CHAPTER 3

EXERCISE-BASED INTERVENTIONS FOR INJURY PREVENTION IN TACKLE COLLISION BALL SPORTS: A SYSTEMATIC REVIEW

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Abstract

Background

The injury burden in collision sports is relatively high compared to other team sports. Therefore, participants in these sports would benefit by having effective injury prevention programs. Exercise-based interventions have successfully reduced injuries in soccer, but evidence on exercise-based interventions in tackle collision sports is limited. The aim of the study was to systematically examine the evidence of exercise-based intervention programs reducing injuries in tackle collision sports.

Methods

Data sources: PubMed, EBSCOHost and Web of Science were searched for articles published between January 1995 and December 2015. The methodological quality was assessed using an adapted Cochrane Bone Joint and Muscle Trauma Group quality assessment tool.

Study selection: The inclusion criteria were: 1) (randomized) control trials and observational studies 2) sporting codes: American, Australian and Gaelic Football, rugby union and rugby league 3) participants of any age or sex 4) exercise-based, prehabilitative intervention, and 5) primary outcome: injury rate or incidence (injury risk). The exclusion criteria were: 1) unavailability of full-text, 2) article unavailable in English.

Results

Nine studies with a total of 3517 participants were included in this review. Seven of these studies showed a significant decrease in injury risk. These studies included three sporting codes and various age groups, making it difficult to make inferences. The two highest methodological quality studies found no effect of an exercise-based intervention on injury risk.

Conclusions

There is evidence that exercise-based injury preventions can be beneficial in reducing injury risk in collision sports, but more studies of high methodological quality are required.

Introduction

Collision sports, including Australian Football, American Football and Rugby union (henceforth referred to as 'rugby') are popular sports played across the globe. These sports are characterized by intermittent, high intensity bouts of exercise interspersed with heavy bodily collisions (such as tackles).[1-3] This contact is of a ballistic nature, with high force- and momentum-generating movements, and thus collision sports are associated with a relatively high injury burden.[4-10] The injury incidence in tackle collision sports is higher than that of other non-collision sports (such as soccer).[11, 10] In collision sports, injuries can have a large economic cost, as well as a negative effect on team performance, which demonstrates the urgent need for effective injury prevention strategies.[12, 13]

Sports injury risk reduction interventions have adopted a wide variety of intervention modalities, including exercise-based programs. Effective exercise-based programs are dependent on good compliance.[14, 15] Another critical component to the program's effectiveness is the exercise intervention itself. In soccer players, Nordic hamstring strengthening exercises were associated with a decrease in hamstring injury incidence.[16] In soccer and basketball, the FIFA 11+ exercise program is an effective whole-body injury reduction intervention. [17-19] However, rugby has different physical characteristics to both soccer and basketball, such as tackling and bodily collisions, and therefore it is not known whether these results can be translated to rugby.

Accordingly, the aim of this review was to systematically examine the evidence for the effectiveness of exercise-based intervention programs in reducing injury risk in collision sports that incorporate tackling in the game.

Methods

Search Methods

The databases PubMed, EBSCOHost and Web of Science were searched for relevant articles that were published between January 1995 and December 2015. The following combination of keywords was used when searching:

((rugby union) or (rugby league) or (rugby) or (AFL) or (NFL) or (Football) or (Gaelic Football)) AND (injury or injuries) AND ((exercise) or (warm-up) or (resistance training) or (proprioception) or (rehabilitation) or (prehabilitation) or (train*) or (balance) or (strength*) or (neuromuscular)). The results of these searches were then combined and the duplicate articles removed. Additionally, the reference list of included studies and relevant systematic reviews were searched for further relevant studies.

