EFFECT OF INTERVENTIONS ON POTENTIAL, MODIFIABLE RISK FACTORS FOR KNEE INJURY IN TEAM BALL SPORTS: A SYSTEMATIC REVIEW.

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Chapter 4

ABSTRACT

Background Knee injuries are one of the most common types of injuries in team ball sports, and prevention is crucial because of health and economic implications. To set up effective prevention programs, these programs must be designed to target potential, modifiable risk factors. In addition, it is essential to evaluate the effects of these prevention programs.

Objective The purpose of this study was to provide an overview of the effect of prevention programs on potential, modifiable risk factors for knee injuries in team ball sports.

Method A systematic review was performed in PUBMED (1978 to December 2013), EMBASE (1973 to December 2013), and CINAHL (1992 to December 2013). The titles, abstracts, and full texts were analyzed according to predefined inclusion criteria to find relevant studies.

Results Neuromuscular control training with plyometric and agility exercises with addition of instructions reduced knee valgus angles and moments in female athletes. Knee flexion angles and moments were enhanced by plyometric and resistance exercises with augmented feedback (verbal or video). The specificity of the exercises must match the task that needs to be improved. Hamstring/quadricep strength ratio and hamstring strength may be improved by isolated hamstring exercises.

Conclusion Various training components are required to reduce the risk of knee injury. Neuromuscular control training and the use of instructions/feedback (verbal or video) seem promising. However, attention should be given to the target populations and the specificity of the programs. More research is needed with respect to reducing risk factors in male athletes as well as in children.
INTRODUCTION

The major cause of injuries in childhood and adolescence is participation in sports.\textsuperscript{1,2} In team ball sports like basketball, volleyball, soccer, and field hockey the most common type of injury is knee injury.\textsuperscript{2-10} Approximately 48\% of these knee injuries are ligament injuries, with one of the most common being rupture of the anterior cruciate ligament (ACL).\textsuperscript{11-13} Swenson et al.\textsuperscript{11} showed that the incidence of knee injuries during games (injuries per 10,000 athlete-exposures, where 1 athlete exposure is one player taking part in one game or practice) was 6.36 in female basketball, 2.96 in male basketball, 10.84 in female soccer, 5.09 in male soccer, 1.99 in female volleyball, 0.84 in male volleyball, and 3.29 in female field hockey. The consequences of knee injuries are usually more serious and costly than injuries to other joints.\textsuperscript{14} Knee injuries can lead to disability ranging from restricting activities in daily life to limited sport activity and even increase the risk for developing knee osteoarthritis, which can cause permanent disability.\textsuperscript{12,15,16} Furthermore, the average cost of an ACL reconstruction in the USA is estimated at US$20,000 per surgery.\textsuperscript{17}

Because of these health and economic implications, it is important to prevent knee injuries.\textsuperscript{18} Many prevention studies have focused on reducing the injury rate.\textsuperscript{19-22} However, when focusing on reducing the injury rate a large sample size is needed to reduce the possibility that any perceived effect of a prevention program is in fact not simply coincidence.

For neuromuscular control training, the number needed to-treat (NNT) is 108 athletes for preventing one noncontact ACL injury.\textsuperscript{23} Most studies that focused on injury rate used either small sample sizes or reported few noncontact ACL injuries.\textsuperscript{19-21,24-26} These studies lacked statistical power and therefore had an increased risk of accepting a false null hypothesis.\textsuperscript{27} In addition, these studies did not mention the effect of the intervention on potential risk factors that may cause knee injuries.\textsuperscript{19-22,24-26} Therefore, the effects of intervention programs on modifiable, potential risk factors remain unclear.

Multiple factors like environmental, anatomical, hormonal, neuromuscular, and biomechanical factors can contribute to the occurrence of an ACL injury.\textsuperscript{28} This needs to be considered when effective injury prevention programs are developed. This review focuses only on biomechanical and neuromuscular risk factors. In cases like noncontact ACL injuries, it is necessary to describe the kinematic and kinetic characteristics related to the injury mechanism.\textsuperscript{27} Most ACL injuries occur in non-contact situations like landing, plant-and-cut movement, and deceleration.\textsuperscript{29-33} Potential risk factors in these situations involve: reduced hip and knee flexion angles,
greater knee valgus angles and moments, and increased hip internal rotation angles with knee external or internal rotations.\textsuperscript{29,34-37} Reduced muscle strength, neuromuscular control, and postural control can be seen as potential risk factors.\textsuperscript{29,30,38-44} These potential risk factors for knee injuries are modifiable, which is important for designing effective prevention programs.\textsuperscript{45} Therefore, the purpose of this review was to give an overview of the literature regarding the effect of interventions on modifiable, potential risk factors for knee injuries in team ball sports.

**METHOD**

**Literature Search**

A systematic literature search was performed in PubMed (1978 to December 2013), EMBASE (1973 to December 2013), and CINAHL (1992 to December 2013) to retrieve articles regarding reducing modifiable, potential risk factors for knee injury in team ball sports. A combination of the following search terms was used: group (1) ‘knee injuries’, ‘sport injuries’; group (2) ‘ball sports’, ‘team sports’, ‘soccer injuries’, ‘basketball injuries’, ‘volleyball injuries’, ‘hockey injuries’, ‘handball injuries’; group (3) ‘prevention’, ‘intervention’, ‘training’, ‘program’; group (4) ‘biomechanics’, ‘musculoskeletal’, ‘balance’, ‘postural sway’, ‘landing’, ‘musculoskeletal system’, ‘jumping’, ‘force’, ‘strength’, ‘neuromuscular’, ‘neuromuscular control’, ‘task performance’, ‘hop’, and ‘range of motion’. The groups of search terms were connected with AND, and the search terms within the groups were connected with OR. The results of the systematic literature search within the three databases were taken together and duplicates were excluded.

**Literature Selection**

The first selection of the articles for potential relevance was determined based on the title and abstract. The full text of each article was analyzed with an eligibility form that included the inclusion criteria. Two authors (M.H.P.S. and J.M.D.) analyzed the articles independently. An additional search was made on the references of the included articles. The inclusion criteria for the studies were: (1) full text; (2) published in English or Dutch; (3) athletes participating in team ball sports; (4) prevention or intervention program; (5) related to knee injury; (6) outcome values based on modifiable, potential risk factor(s). In case of disagreements on inclusion between the two authors, a third author (K.A.P.M.L.) decided whether the article should be included.
Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports.

Data Extraction
The first reviewer (M.H.P.S.) extracted data from each included article. The characteristics of the subjects, potential risk factor, intervention program, and the effect of the intervention program were summarized. Different terms were used in the included articles for similar types of programs. Therefore, in this review one general heading was used for these programs. For example, terms used by the articles as ‘prevention program’ or ‘sport injury prevention program’ were taken together under the heading ‘neuromuscular control’. This was done only when the essence of the programs was the same.

