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Hamstrings injury incidence, risk factors, and prevention in Rugby Union players: A systematic review

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ABSTRACT

Background

Hamstring strain injuries are one of the most common injuries in Rugby Union, representing up to 15% of all injuries sustained. We aimed to systematically review and summarize the scientific literature that addressed hamstring strain injury incidence, risk factors, injury prevention or strengthening strategies, and strength or asymmetry measures in Rugby Union.

Methods

We conducted a systematic search to locate published peer-reviewed articles from PubMed, SPORTDiscusTM, Web of Science®, and Scopus® e-databases. Studies included were original research conducted in Rugby Union that evaluated hamstring strength, hamstring strengthening interventions, and/or hamstring injury outcomes. Included studies were quality assessed using the Newcastle-Ottawa Scale.

Results

Twenty-four studies met inclusion and altogether involved 2866 participants. Isokinetic testing was the most common method used to quantify hamstring strength and imbalances in Rugby Union; with data indicating that professionals are stronger than amateurs, and forwards are stronger than backs. Regarding risk factors, we identified playing position, fatigue, previous injuries, between leg strength imbalances, lack of readiness to return to play post injury, and game actions (i.e., running). There is evidence to support the use of Nordic eccentric strength measures to inform practice, with strength and imbalances useful in

predicting injuries. Strengthening programs with Nordic exercises significantly increased hamstring strength, increased musc

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le thickness, and decreased imbalance ratios in female and male players. A significant reduction in injury incidence and severity in professional players has been observed in players performing routines incorporating progressive Nordic exercises.

Conclusion

The aetiology of hamstring strain injuries is multifactorial, with playing position, fatigue, previous injuries, leg imbalances, lack of readiness to return to play, and running actions identified as contributing factors across levels. Combining strategies to prevent hamstring injuries and recurrences, and to inform return to play, is likely worthwhile and should include Nordic strength assessment and Nordic exercises.

Keywords

Hamstrings; strength; training; injuries; football.

1. Introduction

Hamstring strain injuries are one of the most common injuries in Rugby Union and represent 6 to 15% of all sustained injuries [1]. With respect to the epidemiology of hamstring injuries, acute hamstring strains have the highest recurrence rate of any muscle injury [2]. A previous hamstring injury is a paramount risk factor to sustaining another hamstring injury [3] and the elevated risk is proposed to be due to residual neuromuscular inhibition, strength deficits, altered muscle tendon morphology, and modified contractile mechanics [2].

The 2019 Rugby World Cup injury surveillance data revealed lower limb injuries accounted for almost 50% of all players absence days [4]. Hamstring strains were the second most common match injury after concussion, with hamstring injuries representing 9.8% of all

match injuries and causing 467 missed days. The England Rugby Football Union reported that hamstring strains were their most common injury during training and the second most common injury during match play with 6.4 injuries per 1000 hours [5]. Moreover, the Welsh injury surveillance report from 2012 to 2016 recorded an increase in posterior thigh injury from 6.7 to 7.7 per 1000 hours, as well as 155.7 to 172.6 days lost during that time frame [6]. Hamstring strains are also of considerable concern at a younger school-age level, representing 21% of all injuries [7] and comprising 23% of all training time-loss in male amateur players.

Regarding prevention of sport-related injuries, a multifactorial approach is required and should involve the monitoring of intrinsic and extrinsic factors [8, 9]. For instance, asymmetries in strength between muscle groups and limbs are commonly assessed and used as screening methods in sports [10, 11]. Strength imbalances between quadriceps and hamstrings have been linked to a four to five times greater risk of hamstring strain in football players, with an asymmetry in hamstring strengths between sides of 10-15% also considered to represent a risk for hamstring strains [12]. These imbalances appear more evident at slower angular velocities, and decrease at higher velocities [13]. Hamstring strength deficits and imbalances have been targeted with Nordic eccentric strengthening exercises, and a reduction of 51% in hamstring injury incidence across team sports was reported in a literature review and metanalysis of 8,459 athletes [14], including in Rugby Union [1].

Training and playing load variables, such as the number of high-speed running events, have been associated with hamstring injury occurrence in team sports and investigated mainly in football [15, 16]. Although hamstring injuries often occur during the eccentric phase of running or kicking in rugby, similar to other team sports, severe hamstring strains can also

occur because of specific-game related events in rugby, such as during tackles and competing for the ball on the ground [17]. In the tackling position, the hamstring is stretched fully, and the addition of a collision can further stretch the muscle, leading to a tendinous-junction tear. This mechanism of injury may be responsible for the increasing severity of hamstring injuries seen in Rugby Union in recent years [5], which is dissimilar to hamstring mechanisms in other sports. Thus, rugby demonstrates unique susceptibility and risk factors that require position-specific injury profiling to better target physical preparation and injury prevention strategies [18]. Given that player availability correlates with team success [19], research that targets injury prevention also has performance implications.

To prevent such injuries, it is important to identify how individual characteristics and game dynamics relate to contact and non-contact injury incidence. Therefore, we sought to critically examine and summarize the existing scientific literature on the topic of hamstring strain injuries in Rugby Union specifically. In particular, we aimed to systematically review and summarize the scientific literature that addressed hamstring strain injury incidence, risk factors, injury prevention and strengthening strategies, and strength or asymmetry measures in Rugby Union.

2. Materials and methods

2.1. Information sources and search strategy

We conducted a systematic review of the literature following the Preferred Reporting Items for Systematic Reviews and Metanalysis guidelines [20]. One author (CC) and one reviewer (CC) performed a systematic search on September 4th, 2020 to locate published peer-reviewed articles from four electronic databases: PubMed, SciVerse Scopus,

SPORTDiscus™, and Web of Science®. The search strategy consisted of the following keywords and Boolean operators entered in the main search bar of each e-database: “hamstring AND rugby”. The exact resulting search syntax in PubMed was: ("hamstring muscles"[MeSH Terms] OR ("hamstring"[All Fields] AND "muscles"[All Fields]) OR "hamstring muscles"[All Fields] OR "hamstring"[All Fields] OR "hamstrings"[All Fields]) AND ("football"[MeSH Terms] OR "football"[All Fields] OR "rugby"[All Fields]), SciVerse Scopus was: TITLE-ABS-KEY(hamstring AND rugby), SPORTDiscus™ was: Boolean/Phrase: (hamstring AND rugby), and Web of Science® was: TOPIC: (hamstring AND rugby).

2.2. Inclusion and exclusion criteria

Articles were included when they were original, peer-reviewed research studies written in the English language, involved Rugby Union players, and included one or several of the following hamstring-related information: hamstring injury incidence, risk factors, strengthening or injury prevention programmes, and/or hamstring strength or asymmetry measures in Rugby Union players, regardless of sex, age and level of competition. Articles were excluded if these were not in the English language or did not involve Rugby Union players.

2.3. Screening process

Duplicates from the initial database search were removed first. Subsequently, two reviewers (CC, KHL) independently screened all remaining titles, abstracts, and full texts sequentially for inclusion. The study selection process was replicated for articles that were located through

other sources (e.g. Google Scholar) and reference lists of included full-text articles. The two reviewers met to discuss any disagreements during the screening process and agreed on the articles to be included.

2.4. Quality assessment

Two reviewers (CC, IH) independently assessed the methodological quality of included studies (n = 24) using the Newcastle – Ottawa Scale (NOS) [21]. The reliability of the NOS for case-control and cohort studies has fair to good inter-rater reliability and validity [22]. This tool was used as it is recommended by the Cochrane Collaboration [23], is a suitable alternative to other available tools to assess risk of bias [24], and could be used across the included studies. The NOS for case control and cohort studies was used across studies for ease of implementation and interpretation. Prior to assessment, the two reviewers met to discuss and familiarise themselves with the scales. All identifiable information (i.e., authors, affiliations, countries, and sources of publication) were removed from articles to reduce likelihood of assessment bias. Disagreements in the scores were resolved by discussion between the two reviewers, and consensus scores are presented in this article.

The tool uses a “star system”, wherein more stars indicate a superior methodological quality and lower risk of bias. The NOS awards a maximum of 10 stars: five stars for selection (representativeness of the sample, sample size, non-respondents, and ascertainment of the exposure), two stars for comparability, and three stars for outcome (assessment of outcome and statistical test). Reviewers agreed that for the statistical test item, the highest star rating would be allocated for the reporting of confidence intervals, quartiles, or limits of agreement. The methodological quality of studies was divided into three groups based on the number of stars awarded: *weak* (0 to 3 stars), *moderate* (4 to 6 stars), and *strong* (7 to 10 stars) [25]. The

design of each study was classified as cohort studies, case series, cases and controls, or randomized controlled trial.

2.5. Data extraction and synthesis

The first author (CC) extracted data from the selected full-text articles using a data extraction template customized to suit this review, and the last author (KHL) verified the data extracted. For each study, study design, participant information, level of competition, location of the study, study characteristics, assessment methods, and outcome data specific to hamstrings were extracted. Data were grouped and extracted under main themes of interest: (1) hamstring injury incidence and risk factors; (2) hamstring strengthening and injury prevention programmes; and (3) hamstring strength or asymmetry assessment methods and measures. Data were managed and analysed using Microsoft® Office Excel 2016 (Redmond, Washington). Conducting a meta-analysis on data was not considered given the aims of this review to summarize the existing literature, the high degree of heterogeneity of the data in the included studies, and the inappropriateness of pooling results from studies with different study designs, injury definitions, and outcome measures.