Eligibility Criteria

The citations were initially screened using the title and abstract. Articles were independently screened and selected by two authors (NS, JB) if they fitted the following criteria:

Inclusion

- Controlled trials (i.e. cluster-randomized controlled trial, randomized controlled trials or quasi-randomized controlled trials), observational studies (i.e. prospective cohort, retrospective cohort, time-series studies)
- Sporting code was: rugby union, rugby league, Australian Football, American Football or Gaelic Football players (any age, level of play or sex)
- Primary outcome was injury rate or injury incidence, further referred to as 'injury risk'.
- The intervention was prehabilitative and exercise-based

Exclusion

- Full-text for the article was unavailable
- The article was not available in English

The full-text articles were independently assessed for eligibility using the inclusion and exclusion criteria by two authors (NS, JB). Any disagreements on article eligibility were resolved through discussions between the two reviewers, without the need for the involvement of a third author.

Data Collection

The following information was extracted from the included articles by the two authors (NS, JB) and is presented in Table 1: authors, year of publication, study design, participants' details (type of sport, age, sex, level of competition, number of participants), definition of the primary outcome, details of the intervention and the effect of the intervention (including a level of statistical significance).

Assessment of Methodological Strength of Included Studies

Both reviewers (NS, JB) scored the selected articles independently according to a modified version of the Cochrane Bone Joint and Muscle Trauma Group quality assessment tool (eliminated was measure "G = were care programs, other than the trial options, clearly identical?")[20] to assess the methodological strength, with any disagreements resolved through discussion. Each item on the check-list was given a grade from 0 – 2 (0 = not possible to rate/not defined/ not mentioned, 1 = inadequate description/application or not adjusted for, 2 = clearly defined or effective action in the case of blinding), with a maximum possible composite score of 22 representing the methodological strength. Median scores of studies that did and did not show an effect of the intervention were compared using a Wilcoxon ranked sum test using Stata (StataCorp 2011: Release 12, Collect Station, TX: StataCorp, LP). The study design for each article was also determined using the Oxford Centre for Evidence Based-Medicine – Levels of Evidence.[21]

Results

Study Selection

Electronic (3216) and manual (37) searches for articles resulted in a total of 3253 articles. After duplicate articles were removed, the remaining 2150 articles were screened, using the title and abstract; 2125 articles were excluded for reasons including incorrect sporting code or study design (no articles were excluded on the basis of no full-text available). For the remaining 25 full-text articles a further 16 articles were excluded, due to eligibility criteria without disagreement between NS and JB (Figure 3.1).

Study Characteristics

Following the study selection process (Figure 3.1), nine studies with a total of 3517 participants were included in this review. These nine studies included six observational studies and three controlled trials. The number of participants in the observational studies ranged from 27 to 546 players and the controlled trials ranged from 220 to 1564 participants. These participants were all male, and consisted of both youth and senior players of amateur (five studies) and professional status (four studies). The sporting codes of the selected studies included American and Australian Football and rugby union. The follow-up periods for the observational studies were between two seasons (two years) and four seasons (four years),[22-27] whereas the controlled trials were all one season (26, 22 or 12 weeks).[28-30]

Methodological strength

The methodological strength of the nine studies had a range of scores from 7 to 21 (the lower the score, the worse the methodological quality of the study) (Figure 3.2). Only three of the studies fulfilled more than 50% of the criteria: these three studies were the controlled trials.[28-30] The observational studies had the lowest methodological quality scores, as they did not blind subjects, assessors or therapists.[22-25, 27] The methodological strength was reduced because baseline comparability between experimental and control groups was lacking and frequently not adjusted for in most of the studies, regardless of study design.[22, 23, 28, 24, 25, 27] Only three of the studies were of a high methodological strength (score $\geq$ 16). These three studies were all performed in Australian Football; all three were controlled trials.[28-30] Two of these three studies did not find a decrease in injury risk.[28, 29] However the third study, which assessed a motor control intervention, found a decrease in injury risk.[30] The six lower methodological quality studies all found a decrease in injury risk and were spread across American Football, Australian Football and rugby.[22-27] It is important to note the methodological quality of each study, as this affected the inferences made throughout the Results and Discussion sections.

