able to assess the influence of additional covariates (e.g., body mass index, smoking status, muscular and cardiovascular fitness, battalion, previous injury history, sex, age and sport). As sex, previous injury, and exposure to training are known to influence the incidence of MSK LE injury the lack of reporting and assessment of the impact of these factors on the association between a pre-season movement quality deficit and injury incidence with adequate sample size and biostatistical techniques brings into question the value of only assessing movement quality to establish injury risk.

It is important to consider that the true value of being able to identify risk factors for future injury is dependent upon it actually leading to strategies that result in injury reduction in real world contexts. This empirical validation requires an accumulation of high quality evidence indicating that an intervention program targeting those at high risk of injury based on a screening test is more beneficial than a non-targeted intervention.⁹ However before such a hypothesis can be tested there needs to be an accumulation of high quality evidence demonstrating a strong relationship between the risk factor, which was assessed with a valid and reliable screening test employing a specific cut-off value, and injury. Further, the predictive ability of the specific screening test cut-off value must be validated in multiple populations.⁹

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To date, movement quality tests lack the foundation of rigorous development and validation (e.g. psychometrics) common in other fields³⁵ and there is a lack of high quality evidence demonstrating a strong relationship between any single movement quality outcome and injury. As movement quality tests were not specifically developed as diagnostic tools, but rather to identify deficits that inform clinical interventions from a mechanistic perspective, this is perhaps not surprising.^{9 36} Although several cut-off points for high LE injury risk have been proposed (e.g., FMS total score ≤ 14 ,²⁴ FMS total score ≤ 12 ,³⁰ and LESS total score ≥ 5 ²⁸), none appear to have sufficient diagnostic accuracy to be useful in real world contexts. For example the sensitivity and specificity of a FMS total score ≤ 14 has been shown to range between 0.54-0.83 and 0.61-0.91 respectively.^{22 24 25 37} This suggests that almost half of individuals that go on to suffer a injury may not have a FMS total score ≤ 14 and over half of those that do not go on to suffer an injury may not have a FMS total score ≤ 14 .

The ability to establish a link between poor movement quality and injury risk holds great potential for identifying modifiable causal mechanisms for injury, which can be addressed with a targeted intervention. For example the LESS aims to identify movement quality errors during jump-landing²⁸ such as decreased hip flexion and knee valgus that have been associated with anterior cruciate ligament injury. In doing so provides a starting point for targeted interventions aimed at improving jump-landing mechanics and reducing an individual's future ACL injury risk. However, the link between other movement quality outcomes that have an association with LE injury, such as reduced shoulder mobility,¹⁹ other FMS components or total FMS score, is not as intuitive. Without a theoretical basis linking the 'non-optimal movement' to the injury, it would be difficult to know how to use the finding of an "abnormal" movement to guide an intervention aimed at reducing injury risk. This is a limitation of some movement quality outcomes that will have to be addressed prior to widespread application.

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A final consideration is that this review was unable to identify any investigation that had assessed the value of screening for movement quality for reducing the burden of LE injury through targeted interventions in sport or military/first-responder occupation populations. With that said there are several examples of attempts to do this in the field of sport injury prevention using physical performance outcomes that can provide valuable guidance^{38 39} Specifically, these studies highlight the importance of developing an implementation strategy in conjunction with the intervention and then tracking and accounting for adherence to the prevention programs in the analysis.

Limitations

Meta-analyses were not possible due to the fact that the assumptions for meta-analyses were not satisfied by the included studies. In particular, there was considerable inconsistency in methodology (e.g., reporting and controlling for confounding) and heterogeneity of injury definition. For example, the injury definition covered the span of ‘a MSK injury resulting from organized intercollegiate sport practice or competition that required medical attention or advice from a certified athletic trainer, athletic training student or physician’²² to ‘a MSK injury that occurred during participation in track and field practice or competition that prevented participation for 4 weeks’³³. This inconsistency in injury definition led to injury estimates ranging from 0.8 % to 85% of participants across the included studies. Further, despite a comprehensive search strategy and rigorous approach to study selection, it is important to acknowledge the possibility of omitting a relevant study and inclusion of only English language articles as additional potential limitations. Finally, as the findings of this review are based upon a synthesis and evaluation of existing literature it is important to point out that the current evidence base of studies that have assessed the prospective relationship between poor movement quality and LE injury may not have considered all possible movement quality screening tests (e.g., Nine Battery

1 Test,⁴⁰ Performance Matrix,⁴¹ Single Leg Squat,⁴²⁻⁴⁴ Tuck Jump Assessment and Star Excursion
2 Balance Test⁴⁵).

3

4 **Recommendations**

5 Both cohort and intervention study designs can play an important role in identifying potential risk
6 factors and reducing the burden of LE injury in sport and military/first-responder occupations.^{8,9}

7 While cohort studies are critical for establishing temporality between a risk factor and
8 subsequent injury, randomized controlled trials (RCTs) provide the strongest evidence for the
9 causal nature of a risk factor and the effectiveness of modifying that factor on injury burden.

10 Based upon the studies reviewed it is recommended that future research focus on high quality
11 cohort studies aimed at identifying the most relevant movement quality outcomes for predicting
12 injury followed by establishing the diagnostic accuracy of the movement quality screening tests
13 used to assess these risk factors in relevant populations. Given the challenges and high cost of
14 undertaking high quality cohort studies, an alternative approach may be to simultaneously
15 develop and evaluate pre-participation screening and LE injury prevention programs through
16 high quality RCT's targeting athletes or workers at greater risk of injury based upon previous
17 injury. Further recommendations include; ensuring consistency in injury definition amongst
18 studies attempting to determine the relationship between a movement quality outcome and
19 subsequent injury that aligns with international consensus⁴⁶ and the development of movement
20 quality screening tools according to psychometric principles.³⁵ Implementation of these
21 recommendations will assist in the advancement of injury prediction and prevention.

22

23 **CONCLUSIONS**

24 Overall there is inconsistent level 4 evidence that poor movement quality is a risk factor for LE
25 injury or to support widespread adoption of movement quality screening programs for predicting
26 LE injury in sport and military/first-responder occupation populations. It is recommended that

1 future research focus on high quality cohort studies to identify the most relevant movement
2 quality outcomes for predicting injury. This should be followed by development and evaluation of
3 pre-participation screening and LE injury prevention programs through high quality randomized
4 controlled trials targeting athletes or workers at greater risk of injury based upon
5 psychometrically sound movement screening tests.

6

7 **WHAT ARE THE NEW FINDINGS**

- 8 • There is conflicting level 4 evidence that movement quality outcomes are risk factors for
9 lower extremity injury in sport or to support widespread adoption of movement quality
10 screening programs for predicting LE injury and military/first-responder occupation
11 populations.
- 12 • There is a need for consistency in injury definition amongst studies attempting to determine
13 the relationship between a movement quality outcome and subsequent injury.
- 14 • Based on the work done in the field it is recommended that investigators focus on high
15 quality cohort studies to identify the most relevant movement quality outcomes for predicting
16 injury risk that account for the multifactorial nature of injury by ensuring adequate sample
17 size and employing relevant biostatistical techniques.

18

19 **FUNDING**

20 N Booyesen is funded by the National Institute for Health Research (Grant number: CDRF-2014-
21 05-021), D Wilson and M Warner are funded by Arthritis Research UK (Grant number: 20194),
22 C Lewis is supported by the National Institute of Arthritis and Musculoskeletal and Skin
23 Diseases of the National Institutes of Health (Award number K23 AR063235). C Emery is
24 funded through a Chair in Pediatric Rehabilitation (Alberta Children's Hospital Foundation).
25 These sponsors had no involvement with respect to design, collection or data analyses,
26 interpretation, writing or submission

1

2 **ACKNOWLEDGEMENTS**

3 All of the authors are members of the International Movement Screening group of the Arthritis
4 Research UK Centre for Sport, Exercise and Osteoarthritis
5 [http://www.sportsarthritisresearchuk.org/seoa/international-movement-screening-and-
7 interventions-group-imsig/imsig.aspx](http://www.sportsarthritisresearchuk.org/seoa/international-movement-screening-and-
6 interventions-group-imsig/imsig.aspx). The authors would like to acknowledge the assistance of
8 Matt Attwood (PhD student), Department for Health, University of Bath, Bath UK, Connor Power
9 (PhD student), Faculty of Health Sciences, University of Southampton, Southampton, UK and
10 Tim Gribbin (Research Coordinator), Uniformed Services University of the Health Sciences,
11 Bethesda, Maryland, USA for their help in screening titles and abstracts, as well as Joanne
12 Bartram, Arthritis Research UK Centre for Sport, Exercise and Osteoarthritis Administrator for
13 her administrative support.

13

14 **AUTHORS CONTRIBUTIONS**

15 JW, CE, NB and DW were responsible for the conception of the study while all authors
16 were involved in study design. LD designed and executed the extensive search strategy. All
17 authors (except LD) independently reviewed the literature, participated in rating the literature
18 and extracted data. JW was the primary author in preparing the manuscript however all authors
19 contributed to the interpretation of the findings, critical revision of the manuscript and reviewed
20 the document prior to submission.

21

22 **COMPETING INTERESTS**

23 The authors acknowledge that they have no conflicts of interest that are directly relevant to the
24 contents of this systematic review.