3. Results

3.1. Included studies

The flow diagram from the search strategy and screening process is shown **Figure 1**. Twenty-four studies met the eligibility criteria.

3.2. Study characteristics

The main characteristics of the 24 studies that met inclusion are presented in **Table 1**. Based on Newcastle-Ottawa Scale NOS, most studies were of *moderate* quality ($n = 13$, 54%) [26-36]. Ten articles were of *strong* quality (40%) [1, 37-45], and one study was defined as *weak* quality (6%) [46].

3.3. Participants

The 24 studies that met inclusion comprised of 2866 participants, male players were involved in 21 studies [1, 27-45, 47], one study involved female players [26], and two studies included both males and females [46, 48]. Eleven articles were conducted with professional players [1, 27, 33, 36-39, 41, 43-45], ten with amateur players [26, 28-32, 34, 42, 46-49], two with semi-professional players [40, 42], and not enough information about the level of competition was available in one study [35]. The articles were designed as cohort studies in 18 cases (75%) [1, 28, 30, 32, 34, 35, 37-39, 42-48], case series in three (13%) [27, 31, 33], case-controls in two (8%) [26, 40], and a randomized control trial (4%) [41]. Studies were conducted in the United Kingdom ($n=9$) [1, 26, 29, 36, 38-40, 42, 43], Australia ($n=4$) [37, 41, 44, 45], New Zealand ($n=3$) [28, 30, 33], Ireland ($n=3$) [27, 32, 48], USA ($n=2$) [31, 46], Morocco ($n=1$) [47], Japan ($n=1$) [34], and South Africa ($n=1$) [35] (**Table 1**).

Figure 1.

Table

1.

3.4. Hamstring injuries: Incidence and risk factors

3.4.1. Professional level

Hamstring strain injuries caused the greatest number of days of absence diagnosed in backs and was ranked third in forwards after shoulder and lumbar disc injuries [39]. In a two-part study involving professional players across two seasons, Part One monitored match injuries and Part Two monitored training injuries. In the first part, the incidence of hamstring strain injuries of backs were nearly three times greater than forwards [38]. Additionally, hamstring injuries were the most severe diagnosed injury in the backs and resulted in 17 days of absence. The lower limb was the most common anatomical site injured, with hamstring strains being the second most common injury in backs after thigh hematomas. Running was the most frequent mechanism of hamstring injury in game. In contrast to matches, forwards and backs had a similar incidence and mechanism of hamstring injuries during training [39], with more incidence of injuries during the preseason, with running again being the most common mechanism of injury, see **Table 2**.

Retrospective data analysis across five seasons in professional players indicated that 6% of all injuries were to the hamstring, with most hamstring injuries occurring during training and preseason [45]. Hamstring injuries occurred more whilst running, with similar incidence between forwards and backs. The median days lost for hamstring injury was 26 days, and most of the injuries were moderate (60%), or severe (37%). The running mechanics of 10 professional players were analysed. Injured players had greater ipsilateral thoracic lateral flexion, absorbed greater power at the knee, and had greater hip extension moment [44].

Brooks, Kemp [43] examined player injuries by playing position. Regarding severity of hamstring injuries, fly halves were the most affected players, followed by centres, wings, and

the blind side flankers who presented with the most severe hamstring injuries whilst running. Data regarding hamstring injuries were also collected when implementing different hamstring training programs [1]. The incidence was similar between dominant and non-dominant legs. Overall, the most severe hamstring injuries happened during kicking. During matches, hamstring injuries were most frequent and severe in the last 20 minutes, and substitute players had twice as many injuries as starting players; however, both starters and substitutes had similar rates of recurrence.

Another study on hamstring strain injuries in professional players found that backs were the most affected players, with 21 days of absence overall [37]. The majority (45%) of injuries were recurrences from the past season and 24% recurred in the same season. Most of the injuries involved the biceps femoris and occurred while running. Comparing the players with a recurrent injury, players with a previous hamstring injury in the last 12 months had 4.1 times higher risk of suffering a recurrent injury compared with players with no history of hamstring injury. Imbalances between limbs of more than 15% increased the risk of having a hamstring injury by 2.4 times; moreover, imbalances of more than 20% increased this figure to 3.4 times.

Regarding return to play after injuries, a five-week program to return to play with GPS technology was designed [27], and the recommendation to return to play after a hamstring injury was based on the ability to reach a running speed and intensity similar to pre-injury. The rehabilitation therapy recommended focusing on achieving maximum speed and long distances; involving cutting, passing, kicking, grappling, tackle drills, and wrestling; and achieving full training activities before returning to play. In one case study, a professional

male Rugby Union player demonstrated an “abnormal” force-velocity profile during a 40-m sprint that resulted in an acute hamstring strain. The injurious sprint was characterised by an increase in horizontal force production compared to velocity when contrasted to his previous sprints and force-velocity profiles of his uninjured teammates [33].

3.4.2. Semi-professional, amateur, and school level

A community-level investigation across three seasons identified that hamstring strain injuries occupied the fifth place in terms of total injuries [42]. Running was the most frequent action of the game to produce hamstring injuries, and backs had a higher incidence than forwards. Hamstring injuries more frequently occurred in the first quarter of the game. At the amateur level, a prospective study with 65 players involving questionnaires found that 21% of all match and 30% of all training injuries were hamstring strain injuries [32].

With regards to the risk factors for hamstring injuries, three investigations have been conducted; the first followed semi-professional players with grade I hamstring strain injuries [40]. Their protocol comprised of two parts, one flexibility test and a slump test (validated for neural tension). In the group with a previous hamstring injury, 57% of the players had a positive slump test, whereas no positives were found in the control group. The results suggested that adverse neural tension should be assessed as a risk factor of hamstring injury and could be considered in return to play practices.

A prospective analysis of the relationship between motor imagery capacity of senior players (the ability to mentally perceive a rotated object) and hamstring injuries was undertaken [34]. Motor function was assessed with isokinetic hamstring quadriceps (H:Q) ratio, straight-leg

raise angle, and a vertical jump test on one leg. Six players had symptoms of hamstring injuries (7 legs). The injured group (occurred in non-contact actions) had longer reaction times for the 0° dorsal and -90° plantar views compared to the non-injured group (delay in 2.48 seconds) based motor imagery capacity test, with none of the motor function tests associated with injury. The third study in this area provided the option to players with previous hamstring injuries to wear or not wear thermal pants in training and matches during a season [35]. The incidence of injuries was significantly lower in players who chose to wear thermal pants.

Table

2.

3.5. Hamstring strength and asymmetry assessment: methods and measures

3.5.1. Overview

All methods and outcome measures used to assess hamstring strength are summarized in **Table 3**. Isokinetic testing is considered the “gold standard” method to measure hamstring and quadriceps strength [50], with most of the studies assessing strength in rugby using isokinetic methods [26, 29-31, 41, 46, 47]. All of these isokinetic studies were conducted at 60°/s, with a subset also using 180°/s [29, 31, 47] and the one of poor methodological quality assessing at 35°/s [46]. Concentric hamstring strength was examined across all isokinetic studies, with five subjects considering eccentrics [29-31, 41, 46]. Nine studies measured the hamstring to quadriceps ratio (H:Q) [26, 28-31, 34, 36, 41, 46, 47] and five included dynamic control ratio (DCR) [29-31, 41, 46]. The H:Q is conventionally measured concentrically and used to quantify strength and imbalance between muscles and limbs. The dynamic control

ratio is considered more functional, calculated as the *eccentric* hamstrings to concentric quadriceps strength ratio. There were no H:Q and DCR thresholds specifically established for Rugby Union players in the literature here reviewed. The Rugby Union literature cited thresholds from track and field that recommended H:Q values exceed 0.6 and DCR of 1.0 or above [51]. Other forms of hamstring strength testing methods used in rugby included eccentric [37], isometric [46], isotonic [31], and sphygmomanometer [36].

3.5.2. Protocols

3.5.2.1. Isokinetic strength tests

Concentric hamstring strength at 60°/s ranged from 89 to 252 Nm in amateur to professional players across positions and genders, and at 180°/s ranged from 71 to 121 Nm in male amateurs (no data for professionals or females). Eccentric hamstring strength across at 60°/s from ~135 to 220 Nm, and 209 to 220 Nm at 180°/s in male amateurs (no data for professionals or females). Key findings were that professionals were stronger than academy [30], forwards were stronger than backs [28, 47]. In amateur players, experience had little effect on hamstring values [31] and effect of leg dominance was inconsistent across studies [28, 47] [30].

In amateur players, H:Q values ranged from 0.45 to 0.56, with no difference based on years of experience [31] or playing position [30]. Professional players displayed H:Q values of 0.52 to 0.68 [28, 41], with again no difference between playing positions [28], but the potential to increase with progressive Nordic eccentric training [41]. Concerning DCR values in amateur players, ratios ranged from 0.64 to 1.17, and was significant greater in experienced players

[31], but not affected by playing position or limb dominance [30]. DCR in professionals ranged from 0.74 to 0.81 [41], and was greater subsequent progressive Nordic eccentric hamstring training. Two studies undertook isokinetic knee strength assessment in amateur female athletes [26, 46], with one of these being of poor methodological quality. These studies identified that non-dominant limb H:Q (0.81) and DCR values were significantly greater than the dominant limb (0.74).