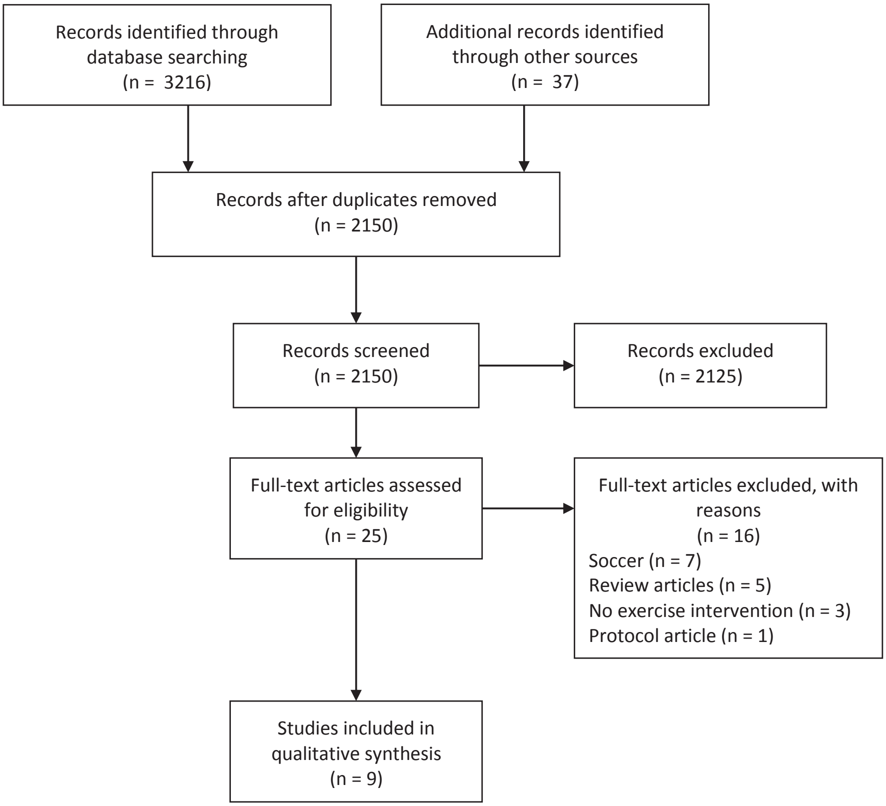

Figure 3.1: Flow diagram of the search strategy and study selection.

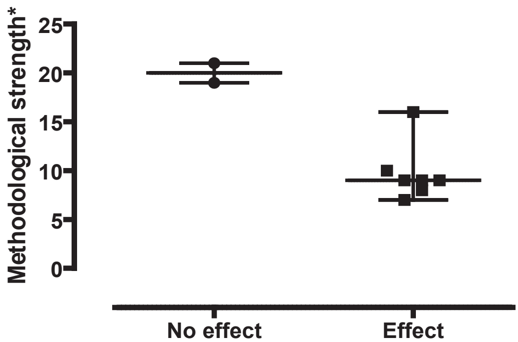

Figure 3.2: Difference between reported intervention effects on injury rates and the methodological strength of the study reporting the effect. On average, those studies reporting an intervention effect on injury rates had a significantly lower methodological strength rating than those studies that showed no effect (p=0.037). Circles represent studies with no significant change, squares represent studies with a significant positive result. Median and range values are depicted. [1]Methodological strength was determined using a modified version of the Cochrane Bone Joint and Muscle Trauma Group quality assessment tool.[20]

Table 3.1: Characteristics of each included study.