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APPENDIX 1: SEARCH TERMS, STRATEGIES AND RESULTS

SEARCH TERMS AND STRATEGIES

1. Search Concepts

- athletic and first responders and military
- injuries
- lower extremity
- movement
- measuring quality
- lower extremity movement quality tests (meet criteria of above 3 concepts)
- clinimetric properties
- limits and exclusions

2. Search terms and Strategies

a. Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) 1946 to Present

1. Athletic Injuries/
2. exp Sports/
3. Athletes/
4. Military Personnel/
5. exp Emergency Responders/
6. (sport or sports or athlet* or runners or (run* adj2 (marathon* or competitive* or casual* or recreation*)) or joggers or police* or officer* or firefighter* or firem* or fire personnel or military or army or navy or air force or airforce or soldier* or armed forces or armed service* or active duty* or veteran* or paramedic or first responder* or (emergency adj2 responder*) or ambulance or emergency medical technician*).mp.
7. (active adj3 (individual* or population* or participant* or male* or female* or men or women or persons or students or adult* or patients or adolescent*)).mp.
8. or/1-7
9. exp hip injuries/ or exp leg injuries/ or hip dislocation/ or knee dislocation/ or patellar dislocation/
10. femoracetabular impingement/ or patellofemoral pain syndrome/
11. ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or instability) adj6 (risk or risks or predict* or associat* or correlat* or screen* or prevent* or sport* or athletic or running)).mp.
12. ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or instability) adj8 (lower extremit* or lower limb* or hip or hips or thigh or thighs or leg or legs or knee or knees or ankle* or foot or foots or toe or toes or ACL or PCL or ((anterior or posterior) adj cruciate adj2 ligament*) or femoracetabular or femur or (menisc* adj3 (tibia* or lateral)) or patellofemoral)).mp.
13. "Sprains and Strains"/

1 14. Joint Instability/
2 15. Pain/
3 16. Athletic Injuries/
4 17. Dislocations/
5 18. "Wounds and Injuries"/
6 19. or/9-18
7
8 20. exp hip injuries/ or exp leg injuries/ or hip dislocation/ or knee dislocation/ or patellar
9 dislocation/
10 21. (lower extremit* or lower limb* or hip or hips or thigh or thighs or leg or legs or knee or knees
11 or ankle* or foot or feet or toe or toes or ACL or PCL or ((anterior or posterior) adj cruciate adj2
12 ligament*) or femoracetabular or femur or (menisc* adj3 (tibia* or lateral)) or patellofemoral).mp.
13 22. (run or running or jog* or squat* or minisquat* or balance or lunge or lunges or hop or jump
14 or jumping or walk or walking or step-up or hurdle or gait).mp.
15 23. 20 or 21 or 22
16
17 24. motor activity/
18 25. (exercis* or (physical adj (activit* or perform* or function*))).mp.
19 26. (function* adj (activ* or perform*)).mp.
20 27. (motor or movement or motion or dynamic or moving).mp.
21 28. (run or running or jog* or squat* or minisquat* or balance or lunge or lunges or hop or jump
22 or jumping or walk or walking or step-up or hurdle or gait).mp.
23 29. or/24-27
24
25 30. "Task Performance and Analysis"/
26 31. (functional test* or grade or grading or rating or rated or score or scoring or rank or ranked
27 or ranking).mp.
28 32. (control adj6 (assess* or test* or measur*)).mp.
29 33. (movement adj2 (screen* or assess* or quality or performance or observation or observe* or
30 test*)).mp.
31 34. ((performance or objective or observation* or quality) adj5 (measur* or test* or instrument*
32 or method or methods or index or indices or assess* or screen*)).mp.
33 35. ((deficit* or varus or valgus or asymmetr* or compensatory movement) and (measur* or test*
34 or instrument* or method or methods or index or indices or assess* or screen*)).mp.
35 36. or 30-35
36
37 37. (((Lunge or Squat or Hop or jump or Reach or Cutting or Step-up or Balance or Push-up or
38 Lift or Rotation or walk*) adj3 (test* or task* or assessment)) or gait analys* or gait
39 evaluation*).mp.
40 38. (deep squat* or one leg squat* or mini-squat* or mini squat* or "in line lunge*" or inline
41 lunge* or double leg drop vertical jump* or "hop and hold*" or Hurdle step* or single leg pickup
42 or single leg pick-up or single leg land or single leg balance or leg raise or tuck jump or vertical
43 jump or drop jump).mp.

1 39. (Functional movement screen* or PPM-16 or ((nine-test or movement or performance or
2 function) adj3 screening battery) or landing error scoring system* or balance error scoring
3 system*).mp.
4 40 or/37-39
5
6 41. (23 and 29 and 36 and 40)
7
8 42. predictive value.mp.
9 43. (predict* or associat* or correlat*).ti.
10 44. ((predict* or correlat* or associat*) adj10 (injur* or pain* or tear or tears or sprain* or strain*
11 or dislocation* or impingement* or instability)).mp.
12 45. (receiver operator curve* or ROC or likelihood ratio* or specificity or ((positive* or negative*
13 or high* or low) adj4 correlat*)).mp.
14 46. validation studies/
15 47. Comparative Study/
16 48. "Outcome Assessment (Health Care)"/
17 49. observer variation/
18 50. Health Status Indicators/
19 51. exp "reproducibility of results"/
20 52. discriminant analysis/
21 53. (outcome assessment or outcome measure or observer variation or instrumentation or
22 psychometr* or clinimetr* or clinometr* or reproducib* or reliab* or unreliab* or valid* or
23 coefficient or homogeneity or homogeneous or internal consistency).mp.
24 54. ((cronbach* adj2 alpha*) or (item adj5 (correlation* or selection* or reduction*)) or
25 agreement or precision or imprecision or precise value* or test-retest or (test adj3 retest) or
26 stability).mp.
27 55. (interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or
28 intra-tester or interobserver or inter-observer or intraobserver or intraobserver or intertechnician
29 or inter-technician or intratechnician or intra-technician or interexaminer or inter-examiner or
30 intraexaminer or intra-examiner or interassay or inter-assay or intraassay or intra-assay or
31 interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-
32 participant or intraparticipant or intra-participant).mp.
33 56. (kappa* or repeatab* or ((replicab* or repeated) adj6 (measure or measures or findings or
34 result or results or test or tests)) or generaliza* or generalisa* or concordance or (intraclass and
35 correlation*) or discriminative or known group or factor analysis or factor analyses or dimension*
36 or subscale* or (multitrait adj6 scaling adj6 analys*) or item discriminant or interscale
37 correlation* or error or errors or individual variability or (variability adj8 (analysis or values)) or
38 (uncertainty adj6 (measurement or measuring)) or standard error of measurement or sensitiv* or
39 responsive* or ((minimal or minimally or clinical or clinically or mall*) adj6 (important or
40 significant or detectable or real) adj6 (change or difference)) or meaningful change or ceiling
41 effect or floor effect or Item response model or IRT or Rasch or Differential item functioning or
42 DIF or computer adaptive testing or item bank or cross-cultural equivalence).mp.
43 57. or/42-56
44

- 1
- 2 58. 8 and 19 and 41 and 57
- 3 59. limit 58 to animals
- 4 60. limit 59 to humans
- 5 61. (mice or mouse or rat or rats or animal model* or bovine or rodent*).ti.
- 6 62. 58 not ((59 not 60) or 61)
- 7 63. (arthroplast* or arthroscop* or TKA or THA or surgery or surgical).ti.
- 8 64. ((after or undergoing) adj5 reconstruction).ti.
- 9 65. (paraplegi* or brain injur* or stroke or post-stroke or concussion or polyneuropath* or
- 10 fibromyalgia or multiple sclerosis or arteriosclerosis or cancer or neoplasm* or malignanc* or
- 11 degenerative).ti.
- 12 66. "return to sport".ti.
- 13 67. (claudication or epidural or platelet-rich plasma or cadaver or spinal cord or spinal chord or
- 14 vibration or arterial disease or caffeine or pregnan* or breast or breasts or steroid*).ti.
- 15 68. 62 not (or/63-67)
- 16 69. limit 68 to "review articles"
- 17 70. 68 not 69
- 18 71. case reports/
- 19 72. case report*.jw.
- 20 73. ((case not (case control or case cohort or case crossover)) adj4 (series or study or
- 21 report*).ti.
- 22 74. 70 not (or/71-73)
- 23 75. limit 74 to english language

24

25 **b. Embase 1974 to 2015 December 31**

26

- 27 1. sport injury/ or battle injury/
- 28 2. exp sport/
- 29 3. athlete/
- 30 4. soldier/
- 31 5. rescue personnel/
- 32 6. (sport or sports or athlet* or runners or (run* adj2 (marathon* or competitive* or casual* or
- 33 recreation*)) or joggers or police* or officer* or firefighter* or firem* or fire personnel or military
- 34 or army or navy or air force or airforce or soldier* or armed forces or armed service* or active
- 35 duty* or veteran* or paramedic or first responder* or (emergency adj2 responder*) or ambulance
- 36 or emergency medical technician*).mp.
- 37 7. (active adj3 (individual* or population* or participant* or male* or female* or men or women or
- 38 persons or students or adult* or patients or adolescent*).mp.
- 39 8. or/1-7
- 40
- 41 9. sport injury/ or battle injury/
- 42 10. exp leg pain/ or exp leg injury/ or femoroacetabular impingement/ or ankle sprain/
- 43 11. injury/ or injury prediction/ or limb injury/ or musculoskeletal injury/ or soft tissue injury/ or
- 44 tissue injury/ or sprain/ or joint injury/ or dislocation/ or joint fracture/ or joint instability/