Methodological Quality
The first reviewer (M.H.P.S.) assessed the methodological quality of the studies using the following criteria, which were adapted from CONSORT 2010,46 Herman et al.,47 and Stojanovic et al.:48 (1) groups at baseline were similar (group size, sex, and age with ≤10 % difference; pretests with p ≥ 0.05); (2) baseline demographic and descriptive characteristics described for each group; (3) clearly mentioned inclusion and/or exclusion criteria for subjects; (4) defined prespecified primary and secondary outcome measures, including how and when they were assessed; (5) investigated reliability of outcome measure; (6) sufficiently described treatment protocol (reproducible); (7) acceptable compliance (≥ 75 %); (8) reported dropouts (maximum ≤ 30 %); (9) group is randomized; (10) for each primary and secondary outcome, results of each group and estimated effect size were reported (optionally with precision, such as 95 % confidence interval). If there was uncertainty about scoring items, a second reviewer (J.M.D.) independently assessed the study under review. For each item, one point could be scored and the total score of the methodological quality ranged between 0 and 10. If an item was not present or not reported, 0 points were scored. Some items were not applicable, depending on the study design of included studies, so these items were excluded from calculation for quality assessment.

RESULTS

Search Findings
Figure 4.1 shows the flow diagram of the search strategy. Reasons for exclusion of studies7,20,44,49-78 after more detailed evaluation were based on the inclusion and exclusion criteria. The characteristics of the included studies are shown in Table 4.1. Table 4.2 shows the assessment of the methodological quality of the included studies.
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The combined search yielded a result of 82 studies in PUBMED, 337 studies in EMBASE, and 125 studies in CINAHL. After excluding 509 studies, 35 studies were included in this study. The mean score for methodological quality of the studies included in this review was 5.7, and ranged from 3 to 9. From the 35 studies, only 11 studies scored a 7 or higher. The number of included subjects per study ranged from 8 to 141.

![Flow diagram of search strategy](image)

**Figure 4.1.** Flow diagram of search strategy. a = 49-55 b = 56 c = 57-59 d = 44,60-63 e = 64-69 f = 7,20,70-78

**Kinematic and Kinetic Variables During Vertical Jump Movement**

Six studies have analyzed the effect of intervention programs on kinematic and kinetic variables of the knee during a double-legged vertical jump in female athletes. One of these studies focused on preventing knee injuries in general, whereas the other studies were designed to reduce ACL injuries specifically. Two studies showed maximum knee valgus moments and greater interknee distances after
plyometric-based interventions.\textsuperscript{79,82} However, one study showed no improvement in knee valgus angles and moments after plyometric training or after resistance training.\textsuperscript{80} This plyometric intervention contained plyometric and agility exercises during 4 weeks compared with a duration of 6 and 8 weeks.\textsuperscript{82} The quality score of these studies ranged from 4 to 6 with a mean score of 5.3.

The results of the effect of intervention on knee flexion angles and moments in female athletes during a double-legged vertical jump are contradictory as well. Two studies showed improved knee flexion angles and moments after plyometric-based training and resistance training.\textsuperscript{80,82} However, one study did not show improvements in (maximum) knee flexion angles and moments after a plyometric program.\textsuperscript{79} On the other hand, no differences were found in the angular position in the sagittal plane of the knee in single and double-legged vertical jumps after a plyometric-based intervention.\textsuperscript{81} Nonetheless, after plyometric-based intervention, the knee range of motion was increased only during a double-legged vertical jump in male athletes.\textsuperscript{81} The mean quality score of these studies was 5.8 with a range of 4–7.

Four studies examined the effect of interventions on the vertical ground reaction forces (VGRF) in female athletes during double-legged vertical jumps. One study demonstrated a decrease in the peak landing force after plyometric training.\textsuperscript{79} A balance program decreased the VGRF only in the dominant leg.\textsuperscript{83} Three studies did not show a reduction in the VGRF after plyometric and resistance training.\textsuperscript{80,83,84} The quality score of these studies ranged from 4 to 6 with a mean score of 5.3.

**Kinematic and Kinetic Variables During Double-Legged Drop Jump Movement**

The effect of prevention programs on knee biomechanics during a double-legged drop jump movement in female athletes was analyzed in 12 studies.\textsuperscript{85,86,88-97} Only 1 study was designed for reducing knee injuries,\textsuperscript{89} while the other studies were designed for reducing ACL injuries specifically.\textsuperscript{85,86,88,90-97} Six studies showed decreased knee valgus angles and moments and greater knee separation distances.\textsuperscript{85,89-91,93-95} In general, these programs contained neuromuscular control training with instructions for the right technique; these sessions lasted at least 90 min per session in comparison with the short duration (i.e., maximum of 25 min) of the sessions without instructions in the ineffective programs. One of these studies contained a deviating age group that included soccer players aged from 9 to 11 years.\textsuperscript{88} The mean quality score of these studies was 5.4 and ranged from 4 to 8. One study had a quality score of 8,\textsuperscript{96} while the other studies scored between 4 and 6.

Six studies examined the effect on knee flexion angles and range of motion in female athletes during a double-legged drop jump movement.\textsuperscript{86,90-92,96,97}
Neuromuscular control and plyometric training increased the initial and maximal knee flexion angles and range of motion.\(^{86,90,91}\) The duration of the programs varied from 10 to 90 min per session. In contrast, prevention training and balance training did not affect maximum knee flexion angles.\(^{91,97}\) Three studies reported the effect of interventions on knee flexion angles during a single-legged drop jump in female athletes. A jump and balance training and balance training alone increased maximum knee flexion angles.\(^{91,92}\) Neuromuscular control training and plyometric training did not increase the maximum knee flexion angles and knee flexion angles at initial contact.\(^{91,96}\) The mean quality score of these studies was 5.7 with a range from 4 to 8. One study scored 8,\(^{96}\) while the others had a score between 4 and 6.

Only one study focused on landing technique in general, and used the Landing Error Scoring System (LESS) to examine this.\(^{87}\) A stratified program was used in which the athletes were divided into different groups based on their level of technique. This program contained stratified exercises to correct certain movement errors as well as a set of team exercises. The poor landing group showed greater reduction on the LESS than all other groups, and high school children showed greater improvement than prehigh school children. The quality score of this study was 7 out of 10.