Study	Composite score (methododological strength)[a]	Study design[b]	Follow-up period	Male participants (n)[c]
Gabbe et al., 2006 [29]	21	Controlled trial	1 season, 12 weeks	Australian Football players from the Victorian Amateur Football Association (n = 220) Control group: n = 106; age 23.9 (17.4-36.0) years Intervention group: n = 114; age 23.4 (18.0-35.0) years
Finch et al., 2015 [28]	19	Controlled trial	1 season, 26 weeks	Non-elite, community-level Australian Football players (n = 1564), age unknown
Hides and Stanton, 2014 [30]	16	Controlled trial	1 season, 22 weeks	Elite, national Australian Football club players (n = 46) age 22.8±3.5 years
McHugh and Mullaney, 2007 [24]	10	Observational	3 seasons, 3 years	University American Football teams (n = 125), age15-18 years
Naish et al., 2013 [25]	9	Observational	2 seasons, 2 years	Professional Super 14 rugby union players (n = 27) age 25.2±3.9 years
Scase et al., 2006 [26]	9	Observational	2 seasons, 2 years	Under 18 Australian Football players from the national competition (n = 723) Control group: n = 609; age 17.0±2.6 years Intervention group: n = 114; age 17.0±2.5 years
Verrall et al., 2005 [27]	9	Observational	4 seasons, 4 years	Male professional Australian Football players (n =70)
Cross and Worrell, 1999 [23]	8	Observational	2 seasons, 2 years	Division III college American Football players (n =195); age 18.6±1.5 years
Brooks et al., 2006 [22]	7	Observational	2 seasons, 2 years	English Premiership rugby union clubs (546) Strengthening group: n = 148; age 25.5±4.1 years Stretching group: n = 144; age 25.8±4.0 years Nordic strengthening: n = 200; age 25.4±4.1 years

Primary outcome	Intervention	Effect of intervention
Hamstring injury; training and match; only time-loss	Control: stretching, range of motion including gastrocnemius, hip flexors, hamstrings (supine and sitting), lumbar spine rotation (3 x 30s) Intervention: eccentric hamstring exercises (6 repetitions, 12 sets). 5 session program, first 3 sessions in pre-season (each 2 weeks apart), 4th and 5th session were in-season (3 weeks apart).	No effect (unknown if match or training or both) RR= 1.2 (95% CI 0.5 – 2.8)
Injury incidence; match injuries; only time-loss	Control group: sham exercise program, similar to regular training (twice a week) Intervention: neuromuscular and biomechanical exercises focusing on lower limb injury prevention (twice a week)	No effect IRR= 0.92 (95% CI 0.68 – 1.23)
Injury incidence; training and match; only time-loss	Group 1: motor control training (7 wk), advanced motor control training (8 wk), Pilates (7 wk) Group 2: Pilates (7 wk), motor control training (8 wk), Pilates (7 wk) Group 3: Pilates (7 wk), Pilates (8 wk), motor control training (7 wk)	**Motor control training occurring before time point 3 significantly decreased the occurrence of an injury (match and training) p=0.017**
Ankle sprain injury number; training and match injuries; only time-loss	Control (Previous player seasons, pre-intervention): status quo Intervention (3 seasons): single-limb balance training on foam stability pad (5min each leg, pre-season: 5 days/week for 4 weeks; in-season: 2x/week for 9 weeks)	**Significantly decreased incidence of ankle injuries (match and training) p<0.01**
Cervical spine injury number and severity; training and match; only time-loss	Control (1st season): status quo Intervention (2nd season): 13-week isometric neck strengthening program, 13-week maintenance phase	**Significant decrease in the number of injuries in matches p=0.03** No effect on severity of injuries p=0.40
Injury incidence and severity; training and match; only time-loss	Control: status quo Intervention: 6 landing, falling and recovery skills taught, initially on a mat, progressed to game situations (8x30 minute sessions) during pre-season	**Significantly reduced injury incidence (match and training) IRR 0.72 (95% CI 0.52-0.98)** No effect on severity of injury (match and training) p=0.39
Hamstring injury incidence; training and match; only time-loss	Control (1st& 2nd season): status quo Intervention (3rd & 4th season): increased high intensity anaerobic interval running drills, hamstring stretches, specific football drill, lower limb weight training.	**Significant decrease in match hamstring injury incidence IRR 0.27 (95% CI 0.08-0.76)**
Lower extremity musculotendinous strains incidence; training and match; only time-loss	Control (1st season): status quo Intervention (2nd season): stretching program incorporated (hamstrings, quadriceps, hip adductors, gastrocnemius)	**Significant decrease in incidence of lower extremity muscle injuries (match and training) p<0.05**
Hamstring injury incidence and severity; training and match; only time-loss	Strengthening group: regular concentric and eccentric hamstring exercises Stretching group: static stretching at least once a week, and regular concentric and eccentric hamstring exercises Nordic strengthening group: same as the above two, and includes Nordic hamstring exercises	No difference in match injury burden. **Significant decrease in all injuries incidence in the stretching (IIR =0.59 (95% CI 0.34-0.84)) and Nordic strengthening group (IIR=0.39 (95% CI 0.25-0.54)) (compared to the strengthening group IIR=1.1 (95% CI 0.74-1.40))**