Deighan et al. [29] examined how conducting testing in seated vs supine influenced isokinetic knee extensor and flexor strength. The DCR at 180°/s and mean peak torque values seated were significantly greater than supine. Furthermore, knee extensors were stronger than flexors, and eccentric produced superior values than concentric. The study highlighted the significance of testing eccentric isokinetic strength with a hip flexion angle of approximately 10° to determine imbalances and to screen for risk of injuries. Analysis in amateur players with both isometric and isokinetic strength tests in experienced and inexperienced player indicated experienced players had greater DCR at 60°/s values [31]. No significant differences were observed between players in DCR and H:Q at 180°/s velocity, which the authors attributed to an adaptation to the high sprint demands of Rugby Union. At the same level of competition, Deighan et al. [29] found similar H:Q 60°/s, but lower DCR values when compared to the results by Beyer et al. [31]

3.5.2.2 Eccentric strength test with Nordic exercises

Preseason Nordic hamstring eccentric testing performed with a load cell device [52], see **Figure 2**, indicated that weaker players (bilateral average < 267.9 N) were at a similar risk of

sustaining a hamstring injury than stronger players. Forwards were stronger than backs. Injured players demonstrated an imbalance between limbs of 17.4 % that was significantly greater than injury-free players who displayed an imbalance of $\leq 10\%$.

Figure 2.

Table 3.

3.6. Hamstring strengthening programs

During two seasons, 12 professional male teams followed a training program with stretching and strengthening exercises in one of three groups: 1) strengthening, 2) strengthening and stretching, and 3) strengthening, stretching, and Nordic exercises [1], see **Table 4**. The group performing Nordic exercises had a lower incidence of hamstring injuries compared to the group performing strengthening exercises alone. Although no significant differences were found in severity, there were less absence days in the Nordic exercise group. Second row players displayed the lowest incidence and severity of hamstring injuries.

In another study, two Nordic exercise 8-week training programs were examined: progressive and constant workload [41]. Along with the Nordic exercises, ultrasonography of the biceps femoris long head was performed. Both Nordic exercises strategies significantly increased the muscle thickness and length, without pennation angle changes. The progressive routine

significantly increased the strength values by 7 to 8%, H:Q from 0.53 to 0.57, and DCR from 0.76 to 0.81; but not the constant workload group.

Intervention strategies with Nordic exercises have also been implemented in female rugby players [26]. Following a 10-week Nordic hamstring training intervention, isokinetic strength at 60°/s improved 11-13%. Also of interest was that, following the training period, a significant reduction in bilateral strength imbalance from 10.3 % to 4.6% was observed.

Table 4.

4. Discussion

4.1. Hamstring injury incidence and risk factors

We aimed to examine the scientific literature specific to Rugby Union and hamstring with focus on injury incidence, risk factors, injury prevention and strengthening strategies, and strength and asymmetry measures. The overall incidence of hamstring injuries during matches in professional players [38] was four times greater than community and amateur players [32, 42]. Across levels, backs suffered more hamstring injuries than forwards [1, 37, 42] due to their greater running actions. The hamstring severity in community players was approximately 2 to 2.5 times higher than professionals [1, 37] suggestively due to lack of appropriate warm-up and hamstring training interventions in these cohorts [42].

In professional players, 23 to 45% of hamstring injuries were recurrences from either the current or previous season [37] [1], with a previous hamstring strain associated with a 4.1 times increased risk of recurrence [37]. The highest injury recurrence occurred in the first month of returning to play [1], suggesting that return to play was too quick and/or rehabilitation and reconditioning insufficient to meet the load demands. Similarly, 18% of the injuries have been found to recur in the first twelve days after returning to play and at the same site of the previous injury [35]. Of concern is that recurrences had more days lost (25 days) compared to new injuries (17 days) [1]. These studies altogether indicate that there is insufficient preparation before returning to training and playing after a hamstring injury, with a previous hamstring strain being a considerable risk factor. These findings align with a meta-analysis indicating that previous hamstring injury was a significant risk factor, in addition to other injuries (Anterior Cruciate Ligament, calf, and knee) for hamstring injuries [3]. Bourne et al. [37] highlighted the significant relationship between leg imbalances in eccentric strength and a previous hamstring strain injury in Rugby Union players, and concluded that players with a previous injury had an increased risk of sustaining another injury if they returned to play with pronounced strength imbalances between legs. In contrast, when isokinetic testing was included as a tool to return to play, van Dyk et al. [53] found no value in this strength measure as a criterion for return to play after a hamstring injury in football players. Whatever the tool used, rugby players should be monitored in their return to play progression and assessed periodically for imbalances, especially if they have sustained a previous hamstring injury.

Running was the most common action of the game to produce a hamstring strain injury across levels, accounting for 68 to 85% of all injuries in professionals [1, 37, 45] and 54% in amateur [42]. There was somewhat conflicting evidence in terms of when in the game

injuries were more likely to occur. In professionals, the majority of the injuries in backs occurred in the last part of each half, but incidences were greater later in the game in forwards [1]. In contrast, hamstring injuries occurred more frequently in the first quarter in community players[42]. These contrasting results suggest insufficient warm-up or game preparation at lower levels of competition as a potential contributor to injury rates, whereas fatigue may be a greater contributor at higher levels. This proposition relating to warm-up strategies is indirectly supported by findings of a significant decrease in hamstring injuries when previously injured players wore warm pants during training and matches [35].

Running training and high speed exposures have been postulated as an effective tool to reduce hamstring injuries [54]. One of the recommendations by Buckthorpe et al. [15] for preventing hamstring injuries involved incorporating high speed-running routines at least twice a week at 95% of maximum speed. Analysis of a player with a hamstring injury identified impaired sprint accelerations with a decrease in horizontal force production, potentially due to weak hamstring or gluteal muscles, before the injury and after return to play [33]. The authors highlighted the importance of running activities for preventing hamstring injuries, and suggested sprint time measurement to detect deficits during the initial acceleration phase. Magnetic resonant imaging of hamstring injuries in professional players showed the biceps femoris long head fascicle was the most injured muscle (73%), and that this injury occurred most frequently in running actions (77%) [45]. In contrast to football players who sustained more Proximal Myofascial junction intramuscular injuries [55], the Distal Myofascial junction site was more common in Rugby Union players, re-emphasising the importance of Nordic exercises to target this portion of the muscle [56].

4.2. Hamstring strength

Playing level and position in rugby have previously been associated with different attributes and demands, including body composition, speed, strength, power, and repeated sprint performance [57]. The isokinetic measures here reviewed support these findings overall, with professionals being stronger than amateurs and forwards being stronger than backs [30, 28]. The differences between playing positions and levels likely relates to the match demands of forwards requiring greater leg strength (i.e., tackling, scrummaging, rucking, mauling, and pick-and-goes) than backs, and strength increasing with years of experience and the greater demands at higher levels.

From the literature reviewed, no H:Q and DCR thresholds from isokinetic testing have been established as optimal or protective of injury for Rugby Union. In track and field, H:Q values exceeding 0.6 [51] and DCR values of 1.0 or above are considered normal [59] and recommended for reducing the risk of hamstring injuries [51]. H:Q values below 0.6 have been shown to increase hamstring injuries 17-fold in sprinters [10]. Across the Rugby Union literature reviewed, H:Q values were typically lower than 0.6 [30, 31][42], although reported to surpass 0.6 in professional players [28]. Similarly, DCR were often below 1.0 [28, 31, 41], even in professionals. Addressing these imbalances could potentially reduce the relatively high incidence of hamstring strains in Rugby Union. That said, van Dyk et al. [60] found no relationship between H:Q isokinetic strength ratios in injured and uninjured football players. Furthermore, the systematic review and meta-analysis for hamstring strain injury risk factors by Freckleton, Pizzari [3] did not find evidence that any isokinetic ratio, at any speed or type of contraction, was associated with

the risk of hamstring injuries. Therefore, it remains uncertain whether improving these ratios would actually reduce hamstring incidence in rugby.

In amateur female players, an increase in strength was found, as well as a reduction in imbalance between limbs, after a Nordic exercise intervention [26]. A systematic review by Hewett et al. [61] found no significant difference between females and males in isokinetic H:Q values at slow velocities; although males had significantly greater H:Q values at higher angular velocities (from 30 to 360°/s). The reduced capacity of females to control the knee joint at high velocities might increase their risk to sustain a hamstring injury during high speed running [62]. These results suggest that assessing H:Q values at higher angular velocities might be more clinically-relevant in the context of Rugby Union and hamstring injuries, and should be used preferentially by clinicians in the context of assessing injury risk.

Nordic eccentric strength assessments are proposed as a more feasible, physiological, and functional test than isokinetic. Forces generated during Nordic exercises are similar to those observed during sprinting [63]. However, only one study measured Nordic eccentric values in Rugby Union. Bourne et al. [37] detected significantly weaker limbs in injured than uninjured limb, as well as greater imbalances between legs in injured than uninjured players. Imbalances of more than 15% and 20% between legs increased the risk of hamstring injuries by 2.4 and 3.4 times, respectively. A review by Kalkhoven et al. [64] found that during all the phases of sprinting, the hamstring muscles are active (from the stance phase to the swing phase). The “hamstring muscle slack”, a term which suggests the hamstring act isometrically in the late swing of sprinting, does not occur. These authors concluded that the hamstring contracts in an eccentric fashion in the late swing

phase, such that an eccentric test may be a more appropriate way to measure hamstring strength and capability. This interpretation of the kinematics of sprinting may also suggest that eccentric exercises are a better way to train hamstring function. That said, authors of a systematic review and meta-analysis of different devices measuring hamstring eccentric strength in different sports with the Nordbord device cautioned when assessing hamstring peak strength and imbalances to estimate hamstring injury risks [65]. This caution was due to the Nordic hamstring test not eliciting the same demands as running, and therefore, it should be used as the sole tool to assess injury risk in-season neuromuscular status [65].