**Kinematic and Kinetic Variables During Jump Stop Movement**

Nine studies described the effect of prevention programs on knee biomechanics during a jump stop movement.\(^{86,90,98-104}\) Eight studies were designed for reducing ACL injury,\(^{86,90,98-101,103,104}\) while one study was designed for reducing knee injuries in general.\(^{102}\)

The effects of a prevention program on the knee valgus angles and moments during a double-legged jump stop movement were examined by six studies.\(^{86,90,98-101}\) Neuromuscular control training, progressive jump training, and training that contained augmented or video feedback with and without strength training reduced knee valgus angles and moments. Only resistance training did not affect knee valgus angles and moments.\(^{99}\) The mean quality of these studies was 6.0, ranging from 4 to 9, with two studies scoring a 7 or higher (out of 10).\(^{99,100}\)

Seven studies have studied knee flexion angles and moments during a jump stop movement.\(^{86,98-100,102-104}\) Video-assisted and verbal feedback training showed increased knee flexion angles and moments in male athletes during a single-legged jump\(^{102}\) and in female athletes during a double-legged jump.\(^{98,100,103,104}\) Strength training and neuromuscular control training without a feedback component did not improve knee flexion angles and moments in female athletes.\(^{86,99}\) The mean quality
score of the studies was 6.0 ranging from 3 to 9. Three studies had a quality score of 7 or higher (out of 10). 99,100,102

Three studies examined the effect of intervention on the VGRF. 99,100,102 A video-assisted feedback intervention decreased the peak VGRF in female athletes. 100 A neuromuscular control program of long duration that included verbal feedback was effective in male athletes. 102 Resistance training did not affect the VGRF. 99 The quality score ranged from 5 to 9 with a mean of 7.0. Two studies had relative high quality scores of 7 and 9 out of 10, 99,100 while the other study had a quality score of 5. 102

The effect of interventions on peak tibial shear force (PTSF) was examined in female athletes by three studies. 99,100,103 A prevention program that included verbal and video-assisted feedback decreased the (anterior) PTSF. 100,103 One study did not show reduction in the PTSF as a result of resistance training. 99 The quality score ranged from 3 to 9, with a mean score of 6.3. One study had a low quality score of 3 out of 8, 103 while the other studies scored a 7 or higher (out of 10).

**Kinematic and Kinetic Variables During Side-Cutting Maneuver**

Three studies, designed to reduce the risk of ACL injury, analyzed the kinematic and kinetic variables of the knee during a side-cutting maneuver. 105-107 One study focused on the effect on knee valgus moments and PTSF. 105 This study contained a pediatric and a traditional program. Both training programs contained exercises for strengthening of the lower extremity, core strengthening, and flexibility, and used plyometric, balance, and agility exercises. However, the traditional program was nonprogressive in comparison with the pediatric program. After these interventions, the knee valgus moments and PTSF were not reduced. Nonetheless, knee internal rotation at initial ground contact and in the first 40% of the stance phase was reduced after the pediatric program. This study examined boys and girls with a mean age of 10 years and had a quality score of 7 out of 10.

All three studies focused on knee flexion angles and moments as a potential risk factor. The prevention programs did not increase knee flexion angles and moments. 105-107 This was shown after agility and neuromuscular control training in female athletes and after a pediatric and traditional program in boys and girls. One study had a quality score of 3 out of 8, 107 while the other studies scored 6 and 7 out of 10.

Two studies examined the effect on VGRF, but again the programs did not affect this variable. 105,106 One of these studies examined children, with a mean age of 10 years. 105 Overall, the studies had a mean quality score of 6.5 ranging from 6 to 7.
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**Strength and Muscle Activation**

Hamstring and quadriceps co-contraction may provide dynamic joint stability and therefore could protect the knee during sports-related tasks.\(^{114-116}\) Female athletes who suffered ACL injury had a combination of decreased hamstring strength without decreased quadriceps strength in contrast with uninjured female athletes who had decreased quadriceps strength and similar hamstring strength.\(^{117,118}\) This suggests that decreased hamstring/quadriceps (H : Q) ratio may be a risk factor for ACL injury. Therefore, improving the H : Q ratio or increasing the strength of the hamstrings may reduce the risk of ACL injury.\(^ {115,118}\)

Six studies have described the effect of intervention on the H : Q ratio.\(^ {79,82,83,108,109,111}\) Two of these studies\(^ {79,108}\) were designed for reducing knee injuries in general, while the other studies were designed to reduce ACL injuries. Five studies showed increased H : Q ratio after neuromuscular control, resistance, and plyometric training in female athletes with mean ages ranging from 15 to 20 years.\(^ {79,82,83,109,111}\) The interventions varied in duration from 20 to 120 min per session and from 6 to 8 weeks. Only one study included male athletes and examined two slightly different programs, the 11+ Program and the HarmoKnee program. The 11+ Program increased the conventional strength ratio (CSR) and fast/slow speed ratio only in the dominant leg.\(^ {108}\) Both programs decreased the dynamic control ratio (DCR) in contrast to what was expected. The quality score of these studies ranged from 4 to 8 with a mean score of 5.3. Only one study had a high quality score of 8 out of 10.\(^ {108}\)

Four studies showed the effect of intervention on hamstring activation in female athletes to reduce the risk of ACL injury.\(^ {80,92,106,107}\) One study showed increased activity of the medial hamstrings in the prelanding and landing phase during a sidecutting task after a neuromuscular prevention program.\(^ {107}\) However, the quality was low (3 out of 10). The reactivity of the medial hamstrings was increased after agility training.\(^ {106}\) The hamstring activity during a single limb drop landing was also increased after jump and balance training.\(^ {92}\) The time to peak reactivity of the medial hamstrings was decreased during a vertical jump after plyometric training.\(^ {80}\) Only resistance training did not improve hamstring activation at all.\(^ {80}\) The mean quality score of these studies was 5.3 with a range of 3–6. Only one study contained a quality score of 3 out of 8,\(^ {103}\) while the other studies scored a 6.

Six studies examined the effect of interventions on the strength of the lower extremities and reduction of ACL injury.\(^ {80,83,96,98,99,110}\) All studies showed improvement in strength of the lower extremity muscles in female athletes. Strength training alone increased strength, but it did not alter the extremity biomechanics and therefore may not be effective in preventing noncontact ACL injuries.\(^ {99}\) In addition, three other
studies showed increased strength in muscles that was undesirable for reducing ACL injuries.\textsuperscript{80,96,98} Only one study used male athletes and showed an improvement in hamstring peak torque at 80° of knee flexion after resistance training with both open and closed kinetic chain exercises.\textsuperscript{110} The mean quality score was 7.2, ranging from 6 to 9, of which three studies contained a score of 8 or higher out of 10.\textsuperscript{96,99,110}