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[a] Based on a modified version of the Cochrane Bone Joint and Muscle Group study quality assessment tool.[20]
[b] Using the Oxford Centre of Evidence-Based Medicine categorization.[21]
[c] Age data are mean (range or ± SD)
RR = relative risk
IRR = injury rate ratio
IIR = injury incidence rate
CI = confidence interval
SD = standard deviation
Bold text indicates that the intervention was associated with a significant reduction in injury risk

Injury Definitions

The definition for an injury was similar throughout most studies, and included a statement similar to that of the rugby injury consensus statement by Fuller *et al.* (2007) for a time-loss injury defined as "an absence from training or match participation for more than 24 hours after the injury".[31] However, the studies included in this review used variations of this definition, with the difference between a time-loss and medical attention injury ("an injury resulting in less than 24 hours absence from training or match participation") being unclear in most of them.[31] The primary outcome was sometimes specific to a body location of specific interest to the intervention, for example hamstring injuries only.[22, 29, 27] Depending on the study, the injury outcome was measured either by injury risk and/or severity of injury (number of days missed due to injury). Some studies recorded only match injuries. However, if a study reported both match and training injuries separately, these results were presented separately (Table 3.1).[22, 30]

Exercise Intervention Type

In the observational studies, balance training, Nordic drops and plyometric training were associated with significant decreases in injury risk. Two of the studies in this review included eccentric hamstring exercises as the primary intervention. In the studies that examined this intervention in rugby union and Australian Football, one found no decrease in match injury risk,[28] and the other found a decrease in training injury risk.[21] The other common exercise intervention used by three of the studies, was that of neuromuscular and proprioceptive training. The controlled trials used neuromuscular and biomechanical exercises as the intervention, but after adjusting for confounders there was no significant change in injury risk.[28] However, in a cohort of junior American Football players, foam pad balance training resulted in a significant decrease in the injury risk of ankle sprains.[24] The majority (n = 6) of the nine interventions used a single modal exercise – five of these six interventions were associated with an injury reduction.[22, 23, 29, 30, 24, 25] Of the three remaining multimodal interventions, two were associated with injury reductions.[28, 26, 27]

Intervention Effectiveness

Seven of the nine studies were associated with a significant decrease in injury risk and therefore were effective in injury risk reduction. Of these seven studies, four grouped training and match injuries together,[23, 30, 24, 26] two used only match injuries and showed a decrease in injury risk (Naish *et al.* p=0.03;[25] Verrall *et al.* relative risk (RR) 0.267, 95% CI 0.076 to 0.764)[27] and one separated match and training injuries and showed a decrease in training injury risk (p-value or RR not mentioned).[22] However, the two studies that were not associated with a decrease in injury risk had significantly higher median methodological quality (p=0.037, Finch *et al*.,[28] and Gabbe *et al*.).[29] Despite having the highest methodological quality, these two studies were difficult to compare due to differences in injury definitions. Specifically, the definitions of Finch *et al*. [28] were aligned with those of the rugby consensus statement (without directly referring to it).[31] In contrast, the study of Gabbe *et al.* [29] was published before the rugby consensus statement and their injury definition did not require a player to be absent from training or match participation.[31] Scase *et al.* (2006) found that their falling, landing and recovery skills-based exercise intervention was associated with a significant increase in time to sustaining a landing injury compared to the control group who continued as per usual (RR 0.40, 95% CI 0.17 to 0.92).[26] In this original paper, the authors incorrectly stated "the time to sustaining a landing injury was significantly less for the intervention group". However, their graphical representation clearly indicates that the time to injury increased, not decreased. Although three of the nine studies assessed the effect of an exercise modality on severity of injury, none found an effect on this outcome.[22, 25, 26]