4.3. Hamstring strengthening programs

Rugby Union players that followed a Nordic eccentric exercise program exhibited significantly improved hamstring strength [26, 41], decreased bilateral strength imbalances [26], and reduced hamstring injury incidence and severity (i.e., less days absent from training and matches) [1]. Interventions also improved H:Q and DCR values, as well as an increased the biceps femoris long head fascicle length and thickness. As a short fascicle length has been shown to increase the risk of hamstring injuries, and longer fascicles identified as a protective factor of hamstring strain injuries in older football players with previous hamstring injuries [66], the progressive Nordic program in Rugby Union can promote beneficial morphological adaptations. Giakoumis [67] suggested a number of possible mechanisms underpinning the beneficial effects of Nordic exercises in athletes other than semitendinosus and biceps femoris fascicle lengthening, including hypertrophy of these muscles and synergistic role of the semitendinosus in sprinting activities. Compared to other exercises, eccentrics elicit greater electromyographic

activity, increases in strength, and muscle adaptations [67]. Therefore, although cautioned against being used as a sole screening measure [65], the integration of Nordic exercises appear of benefit to Rugby Union and are recommended. The intervention programs in Rugby Union with beneficial effects followed similar training strategies over the course of 8 to 10 weeks, and can be recommended to practitioners. These programs involved eccentric hamstring training 2 to 3 times a week, completing 3 to 4 sets of 6 to 10 repetitions.

5. Conclusion

Current literature is lacking to support the evidence-based use of isokinetic strength, H:Q, and DCR measures to inform injury prevention and return to play strategies for hamstring injuries in Rugby Union. Nordic eccentric strength assessment has been shown to be a better physiological and functional test, with differences in strength and imbalances predicting new and recurrent injuries. Strengthening programs with Nordic exercises significantly increased hamstring strength measures, decreased imbalance ratios, and reduced injury incidence and severity. The aetiology of hamstring injuries is multifactorial, with playing position, fatigue, previous injuries, leg imbalances, lack of readiness to return to play, and running actions identified as contributing factors across levels. Combining strategies to prevent hamstring injuries and recurrences, and to inform return to play, is likely worthwhile and should include Nordic strength assessment and Nordic exercises. It has been proposed that high-speed running and warm-up routines may be important in the prevention of hamstring injuries, although strong evidence for these suggestions is lacking.

5. References

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6. Figures legends

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart.

Figure 2. Illustration of a Nordic hamstring exercise.

8. Tables

Table 1. Characteristics of the 24 included studies.

Study	NOS rating*	Player characteristics	Study design Location	Study aims	Key study characteristics
Abdelfettah et al. [47]	Moderate 5 stars	10 male amateur players Age: 26.4 ± 5.1 y Mass: 83.2 ± 15.3 kg Height: 177.9 ± 8.3 cm	Cohort (cross-sectional) Morocco	Compare the strength of the knee flexors and extensors between soccer and rugby players and the level of strength by playing positions	Duration: 1 season Injuries: No Intervention: No
Anastasi, Hamzeh [26]	Moderate 5 stars	24 female amateur players (13 test players and 11 controls) Age: 25.2 ± 5.3 y Mass: 69.5 ± 10.9 kg Height: 166 ± 5.0 cm	Case control United Kingdom	Evaluate the effect of hamstring eccentric program on leg strength imbalance and maximal vertical jump height	Duration: 1 season Injuries: No Intervention: Yes

Beyer et al. [31]	Moderate 4 stars	25 male amateur players. Age: 20.7 ± 2 y Mass: 86.8 ± 15.4 kg Height: 179 ± 8.0 cm	Case series (laboratory investigation) USA	Compare isotonic versus isometric strength measures between players with < 2 years and ≥ 2 years of experience	Duration: 1 season Injuries: No Intervention: No
Bourne et al. [37]	Strong 8 stars	178 male players (75 professionals and 103 semi-professionals subdivided in 65 sub-elite and 38 under 19s) Age: 22.6 ± 3.8 y Mass: 96.5 ± 13.1 kg Height: 185.0 ± 6.8 cm	Cohort (prospective) Australia	Determine the thresholds of hamstring strength imbalance in eccentric Nordic exercises and association with hamstring injuries	Duration: 1 season Injuries: Yes Intervention: No
Brooks et al. [38]	Strong 9 stars	546 male professional players Age: 25.3 ± 4.1 y Mass: 100.0 ± 12.1 kg Height: 185.1 ± 7.4 cm	Cohort (prospective) United Kingdom	Study match injuries in professional players and define incidence, aetiology, and severity	Duration: 2 seasons Injuries: Yes Intervention: No

Brooks et al. [39]	Strong 9 stars	502 male professional players Age: 25.3 ± 4.1 y Mass: 100 ± 12.1 kg Height: 185.1 ± 7.4 cm	Cohort (prospective) United Kingdom	Study training injuries in professional players and seasons define incidence, aetiology, and severity	Duration: 2 Injuries: Yes Intervention: No
Brooks et al. [1]	Strong 9 stars	546 male professional players Age: 25.3 ± 4.1 y Mass: 100 ± 12.1 kg Height: 185.1 ± 7.4 cm	Cohort (prospective) United Kingdom	Describe incidence, risk factors, and severity of hamstring injuries and the impact of hamstring strengthening and stretching exercises on injury incidence and severity	Duration: 2 Injuries: Yes Intervention: No
Brooks, Kemp [43]	Strong 7 stars	899 male professional players Age: 25.3 ± 4.1 y Mass: 100 ± 12.1 kg Height: 185.1 ± 7.4 cm	Cohort (prospective) United Kingdom	Examine match injury profile of professional players by playing positions	Duration: 2 Injuries: Yes Intervention: No

Brown et al. [28]	Moderate	25 male professional players	Cohort	Determine	lower-limb	Duration: 1 season
	4 stars	Age: 25 ± 3 y	(cross-sectional)	strength profiles and compare	Injuries: No	
		Mass: 103 ± 12 kg	New Zealand	isokinetic knee and hip	Intervention: No	
		Height: 186 ± 7.0 cm		strength of professional players		
Brown et al. [30]	Moderate	30 male amateur players	Cohort	Determine	lower-limb	Duration: 1 season
	4 stars	(15 forwards and 15 backs)	(cross-sectional)	strength profile and compare	Injuries: No	
		Forwards	New Zealand	isokinetic measures between	Intervention: No	
		Age: 20 ± 1 y		limbs and positions		
		Mass: 103 ± 11 kg				
		Height: 190 ± 1.0 cm				
		Backs				
	Age: 24 ± 4 years					
	Mass: 90 ± 8 kg					
	Height: 180 ± 0.0 cm					

Deighan et al. [29]	Moderate 4 stars	11 male amateur players Age: 19.3 ± 0.8 y Mass: 92.8 ± 12.6 kg Height: 182.2 ± 8.0 cm	Cohort (cross sectional repeated measure laboratory test) United Kingdom	Determine differences in peak torque and strength ratios between positions (seated and supine) and examine the relation of position with joint velocity	Duration: 1 season Injuries: No Intervention: No
Dobbs et al. [46]	Weak 2 stars	19 amateur players (11 females and 8 males) Males Age: 22.0 ± 2.6 y Mass: 80.3 ± 11.1 kg Height: 172.7 ± 6.1 cm Females Age 24.7 ± 3.7 y Mass: 74 ± 18.1 kg Height: 164 ± 5.2 cm	Cohort (cross-sectional) USA	Measure H:Q and DCR in male and female amateur players and assess differences in muscle strength and imbalance	Duration: 1 season Injuries: No Intervention: No

Farnan et al. [32]	Moderate 5 stars	54 male amateur players Age: 21 ± 2 y Mass: 88.1 ± 10.7 kg Height: 183 ± 5.2 cm	Cohort (prospective) Ireland	Determine hamstring injuries incidence, and severity	Duration: 1 season Injuries: Yes Intervention: No
Kenneally- Dabrowski et al. [45]	Strong 7 stars	74 male professional players Age: NR Mass: NR Height: NR	Cohort (retrospective) Australia	Describe hamstring injuries (severity, grade, and location) and the relationship with game demands	Duration: 5 seasons Injuries: Yes Intervention: No
Kenneally- Dabrowski et al. [44]	Strong 7 stars	10 male professional players Age: 27.3 ± 3.2 y Mass: 100.9 ± 13.1 kg Height: 193 ± 9.0 cm	Cohort (prospective) Australia	Analysis of the relationship between overground high- speed running mechanics and hamstring injury	Duration: 1 season Injuries: Yes Intervention: No
Mendiguchia et al. [33]	Moderate 4 stars	1 male professional player Age: 23 y Mass: 94 kg Height: 187 cm	Case series (laboratory investigation) New Zealand	Determine the changes in sprinting mechanics in relation to hamstring injuries	Duration: 1 season Injuries: No Intervention: No