**Balance**

The effect of an intervention program on balance was described in two studies.\textsuperscript{112,113} The anterior–posterior stability was increased after neuromuscular control training and a traditional prevention program.\textsuperscript{112} Anterior–posterior time to stabilization was also increased after a traditional prevention program.\textsuperscript{112} Furthermore, neuromuscular control training increased single-limb total postural stability.\textsuperscript{113} The traditional program was examined in boys and girls with a mean age of 10 years. The neuromuscular control program was examined in female athletes with age ranging from 13 to 17 years. However, a pediatric program did not enhance balance variables in boys and girls with a mean age of 10 years.\textsuperscript{112} The quality score of one study was 7 out of 10,\textsuperscript{112} while the other study scored 7 out of 8.\textsuperscript{113}
Table 4.1. Study characteristics of the included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjecta</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
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<tbody>
<tr>
<td><strong>Vertical jump movement</strong></td>
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<tr>
<td>Hewett et al.⁷⁹</td>
<td>IG: 11 F; 15±0.6 years Volleyball players</td>
<td>Landing forces Knee flexion angles, moments Knee valgus moments</td>
<td>IG: Plyometric training program; 6 weeks, 3 days/week, 120 min/session Three phases: technique, fundamental, performance phase CG: no plyometric training program</td>
<td>Decreased landing forces in the peak force (p = 0.006) and compared with CG (p &lt; 0.001) Smaller valgus moments (p = 0.006) No difference in (maximum) knee flexion angles and moments</td>
</tr>
<tr>
<td>Lephart et al.⁸⁰</td>
<td>Plyometric group: 14 F; 14.5±1.3 years Basic resistance group: 13 F; 14.2±1.3 years Basketball and soccer athletes</td>
<td>VGRF Knee valgus angles, moments Knee flexion angles, moments</td>
<td>Plyometric training program: Phase 1: flexibility, resistance, and balance exercises. Phase 2: plyometric and agility exercises and exercises of phase 1 Basic resistance program: Phase 1: flexibility, resistance, and balance exercises. Phase 2: increasing amount of time and number of repetitions</td>
<td>Both groups Increased hip flexion at initial contact (p=0.016), peak hip flexion angles (p=0.017), peak knee flexion angles (p=0.009), and time to peak knee flexion angles (p=0.006) Decreased peak knee flexion moments (p=0.013) and hip flexion moments (p=0.008) No differences in VGRF and in peak knee valgus moments</td>
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<tr>
<td>Leporace et al.⁸¹</td>
<td>15 M, regional volleyball players; 13±0.7 years</td>
<td>Knee flexion angles</td>
<td>Preventive training program; 6 weeks, 3 days/week, 45–60 min/session Plyometric, balance, and core stability exercises Three phases: technique, fundamental, and performance phase</td>
<td>Increased knee RoM (p = 0.037) during a double-legged vertical jump No significant changes in angular position during lowest point of body’s center of gravity and upon ground contact</td>
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<tr>
<td>Lim et al.⁸²</td>
<td>IG: 11 F; 16.2±1.2; 15-17 years Competitive basketball players</td>
<td>Knee flexion angles Knee extension moments Knee valgus moments</td>
<td>IG: sports injury prevention training program; 8 weeks, 20 min/session Warm up, stretching, strengthening, plyometrics, agilities, and alternative exercise warm down CG: regular training program</td>
<td>Improved knee flexion angles (p = 0.024) compared with CG (p = 0.023) Greater interknee distances (p = 0.004) compared with CG (p = 0.005) Smaller maximum knee extension moments (p = 0.043) compared with CG not significant Smaller maximum knee valgus moment (p = 0.043) compared with CG</td>
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<tr>
<td>Myer et al.⁸³</td>
<td>Plyometric group: 8 F; 15.9±0.8 years Balance group: 11 F; 15.6±1.2 years Volleyball players</td>
<td>VGRF</td>
<td>6 weeks, 3 days/week, 90 min/session Plyometric group: maximum-effort plyometric jump and cut maneuvers Balance group: dynamic lower extremity stabilization and balance exercises</td>
<td>Balance group compared with plyometric group Reduced VGRF in dominant leg (p &lt; 0.05)</td>
</tr>
<tr>
<td>Vescovi et al.⁸⁴</td>
<td>IG: 10 F; 20.3±1.2 years Recreational volleyball players</td>
<td>VGRF</td>
<td>IG: plyometric program; 6 weeks, 3 days/week, 45–60 min/session Warm-up, jump exercises (plyometric) and cool down Three phases: technique, fundamental, and performance CG: no training</td>
<td>No significant decrease in VGRF</td>
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<td>Study</td>
<td>Subjects*</td>
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<td><strong>Drop jump movement</strong></td>
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<td>Barber-Westin et al.</td>
<td>16 F, competitive volleyball players; 14.6±0.7 years</td>
<td>Knee valgus angles</td>
<td>Neuromuscular retraining program; 6 weeks, 3 days/week, 90–120 min/session Warm-up, jump training, speed and agility drills, strength training, and static stretching</td>
<td>Improved mean normalized knee separation distance (p &lt; 0.01)</td>
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<tr>
<td>Chappell &amp; Limpisvasti</td>
<td>30 F, 12 basketball players, 18 soccer players; 19±1.2 years</td>
<td>Knee valgus moments</td>
<td>Neuromuscular training program; 6 weeks, 6 days/week, 10–15 min/session Core strengthening exercises, dynamic joint stability and balance training, jump training, and plyometric exercises</td>