Injury Type

Three of the nine studies focused on interventions to reduce hamstring injury risk. One of these three hamstring studies found no intervention effect.[29] However, the two hamstring studies that were associated with a decrease in injury risk were observational studies that also had the lowest level of evidence, and methodological quality.[22, 27] One of the hamstring studies that had an effect was an observational study where the teams were grouped according to their usual training regime: (i) strengthening exercises, (ii) static stretching and (iii) a group that included both (i) and (ii) components and further added Nordic hamstring exercises.[22] The second observational study, which also found a decrease in hamstring injury risk, implemented a two-year intervention, after two seasons of prior baseline measurement, with the intervention consisting of high intensity anaerobic interval running drills, hamstring stretches, weight training and football drills.[27] The hamstring study that was not associated with a change in injury risk was a controlled trial where the intervention group implemented eccentric hamstring exercises and the control group performed lower body stretching and range of motion exercises.[29] The six other studies focused on a wider range of injuries, using and including a range of different exercise modalities. These modalities included motor control training,[30] neuromuscular and biomechanical training,[28] and landing, falling and recovery skills, specifically for game situations.[26] For example, a stretching program was used as an intervention for lower extremity injuries,[23] a single limb balance training intervention was implemented for ankle sprains,[24] and a progressive isometric neck strengthening program was used to reduce cervical neck injuries.[25]

Sporting Code

The nine studies were performed in three sports: Australian Football (n=5), American Football (n=2) and rugby union (n=2). The two American Football studies were associated with significant reductions in injury risk, one specifically in ankle injuries and the other in lower extremity injury risk.[23, 24] Both these studies were observational studies and their definitions of an injury included both match and training injuries together. However, the age groups of the two study samples were distinctly different; one was college athletes and the other group below eighteen years.[23, 24] Of the five Australian Football studies, three were associated with a significant decrease in injury risk. The variation in study designs and age of participants of the five Australian Football studies made them difficult to compare.[28-30, 26, 27] The last two studies were observational studies conducted in rugby union; the one in professional and the other in amateur clubs with participants over the age of eighteen.[22, 25]

Compliance

Compliance is another important aspect of the effectiveness of an intervention program. Four studies report compliance as a factor.[22, 23, 27, 28] Two of these studies measured compliance in some way; Finch *et al.* [27] reported compliance in terms of numbers of sessions attended but merely stated that most players did not attend both sessions every week (determined to be ineffective in injury prevention), while Gabbe *et al.*[28] reported the percentage of players attending at least two of the five sessions (an effective injury prevention program). The two American Football studies simply reported that compliance was "good" as the coaches and athletic trainers ensured attendance.[22, 23] Another possible reason for the "good" compliance in these two studies might have been that the intervention was easily incorporated into regular training as it was a simple stretching program prior to practice and balance training, performed at weight training sessions.

Discussion

This review systematically evaluated the effectiveness of various exercise-based interventions on injury risk in sports involving tackle collisions such as Australian Football, American Football and rugby union. Seven of the nine reviewed interventions were effective in reducing injury risk, with one of these having a high methodological quality. The two studies which showed no change in injury risk were both of high methodological quality, illustrating conflicting evidence. This outcome suggests that more research is necessary to evaluate the potential to prevent injury in collision sports through exercise-based interventions.