Mondin et al. [36]	Moderate 4 stars	10 male professional players and 14 healthy controls Age: 23.1 ± 2.5 y Mass: 88.4 ± 8.5 kg Height: 180.9 ± 8.2 cm	Cohort (repeated- measures reliability) United Kingdom and Italy	Measure hamstring strength with a sphygmomanometer test and the correspondence with an isokinetic dynamometry test.	Duration: 1 season Injuries: No Intervention: No
Reid et al. [27]	Moderate 6 stars	8 male professional players Age: 27.9 ± 4.8 y Mass: 99.1 ± 9.9 kg Height: 185 ± 8.0 cm	Case series Ireland	Demonstrate the application of GPS technology in the management of return to play	Duration: 1 season Injuries: No Intervention: No
Roberts et al. [42]	Strong 7 stars	189 male community players Group A: semi-professional Group B: amateur Group C: recreational Age: NR Mass: NR	Cohort (prospective) United Kingdom	Establish injury incidence and severity in community rugby and assess differences between levels	Duration: 3 seasons Injuries: Yes Intervention: No

Height: NR

Severo-Silveira et al. [41]	Strong 8 stars	21 male professional players (11 in the Constant group and 10 in the Progressive group)	Randomized control trial	Study the effect of 2 different Nordic hamstring training programs (constant versus progressive) on multiple risk factors for hamstring strain injury	Duration: 1 season Injuries: No Intervention: Yes
		Constant group	Brazil and Australia		
		Age: 27.2 ± 3.4 y			
		Mass: 90.1 ± 14.3 kg			
		Height: 175 ± 0.1 cm			
		Progressive group			
		Age: 25.2 ± 3.3 y			
		Mass: 88.6 ± 12.8 kg			
		Height: 176 ± 0.1 cm			
Turl, George [40]	Strong 7 stars	28 male semi-professional (14 tested players and 14 controls)	Cases and controls (cross	Existence of adverse neural tension in players with grade	Duration: 1 season Injuries: Yes

		Age: 29 ± 3 y	sectional)	I hamstring injuries	Intervention: No
		Weight: 88 ± 12 kg	United Kingdom		
		Height: 181 ± 1.0 cm			
Upton et al. [35]	Moderate	44 male NR level players	Cohort	Determine if the use of	Duration: 1 season
	5 stars	Age: 23 ± 3 y	(prospective)	thermal pants reduce the risk	Injuries: Yes
		Weight: NR	South Africa	of hamstring injuries.	Intervention: Yes
		Height: NR			
Yamada,	Moderate	21 male amateur players	Cohort	Determine the relationship	Duration: 1 season
Mastumoto [34]	5 stars	Age: 21.3 ± 0.3 y	(laboratory	between motor imagery and	Injuries: Yes
		Weight: 71.8 ± 6.3 kg	investigation)	hamstring injuries.	Intervention: No
		Height: 172.2 ± 4.1 cm	Japan		
Yeomans et al. [48]	Moderate	137 amateur players (13 males	Cohort	Determine risk factors	Duration: 1 season
	6 stars	and 24 females)	(prospective)	associate to injuries.	Injuries: Yes
		Males	Ireland		Intervention: No
		Age: 22.7 ± 3.9 y			
		Weight: Forwards 102.8 ±			

10.9; Backs 85.4 ± 7.9 kg

Height: Forwards $180.5 \pm$

23.6; Backs 179.5 ± 4.8 cm

Females

Age: 25.6 ± 4.9 y

Weight: Forwards $87.3 \pm$

14.1; Backs 69.5 ± 11.3 kg

Height: Forwards 169.8 ± 3.8 ;

Backs 165.9 ± 7.1 cm

Notes. Values are means \pm standard deviations.

Abbreviations: DCR, isokinetic dynamic control ratio; H:Q, isokinetic hamstring quadriceps ratio; GPS, global positioning system; NOS, Newcastle-Ottawa Scale; NR, not reported.

* Weak: 0 to 3 stars; moderate: 4 to 6 stars; strong: 7 to 10 stars.

Table 2. Hamstring injury studies involving Rugby Union players.

Study	Participants	Incidence	Severity	Training	Playing matches	Intervention/ Test	Outcome
Brooks et al. [38]	546 professional players	All: 5.6 injuries / 1000 player- hours Forwards: 3 injuries / 1000 player-hours Backs: 8.6 injuries / 1000 player-hours	All: 17 days of absence Forwards: 15 days of absence Backs: 1176 total days of absence 18 days of absence 151 days absence/1000 hours	0%	100%	No	Hamstring injuries were the second most common injury. Hamstring injuries were the most severe injury.
Brooks et al.	502	All: 0.30 injuries	All: 17 days	100%	0%	No	The most

[39]	professional players	/1000 player-hours	absence				common injury mechanism for forwards and backs was running.
		Forwards: 0.28 injuries /1000 player-hours	Forwards: 478 total days. 15 days of absence. 4.3 days absence/1000 hours				
		Backs: 0.32 injuries/1000 player-hours	Backs: 502 total days. 19 days of absence. 6 days absence/1000 hours				
Brooks et al.	546	All: 164 injuries (94 match and 70 training injuries)	All: 2707 total days lost. 17 days lost per injury	70 injuries	94 injuries	Stretching, strengthening, and Nordic eccentric exercises	The group performing Nordic exercises had a lower incidence of
[1]	professional players	122 players (22%) at least	Each of the 12 teams 123 days	42%	58%		

one injury. absence (81 days hamstring injuries
-5.6 injuries/1000 for new and 42 compared to the
player-hours days for a group performing
-Each of the 12 recurrent injury). strengthening
teams 7.5 exercises
hamstring
injuries (5.8%
new and 1.7% **New:** 1775 total
recurrent) days. 14 [12-16]
New: 127 injuries days lost per injury
Recurrent: 37 **Recurrent:** 932
injuries total days. 25 [17-
24% match 33] days lost per
20% training injury

Brooks,	899	All: 164 injuries	Blind side	NR	NR	NR	Absence due to
Kemp [43]	professional		flankers: 99 days				thigh injuries was

	players	5.6 injuries/1000	absence per 1000 player-hours				high for most backs and a consequence of the faster running speed. While absence due to hamstring muscle injuries was high in wingers, it was the absence due to thigh haematomas that was most significant.
			Fly halves: 241 days absence per 1000 player-hours Centres: 173 days absence per 1000 player-hours Wingers: 157 days absence per 1000 player-hours Full backs: 161 days absence per 1000 player-hours				
Bourne et al. [37]	178 professional	All: 20 injuries Forwards: 40%	21 days lost average	NR	NR	Nordic eccentric test:	80% affected the biceps femoris as

	players	Backs: 60%					Injured players: the primary site of Injured limb 355 N injury, 85% and for the resulted from uninjured limb 410 high-speed N imbalance running. 17.37% Previous Non-injured: the hamstring strain raw average injury and limb strength was 367 imbalance was N with 10% associated with an imbalance. increased risk of future hamstring injury in Rugby Union
		New: 55%					
		Recurrent: 45%					
Farnan et al.	54 amateur	All: 13.1 injuries	NR	1.2 /1000	7.9 /1000	No	Severe injuries
[32]	players	/1000 player-		player-hours	player-		were not common

		hours			hours		at the amateur level. The injury risk was like the professional level.
Kenneally-Dabrowski et al. [45]	74 professional players	All: 6% = 30 injured players Forwards: 47% Backs: 53% New: 93% Recurrent: 7% at days 157 and 166	Median of days lost: 26 days In average 207 days were lost per season. Severity Slight (0-1 day): 0% Minimal (2-3 days): 0% Mild (4-7 days): 3%	11 injuries Preseason 0 Early season 4 (36%) Late season 6 (55%) Off-season 1 (9%)	19 injuries Preseason 9 (47%) Early season 3 (16%) Late season 6 (31%) Off-season 1 (5%)	MRI injury test Grade II 80% Grade III 20%	The incidence of injuries in the late season was almost double that of early season injuries (12 and 7 injuries, respectively).

Moderate (7-28

days): 68%

Severe (more than

28 days): 37%

Career ending:

0%

Kenneally- Dabrowski et al. [44]	10 professional players	All: 4 injured players	NR	NR	NR	Biomechanical analysis Hamstring injuries classification OSICS diagnosis codes: TMHX (Hamstring strain), TMHS (Hamstring strain – semimembranosus/	Compared to uninjured athletes recurrent injured athletes demonstrated a tendency for greater thoracic lateral flexion, greater hip extension
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						tendinous strain, grade 1–2), TMHB (Hamstring strain – biceps femoris strain, grade 1–2) and TMHR (Grade 3 hamstring strain).	moments and greater knee power absorption during running.
Mendiguchia et al. [33]	1 professional player	1 hamstring strain injury	NR	NR	NR	Test: Instantaneous sprint velocity	Injured player Change in force and velocity relationship (from –0.76 to –0.92; +21.1%) associated with an increase in force
						Protocol: The test comprised of ten 40 m sprints on 30 s running cycle, and the speed was	

recorded with a sport radar. (from 7.6 N/kg to 8.7 N/kg, +14%) and a minor decrease in velocity (from 10.1 m/s to 9.5 m/s, -6%).