1 12. ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or
2 instability) adj6 (risk or risks or predict* or associat* or correlat* or screen* or prevent* or sport*
3 or athletic or running)).mp.
4 13. ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or
5 instability) adj8 (lower extremit* or lower limb* or hip or hips or thigh or thighs or leg or legs or
6 knee or knees or ankle* or foot or feet or toe or toes or ACL or PCL or ((anterior or posterior)
7 adj cruciate adj2 ligament*) or femoracetabular or femur or (menisc* adj3 (tibia* or lateral)) or
8 patellofemoral)).mp.
9 14.or 9-13
10
11 15. exp leg pain/ or exp leg injury/ or femoroacetabular impingement/ or ankle sprain/
12 16. hip/ or exp leg/ or exp "bones of the leg and foot"/ or quadratus femoris muscle/ or
13 quadriceps femoris muscle/ or sartorius muscle/ or soleus muscle/ or tibialis anterior muscle/ or
14 tibialis posterior muscle/ or vastus lateralis muscle/ or vastus medialis muscle/ or ligament/ or
15 ankle lateral ligament/ or exp knee ligament/ or "ligament of head of femur"/ or patella ligament/
16 17. (lower extremit* or lower limb* or hip or hips or thigh or thighs or leg or legs or knee or knees
17 or ankle* or foot or feet or toe or toes or ACL or PCL or ((anterior or posterior) adj cruciate adj2
18 ligament*) or femoracetabular or femur or (menisc* adj3 (tibia* or lateral)) or patellofemoral).mp.
19 18. (run or running or jog* or squat* or minisquat* or balance or lunge or lunges or hop or jump
20 or jumping or walk or walking or step-up or hurdle or gait).mp.
21 19. or/15-18
22
23 20. motor activity/ or physical activity/ or physical performance/ or "physical activity, capacity
24 and performance"/ or motor performance/
25 21. (exercis* or (physical adj (activit* or perform* or function*))).mp.
26 22. (function* adj (activ* or perform*)).mp.
27 23. (motor or movement or motion or dynamic or moving).mp.
28 24. (run or running or jog* or squat* or minisquat* or balance or lunge or lunges or hop or jump
29 or jumping or walk or walking or step-up or hurdle or gait).mp.
30 25. or/20-24
31
32 26. (functional test* or grade or grading or rating or rated or score or scoring or rank or ranked
33 or ranking).mp.
34 27. (control adj6 (assess* or test* or measur*)).mp.
35 28. (movement adj2 (screen* or assess* or quality or performance or observation or observe* or
36 test*)).mp.
37 29. ((performance or objective or observation* or quality) adj5 (measur* or test* or instrument*
38 or method or methods or index or indices or assess* or screen*)).mp.
39 30. ((deficit* or varus or valgus or asymmetr* or compensatory movement) and (measur* or test*
40 or instrument* or method or methods or index or indices or assess* or screen*)).mp.
41 31. or/26-30
42

1 32. (((Lunge or Squat or Hop or jump or Reach or Cutting or Step-up or Balance or Push-up or
2 Lift or Rotation or walk*) adj3 (test* or task* or assessment)) or gait analys* or gait
3 evaluation*).mp.

4 33. (deep squat* or one leg squat* or mini-squat* or mini squat* or "in line lunge*" or inline
5 lunge* or double leg drop vertical jump* or "hop and hold*" or Hurdle step* or single leg pickup
6 or single leg pick-up or single leg land or single leg balance or leg raise or tuck jump or vertical
7 jump or drop jump).mp.

8 34. (Functional movement screen* or PPM-16 or ((nine-test or movement or performance or
9 function) adj3 screening battery) or landing error scoring system* or balance error scoring
10 system*).mp.

11 35. or/32-34

12

13 36. (19 and 25 and 31) or 35

14

15 37. predictive value.mp.

16 38. (predict* or associat* or correlat*).ti.

17 39. ((predict* or correlat* or associat*) adj10 injur*).mp.

18 40. (receiver operator curve* or ROC or likelihood ratio* or specificity or ((positive* or negative*
19 or high* or low) adj4 correlat*).mp.

20 41. validation study/
21 42. comparative study/
22 43. outcome assessment/
23 44. observer variation/
24 45. health status indicator/
25 46. exp measurement precision/
26 47. statistical parameters/ or exp reliability/ or exp validity/
27 48. discriminant analysis/
28 49. (outcome assessment or outcome measure or observer variation or instrumentation or
29 psychometr* or clinimetr* or clinometr* or reproducib* or reliab* or unreliab* or valid* or
30 coefficient or homogeneity or homogeneous or internal consistency).mp.

31 50. ((cronbach* adj2 alpha*) or (item adj5 (correlation* or selection* or reduction*)) or
32 agreement or precision or imprecision or precise value* or test-retest or (test adj3 retest) or
33 stability).mp.

34 51. (interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or
35 intra-tester or interobserver or inter-observer or intraobserver or intraobserver or intertechnician
36 or inter-technician or intratechnician or intra-technician or interexaminer or inter-examiner or
37 intraexaminer or intra-examiner or interassay or inter-assay or intraassay or intra-assay or
38 interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-
39 participant or intraparticipant or intra-participant).mp.

40 52. (kappa* or repeatab* or ((replicab* or repeated) adj6 (measure or measures or findings or
41 result or results or test or tests)) or generaliza* or generalisa* or concordance or (intraclass and
42 correlation*) or discriminative or known group or factor analysis or factor analyses or dimension*
43 or subscale* or (multitrait adj6 scaling adj6 analys*) or item discriminant or interscale
44 correlation* or error or errors or individual variability or (variability adj8 (analysis or values)) or

1 (uncertainty adj6 (measurement or measuring)) or standard error of measurement or sensitiv* or
2 responsive* or ((minimal or minimally or clinical or clinically or mall*) adj6 (important or
3 significant or detectable or real) adj6 (change or difference)) or meaningful change or ceiling
4 effect or floor effect or Item response model or IRT or Rasch or Differential item functioning or
5 DIF or computer adaptive testing or item bank or cross-cultural equivalence).mp.
6 53. or/37-52
7
8 54. 8 and 14 and 36 and 53
9
10 55. limit 54 to animals
11 56. (mice or mouse or rat or rats or animal model* or bovine or rodent*).ti.
12 57. 54 not (55 or 56)
13 58. (arthroplast* or arthroscop* or TKA or THA or surgery or surgical).ti.
14 59. ((after or undergoing) adj5 reconstruction).ti.
15 60. (paraplegi* or brain injur* or stroke or post-stroke or concussion or polyneuropath* or
16 fibromyalgia or multiple sclerosis or arteriosclerosis or cancer or neoplasm* or malignanc* or
17 degenerative).ti.
18 61. "return to sport".ti.
19 62. (claudication or epidural or platelet-rich plasma or cadaver or spinal cord or spinal chord or
20 vibration or arterial disease or caffeine or pregnan* or breast or breasts or steroid*).ti.
21 63. 57 not (or/58-62)
22 64. limit 63 to (conference abstract or "conference review" or "review")
23 65. 63 not 64
24 66. case report/
25 67. case study/
26 68. case report*.jx.
27 69. ((case not (case control or case cohort or case crossover)) adj4 (series or study or
28 report*).ti.
29 70. 65 not (66 or 67 or 68)
30 71. limit 70 to english language
31

32 c. CINAHL Plus with Full Text

33 Search mode: Boolean/Phrase
34

35 S1: ((MH "Athletic Injuries+") OR (MH "Sports+") OR (MH "Military Personnel+")) OR (sport or
36 sports or athlet* or runners or (run* n2 (marathon* or competitive* or casual* or recreation*)) or
37 joggers or police* or officer* or firefighter* or firem* or "fire personnel" or military or army or navy
38 or "air force" or airforce or soldier* or "armed forces" or "armed service*" or "active duty*" or
39 veteran* or paramedic or "first responder*" or (emergency n2 responder*) or ambulance or
40 "emergency medical technician*") OR (active n3 (individual* or population* or participant* or
41 male* or female* or men or women or persons or students or adult* or patients or adolescent*))
42

43 S2: ((MH "Leg Injuries+") OR (MH "Knee Pain+") OR (MH "Femoracetabular Impingement") OR
44 (MH "Wounds and Injuries") OR (MH "Fractures") OR (MH "Sprains and Strains") OR (MH

1 "Dislocations") OR (MH "Athletic Injuries+") OR (MH "Tendon Injuries") OR (MH "Pain") OR (MH
2 "Joint Instability")) OR ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or
3 impingement* or instability) n6 (risk or risks or predict* or associat* or correlat* or screen* or
4 prevent* or sport* or athletic or running)) OR ((injur* or pain* or tear or tears or sprain* or
5 strain* or dislocation* or impingement* or instability) n8 ("lower extremit*" or "lower limb*" or hip
6 or hips or thigh or thighs or leg or legs or knee or knees or ankle* or foot or foots or toe or toes
7 or ACL or PCL or (cruciate n2 ligament*) or femoracetabular or femur or tibia* or patellofemoral
8 or patella*))
9
10 S3: ((MH "Leg Injuries+") OR (MH "Knee Pain+") OR (MH "Femoracetabular Impingement"))
11 OR ("lower extremit*" or "lower limb*" or hip or hips or thigh or thighs or leg or legs or knee or
12 knees or ankle* or foot or foots or toe or toes or ACL or PCL or (cruciate n2 ligament*) or
13 femoracetabular or femur or tibia* or patellofemoral or patella*) OR (run or running or jog* or
14 squat* or minisquat* or balance or lunge or lunges or hop or jump or jumping or walk or walking
15 or step-up or hurdle or gait)
16
17 S4: (motor or movement or motion or dynamic or moving) OR (exercis* or (physical n1 (activit*
18 or perform* or function*))) OR ((function* n1 (activ* or perform*))) OR (run or running or jog*
19 or squat* or minisquat* or balance or lunge or lunges or hop or jump or jumping or walk or
20 walking or step-up or hurdle or gait)
21
22 S5: (MH "Task Performance and Analysis") OR ("functional test*" or grade or grading or rating
23 or rated or score or scoring or rank or ranked or ranking) OR (movement n2 (screen* or
24 assess* or quality or performance or observation or observe* or test*)) OR ((performance or
25 objective or observation* or quality or control) n5 (measur* or test* or instrument* or method or
26 methods or index or indices or assess* or screen*)) OR ((deficit* or varus or valgus or
27 asymmetr* or "compensatory movement") and (measur* or test* or instrument* or method or
28 methods or index or indices or assess* or screen*))
29
30 S6: ((Lunge or Squat or Hop or jump or Reach or Cutting or Step-up or Balance or Push-up or
31 Lift or Rotation or walk*) n3 (test* or task* or assessment)) OR ("gait analys*" or "gait
32 evaluation*" or "deep squat*" or "one leg squat*" or mini-squat* or "mini squat*" or "in line
33 lunge*" or "inline lunge*" or "double leg drop" or "hop and hold*" or "Hurdle step*" or "single leg
34 pickup" or "single leg pick-up" or "single leg land" or "single leg balance" or "leg raise" or "tuck
35 jump" or "vertical jump" or "drop jump") OR ("functional movement screen*" or "landing error
36 scoring system*" or "balance error scoring system*" or ppm-16) OR ((nine-test or movement or
37 performance or function) n3 "screening battery")
38
39 S7: (S3 AND S4 AND S5) OR S6
40
41 S8: TI (predict* or associat* or correlat*)
42 S9: (MH "Discriminant Analysis") or (MH "Health Status Indicators") or (MH "Comparative
43 Studies")