<td>Increased initial knee flexion (p = 0.003) and maximum knee flexion (p = 0.006) angles during stance phase No difference in dynamic knee valgus moment during stance phase</td>
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<tr>
<td>DiStefano et al.</td>
<td>Stratified program: Medial knee displacement (MKD); 48; M: 12 ± 1 years; F: 13 ± 2 years Toe out (TO); 67; M: 14 ± 2 years; F: 13 ± 2 years Normal (NA); 26; M: 13 ± 1 years; F: 13 ± 2 years General program: 155; M: 13 ± 2 years; F: 14 ± 2 years Soccer athletes</td>
<td>Landing technique</td>
<td>10–13 years 9-months and 14–17 years 4-months, 3–4 days/week, 10–15 min/session MKD: static stretching and strengthening hip ab- and adductor muscles. Activating muscles to correct their movement pattern TO: static stretching and strengthening of lower leg muscles NA: core and lower extremity stability and strength Generalized program: strengthening and stretching lower leg muscles and good postural alignment during activity</td>
<td>Poor landing group Greater improvement in LESS system than all other groups (P &lt; 0.001). High school children Greater improvement in LESS system compared with prehigh school children (p = 0.007).</td>
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<tr>
<td>Grandstand et al.</td>
<td>IG: 12 F CG: 9 F Soccer players; 9–11 years</td>
<td>Knee valgus angles</td>
<td>IG: preventive warm-up; 8 weeks, 2 days/week, 20 min/session Plyometrics, strength, and flexibility exercises CG: normal conditioning regime</td>
<td>No significant changes in knee separation values</td>
</tr>
<tr>
<td>Herrington</td>
<td>15 F, basketball players, National League Division 1; 19±1 years</td>
<td>Knee valgus angles</td>
<td>Progressive jump training; 4 weeks, 3 days/week, 15 min/session</td>
<td>Reduced knee valgus angle in left (p = 0.002) and right leg (p &lt; 0.001)</td>
</tr>
<tr>
<td>Myer et al.</td>
<td>IG: 41 F; 15.3±0.9 years CG: 12 F; 16.5±1 years Basketball, soccer and volleyball players</td>
<td>Knee flexion angles Knee valgus moments</td>
<td>IG: Neuromuscular training; 6 weeks, 3 days/week, 90 min/session Plyometric and movement, core strengthening and balance, resistance and speed exercises CG: no training</td>
<td>Increased knee flexion-extension ROM during landing phase (p &lt; 0.001) in the right side Reduced knee joint maximum valgus and maximum varus moments in the right side (p &lt; 0.001). No reduction in the left side</td>
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<td>Study</td>
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<tr>
<td>Myer et al.</td>
<td>Plyometric group: 8 F; 15.9±0.8 years Knee valgus angles Balance group: 10 F; 15.6±1.2 years Volleyball players</td>
<td>Knee flexion angles</td>
<td>Plyometric group: 7 weeks, 2–3 days/week, 90 min/session Maximum-effort jumping and cutting exercises with oral feedback and resistance training Balance group: 7 weeks, 2–3 days/week, 90 min/session Dynamic stabilization/balance exercises with oral feedback, resistance training</td>
<td>Both groups Decreased maximum knee valgus angle ( p = 0.015 ) during drop vertical jump and maximum knee valgus angle ( p = 0.038 ) during medial drop jump Plyometric group during drop vertical jump Increased initial contact ( p = 0.047 ) and maximum knee flexion angle ( p = 0.031 ) Balance group during medial drop landing Increased maximum knee flexion angle ( p = 0.005 )</td>
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<tr>
<td>Nagano et al.</td>
<td>8 F, basketball players; 19.4±0.7 Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>Jump and balance training; 5 weeks, 3 days/week, 20 min/session Two phases: technique, performance</td>
<td>Increased knee flexion during landing ( p &lt; 0.001 ) Knee valgus angle did not improve significantly</td>
</tr>
<tr>
<td>Noyes et al.</td>
<td>34 F, volleyball players; 14.5±1.0 Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>Neuromuscular training; 6 weeks, 3 days/week, 90–120 min/session Dynamic warm-up, jump training, flexibility exercises, strength, agility, acceleration, speed and endurance drills</td>
<td>Increased mean absolute ( p = 0.002 ) and normalized ( p = 0.04 ) knee separation distance</td>
</tr>
<tr>
<td>Noyes et al.</td>
<td>57 F, basketball players; 14-17 years Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>Neuromuscular training; 6 weeks, 3 days/week, 90–120 min/session Dynamic warm-up, jump training, flexibility exercises, strength, agility, acceleration, speed and endurance drills</td>
<td>Increased mean ( p &lt; 0.001 ) and normalized ( p &lt; 0.001 ) absolute knee separation distance and increased distribution of the subjects in the normalized knee separation distance categories ( p &lt; 0.001 )</td>
</tr>
<tr>
<td>Noyes et al.</td>
<td>62 F, competitive soccer players; 15±1 years Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>Neuromuscular training; 6 weeks, 3 days/week, 90–120 min/session Dynamic warm-up, jump training, lower extremity strength, flexibility exercises, core strength, agility and speed drills</td>
<td>Improved mean absolute ( p &lt; 0.001 ) and normalized ( p &lt; 0.001 ) knee separation distance</td>
</tr>
<tr>
<td>Ortiz et al.</td>
<td>IG: 14 F; 14-15 years Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>IG: SIPP; 6 weeks, 2–3 days/week, 20–25 min/session Warm-up, stretching, strengthening, jumping and landing exercises CG: no SIPP</td>
<td>Knee valgus moments and angles, and knee flexion angles did not improve significantly</td>
</tr>
<tr>
<td>Pollard et al.</td>
<td>18 F, soccer players; 14-17 years Knee valgus angles Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>PEP-training; 6 week, 2-3 days/week, 20 min/session Contains warm-up, stretching, strength, plyometric, and agility exercises</td>
<td>Knee valgus and knee flexion angles did not improve significantly</td>
</tr>
</tbody>
</table>