Reid et al.	8 professional	NR	NR	NR	NR	RTP Strategies	RTP Program
[68]	players					Phase I and II (0-6 days) Return to run with no pain and medium intensities	Phase I and II AD: 0.6-5 m/sprint Distance 2500-5500 m
						Phase III and IV (7-12 days) High intensity	Phase III and IV AD: 0.6-5

						running and agility, return to sprinting and skills	m/sprint Distance 3500-4700m
						Phase V (13-17 days) Full team training, skills, and contact	Phase V AD: 0.6-5 m/s Distance 4000-4500m
Roberts et al. [42]	189 community players	All: 1.4 [1.2, 1.7] injuries/1000 player-hours Backs: 1.4 [1.1, 1.8] injuries/1000 player-hours Forwards: 0.5	All: 5.9 mean weeks missed (4.6 to 6.4). 41 days lost	First quarter 1.9 [1.4 ,2.5] injuries/1000 player-hours Third quarter 1.1 [0.7 ,1.6]	NR	No	Hamstring strains are the most common non-contact injury. Backs had higher incidence than forwards. Running actions

		[0.3,0.7]		injuries/1000			accounted for
		injuries/1000		player-hours			10% of all
		player-hours					injuries and of
							those 54% were
							hamstring strain
							injuries
Turl, George	28 semi-	All: 14 injured	NR	NR	NR	Slump test: In a	A positive slump
[40]	professional	players				seated position,	test reproduced
	players					with the knees and	radicular
	(14 tested					hips at 90 degrees,	symptoms 57%
	players and 14					the player had to	positive in test
	controls)					slump forward	group, 0% in
						with the chin	control group.
						flexed to the chest.	
						Pressure is applied	
						to the thoracic	

						spine while extending the ipsilateral leg.	
Upton et al.	44 players NR	All: 3 users vs 57	275 matches hours	55%	45%	Thermal pants	Significant
[35]	level players	non-users	832 training hours				reduction in hamstring injury incidence wearing thermal pants sometimes: 3 injuries/1000 hours playing wearing thermal pants vs 57 injuries/1000 hours playing without thermal

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Recurrent: 42%

							pants.
Yamada,	21 amateur	All: 6 injured	NR	0%	100%	H:Q 60°/s	Motor imagery
Mastumoto	players	players				Injured 0.63 ± 0.03	capacity, and the
[34]						Non injured 0.60 ± 0.10	time to identify the foot picture
						H:Q 180°/s	was defined as the
						Injured 0.91 ± 0.57	reaction time
						Non injured 0.64 ± 0.13	(ms).
						DCR 60°	Motor imagery influences the
						Injured 0.74 ± 0.13	development of
						Non injured 0.70 ± 0.13	hamstring strain.
						DCR 180°	
						Injured 1.07 ± 0.59	
						Non injured 0.79 ±	

						0.16	
Yeomans et al. [48]	137 amateur players	All: Hamstring muscle strains 9%	NR	NR	NR	Test: Hamstring flexibility (higher score more flexibility) Protocol: Straight leg raise test Hamstring board scores Males: Forwards: 78.6° ± 8.1 Backs: 80.9° ± 5.3 Females: Forwards: 73.3° ± 11.3	NR results regarding hamstrings straight leg raise measures and injuries

Backs: 78.9° ±

10.1

Abbreviations: AD, average distance; N Newton; NR, not reported; RTP, return to play.

Notes. Values are means ± standard deviation, means [95% confidence intervals], and minimum – maximum range.

Table 3. Hamstring strength measures and imbalances

Study	Strength assessment protocols	Hamstring Measures	Bilateral strength imbalances and values (H:Q, DCR, Newtons, etc)	Key findings
Abdelfetta h et al. [47]	Male amateur players Test: Isokinetic (concentric)	Dominant limb Concentric hamstring 60°/s Backs 101.5 ± 10.4 Nm	Average value of the H:Q ratio in percentages H:Q 60°/s	Peak torque values in extension of the non-dominant limb were higher in forwards than backs.

		Forwards 133.1 ± 30.4 Nm	Dominant limb	
	Equipment: Cybex Norm	Concentric hamstring 180°/s	$56.4 \pm 9.5\%$	
	isokinetic dynamometer	Backs 70.7 ± 8.9 Nm	Non dominant limb	
		Forwards 91 ± 21.3 Nm	$53.9 \pm 10.2\%$	
	Protocol: Peak 1RM at 60 and	Non dominant limb		
	180°/s for series of successive	Concentric hamstring 60°/s	H:Q 180°/s	
	movements of 5 and 30	Backs 98 ± 21.8 Nm	Dominant limb	
	repetitions.	Forwards 130.5 ± 35 Nm	$56.1 \pm 10.25\%$	
		Concentric hamstring 180°/s	Non dominant limb	
		Backs 72.7 ± 15.6 Nm	$56 \pm 6.6\%$	
		Forwards 83.7 ± 14.2 Nm		
Anastasi,	Female amateur players	Dominant limb	Bilateral strength	Intervention group had a significant
Hamzeh		Pre-intervention	imbalances in percentage	decrease in the percentage of
[26]	Test: Isokinetic (concentric)	89.2 ± 19.9 Nm		bilateral strength imbalances.
		Post intervention	Pre-training	
	Equipment: Cybex Norm	102.2 ± 21.2 Nm	$10.4 \pm 3.5\%$	

	isokinetic dynamometer	Non dominant limb		
		Pre-intervention		Post-training
	Protocol: Peak during pre- and post-training in both legs at 60°/s	93.15 ± 20.0 Nm		4.7 ± 2.2%
		Post intervention		
		104.23 ± 18.8 Nm		
Beyer et al. [31]	Male amateur players	Dominant leg	H:Q 60°/s	Experience group had a
		Concentric hamstring 60°/s	Inexperienced 0.45 ± 0.02	significantly greater DCR 60°/s
	Test: Isokinetic (concentric, eccentric). Isotonic test (squatting).	Inexperienced 114.3 ± 4.8 Nm	Experienced 0.50 ± 0.02	than the inexperienced group. No
		Experienced 119.3 ± 5.8 Nm	H:Q 180°/s	significant differences in mass, age,
		Concentric hamstring 180°/s	Inexperienced 0.47 ± 0.02	eccentric hamstring strength values
		Inexperienced 91.9 ± 3.9 Nm	Experienced 0.50 ± 0.03	at H:Q 60°/s, 180°/s, or DCR
	Equipment: Biodex Medical System isokinetic dynamometer	Experienced 92.8 ± 4.7 Nm	DCR 60°/s	180°/s between groups.
		Eccentric hamstring 60°/s	Inexperienced 0.81 ± 0.04	
		Inexperienced 207.3 ± 8.2 Nm	Experienced 0.95 ± 0.05	
	Protocol: 10 experienced players (≥ 2 years) and 14 inexperience	Experienced 225.8 ± 9.9 Nm	DCR 180°/s	
		Eccentric hamstring 180°/s	Inexperienced 1.07 ± 0.05	

	players (< 2 years).	Inexperienced 208.8 ± 9.6 Nm	Experienced 1.17 ± 0.06	
	Isokinetic: Peak of 3 RM	Experienced 220.4 ± 11.4 Nm		
	measured at 60°/s and 180°/s	Squat 1RM		
	Isotonic: 1 RM squat	Inexperienced 132.4 ± 9.5 kg		
		Experienced 143.9 ± 11.8 kg		
Bourne et al. [52]	Male professional players	Professional	Bilateral strength imbalances	No significant difference was found between professional and semi-professional players; whilst among semi-professionals, sub-elites were significantly stronger than under 19s. Relative to body mass, these values significantly differed from professional to semi-professional players, the sub-elite and the under 19s were significantly stronger than the
	Test: Nordic eccentrics	366.9 ± 76.9 N	Injured	
		Semi-professional (sub-elite)	17.3 ± 16.1%	
	Equipment: Nordic board with custom-made uniaxial load cells	387.9 ± 96.3 N	Uninjured	
		(under 19)	10.0 ± 9.8%	
		342.8 ± 81.5 N		
	Protocol: Peak of 3RM of bilateral Nordic exercises	Combined: Forwards		
		388.5 ± 95.5 N		
		Backs		

353.1 ± 74.9 N

former players, whilst among sub-elite and under 19 players no significant difference was found. Forwards were stronger than backs; but relative to body weight, no significant differences were found.

Brown et al. [28]	Male professional players	Leg Extension	H:Q	In two rugby codes, forwards were taller and heavier than backs.
		Forwards	Forwards	Professional Rugby Union
	Test: Isokinetic (concentric)	Dominant 281 ± 45 Nm	Dominant 0.66 ± 0.09	forwards had significantly larger
		Non-dominant 268 ± 44 Nm	Non-dominant 0.68 ± 0.10	peak torque during knee flexion in
	Equipment: Humac Norm dynamometer	Backs	Backs	both dominant and non-dominant
		Dominant 244 ± 29 Nm	Dominant 0.64 ± 0.10	limbs compared to professional
		Non-dominant 247 ± 38 Nm	Non-dominant 0.64 ± 0.08	rugby league forwards and Rugby
	Protocol: Average peak torque from 4 RM measured at 60°/s during seated knee-extension/	Leg Flexion		Union backs.
		Forwards		
		Dominant 184 ± 27 Nm		

	flexion and supine hip- extension/flexion at 60°/s.	Non-dominant 180 ± 20 Nm Backs Dominant 157 ± 27 Nm Non-dominant 156 ± 27 Nm		
Brown et al. [30]	Male amateur players Test: Isokinetic (concentric and eccentric) Equipment: Humac Norm dynamometer Protocol: 1 RM with the dominant and nondominant limb in sitting and in a supine position at 60°/s. Dominant limb was	Leg Extension Concentric Forwards Dominant 252 ± 62 Nm Non-dominant 228 ± 38 Nm Backs Dominant 225 ± 38 Nm Non-dominant 214 ± 53 Nm Leg Flexion Concentric Forwards Dominant 129 ± 25 Nm Non-dominant 124 ± 19 Nm Backs	H:Q Forwards Dominant 0.52 Non-dominant 0.55 Backs Dominant 0.52 Non-dominant 0.56 DCR Forwards Dominant 0.65 Non-dominant 0.64 Backs	Professionals were stronger in all the peak torque measures compared to academy players. In forwards, the dominant limb was stronger than the non-dominant limb. The average H:Q ratio was less than 0.6 and the DCR was more than 0.6. In the isokinetic eccentric knee strength test, results showed forwards were stronger in the dominant leg compared to the non-