1 S10: ("predictive value" or "receiver operator curve*" or ROC or "likelihood ratio*" or specificity)
2 OR ((predict* or correlat* or associat*) n10 (injur* or pain* or tear or tears or sprain* or strain* or
3 dislocation* or impingement* or instability)) OR ((positive* or negative* or high* or low) n4
4 correlat*)) OR ("outcome assessment" or "outcome measure*" or "observer variation*" or
5 instrumentation or psychometr* or clinimetr* or clinometr* or reproducib* or reliab* or unreliab*
6 or valid* or coefficient or homogeneity or homogeneous or "internal consistency")
7 S11: ((item n5 (correlation* or selection* or reduction*)) OR ("cronbach* alpha" or agreement
8 or precision or imprecision or "precise value*" or test-retest or (test n3 retest) or stability) OR (
9 interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or
10 intra-tester or interobserver or inter-observer or intraobserver or intraobserver or intertechnician
11 or inter-technician or intratechnician or intra-technician or interexaminer or inter-examiner or
12 intraexaminer or intra-examiner or interassay or inter-assay or intraassay or intra-assay or
13 interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-
14 participant or intraparticipant or intra-participant)
15 S12: ((replicab* or repeated) n6 (measure or measures or findings or result or results or test or
16 tests)) OR (kappa* or repeatab* or generaliza* or generalisa* or concordance or (intraclass
17 and correlation*) or discriminative or "known group" or "factor analysis" or "factor analyses" or
18 dimension* or subscale*) OR (multitrait n6 scaling n6 analys*) OR ("item discriminant" or
19 "interscale correlation*" or error or errors or "individual variability" or "standard error of
20 measurement" or sensitiv* or responsive*) OR (variability n8 (analysis or values)) OR (
21 uncertainty n6 (measurement or measuring)) OR ((minimal or minimally or clinical or clinically
22 or mall*) n6 (important or significant or detectable or real) n6 (change or difference)) OR (
23 "meaningful change" or "ceiling effect" or "floor effect" or "item response model" or IRT or Rasch
24 or "Differential item functioning" or DIF or "computer adaptive testing" or "item bank" or "cross-
25 cultural equivalence")
26 S13: S8 OR S9 OR S10 OR S11 OR S12
27 S14: S1 AND S2 AND S7 AND S13
28 S15: TI (ice or mouse or rat or rats or animal model* or bovine or rodent*) OR TI (arthroplast*
29 or arthroscop* or TKA or THA or surgery or surgical or paraplegi* or brain injur* or stroke or
30 post-stroke or concussion or polyneuropath* or fibromyalgia or multiple sclerosis or
31 arteriosclerosis or cancer or neoplasm* or malignanc* or degenerative or "return to sport" or
32 claudication or epidural or platelet-rich plasma or cadaver or spinal cord or spinal chord or
33 vibration or arterial disease or caffeine or pregnan* or breast or breasts or steroid*) OR TI ((after or undergoing) n5 reconstruction)
34 S16: PT review
35 S17: (MH "Case Studies")
36 S18: TI ((case NOT (case control or case cohort or case crossover)) n4 (series or study or
37 report*))
38 S19: SO case report*
39 S20: S14 NOT ((S15 OR S16 OR S17 OR S18 OR S19))
40 S21: S20 Limiters - Language: English
41
42
43 **d. SPORTDiscus**
44 Search mode: Boolean/Phrase

1
2 S1: AB ((athlet* or players or sport or sports or rugby or netball* or basketball* or hockey or
3 volleyball or skiers or snowboard* or soccer or football* or lacrosse or rowers or gymnasts or
4 "figure skaters" or dancers or tennis or badminton) OR (runners or (run* n2 (marathon* or
5 competitive* or casual* or recreation*)) or joggers or police* or officer* or firefighter* or fire* or
6 "fire personnel" or military or army or navy or "air force" or airforce or soldier* or "armed forces"
7 or "armed service*" or "active duty*" or veteran* or paramedic or "first responder*" or
8 (emergency n2 responder*) or ambulance or "emergency medical technician*") OR (active n3
9 (individual* or population* or participant* or male* or female* or men or women or persons or
10 students or adult* or patients or adolescent*))) OR KW ((athletes or players or sport or sports
11 or rugby or netball* or basketball* or hockey or volleyball or skiers or snowboard* or soccer or
12 football* or lacrosse or rowers or gymnasts or "figure skaters" or dancers or tennis or badminton
13) OR (runners or (run* n2 (marathon* or competitive* or casual* or recreation*)) or joggers or
14 police* or officer* or firefighter* or fire* or "fire personnel" or military or army or navy or "air
15 force" or airforce or soldier* or "armed forces" or "armed service*" or "active duty*" or veteran*
16 or paramedic or "first responder*" or (emergency n2 responder*) or ambulance or "emergency
17 medical technician*") OR (active n3 (individual* or population* or participant* or male* or
18 female* or men or women or persons or students or adult* or patients or adolescent*))) OR TI ((athletes or players or sport or sports or rugby or netball* or basketball* or hockey or volleyball
19 or skiers or snowboard* or soccer or football* or lacrosse or rowers or gymnasts or "figure
20 skaters" or dancers or tennis or badminton) OR (runners or (run* n2 (marathon* or
21 competitive* or casual* or recreation*)) or joggers or police* or officer* or firefighter* or fire* or
22 "fire personnel" or military or army or navy or "air force" or airforce or soldier* or "armed forces"
23 or "armed service*" or "active duty*" or veteran* or paramedic or "first responder*" or
24 (emergency n2 responder*) or ambulance or "emergency medical technician*") OR (active n3
25 (individual* or population* or participant* or male* or female* or men or women or persons or
26 students or adult* or patients or adolescent*))) OR SU ((athletes or players or sport or sports
27 or rugby or netball* or basketball* or hockey or volleyball or skiers or snowboard* or soccer or
28 football* or lacrosse or rowers or gymnasts or "figure skaters" or dancers or tennis or badminton
29) OR (runners or (run* n2 (marathon* or competitive* or casual* or recreation*)) or joggers or
30 police* or officer* or firefighter* or fire* or "fire personnel" or military or army or navy or "air
31 force" or airforce or soldier* or "armed forces" or "armed service*" or "active duty*" or veteran*
32 or paramedic or "first responder*" or (emergency n2 responder*) or ambulance or "emergency
33 medical technician*") OR (active n3 (individual* or population* or participant* or male* or
34 female* or men or women or persons or students or adult* or patients or adolescent*)))
35 S2: SU (injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or
36 instability)
37
38
39 S3: ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or impingement* or
40 instability) n6 (risk or risks or predict* or associat* or correlat* or screen* or prevent* or sport* or
41 athletic or running)) OR ((injur* or pain* or tear or tears or sprain* or strain* or dislocation* or
42 impingement* or instability) n8 ("lower extremit*" or "lower limb*" or hip or hips or thigh or thighs
43 or leg or legs or knee or knees or ankle* or foot or foots or toe or toes or ACL or PCL or
44 (cruciate n2 ligament*) or femoracetabular or femur or tibia* or patellofemoral or patella*))