Whilst the sporting codes included in this review all have similar physical demands in terms of their collision nature, their rules differ fundamentally and therefore affect the injury etiology. This feature of multiple sporting codes in this review, makes it difficult to compare to previous reviews performed in single sports such as soccer. There are multiple reviews looking at soccer injury prevention programs. In one review, half of the studies had a statistically significant outcome, with six out of the seven studies having at least a moderate methodological quality.[32] This moderate methodological quality can be attributed to the fact that four of the studies included in the said review were randomized controlled trials. A second review of intervention effectiveness in soccer only included the FIFA 11+

exercises and showed a 30-70% reduction in injuries across the included studies. This review consisted of five randomized controlled trials, six observational studies showing the effectiveness of a warm-up integrated injury prevention program in soccer.[33] The difference between the soccer reviews and the present review is the nature of the sports. The sports included in this review include a constant aspect of collisions/tackles, which is absent from soccer. To identify and develop an injury prevention program for such sporting codes is far more complex, than for a sport where the main contact focus is on the lower limbs. This dynamic and unpredictable nature of collision sports could be a contributing factor to the inconclusive data obtained in the present review.[2]

The type of exercise intervention implemented is important to an effective program. For example American Football players had a significant decrease in the injury incidence of ankle sprains following foam pad balance training.[24] This is consistent with previous literature in soccer players and basketball players, where balance training (using wobble boards, single leg balance and functional activities performed on one leg) was associated with a decrease in ankle injury risk.[34, 35] Eccentric hamstring curls (also known as Nordic drops) were included in two of the studies in this review. They have also been shown to be effective in various age groups in multiple studies in soccer and basketball players, and are a widely accepted preventative exercise.[16, 36, 37] However, in the studies that examined this intervention in rugby union and Australian Football, one found no decrease in match injury risk,[28] and the other (in rugby union) found a decrease in training injury risk.[21] A review performed by Rössler *et al.* (2014) showed that interventions that included balance, jumping and plyometric exercises provided better results than those that did not, and this would support the present review's results.[38] This indicates that even with the collision nature of the sports, these aspects of training are important to incorporate into a prevention program. Furthermore Rössler *et al.* (2014) concluded that injury-specific programs, as opposed to "global" prevention programs, tended to deliver better results.[38] In our review there was only one true "global" program (Finch *et al.*),[27] and we therefore could not compare global programs to single programs and determine which had better results.[28] However, it must be noted that the comparison between injury-specific and "global" programs is problematic as certain injuries often deemed non-preventable are not included in the data analysis of injury-specific programs.

Although compliance is an important factor for intervention effectiveness,[39] only two of the nine studies included in our review reported on this effect. The "Preventing Australian Football injuries" intervention had low compliance and no effect on injury risk. Most participants did not attend both sessions every week, and their intervention consisted of multiple components, requiring considerable time.[28] Whilst the study design was of a high quality, its complex nature could have made it too demanding for the participants and therefore difficult to adhere to. It must be noted that Finch *et al.* (2015) [28] used an ITT (intention-to-treat) analysis to account for compliance. However, this method has recently come under scrutiny and it is worth considering PP (per protocol) analysis to determine the effects of the intervention as per the protocol performed by the participant.[15] As a result, it was not possible to conclude whether the lack of intervention effectiveness in the Finch *et al.* (2015) study was a result of poor compliance or not.[28]