	defined as the limb that the player preferred to kick the ball or could kick the ball the farthest.	<p>Dominant 115 ± 14 Nm</p> <p>Non-dominant 118 ± 28 Nm</p> <p>Leg Flexion Eccentric</p> <p>Backs</p> <p>Dominant 148 Nm</p> <p>Non-dominant 125 Nm</p> <p>Forwards</p> <p>Dominant 155 Nm</p> <p>Non-dominant 145 Nm</p>	<p>Dominant 0.65</p> <p>Non-dominant 0.66</p>	<p>dominant leg. Backs had similar strength torque values in both legs in flexion, however the dominant leg was stronger in extension. No differences between positions and limbs were found. Isokinetic concentric hip strength in forwards were similar between dominant and non-dominant legs. Forwards displayed greater values in the dominant leg during flexion compared to backs.</p>
Deighan et al. [29]	<p>Male amateur players</p> <p>Test: Isokinetic (Concentric)</p>	<p>Seated peak torque</p> <p>Hamstring concentric</p> <p>60°/s: 144 ± 26 Nm</p> <p>180°/s: 121 ± 16 Nm</p>	<p>H:Q</p> <p>Seated</p> <p>60°/s: 0.53 ± 0.07</p> <p>180°/s: 0.56 ± 0.07</p>	<p>In a seated position, concentric peak torque was greater compared to supine eccentric. The H:Q in the seated position showed no</p>

<p>Equipment: Biodex System 3 dynamometer</p>	<p>Hamstring eccentric</p> <p>60°/s: 179 ± 45 Nm</p> <p>180°/s: 186 ± 60 Nm</p>	<p>Supine</p> <p>60°/s: 0.47 ± 0.06</p> <p>180°/s: 0.51 ± 0.09</p>	<p>significant difference compared supine.</p>
<p>Protocol: 1RM isokinetic seated.</p> <p>For supine, participants were placed lying on their backs at 60 and 180°/s.</p>	<p>Supine peak torque</p> <p>Hamstring concentric</p> <p>60°/s: 123 ± 19 Nm</p> <p>180°/s: 109 ± 18 Nm</p> <p>Hamstring eccentric</p> <p>60°/s: 147 ± 20 Nm</p> <p>180°/s: 138 ± 30 Nm</p>	<p>DCR</p> <p>Seated</p> <p>60°/s: 0.66 ± 0.09</p> <p>180°/s: 0.86 ± 0.23</p> <p>Supine</p> <p>60°/s: 0.58 ± 0.07</p> <p>180°/s: 0.68 ± 0.15</p>	
<p>Dobbs et al. [46] Female and male amateur players</p> <p>Test: Isokinetic (concentric and eccentric) and isometric (leg pull)</p>	<p>NR</p>	<p>H:Q</p> <p>Non-dominant limb : 0.81 ± 0.13</p> <p>Dominant limb : 0.74 ± 0.14</p>	<p>The non-dominant limb H:Q ratio was significantly greater than the dominant leg whilst the DCR was significantly greater than the simple H:Q</p>

DCR

Equipment: Biodex Pro 4

0.81 ± 0.14

dynamometer

Protocol:

Isokinetic tests: Average of 3RM

at 60°/s; 1RM isometric

quadriceps strength at 60°/s, and

1RM isometric hamstring

strength at 35°/s

Isometric: Bilateral and

unilateral leg isometric mid-thigh

pull. 3RM for both legs, and 2RM

for a single leg were recorded on

force plates.

Dominant limb was defined as

the preferred leg to kick a ball.

<p>Mondin et al. [36]</p>	<p>Male professional players</p> <p>Test: Sphygmomanometer measures of maximal isometric strength. Isokinetic dynamometry (concentric) strength.</p> <p>Equipment: Humac Norm dynamometer and an adapted sphygmomanometer</p> <p>Protocol:</p> <p>Isokinetic tests: Peak of 3RM at 60°/s.</p> <p>The sphygmomanometer test: Subjects in supine with knees</p>	<p>NR</p>	<p>ICC (95% CI):</p> <p>Quadriceps 90° right 0.64 (-0.28–0.91)</p> <p>Quadriceps 90° left 0.81 (0.21–0.95)</p> <p>Hamstrings 90° right 0.83 (0.30–0.96)</p> <p>Hamstrings 90° left 0.87 (0.45–0.97)</p> <p>Hamstrings 30° right 0.92 (0.69–0.98)</p> <p>Hamstrings 30° left 0.87 (0.45–0.97)</p>	<p>A positive correlation in 90° of knee flexion between sphygmomanometer and isokinetic tests was found, as well as hamstring strength at 90° and 30° of knee flexion for both measures. No relation in strength asymmetry between legs or tests at 30° or 90° when testing the efficacy of the sphygmomanometer compared to the isokinetic test. No correlation in hamstring to quadriceps ratio at 90° between test for dominant and non-dominant leg.</p> <p>The group found reliability and</p>
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	flexed at 30° or 90° and heel of one leg on the cuff, and opposite leg resting on the floor and extended. 3RM isometric strength of hamstring at 30° and 90° were recorded.			validity measuring hamstring strength with the adapted sphygmomanometer test, although the test was not valid or reliable assessing bilateral or hamstrings to quadriceps asymmetries.
Severo-Silveira et al. [41]	Male professional players Test: Isokinetic (concentric and eccentric) Equipment: ultrasound assessment B-mode ultrasonography and Biodex Pro 4 dynamometer	Pre-intervention Quadriceps concentric Constant group: 275.5 ± 27.1 Nm Progressive group: 278 ± 48.8 Nm Hamstrings concentric Constant group: 142.2 ± 19.6 Nm Progressive group: 146.6 ±	Pre-intervention H:Q Constant group: 0.52 ± 0.05 Progressive group: 0.53 ± 0.07 DCR Constant group: 0.74 ± 0.14 Progressive group: 0.76 ± 0.06	After the training intervention only the progressive group had an increased in hamstring concentric and eccentric peak torques, H:Q and DCR.

Protocol: Peak of 3RM of 24.3 Nm

flexion-extension at 60°/s

Hamstrings eccentric

Constant group 204.5 ± 43.3

Nm

Progressive group 211.1 ± 31.8

Nm

Notes. Values are means ± standard deviations.

Abbreviations: DCR, isokinetic dynamic control ratio; H:Q, isokinetic hamstring quadriceps ratio; Nm, Nanometre; NR, not reported; RM, repetition maximum.

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Table 4. Hamstring training protocols and results

Study	Participants	Duration and Protocol exercises	Outcome
Brooks et al. [1]	492 professional males	<p>1st group</p> <p>1st group strengthening</p> <p>Sessions per week: 1.2 ± 0.2</p> <p>Sets per session : 3.6 ± 0.4</p> <p>Reps per set: 8.2 ± 2.5</p> <p>Proportion of weeks:</p> <p>87% of weeks strengthening</p> <p>2nd group strengthening and stretching</p> <p>2nd group Strengthening</p> <p>(n=148)</p> <p>Sessions per week: 1.8 ± 0.4</p> <p>Strengthening</p> <p>Sets per session : 3.3 ± 0.3</p> <p>and stretching</p> <p>Reps per set: 7.5 ± 1.0</p> <p>Proportion of Stretching</p>	<p>The group performing Nordic exercises had a lower incidence of hamstring injuries compared to the group performing strengthening exercises.</p> <p>The incidence of injuries in matches and training was not significantly different between the group performing Nordic exercises (0.39 injuries per 1000 hours player) and the group with stretching and strengthening exercises (0.59 injuries per 1000 hours player).</p>

weeks: Sessions per week: 2.6 ± 0.4
 77% of weeks Sets per session : 2.8 ± 0.3
 strengthening and Reps per set: 2.5 ± 9.0
 87% of weeks
 stretching **3rd group strengthening stretching
 and Nordic exercises**
Strengthening
 Sessions per week: 1.3 ± 0.3
3rd group Sets per session : 3.0 ± 0.4
(n=200) Reps per set: 7.5 ± 2.1
Proportion of Stretching
weeks: Sessions per week: 1.8 ± 0.2
 44% of weeks Sets per session : 2.6 ± 0.4
 strengthening, Reps per set: 28 ± 20
 87 % of weeks **Nordic exercises**
 stretching, and Sessions per week: 1.3 ± 0.5

		65% of weeks	Sets per session	: 2.8 ± 0.7	
		Nordic exercises	Reps per set	6.7 ± 1.5	
Anastasi,	24 females	10 weeks	Program		The 10-week training program significantly decreased
Hamzeh	amateur (11	Nordic exercises	Weeks 1 – 2: 3 sets x 6 reps		the bilateral strength imbalances from: $10.38 \pm 3.53\%$ to
[26]	tested	performed in	Weeks 3 – 4: 3 sets x 7 reps		$4.69 \pm 2.18\%$.
	players, 11	couples of	Weeks 5 – 7: 3 sets x 8 reps		The Nordic exercise group displayed a significant change
	control	players, 3	Weeks 8 -10: 3 sets x 10 reps		in the mean maximal vertical jump height from 31.22 to
	players)	per week			35.93 cm
Severo-	21 male	8 weeks	Training Constant [Progressive]		An 8-week training program significantly increased
Silveira	professionals	Nordic exercises	Week 1: 2 sets x 6 reps [2 sets x 6		hamstring strength values by 7 - 8%, and H:Q from 0.53
et al.			reps]		to 0.57 and DCR from 0.76 to 0.81 in the progressive
[41]			Week 2: 3 sets x 6 reps [3 sets x 6		training group only.
			reps]		