1
2 S4: S2 OR S3
3
4 S5: ("lower extremit*" or "lower limb*" or hip or hips or thigh or thighs or leg or legs or knee or
5 knees or ankle* or foot or foots or toe or toes or ACL or PCL or (cruciate n2 ligament*) or
6 femoracetabular or femur or tibia* or patellofemoral or patella*) OR (run or running or jog* or
7 squat* or minisquat* or balance or lunge or lunges or hop or jump or jumping or walk or walking
8 or step-up or hurdle or gait)
9
10
11 S6: (motor or movement or motion or dynamic or moving or exercise) OR ((physical n1
12 (activit* or perform* or function*))) OR ((function* n1 (activ* or perform*))) OR (run or running
13 or jog* or squat* or minisquat* or balance or lunge or lunges or hop or jump or jumping or walk
14 or walking or step-up or hurdle or gait)
15
16 S7: ("functional test*" or grade or grading or rating or rated or score or scoring or rank or
17 ranked or ranking) OR (movement n2 (screen* or assess* or quality or performance or
18 observation or observe* or test*)) OR ((performance or objective or observation* or quality or
19 control) n5 (measur* or test* or instrument* or method or methods or index or indices or assess*
20 or screen*)) OR ((deficit* or varus or valgus or asymmetr* or "compensatory movement") and
21 (measur* or test* or instrument* or method or methods or index or indices or assess* or screen*
22))
23
24 S8: ((Lunge or Squat or Hop or jump or Reach or Cutting or Step-up or Balance or Push-up or
25 Lift or Rotation or walk*) n3 (test* or task* or assessment)) OR ("gait analys*" or "gait
26 evaluation*" or "deep squat*" or "one leg squat*" or "mini-squat*" or "mini squat*" or "in line
27 lunge*" or "inline lunge*" or "double leg drop" or "hop and hold*" or "Hurdle step*" or "single leg
28 pickup" or "single leg pick-up" or "single leg land" or "single leg balance" or "leg raise" or "tuck
29 jump" or "vertical jump" or "drop jump" or "functional movement screen*" or "landing error
30 scoring system*" or "balance error scoring system*" or ppm-16) OR ((nine-test or movement or
31 performance or function) n3 "screening battery")
32
33 S9: (S5 AND S6 AND S7) OR S8
34
35 S10:TI(predict* or associat* or correlat*)
36
37 S11: ("discriminant analys*" or "health status indicators" or "health indicators" or "predictive
38 value" or "receiver operator curve*" or ROC or "likelihood ratio*" or specificity) OR ((predict* or
39 correlat* or associat*) n10 (injur* or pain* or tear or tears or sprain* or strain* or dislocation* or
40 impingement* or instability)) OR ((positive* or negative* or high* or low) n4 correlat*)) OR ("outcome assessment" or "outcome measure*" or "observer variation*" or instrumentation or
41 psychometr* or clinimetr* or clinometr* or reproducib* or reliab* or unreliab* or valid* or
42 coefficient or homogeneity or homogeneous or "internal consistency")
43
44

1 S12:((item n5 (correlation* or selection* or reduction*))) OR ("cronbach* alpha" or agreement
2 or precision or imprecision or "precise value*" or test-retest or (test n3 retest) or stability) OR (
3 interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or
4 intra-tester or interobserver or inter-observer or intraobserver or intraobserver or intertechnician
5 or inter-technician or intratechnician or intra-technician or interexaminer or inter-examiner or
6 intraexaminer or intra-examiner or interassay or inter-assay or intraassay or intra-assay or
7 interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-
8 participant or intraparticipant or intra-participant)

9
10 S13: ((replicab* or repeated) n6 (measure or measures or findings or result or results or test or
11 tests)) OR (kappa* or repeatab* or generaliza* or generalisa* or concordance or (intraclass
12 and correlation*) or discriminative or "known group" or "factor analysis" or "factor analyses" or
13 dimension* or subscale*) OR (multitrait n6 scaling n6 analys*) OR ("item discriminant" or
14 "interscale correlation*" or error or errors or "individual variability" or "standard error of
15 measurement" or sensitiv* or responsive*) OR (variability n8 (analysis or values)) OR (
16 uncertainty n6 (measurement or measuring)) OR ((minimal or minimally or clinical or clinically
17 or mall*) n6 (important or significant or detectable or real) n6 (change or difference)) OR (
18 "meaningful change" or "ceiling effect" or "floor effect" or "item response model" or IRT or Rasch
19 or "Differential item functioning" or DIF or "computer adaptive testing" or "item bank" or "cross-
20 cultural equivalence")

21
22 S14: S10 OR S11 OR S12 OR S13

23
24 S15:S1 AND S4 AND S9 AND S14

25
26 S16: TI (mice or mouse or rat or rats or animal model* or bovine or rodent*) OR TI (
27 arthroplast* or arthroscop* or TKA or THA or surgery or surgical or paraplegi* or brain injur* or
28 stroke or post-stroke or concussion or polyneuropath* or fibromyalgia or multiple sclerosis or
29 arteriosclerosis or cancer or neoplasm* or malignanc* or degenerative or "return to sport" or
30 claudication or epidural or platelet-rich plasma or cadaver or spinal cord or spinal chord or
31 vibration or arterial disease or caffeine or pregnan* or breast or breasts or steroid*) OR TI (
32 (after or undergoing) n5 reconstruction)

33
34 S17:PT review OR PT (conference proceeding)

35
36 S18:SO "case report*" or "case stud*"

37
38 S19:TI ((case NOT (case control or case cohort or case crossover)) n4 (series or study or
39 report*))

40
41 S20: S15 NOT (S16 OR S17 OR S18 OR S19)

42
43
44

1 e. Scopus

2
3 ((((((TITLE-ABS-KEY (athlet* OR players OR sport OR sports OR rugby OR netball*
4 OR basketball* OR hockey OR volleyball OR skiers OR snowboard* OR soccer OR
5 football* OR lacrosse OR rowers OR gymnasts OR "figure skaters" OR dancers OR
6 tennis) OR TITLE-ABS-KEY (runners OR marathoners OR joggers OR police* OR
7 officer* OR firefighter* OR fire* OR "fire personnel" OR military OR army OR navy OR
8 "air force" OR airforce OR soldier* OR "armed forces" OR "armed service*" OR "active
9 duty*" OR veteran* OR paramedic*) OR TITLE-ABS-KEY ("first responder*" OR
10 ambulance OR "emergency medical technician*") OR TITLE-ABS-KEY ((active W/3 (
11 individual* OR population* OR participant* OR male* OR female* OR men OR women
12 OR persons OR students OR adult* OR patients OR adolescent*)))) AND ((TITLE-
13 ABS-KEY (((injur* OR pain* OR tear OR tears OR sprain* OR strain* OR dislocation*
14 OR impingement* OR instability) W/6 (risk OR risks OR predict* OR associat* OR
15 correlat* OR screen* OR prevent* OR sport* OR athletic OR running))) OR TITLE-
16 ABS-KEY (((injur* OR pain* OR tear OR tears OR sprain* OR strain* OR dislocation*
17 OR impingement* OR instability) W/8 ("lower extremit*" OR "lower limb*" OR hip OR
18 hips OR thigh OR thighs OR leg OR legs OR knee OR knees OR ankle* OR foot OR
19 foos OR toe OR toes))) OR TITLE-ABS-KEY (((injur* OR pain* OR tear OR tears
20 OR sprain* OR strain* OR dislocation* OR impingement* OR instability) W/8 (acl OR
21 pcl OR "cruciate ligament*" OR femoracetabular OR femur OR tibia* OR patellofemoral
22 OR patella))))) AND ((((TITLE-ABS-KEY ("lower extremit*" OR "lower limb*" OR hip
23 OR hips OR thigh OR thighs OR leg OR legs OR knee OR knees OR ankle* OR foot
24 OR foos OR toe OR toes OR acl OR pcl OR "cruciate ligament*" OR femoracetabular
25 OR femur OR tibia* OR patell*) OR TITLE-ABS-KEY (run OR running OR jog* OR
26 squat* OR lunge OR lunges OR hop OR jump OR jumping OR walk OR walking OR
27 step-up OR hurdle OR gait))) AND ((TITLE-ABS-KEY (motor OR movement OR
28 motion OR dynamic OR moving OR exercise) OR TITLE-ABS-KEY ((physical W/1 (
29 activit* OR perform* OR function*))) OR TITLE-ABS-KEY ((function* W/1 (activ* OR
30 perform*))) OR TITLE-ABS-KEY (run OR running OR jog* OR squat* OR minisquat*
31 OR balance OR lunge OR lunges OR hop OR jump OR jumping OR walk OR walking
32 OR step-up OR hurdle OR gait))) AND ((TITLE-ABS-KEY ("functional test*" OR grade
33 OR grading OR rating OR rated OR score OR scoring OR RANK OR ranked OR
34 ranking) OR TITLE-ABS-KEY (movement W/2 (screen* OR assess* OR quality OR
35 performance OR observation OR observe* OR test*)) OR TITLE-ABS-KEY ((
36 performance OR objective OR observation* OR quality OR control) W/5 (measur* OR
37 test* OR instrument* OR method OR methods OR INDEX OR indices OR assess* OR
38 screen*)) OR TITLE-ABS-KEY ((deficit* OR varus OR valgus OR asymmetr* OR
39 "compensatory movement") AND (measur* OR test* OR instrument* OR method OR
40 methods OR INDEX OR indices OR assess* OR screen*))))) OR ((TITLE-ABS-KEY (
41 lunge OR squat OR hop OR jump OR reach OR cutting OR step-up OR balance OR
42 push-up OR lift OR rotation OR walk*) W/3 (test* OR task* OR assessment)) OR
43 TITLE-ABS-KEY ("gait analys*" OR "gait evaluation*" OR "deep squat*" OR "one leg
44 squat*" OR mini-squat* OR "mini squat*" OR "in line lunge*" OR "inline lunge*" OR