### Jump stop movement

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects*</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chappell &amp; Limpis-vastå</td>
<td>30 F, athletes (12 basketball; 18 soccer); 19±1.2 years Knee valgus moments Knee flexion angles</td>
<td>Knee flexion angles</td>
<td>Neuromuscular training program; 6 weeks, 6 days/week, 10-15 min/session Core strengthening, dynamic joint stability, balance, jump, and plyometric exercises.</td>
<td>Decreased dynamic knee valgus moment during stance phase ( p = 0.04 ) No significant difference in knee flexion angle</td>
</tr>
</tbody>
</table>
Table 4.1. Continued.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects*</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greska et al.98</td>
<td>Resistance training group (STR): 4 F; 19.25±0.96 years Maintenance training group (MNT): 5 F; 19.40±0.89 years Endurance training group (END): 3 F; 18.67±0.58 years Soccer players, Division 1</td>
<td>Knee valgus angles Knee flexion moments</td>
<td>Resistance training with augmented feedback; 10 weeks, 2 days/week, 60 min/session STR: low volume of exercises, self-selected rest interval END: high volume of exercises, 30-s rest interval MNT: hybrid scheme between the STR and END groups Field training with augmented feedback, 2 days/week; first 4 weeks 60 min/session; last 6 weeks 30 min/session Plyometric, agility, and speed drills</td>
<td>Decreased knee valgus angle (p = 0.007) at initial contact Decreased knee valgus angle at peak knee flexion (p = 0.002) and maximum knee extension moment at peak stance (p = 0.027)</td>
</tr>
<tr>
<td>Herman et al.99</td>
<td>IG: 33 F; 22.47±2.25 years CG: 33 F; 22.53±3.81 years Recreational basketball, soccer or volleyball players</td>
<td>Knee valgus angles, moments Knee flexion angles, moments VGRF PTSF</td>
<td>IG: strength training; 9 weeks, 3 days/week, 45 min/session Strength training targeting quadriceps, hamstrings, gluteus medius, and gluteus maximus CG: no strength training</td>
<td>No significant differences in knee and hip kinematics and kinetics between groups.</td>
</tr>
<tr>
<td>Herman et al.100</td>
<td>IG: 29 F; 22.5±2.3 years CG: 29 F; 22.5±3.8 years Recreational basketball, soccer or volleyball players</td>
<td>Knee valgus angles, moments Knee flexion angles, moments VGRF PTSF</td>
<td>IG: strength training and video-assisted feedback intervention; 9 weeks, 3 days/week, 45 min/session Strength training targeting quadriceps, hamstrings, gluteus medius, and gluteus maximus CG: video-assisted feedback only intervention</td>
<td>Decreased anterior PTSF (p=0.015) (increased in the CG (p=0.0099)) Both groups Decreased knee valgus moment (p &lt; 0.001) and peak VGRF (p &lt; 0.001) Increased knee flexion (p = 0.050), and hip abduction angle (p = 0.032)</td>
</tr>
<tr>
<td>Herrington 89</td>
<td>15 F, basketball players National league Division 1; 19.1±1 years</td>
<td>Knee valgus angles</td>
<td>Progressive jump training; 4 weeks, 3 days/week, 15 min/session</td>
<td>Reduced knee valgus angle in left (p = 0.035) and right leg (p = 0.01)</td>
</tr>
<tr>
<td>Kato et al.101</td>
<td>IG: 10 F; 20.4±1.0 years CG: 10 F; 20.5±0.9 years Basketball players</td>
<td>Knee valgus angles</td>
<td>IG: exercise program; 4 weeks, 3 days/week, 20 min/session Balance training and squats, lunges, jump landing, lunge walking, and twist exercises. With video feedback CG: usual basketball practice</td>
<td>Decreased knee angles of the coronal plane after 2 (p &lt; 0.05) and 4 weeks (p &lt; 0.05) Smaller angles of the coronal plane in lower extremity (p &lt; 0.05) in weeks 2 and 4 compared with CG</td>
</tr>
</tbody>
</table>
Table 4.1. Continued.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louw et al. 102</td>
<td>IG: 5 M</td>
<td>Knee flexion angles</td>
<td>IG: Neuromuscular exercise program with verbal feedback; 6 weeks, 2 days/week, 40 min/session. CG: only usual basketball training</td>
<td>Difference for time and group allocation in peak knee flexion angles (p &lt; 0.001), and in peak GRF (p = 0.017) Improved post-intervention peak GRF (p = 0.007) and peak knee flexion angle (p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td>CG: 5 M</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Basketball players; 15.6±0.8 years</td>
<td>GRF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myers &amp; Hawkins 103</td>
<td>14 F, basketball players</td>
<td>Knee flexion angles</td>
<td>Verbal feedback and physical demonstration to use the modified movement strategy</td>
<td>Decreased PTSF (p &lt; 0.001) Increased knee flexion at foot contact (p &lt; 0.01)</td>
</tr>
<tr>
<td>Parsons &amp; Alexander 104</td>
<td>IG: 10 F; 13.2±0.4 years</td>
<td>Knee flexion angles</td>
<td>IG: Single session of courtside video and verbal feedback 3-4 min. CG: no feedback</td>
<td>Increased maximal hip and trunk flexion compared with the CG at week 4 (p &lt; 0.05) Increased ankle dorsiflexion, right knee and hip flexion, and trunk flexion (p &lt; 0.05)</td>
</tr>
<tr>
<td></td>
<td>CG: 9 F; 13.1±0.3 years</td>
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<tr>
<td></td>
<td>Volleyball players</td>
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<tr>
<td>DiStefano et al. 105</td>
<td>Pediatric group: 11 M, 8 F</td>
<td>Knee valgus moments</td>
<td>9 weeks, 2–3 days/week, 12–14 min/session Flexibility, balance, strengthening, agility, and plyometric exercises Pediatric group: progressive exercises and included dynamic flexibility. Three phases: first phase 2 days/week, last 2 phases 3 days/week Traditional group: 3 days/week, included static flexibility CG: no program at all</td>
<td>Both programs No reduction in knee valgus moment, knee flexion moment, VGRF and PTSF Pediatric program Reduced knee internal rotation at initial ground contact (p = 0.03) compared with CG Reduced peak knee internal rotation during first 40% of the stance phase (p = 0.01)</td>
</tr>
<tr>
<td></td>
<td>Traditional group: 11 M, 11 F</td>
<td>Knee flexion moments</td>
<td>VGRF PTSF</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IG: 15 M, 9 F Soccer athletes; 10±1 years</td>
<td>Knee valgus moments</td>
<td></td>
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</tr>
<tr>
<td>Wilderman et al. 106</td>
<td>IG: 15 F; 21.07±3.62 years</td>
<td>Knee flexion angles</td>
<td>IG: agility training; 6 weeks, 4 days/week, 15 min/session Four phases; early phases: drills to get advance notice of required motion patterns, direction changes, and speeds. Later phases: performing unanticipated motion patterns and direction changes CG: only usual basketball training</td>
<td>No differences were found in knee flexion angles, and peak VGRF</td>
</tr>
<tr>
<td></td>
<td>CG: 15 F; 21.07±1.83 years</td>
<td>Peak VGRF</td>
<td></td>
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<tr>
<td></td>
<td>Intramural basketball players</td>
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<td></td>
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<tr>
<td>Zebis et al. 107</td>
<td>12 F, elite soccer players, 8 F, elite handball players 26±3 years</td>
<td>Knee flexion angles</td>
<td>Neuromuscular training, including 6 levels consisting of 3 exercises. Each level 3 weeks, 2 days/week, 20 min/session</td>
<td>No differences were found in knee flexion angles and GRF</td>
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<tr>
<td></td>
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<td>GRF</td>
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</tr>
</tbody>
</table>
Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daneshjoo et al.</td>
<td>The 11+ IG; 12 M; 19.2±0.9 years, HamoKnee IG; 12 M; 17.7±0.4 years, CG: 12 M; 19.7±1.6 years Professional soccer players</td>
<td>H : Q ratio</td>
<td>The 11+: 2 months, 3 days/week, 20–25 min/session Running, strength, balance, muscle control, and core stability exercises. Focus on core stability, neuromuscular control, eccentric hamstring strength, and agility HamoKnee: 2 months, 3 days/week, 20–25 min/session Increasing awareness of injury risk. Warm-up, muscle activation, balance, strength, and core stability CG: regular team training</td>
<td>Conventional strength ratio and fast/slow speed ratio improved in the 11+ group (p = 0.01, p = 0.03) Non-dominant leg improved dynamic control ratio (p=0.04)</td>
</tr>
<tr>
<td>Greska et al.</td>
<td>Resistance training group (STR): 4 F; 19.25±0.96 years Maintenance training group (MNT): 5 F; 19.40±0.89 years Endurance training group (END): 3 F; 18.67±0.58 years Soccer players, Division 1</td>