Week 3: 3 sets x 6 reps [3 sets x 8

reps]

Week 4: 3 sets x 6 reps [3 sets x 10

reps]

Week 5: 3 sets x 6 reps [4 sets x 8-

10 reps]

Week 6: 3 sets X 6 reps [4 sets x 8-

10 reps]

Week 7: 3 sets X 6 reps [4 sets x 10

reps]

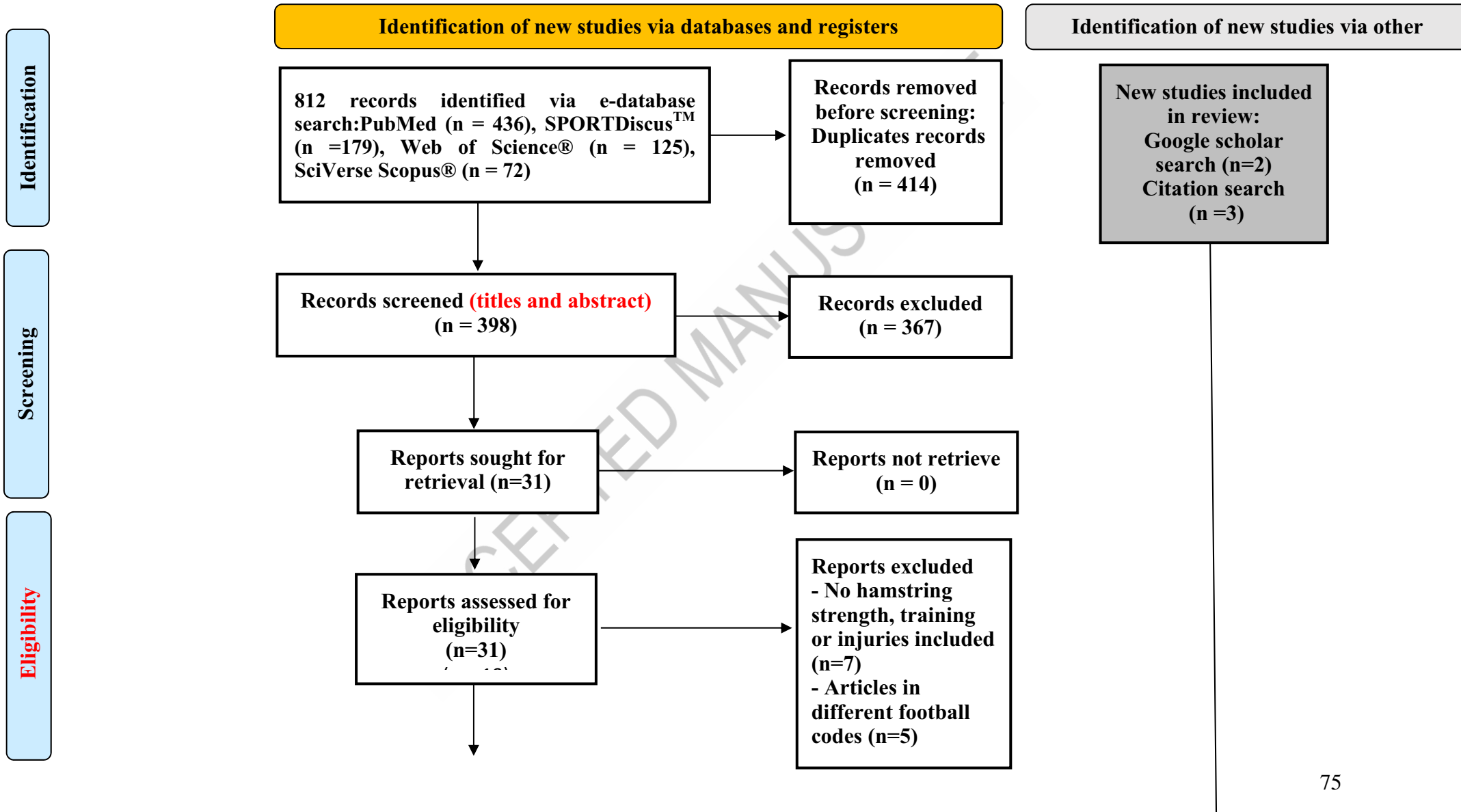
Week 8: 3 sets X 6 reps [4 sets x 10

reps]

Notes. Values are means \pm standard deviation.

Abbreviations: DCR, dynamic ratio; H:Q Hamstring to quadriceps ratio

9. Figures



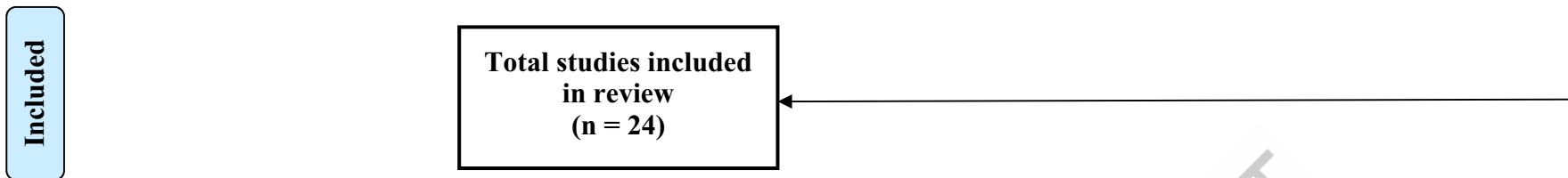


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart.

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Figure 2. Illustration of a Nordic hamstring exercise.

10. Supplemental material

Appendix 1

Quality assessment tool

NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE

Selection: (Maximum 5 stars)

1) Representativeness of the sample:

- a) Truly representative of the average in the target population. * (all subjects or random sampling)
- b) Somewhat representative of the average in the target population. * (non-random sampling)
- c) Selected group of users.
- d) No description of the sampling strategy.

2) Sample size:

- a) Justified and satisfactory. *
- b) Not justified.

3) Non-respondents: Rate between participants asked to participate and participants actually participated

a) Comparability between respondents and non-respondents characteristics is

established, and the response rate is satisfactory. * Rate more than 60%

b) The response rate is unsatisfactory, or the comparability between respondents and non-respondents is unsatisfactory.

c) No description of the response rate or the characteristics of the responders and the non-responders.

4) Ascertainment of the exposure (risk factor):

a) Validated measurement tool. **

b) Non-validated measurement tool, but the tool is available or described.*

c) No description of the measurement tool.

Comparability: (Maximum 2 stars)

1) The subjects in different outcome groups are comparable, based on the study design or analysis. Confounding factors are controlled.

a) The study controls for the most important factor (select one). * Age

b) The study control for any additional factor. * Weight , height

Outcome: (Maximum 3 stars)

1) Assessment of the outcome:

- a) Independent blind assessment. **
- b) Record linkage. **
- c) Self report. *
- d) No description.

2) Statistical test:

- a) The statistical test used to analyze the data is clearly described and appropriate, and the measurement of the association is presented, including confidence intervals and the probability level (p value). *
- b) The statistical test is not appropriate, not described or incomplete.

Table 5. Summary of the risk of bias assessment of the reviewed studies (Modified Newcastle - Ottawa Quality score).

	SELECTION		COMPARABILITY		OUTCOME		TOTAL	
	1	1	3	4	1	1	2	
Anastasi, Hamzeh [26]	b	b	c	a	b	d	a	5
Beyer et al. [31]	b	b	ca	a	b	d	b	4
Bourne et al. [37]	b	b	c	a	a,b	b	a	8
Brooks et al. [38]	a	b	a	a	a,b	b	a	9

Brooks et al. [39]	a	b	a	a	a,b	b	a	9
Brooks et al. [69]	a	b	c	a	b	b	a	9
Brooks, Kemp [43]	a	b	c	a	b	b	a	7
Brown et al. [28]	b	b	c	b	a,b	d	B	4
Brown et al. [30]	b	b	c	b	a,b	d	b	4
Deighan et al. [29]	b	b	c	b	b	d	a	4
[46]	c	b	c	b	b	D	b	2

Farnan et al. [32]	b	b	a	b	b	c	a	5
Kenneally-Dabrowski et al. [45]	a	b	c	a	b	b	a	7
Kenneally-Dabrowski et al. [44]	b	b	c	a	a,b	b	b	7
Mendiguchia et al. [33]	c	b	c	a	a,b	d	b	4
Mondin et al. [36]	c	b	c	a	b	d	a	4
Reid et al. [27]	c	b	c	a	a,b	b	b	6
Roberts et al. [42]	a	b	c	a	b	b	a	7

Severo-Silveira et al. [41]	b	b	a	a	b	a	a	8
Turl, George [40]	b	b	c	a	a,b	a	b	7
Upton et al. [35]	b	b	c	b	a,b	c	b	5
Yamada, Mastumoto [34]	b	b	c	b	b	b	b	5

Methodology quality assessment score based on Newcastle-Ottawa Quality Assessment Scale adapted for cross-sectional studies, weak (0-3 stars), moderate (4-6 stars), and strong (7-10 stars).