1 "double leg drop" OR "hop and hold*" OR "Hurdle step*") OR TITLE-ABS-KEY ("single leg
2 pickup" OR "single leg pick-up" OR "single leg land" OR "single leg balance" OR "leg raise"
3 OR "tuck jump" OR "vertical jump" OR "drop jump" OR "functional movement screen*" OR
4 "landing error scoring system*") OR TITLE-ABS-KEY ("balance error scoring system*" OR
5 ppm-16) OR ((nine-test OR movement OR performance OR function) n3 "screening
6 battery"))) AND (((TITLE (predict* OR associat* OR correlat*) OR TITLE-ABS-KEY
7 ("discriminant analys*" OR "health status indicators" OR "health indicators" OR "predictive
8 value" OR "receiver operator curve*" OR roc OR "likelihood ratio*" OR specificity) OR
9 TITLE-ABS-KEY ((predict* OR correlat* OR associat*) W/10 (injur* OR pain* OR tear
10 OR tears OR sprain* OR strain* OR dislocation* OR impingement* OR instability)) OR
11 TITLE-ABS-KEY ((positive* OR negative* OR high* OR low) W/4 correlat*) OR TITLE-
12 ABS-KEY ("observer variation*" OR instrumentation OR psychometr* OR clinimetr* OR
13 clinometr* OR reproducib* OR reliab* OR unreliab* OR valid* OR coefficient OR
14 homogeneity OR homogeneous OR "internal consistency"))) OR ((TITLE-ABS-KEY (
15 item W/5 (correlation* OR selection* OR reduction*)) OR TITLE-ABS-KEY ("cronbach*
16 alpha" OR agreement OR precision OR imprecision OR "precise value*" OR test-retest
17 OR (test W/3 retest)) OR TITLE-ABS-KEY (interrater OR inter-rater OR intrarater OR
18 intra-rater OR intertester OR inter-tester OR intratester OR intra-tester OR interobserver
19 OR inter-observer OR intraobserver OR intraobserver OR intertechnician OR inter-
20 technician OR intratechnician) OR TITLE-ABS-KEY (intra-technician OR interexaminer
21 OR inter-examiner OR intraexaminer OR intra-examiner OR interassay OR inter-assay
22 OR intraassay OR intra-assay OR interindividual OR inter-individual OR intraindividual)
23 OR TITLE-ABS-KEY (intra-individual OR interparticipant OR inter-participant OR
24 intraparticipant OR intra-participant))) OR ((TITLE-ABS-KEY ((replicab* OR repeated)
25 W/6 (measure OR measures OR findings OR result OR results OR test OR tests))
26 OR TITLE-ABS-KEY (kappa* OR repeatab* OR generaliza* OR generalisa* OR
27 concordance OR (intraclass AND correlation*)) OR TITLE-ABS-KEY (discriminative OR
28 "known group" OR "factor analysis" OR "factor analyses" OR dimension* OR subscale*)
29 OR TITLE-ABS-KEY (multitrait W/6 scaling W/6 analys*) OR TITLE-ABS-KEY ("item
30 discriminant" OR "interscale correlation*" OR "individual variability" OR "standard error of
31 measurement" OR sensitiv* OR responsive*) OR TITLE-ABS-KEY ((minimal OR
32 minimally OR clinical OR clinically OR mall*) W/6 (important OR significant OR
33 detectable OR real) W/6 (change OR difference)) OR TITLE-ABS-KEY ("meaningful
34 change" OR "ceiling effect" OR "floor effect" OR "item response model" OR irt OR rasch
35 OR "Differential item functioning" OR dif OR "computer adaptive testing" OR "item bank"
36 OR "cross-cultural equivalence")))) AND NOT ((TITLE (mice OR mouse OR rat OR
37 rats OR animal model* OR bovine OR rodent*) OR TITLE (arthroplast* OR arthroscop*
38 OR tka OR tha OR surgery OR surgical OR paraplegi* OR brain injur* OR stroke OR
39 post-stroke OR concussion OR polyneuropath* OR fibromyalgia OR "multiple sclerosis")
40 OR TITLE (arteriosclerosis OR cancer OR neoplasm* OR malignanc* OR degenerative
41 OR "return to sport" OR claudication OR epidural OR platelet-rich plasma OR cadaver
42 OR spinal cord OR spinal chord OR vibration OR arterial disease OR caffeine OR
43 pregnan* OR breast) OR TITLE ((after OR undergoing) n5 reconstruction))) AND
44 NOT ((TITLE ("case report" OR "case study" OR "case series") AND KEY ("case report"

1 OR "case study" OR "case series") AND SRCTITLE ("case report*" OR "case stud*")))
2 AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (DOCTYPE , "re") OR
3 EXCLUDE (DOCTYPE , "cp") OR EXCLUDE (DOCTYPE , "cr"))

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5 **RESULTS**

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Database	Date searched	# of results
Medline	Jan 5, 2016	1716
CINAHL	Jan 5, 2016	1329
EMBASE	Jan 5, 2016	1505
SportDiscus	Jan 5, 2016	1497
Scopus	Jan 5, 2016	2172
Total		8219

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1 **APPENDIX 2: DOWN'S AND BLACK QUALITY ASSESSMENT CRITERIA SCORED FOR**
 2 **INCLUDED STUDIES.**
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	Item	Score
1	Is the hypothesis/aim/objective of the study clearly described?	yes=1; no=0
2	Are the main outcomes to be measured clearly described in the Introduction or Methods section?	yes=1; no=0
3	Are the characteristics of the patients included in the study clearly described?	yes=1; no=0
4	*Are the interventions of interest clearly described?	yes=1; no=0
5	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	yes=2; partially=1; no=0
6	Are the main findings of the study clearly described?	yes=1; no=0
7	Does the study provide estimates of the random variability in the data for the main outcomes?	yes=1; no=0
8	*Have all important adverse events that may be a consequence of the intervention been reported?	yes=1; no=0
9	Have the characteristics of patients lost to follow-up been described?	yes=1; no=0
10	Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	yes=1; no=0
11	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	yes=1; no=0
12	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	yes=1; no=0
13	Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?	yes=1; no=0
14	*Was an attempt made to blind study subjects to the intervention they have received?	yes=1; no=0
15	Was an attempt made to blind those measuring the main outcomes of the intervention?	yes=1; no=0
16	If any of the results of the study were based on "data dredging", was this made clear?	yes=1; no=0
17	In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?	yes=1; no=0
18	Were the statistical tests used to assess the main outcomes appropriate?	yes=1; no=0
19	*Was compliance with the intervention/s reliable?	yes=1; no=0
20	Were the main outcome measures used accurate (valid and reliable)?	yes=1; no=0
21	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	yes=1; no=0
22	Were study subjects in different intervention groups (trials and	yes=1; no=0

	cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	
23	*Were study subjects randomized to intervention groups?	yes=1; no=0
24	*Was the randomized intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?	yes=1; no=0
25	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	yes=1; no=0
26	Were losses of patients to follow-up taken into account?	yes=1; no=0
27	*Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	Size of smallest intervent group: <n1=0; n1-n2=1; n3-n4=2; n5-n6=3; n7-n8; n8+=5

1 Items 1-10 = reporting, 11-13 = external validity, 14-20 = internal validity (bias), 21-26 = internal
2 validity (confounding) and 27 = power. *not applicable to observational studies.
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APPENDIX 3: LEVELS OF EVIDENCE ADAPTED FROM THE OXFORD CENTRE FOR EVIDENCE-BASED MEDICINE MODEL 2009¹⁶

Level	Description	
1	a	Systematic reviews (with homogeneity) of randomized controlled trials
	b	Individual randomized controlled trials (with narrow confidence intervals)
	c	All or none randomized controlled trials
2	a	Systematic reviews (with homogeneity) of cohort studies
	b	Individual cohort study or low quality randomized controlled trials (e.g. <80% follow-up)
	c	"Outcomes" research; ecological studies
3	a	Systematic review (with homogeneity) of case-control studies
	b	Individual case-control study
	c	Cross-sectional studies
4		Case-series (and poor quality cohort and case-control studies)
5		Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles"

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Appendix 4. Summary of Data Extracted from Included Studies

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Study Features (author, year, design, country)	Participants (sport, level, sex, age, sample size)	Outcome (definition and ascertainment)	Injury estimate	Exposure (Risk factor(s))	Reported as significant risk factor(s)	Reported statistics	Reported non-significant risk factor(s)	DB score (/23)^	Level of Evidence
Azzam et al., 2015 ¹⁸ Historical Cohort United States	Professional Basketball Players Male = 34 Age = not reported n = 34 (17 injuries)	Injury = traumatic or overuse MSK event resulting from basketball that led to time loss of ≥7 days from practice and/or games. Ascertained by ATC	50% of players experienced an injury over the 2008-2011 seasons	<i>Movement Quality</i> • DS • HS • ILL • SM • ASLR • TSPU • RS • FMS total ≤ 14 <i>Other</i> • Minutes/game • Total games	1. Higher HS score	1. p<0.001*	• DS • ILL • SM • ASLR • TSPU • RS • FMS total score ≤ 14	9	4
Bardenett et al., 2015 ¹⁹ Cohort United States	High School Athletes (multiple sports) Male = 77 Female = 97 Mean age (range): 15.2 (11-18) n=176 (39 injuries)	Injury = a MSK injury resulting from organized high school sport practice or competition that required medical attention (sought care from ATC, PT, physician or other health care provider) and was restricted from full participation ≥1 practice or game. Ascertained by ATC	69.5% of players experienced an injury over the 2012 fall season	<i>Movement Quality</i> • DS • HS • ILL • SM • ASLR • TSPU • RS • FMS total • FMS total ≤11, 12, 13, 14, 15, 16, 17 <i>Other</i> • Age	1. Higher ILL score 2. Lower SM score	1. p=0.02* 2. p=0.001*	• Age • DS • HS • ASLR • TSPU • RS • FMS total score • FMS total score ≤ 11, 12, 13, 14, 15, 16, 17	12	4
Bushman et al., 2015 ²⁰ Cohort United States	Military Soldiers Male = 2,476 Age range: 18-57	Injury = all inpatient and outpatient medical encounters for any overuse and traumatic injury	Any injury: 37% Overuse: 28% Traumatic 16% In the 6 months following	<i>Movement Quality</i> • DS • HS • ILL • SM • ASLR	<i>Any injury</i> 1. FMS = 0 2. BMI (≥25.0 kg/m ²) 3. DS = 0 4. HS = 0	1. RR 1.3-2.1* 2. OR 1.3 (95% CI: 1.0,1.9)* p=0.02 3. OR 1.5 (1.1,2.0)*§	• Sex • Age • Military rank • Current smoker • SM	12	4