<td>Strength</td>
<td>Resistance training with augmented feedback; 10 weeks, 2 days/week, 60 min/session STR: low volume of exercises, self-selected rest interval END: high volume of exercises, 30-s rest interval MNT: hybrid scheme between the STR and END groups Field training with augmented feedback, 2 days/week; first 4 weeks 60 min/session; last 6 weeks 30 min/session Plyometric, agility, and speed drills</td>
<td>Increased left hip extension (p = 0.008), left (p = 0.001) and right hip flexion (p = 0.023), and right hip adduction (p = 0.036) isometric strength</td>
</tr>
<tr>
<td>Herman et al.</td>
<td>IG: 33 F; 22.47±2.25 years CG: 33 F; 22.53±3.81 years Recreational basketball, soccer or volleyball players</td>
<td>Strength</td>
<td>IG: strength training; 9 weeks, 3 days/week, 45 min/session Strength training targeting quadriceps, hamstrings, gluteus medius, and gluteus maximus CG: no strength training</td>
<td>Increased strength (p &lt; 0.001 for all muscles)</td>
</tr>
<tr>
<td>Hewett et al.</td>
<td>IG: 11 F; 15±0.6 years CG: 9 M; 15±0.3 years Volleyball players</td>
<td>H : Q ratio</td>
<td>IG: plyometric training program; 6 weeks, 3 days/week, 120 min/session Three phases: technique, fundamental, performance phase CG: no plyometric training program</td>
<td>Increased H : Q muscle peak moment ratio (P &lt; 0.05)</td>
</tr>
<tr>
<td>Study</td>
<td>Subjects*</td>
<td>Modifiable factor</td>
<td>Intervention</td>
<td>Effect of intervention</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------</td>
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<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Holcomb et al.* | 12 F, soccer players, Division 1; 20±0.8 years | H : Q ratio       | Hamstring-emphasized resistance training; 6 weeks, 4 days/week  
Agility training, endurance conditioning combined with upper-body and lowerbody resistance training | Increased functional (p = 0.049) and conventional (p = 0.172) H : Q ratio  
Main effect in functional (p=0.013) and conventional (p = 0.002) H : Q ratio by comparison of dominant and non-dominant legs  
Increased angular velocities in functional (p < 0.001) and conventional (p < 0.01) H : Q ratio |
| Lephart et al.* | Plyometric group: 14 F; 14.5±1.3 years  
Basic resistance group: 13 F; 14.2±1.3 years  
Basketball and soccer athletes | Hamstring activation  
Strength | 8 weeks, 3 days/week, 30 min/session  
Plyometric training program: phase 1: flexibility, resistance, and balance exercises. Phase 2: plyometric and agility exercises plus exercises of phase 1  
Basic resistance program: phase 1: flexibility, resistance, and balance exercises. Phase 2: increasing amount of time and number of repetitions of each exercise in phase 1 | Both groups  
Improved peak quadriceps torque at 60 and 180 degrees (p < 0.05) and gluteus medius pre-activity (p < 0.05)  
No difference in peak hamstring torque and hip abduction  
Isometric peak torque  
Plyometric group  
Less time to the peak reactivity in medial hamstrings after foot contact. | Lower H : Q ratios (p = 0.023) and compared with CG (p = 0.021) |
| Lim et al.*     | IG: 11 F; 16.2±1.2 years  
CG: 11 F; 17.1±1.1 years  
Competitive basketball players | H : Q ratio | IG: Sports injury prevention training program; 8 weeks, 20 min/session  
Warm up, stretching, strengthening, plyometrics, agility, and alternative exercise warm down.  
CG: regular training program | Both groups  
Improved H : Q ratio (p < 0.01), hamstring strength (p < 0.01) and 1 RM of bench press, hang clean and parallel squat (p < 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. | Increased hamstrings peak torque at 80˚ (p = 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. |
| Myer et al.*    | Plyometric group: 8 F; 15.9±0.8 years  
Balance group: 11 F; 15.6±1.2 years  
Volleyball players | H : Q ratio  
Strength | 6 weeks, 3 days/week, 90 min/session  
Plyometric group: maximum-effort plyometric jumps and cut maneuvers  
Balance group: dynamic lower extremity stabilization and balance exercises | Both groups  
Improved H : Q ratio (p < 0.01), hamstring strength (p < 0.01) and 1 RM of bench press, hang clean and parallel squat (p < 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. | Increased hamstrings peak torque at 80˚ (p = 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. |
| Naclerio et al.* | IG: 10 M  
CG: 10 M  
23.8±3.1 years  
Soccer players | Hamstring activation | IG: strength training. One open chain and two closed chain exercises. With body mass as resistance 4 weeks, 3 days/week, 15 min/session  
CG: normal training routine without lower body resistance exercises | Increased hamstrings peak torque at 80˚ (p = 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. | Increased hamstrings peak torque at 80˚ (p = 0.001)  
No improvement at 35˚, 45˚, 60˚, 90˚ and 100˚. |
| Nagano et al.*  | 8 F, basketball players; 19.4±0.7 years | Hamstring activation | Jump and balance training; 5 weeks, 3 days/week, 20 min/sessiion  
Two phases: technique, performance | Increased activity of hamstrings 50 ms before foot contact (p < 0.05)  
No changes in m. rectus femoris | Increased activity of hamstrings 50 ms before foot contact (p < 0.05)  
No changes in m. rectus femoris |
| Ortiz et al.*   | IG: 14 F; 14-15 years  
CG: 16 F; 14-15 years  
Competitive soccer players | Strength | IG: SIPP; 6 weeks, 2–3 days/week, 20–25 min/session  
Warm-up, stretching, strengthening, jumping, and landing exercises  
CG: no SIPP | M. quadriceps strength increased significantly (p = 0.004)  
No improvement in strength in hip extensors, hip external rotators, knee extensors and flexors. | M. quadriceps strength increased significantly (p = 0.004)  
No improvement in strength in hip extensors, hip external rotators, knee extensors and flexors. |
### Table 4.1. Continued.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects¹</th>
<th>Modifiable factor</th>
<th>Intervention</th>
<th>Effect of intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilder-man et al. ¹⁰⁶</td>
<td>IG: 15 F; 21.07±3.62 years CG: 15 F; 21.07±1.83 years Intramural basketball players</td>
<td>Hamstring activation</td>
<td>IG: agility training, 15 min/session, 4 days/week for 6 weeks Four phases; early phases: drills to get advance notice of required motion patterns, direction changes, and speeds Later phases: performing unanticipated motion patterns and direction changes CG: usual basketball training</td>
<td>Increased medial hamstring muscle activation during loading phase (p &lt; 0.001), and in comparison with CG (p = 0.002)</td>
</tr>
<tr>
<td>Wilkerson et al. ¹¹¹</td>
<td>IG: 11 F, basketball players, Division 2; 19±1.4 years. CG: 8 F basketball players, Division 1; 19±1.1 years.</td>
<td>H : Q ratio</td>
<td>IG: Plyometric jump-training program 6 weeks Plyometric jump training, stretching, and isotonic strengthening; 3 phases of progressively increasing jump complexity and intensity. CG: 6-weeks pre-season conditioning program. Stretching, isotonic strengthening, and periodic performance of plyometric jumping drills</td>
<td>Improved hamstrings peak torque at 60° (p &lt; 0.01) and H : Q ratio (p &lt; 0.05) No improvement in 300° hamstrings peak-torque</td>
</tr>
<tr>
<td>Zebis et al. ¹⁰⁷</td>
<td>12 F, elite soccer players 8 F, elite handball players. 26±3 years.</td>
<td>Hamstring activity</td>
<td>Neuromuscular training, including 6 levels consisting of 3 exercises. Each level 20 min/session, 2 days/week for 3 weeks. Total 18 weeks</td>
<td>Increased pre-landing and landing activity of the m. semitendinosus (p &lt; 0.05) M. quadriceps activity remained unchanged</td>
</tr>
<tr>
<td>Balance</td>
<td>DiStefano et al. ¹¹²</td>
<td>Balance</td>
<td>9 weeks, 2-3 days/week, 12-14 min/session Flexibility, balance, strengthening, agility, and plyometric exercises. Pediatric program: Progressive exercises, included dynamic flexibility. 3 phases: first phase 2 days/week, last 2 phases 3 days/week Traditional program: 3 days/week, included static flexibility CG: warm-up designated by their coaches</td>
<td>Traditional program compared with CG Decreased anterior-posterior time-to-stabilization (p = 0.003)</td>
</tr>
<tr>
<td>Balance</td>
<td>Paterno et al. ¹¹³</td>
<td>Balance</td>
<td>Neuromuscular training; 6 weeks, 3 days/week, 90 min/session Balance training, hip/pelvis/trunk strengthening, plyometrics and dynamic movement training, and resistance training.</td>
<td>Improved single-limb total stability (p = 0.004) Improved anterior-posterior stability (p = 0.001)</td>
</tr>
</tbody>
</table>