However, another program in Australian Football, with a relatively simple intervention consisting of eccentric hamstring curls, had a 50% drop in attendance from the first to second session. Only 49% of players completed at least two of the sessions.[29] Thus, despite this intervention's simplicity and time-efficiency this study also reported poor compliance and no effect on injury risk.[29] The compliance in the motor control training program in Australian Football is unknown. The intervention consisted of predominantly individual sessions, which could have been a contributing factor to the program being more effective in injury risk reduction.[30] Similarly, both Scase *et al*. [26] and Verrall *et al.* [27] (also Australian Football) made no mention of the compliance with their programs, but both had positive reductions in injury risk. This is important to note, as one of the programs was integrated into the preseason team training, and therefore, did not require extra time from the participants.[27] Compliance in the Brooks *et al*. [22] rugby union study was not measured and groups were only stratified conveniently according to their habitual training regimes. Nonetheless, these authors found a significant reduction in training-related hamstring injuries in the "intervention" group. However, as the "intervention" was merely what the team already did at training, it is difficult to make any confident inferences from this study.[22] Compliance with the neck strengthening program in rugby union players was also unclear.[25] This study also had a complicated and time-consuming program, yet had positive injury risk reductions.[25] When analyzing the data on program effectiveness, adherence/compliance must be accounted for in the analysis to provide better context to the results and to better describe the program's 'real world' application.

Although this review has comparisons to previous exercise-based intervention reviews performed in other sporting codes, the results are different and must be interpreted within the contexts that they have been implemented.

Limitations

The aim of the review was to systematically examine the evidence available on exercise-based interventions and their effectiveness in preventing injuries in sports with collision characteristics similar to rugby union. Whilst the review achieved its aim, there are limitations with the results presented in the review. The main limitation is that there is very limited research in this field for these types of sports. Only nine studies were included in this review. These studies span two decades of research and included multiple study design types. This indicates that the area is under-researched and lacks evidence for effective prevention strategies, despite the high injury risk that is present in these collision sports.

Additionally, the studies did not address all types of injuries. In particular there was a lack of evidence for upper body injuries. This needs to be addressed because the shoulder is one of the most commonly injured sites in tackle collision sports.[10] The review also included studies conducted on a variety of age groups – it is unknown if the intervention effectiveness would be affected by the age of the participant. Another potential limiting factor in this review is the heterogeneity of sporting codes included. Although we only included sports where collisions and tackles occur, the demands of the sporting codes are not completely comparable and thus caution must be exercised when extrapolating these findings to other sports.[39] The lack of methodological strength of six of the nine studies is an important limitation of this review. This methodological strength was calculated using a quality assessment tool. However, a limitation of any methodological assessment tool is that it can only assess what its authors report on. Hypothetically, a study design can actually be worse or better than the score derived from the information provided by the authors. Additionally, certain study designs could be scored poorly, but be appropriate in a certain setting. An example of this in our review is the studies in an elite/professional setting that used teams as their own controls over subsequent seasons.[22, 25, 27] It would be very difficult to have a true control for an elite team. Neither of these identified drawbacks are unique to our assessment tool or easy to correct, but should be considered when interpreting study strength. Furthermore, with regards to the observational studies, two did perform the interventions for longer periods of time, and this greater exposure to the intervention could have contributed to the positive results. However, it is unknown if the same players participated in the intervention in both seasons and therefore received a greater exposure.

Conclusion

Based on the high-quality studies (n=3, out of 9) in this review, there are currently minimal effective exercise-based injury prevention programs for tackle collision sports. The interventions in the low methodological strength studies that reduced injury risk also warrant further investigation. These studies with low methodological quality listed simple and easy to implement interventions, and were conducted over prolonged periods (2 – 4 seasons). They all incorporated hamstring exercises, balance training and stretching components. However, the lack of consistency, generally low methodological quality and low number of studies available limits the conclusions that can be drawn. There is a need for further high-quality research and more randomized controlled trials to be performed in interventions designed to reduce the injury risk in tackle collision sports. The results of these studies should also be reported in accordance with available injury surveillance consensus statements for comparability. The studies also need to record and report compliance with the intervention to obtain a measure of exposure or 'dose' of the intervention, and relate changes in injury data to this exposure. That said, this review does add new information, as these collision sports have yet to be grouped and viewed as a unit. Furthermore, this review provides components to consider for research into, and design of, injury prevention programs for tackle collision sports.

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