	n = 2,476 (916 injuries)	found in a soldiers' electronic medical records with ECD-9_CM diagnostic code determined to be an injury. Overuse injuries ICD-9-CM codes 710-739 Traumatic injuries ICD-9-CM codes 800-999 Ascertained by Defense Medial Surveillance System	screening	<ul style="list-style-type: none"> • TSPU • RS • FMS individual test = 0 • FMS total = 0 <p><i>Other</i></p> <ul style="list-style-type: none"> • Sex • Age • Military rank • BMI • Current smoker 	5. ILL = 0 6. TSPU = 0 7. RS = 0 <i>Overuse</i> 8. DS = 0 9. HS = 0 10. ILL = 0 11. TSPU = 0 12. RS = 0 <i>Traumatic</i> 13. HS 14. TSPU	p<0.01 4. OR 3.5 (2.1,6.0)*§ p<0.01 5. OR 2.4 (1.5,3.8)*§ p<0.01 6. OR 2.0 (1.3,3.3)*§ p<0.01 7. OR 1.7 (1.0,2.8)*§ p=0.03 8. Not reported 9. Not reported 10. Not reported 11. Not reported 12. Not reported 13. Not reported 14. Not reported	<ul style="list-style-type: none"> • ASLR 		
Butler et al., 2013 ²¹ Cohort United States	Firefighter trainees Sex = not reported Age: not reported n=108 (number of injuries not reported)	Injury = any episode that resulted in 3 consecutive missed days of training due to MSK pain Ascertained: Strength and conditioning staff	No injury estimate was reported for the 16 week training academy	<ul style="list-style-type: none"> • DS • HS • ILL • SM • ASLR • TSPU • RS • FMS total ≤14 	1. Lower DS score 2. Lower TSPU score 3. FMS total ≤ 14	1. OR 1.2 (1.0,1.4)* 2. OR 1.3 (1.1,1.5)* 3. OR 8.31 (3.2,21.6)* SEN: 0.83 SPE: 0.62 PLR: 2.2 NLR: 0.26	<ul style="list-style-type: none"> • HS • ILL • SM • ASLR • RS 	8	4
Chorba et al., 2010 ²² Cohort United States	NCAA Division II collegiate athletes Female = 38 Mean age (SD): 19.2±1.2 n=38 (18 injuries)	Injury = a MSK injury resulting from organized intercollegiate sport practice or competition that required medical attention or advice from an ATC, AT student or physician.	47% of players experienced an injury over the 2007-2008 season	<ul style="list-style-type: none"> • FMS total ≤14 	1. FMS total ≤ 14	1. OR 3.85 (0.98,0.15.1) p=0.05 SEN = 0.58 SPE = 0.74	n/a	9	4

Dossa et al., 2014 ³¹	Junior hockey players	Ascertained: ATC Injury = a physical condition which occurred during a game or practice which resulted in the player missing ≥ 1 game. Contact = involved collision with another body, ice, boards, puck or stick. Non-contact = not a contact injury Ascertained: ATC	85% of players experienced an injury over the 2013-2014 season (76 games)	<ul style="list-style-type: none"> FMS total ≤ 14 	n/a	n/a	<ul style="list-style-type: none"> FMS total ≤ 14 SEN: 0.5 (0.2,0.8) SPE: 0.7 (0.3,0.9) PLR: 1.7 (0.6,5.2) NLR: 0.7 (0.2,0.9)	12	4
Garrison et al., 2015 ²³	NCAA Division I collegiate athletes	Injury = any MSK pain complaint associated with athletic participation, that required consultation with an ATC, PT or MD and resulted in modified training for ≥ 24 hours or required protective splinting or taping for continued participation Ascertained: ATC	32.5% of players experienced an injury over the season	<i>Movement Quality</i> <ul style="list-style-type: none"> FMS total FMS total ≤ 14 Prior injury + FMS total ≤ 14 FMS total ≤ 13 Prior injury + FMS total ≤ 13 <i>Other</i> <ul style="list-style-type: none"> Prior injury 	1. Prior injury 2. FMS total 3. FMS total ≤ 14 4. Prior injury + FMS total ≤ 14 5. FMS total ≤ 13 6. Prior injury + FMS total ≤ 13	1. OR 3.45 (1.7,7.0)* 2. $p < 0.05$ 3. OR 5.61* (2.7,11.5) 4. OR 15.11* (6.6,34.6) 5. OR 9.52* (4.1,21.8) 6. OR 11.86* (4.1,34.2)	n/a	8	4
Hotta et al., 2015 ³³	Collegiate track and field athletes	Running injury = a MSK injury that occurred during participation in track and field practice or competition that	17.9% of runners experienced an injury over a 6 month season	<i>Movement Quality</i> <ul style="list-style-type: none"> DS HS ILL SM ASLR TSPU 	1. Lower DS score 2. Lower ASLR score 3. DS+ASLR score ≤ 3	1. $p = 0.01^*$ 2. $p < 0.01^*$ 3. OR = 9.7 (2.1,44.4)* [§] $p < 0.01$	<ul style="list-style-type: none"> HS ILL SM TSPU RS FMS total ≤ 14 Age 	14	4

	(range): 20.0 (18-24) n= 84 (15 injuries)	prevented participation for 4 weeks. Ascertained: not reported		<ul style="list-style-type: none"> • RS • FMS total ≤ 14 <i>Other</i> <ul style="list-style-type: none"> • Age • Height • Weight • Running experience • Weekly training sessions • Weekly mileage • Performance level • Prior injury 			<ul style="list-style-type: none"> • Height • Weight • Running experience • Weekly training sessions • Weekly mileage • Performance level • Prior injury 		
Kiesel et al., 2007 ²⁴ Cohort United States	Professional American football players Sex = not reported Age = not reported n=46 (13 injuries)	Injury = on the injury reserve list and a time loss of ≥ 3 weeks. Ascertained: not reported	28.3% of players experienced an injury over the season	<ul style="list-style-type: none"> • FMS total • FMS total ≤ 14 	1. Lower FMS score 2. FMS total ≤ 14	1. $p < 0.05^*$ ($t = 5.62$) 2. OR 11.67* (2.5,54.5) SEN: 0.54 (0.3,0.7) SPE: 0.91 (0.8,0.96) PLR: 5.92 (2.0,18.4) NLR: 0.51 (0.3,0.8)	n/a	7	4
Kiesel et al., 2014 ²⁵ Cohort United States	Professional American football players Sex = not reported Age = not reported n=238 (60 injuries)	Injury = MSK injury resulting in time loss from preseason practice or games. Ascertained: Sports medicine staff	25% of players experienced an injury over the preseason	<ul style="list-style-type: none"> • FMS total • FMS asymmetry • FMS total ≤ 14 • Asymmetry + FMS total ≤ 14 	1. FMS total 2. FMS asymmetry 3. FMS total ≤ 14 4. Asymmetry + FMS total ≤ 14	1. $p = 0.02^*$ 2. RR 1.80 (1.1,2.7)* SEN: 0.58 (0.5,0.7) SPE: 0.62 (0.6,0.7) 3. RR 1.87 (1.2,3.0)* SEN: 0.26 (0.2,0.4) SPE: 0.87 (0.8,0.9)	<ul style="list-style-type: none"> • Asymmetry + FMS total ≤ 14 (not reported) 	8	4

<p>Knapik et al., 2015²⁶</p> <p>Historical Cohort</p> <p>United States</p>	<p>Coast Guard cadets</p> <p>Male = 770 Female = 275</p> <p>Mean age (SD) Male: 18.1 (0.7) Female: 17.9 (0.7)</p> <p>n=1,045 (number of injuries not reported)</p>	<p>Injury = any physical bodily damage resulting in a clinic visit which was suspected to be caused by cadet training.</p> <p>Ascertained: PT and other health care providers</p>	<p>Male = CII 18.6%</p> <p>Female = CII 24.7%</p> <p>For candidates attending classes between 2004-2007</p>	<ul style="list-style-type: none"> • FMS total ≤9 • FMS total ≤10 • FMS total ≤11 • FMS total ≤12 • FMS total ≤13 • FMS total ≤14 • FMS total ≤15 • FMS total ≤16 • FMS total ≤17 • FMS total ≤18 • FMS total ≤19 <p>Calculated for males and females separately</p>	<p><i>Males</i></p> <ol style="list-style-type: none"> 1. FMS total ≤9 2. FMS total ≤10 3. FMS total ≤11 <p><i>Females</i></p> <ol style="list-style-type: none"> 4. FMS total ≤9 5. FMS total ≤10 6. FMS total ≤11 7. FMS total ≤12 8. FMS total ≤13 9. FMS total ≤14 10. FMS total ≤15 	<p><i>Males</i></p> <ol style="list-style-type: none"> 1. RR 1.63 (1.1,2.4) p=0.02* 2. RR 1.73 (1.2,2.5) p<0.01* 3. RR 1.64 (1.2,2.3) p<0.01* <p>SEN: 0.22 SPE: 0.87</p> <p><i>Females</i></p> <ol style="list-style-type: none"> 4. RR 1.91 (1.2,3.0) p<0.01* 5. RR 1.81 (1.2,2.8) p=0.02* 6. RR 1.85 (1.1,2.7) p=0.02* 7. RR 1.66 (1.1,2.6) p=0.03* 8. RR 1.83 (1.2,2.7) p<0.01* 9. RR 1.93 (1.2,3.0) p<0.01* <p>SEN: 0.60 SPE: 0.61</p> <p>10. RR 1.97 (1.2,3.2) p<0.01*</p>	<p><i>Males</i></p> <ul style="list-style-type: none"> • FMS total ≤12 • FMS total ≤13 • FMS total ≤14 • FMS total ≤15 • FMS total ≤16 • FMS total ≤17 • FMS total ≤18 • FMS total ≤19 <p><i>Females</i></p> <ul style="list-style-type: none"> • FMS total ≤16 • FMS total ≤17 • FMS total ≤18 • FMS total ≤19 	<p>9</p>	<p>4</p>
<p>Lisman et al., 2013²⁷</p> <p>Cohort</p>	<p>Marine Corps Officer Trainees</p> <p>Male = 874</p>	<p>Any Injury = sought medical care ≥1 times during training due to physical</p>	<p>Not reported (6 or 10 week training)</p>	<p><i>Movement Quality</i></p> <ul style="list-style-type: none"> • FMS total ≤14 <p><i>Other</i></p>	<p><i>Any Injury</i></p> <ol style="list-style-type: none"> 1. Prior injury 2. Longer training 3. Slower RT 	<p><i>Any Injury</i></p> <ol style="list-style-type: none"> 1. OR 1.41 (1.1,1.9)* p=0.02 2. OR 1.49 	<ul style="list-style-type: none"> • Baseline running frequency ≥5 • Baseline 	<p>15</p>	<p>2b</p>

United States	Mean age (SD): 22.4±2.7 n=874 (number of injuries not reported)	bodily damage resulting from training Overuse = sought medical care for presumed long-term repetitive energy exchanges that led to cumulative micro-trauma Traumatic = sought medical care for acute or sudden energy exchanges leading to abrupt overload and tissue damage Ascertained: Health care providers		<ul style="list-style-type: none"> • Prior injury • Baseline GES frequency ≥5 • Baseline running frequency ≥5 • Run history • Baseline weight training frequency ≤1, 2-4, ≥5 • Training length (6 or 10 weeks) • PU ≥17 • AC ≥100 • RT ≥20.5 	4. FMS total ≤14 <i>Overuse</i> 5. Less GES 6. Longer training 7. Slower RT <i>Traumatic</i> 8. Less running history 9. Longer training 10. Slower RT 11. FMS total ≤14	(1.1,2.0)*§ p=0.009 3. OR 1.74 (1.3,2.4)*§ p<0.001 4. OR 2.10 (1.3,3.3)*§ p=0.001 <i>Overuse</i> 5. OR 1.78 (1.1,2.9)*§ p=0.014 6. OR 1.6 (1.0,2.6)* p=0.32 7. OR 1.65 (1.0,2.6)* p=0.032 <i>Traumatic</i> 8. OR 2.07 (1.1,3.9)* p=0.023 9. OR 1.47 (1.1,2.0)*§ p=0.021 10. OR 1.64 (1.2,2.3)*§ p=0.003 11. OR 1.80 (1.1,2.9)*§ p=0.015	weight training frequency <ul style="list-style-type: none"> • PU ≥17 • AC ≥100 		
Padua et al., 2015 ²⁸ Cohort United States	Elite youth soccer players Male = 348 Female = 481 Mean age (SD, Range): 13.9 (1.8, 11-18)	Injury = ACL tear verified at surgical reconstruction Non-contact = no direct contact to the LE by an external force Indirect-Contact =	0.8 % of players experienced an ACL tear over 2006-2009 seasons IRR = 0.006 (0.002,0.012)	<ul style="list-style-type: none"> • LESS total • LESS ≥5 	1. Higher LESS total 2. LESS ≥5	1. t=-2.78, p< 0.005* 2. RR 10.7 SEN: 0.86 (0.42, 0.99) SPE: 0.65 (0.62,0.67) PPV: 0.01 (0.006,0.03)	n/a	11	2b

	n=829 (7 injuries)	contact with a body part other than the knee Ascertained: self-report verified by surgeon				NPV: 0.998 (0.991,0.999)			
Shojaedin et al., 2014 ³² Cohort Iran	Competitive or recreational university athletes Male = 50 Female = 50 Mean age (SD; range): 22.6 (3.0; 18-25) n=100 (35 injuries)	Any injury = not reported Knee injury = not reported Ankle injury = not reported	35% sustained injury during the season	<ul style="list-style-type: none"> • FMS total • FMS score <17 	<i>Any injury</i> 1. FMS total <17 2. FMS total <17 <i>Knee Injury</i> 3. FMS total <17 <i>Ankle Injury</i> 4. FMS total <17	<i>Any Injury</i> 1. p=0.005 2. OR 4.70 (no p-value or 95%CI reported) SEN: 0.65 SPE: 0.78 PLR: 2.46 NLR: 0.62	<ul style="list-style-type: none"> • FMS total <17 for knee and ankle injury 	3	4
Smith et al., 2012 ³⁴ Case-control (embedded in a cohort) United States	High school and college athletes Male = 29 Female = 73 Mean age (SD): 18.3 (2) n= 92 (28 injured)	Noncontact ACL tear = ACL tear resulting from a non- knee contact event with another athlete, ground, or extraneous structure Ascertained: orthopedic surgeon, MRI and surgery	30.4% of athletes sustained an injury over 1 season	<ul style="list-style-type: none"> • LESS total • LESS ≤ 4 • LESS >4- ≤5 • LESS >5 -≤6 • LESS >6 	• n/a	• n/a	<ul style="list-style-type: none"> • LESS total • LESS ≤ 4 • LESS >4- ≤5 • LESS >5 -≤6 • LESS >6 	14	3b
Warren et al., 2015 ²⁹ Cohort United States	NCAA Division 1 collegiate athletes Male = 89 Female = 78 Age range: 18-	Injury = First non-contact MSK problem that resulted in medical intervention. Non-contact injury: non-contact	44% of athletes experienced an injury over the competitive season	<i>Movement Quality</i> <ul style="list-style-type: none"> • DS • HS • ILL • SM • ASLR • TSPU • RS • FMS total 	1. Female sex 2. Older age 3. Lower BMI 4. ILL = 2	1. p=0.003* 2. p=0.006* 3. p=0.006* 4. OR 0.21* [§] (0.08,0.59)	1. Prior injury 2. Sport 3. DS 4. HS 5. SM 6. ASLR 7. TSPU 8. RS 9. FMS total	11	4

	24 n= 167 (74 injuries)	mechanism Contact injury = contact mechanism Ascertained: ATC		<ul style="list-style-type: none"> • FMS total ≤10 • FMS total ≤12 • FMS total ≤14 • FMS total ≤16 • FMS total ≤18 • Asymmetry of 5 bilateral FMS tests <p><i>Other</i></p> <ul style="list-style-type: none"> • Prior injury • Sex • Age • BMI • Sport 			<ul style="list-style-type: none"> 10.FMS total ≤10 11.FMS total ≤12 12.FMS total ≤14 13.FMS total ≤16 14.FMS total ≤18 15.Asymmetry of 5 bilateral FMS tests 		
Wiese et al., 2014 ³⁰ Cohort United States	NCAA Division 1 collegiate American football players Sex: not reported Mean age (SD): 18.9 ± 1.3 n = 144 (93 injuries)	Injury = initial MSK problem arising from organized training or game requiring medical attention and restricted participation for ≤1 days LE injury = groin – toes Overuse injury = tendinopathy, muscle spasm, tightness or soreness Non-contact injury = non-contact mechanism Injury >10 days Ascertained: ATC	65% of players experienced an injury over 1 season 52% LE 39% overuse 42% noncontact 20% >10 days	<ul style="list-style-type: none"> • FMS total • FMS total ≤12 • FMS total ≤17 • FMS total ≤18 	• n/a	• n/a	<ul style="list-style-type: none"> • FMS total • FMS total ≤12 • FMS total ≤17 • FMS total ≤18 	10	4

1 *Statistically significant $p < 0.05$, §Multivariable analyses, ¶Estimated from reported injury incidence, +analyses did not account for
2 matched design, ^Maximum Downs and Black Score for prospective cohort study = 23, while the maximum score for a randomized
3 control trial is 33, AC = abdominal crunch, ASLR = active straight leg raise, ATC = certified athletic trainers, BMI = body mass index
4 (kg/m^2), CI = confidence interval, DB = Downs and Black Score, DF = dorsiflexion, DS = deep squat, FMS = Functional Movement
5 Screen, GES = general sport and exercise, HR = Hazard ratio, hrs=hours, HS = hurdle step, ICD-9-CM = International Classification
6 of Disease, Ninth Revision, Clinical Modification, ILL = in-line lunge, IR = incidence rate, IRR = incidence rate ratio, LE = lower
7 extremity, LESS = Landing Error Scoring System, LOE = level of evidence, n/a = not applicable, MD = medical doctor, MSK =
8 musculoskeletal, n/a = not applicable, NLR = negative likelihood ratio, OR = odds ratio, PLR = positive likelihood ratio, PT = physical
9 therapists, PU = pull ups, ROM=range of motion, RR = risk ratio, RS = rotary stability, RT = 3-mile run time, SD = standard deviation,
10 SLHB = single leg hamstring bridge, SLR = straight leg raise, SM = shoulder mobility, TOP = tenderness on palpation, TSPU = trunk
11 stability push-up, TXHD = triple cross-over hop for distance, UE = upper extremity, VDJ = vertical drop jump, wks = weeks, YBT = Y-
12 balance test, yrs = years.

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