CG = control group; EMG = electromyography; F = female; GRF = ground reaction force; H : Q = hamstring/quadriceps; IG = intervention group; M = male; PEP = preventive injury and enhance performance; PTSF = peak tibial shear force; RM = repetition maximum; SIPP = sport injury prevention program; VGRF = vertical ground reaction force.

¹ Ages are presented in actual, mean age ± SD, and ranges where stated.
### Table 4.2. Methodological quality of studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Quality score</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
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<tbody>
<tr>
<td><strong>Methodological Quality Criteria</strong></td>
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<tr>
<td>Hewett et al.79</td>
<td>4/10</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
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<td>Y</td>
<td>NR</td>
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<tr>
<td>Lephart et al.80</td>
<td>6/10</td>
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<td>Y</td>
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<td>Y</td>
<td>NR</td>
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<tr>
<td>Leporace et al.71</td>
<td>7/8</td>
<td>NA</td>
<td>Y</td>
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<td>Y</td>
<td>NA</td>
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<td></td>
<td></td>
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<tr>
<td>Lim et al.82</td>
<td>6/10</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
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<tr>
<td>Myer et al.83</td>
<td>6/10</td>
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<tr>
<td>Vescovi et al.84</td>
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<td>Barber-Westin et al.85</td>
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**Note:**

- NA, not applicable; N, no; NR, not reported; Y, yes
- **a** Groups at baseline were similar (group size, sex, age ≤10% difference; pretests with p≥0.05)
- **b** Baseline descriptive characteristics for each group
- **c** In- and/or exclusion criteria for subjects
- **d** Defined pre-specified primary and secondary outcome measures, including how and when they were assessed
- **e** Investigated reliability of outcome measures
- **f** Sufficiently described treatment protocol (replicable)
- **g** Acceptable compliance (≥75%)
- **h** Reported dropouts (maximum ≤30%)
- **i** Group randomized
- **j** For each primary and secondary outcome, results of each group and its estimated effect size (optionally with precision, such as 95% CI)
DISCUSSION

The main purpose of this review was to give an overview of the literature regarding the effect of interventions on modifiable, potential risk factors for knee injury in team ball sports. The main finding of the review is that different types of interventions can modify a potential risk factor for knee injury.

Methodological Quality
Within this review the methodological quality of the included studies was taken into account. The methodological quality ranged from 3 out of 8 to 9 out of 10. Only five included studies scored less than half of the criteria. Most of the studies did not report the compliance and/or the dropouts. Therefore, it may be that some results of included studies were biased by poor compliance. Because of the lack of knowledge about the compliance within these studies, the conclusion of important aspects for creating high compliance in a prevention program can only be drawn based on a few studies. Therefore, any such conclusion can only be suggested. In addition, most studies did not report the effect size.

Studies with a poor methodological quality score were included in this systematic review (i.e., 3 out of 8). These studies were not excluded from this review because they still provided valuable information on reducing biomechanical risk factors for knee injuries. The results of the poor-quality studies were used with caution. This review put less weight on these studies in providing suggestions for practical implications. However, it should be noted that the methodological quality of included studies was moderate, which may indicate that higher-quality studies including newer, more accurate methodologies, may be needed to draw stronger conclusions in the future.

Most of the studies contained a sufficiently described treatment protocol and described the baseline descriptive characteristics for each group. Overall, the quality of the included studies was moderate. Further research should report the compliance and its effect for more insightful information.

Kinematic and Kinetic Variables During Vertical Jump Movement
Although there is some conflicting evidence on the effect of plyometric training for improving knee valgus angles and moments during a double-legged vertical jump, it seems that agility and plyometric exercises performed for 20 min per session over 8 weeks are effective. The exercise programs of Lephart et al. were home based, which could have influenced the compliance in a negative way and thereby reduced
the effect of training. In addition, the study of Lim et al.82 tried to encourage compliance by having trained personnel present at all training sessions. However, compliance was not described in either study. The studies used only female athletes, so no conclusion can be drawn for male athletes.

Knee flexion angles and moments during a double-legged vertical jump were enhanced in female athletes by plyometric and resistance training,80,82 while plyometric training in another study did not improve knee flexion angles and moments.79 However, the latter study did show a trend of increased knee flexion angles after a plyometric intervention. Differences observed between the effect of the interventions may have been a result of the long session duration (120 min per session) in the ineffective program, which is likely to have had poor compliance. The duration of the programs that were effective was 20–30 min per session. Previous studies reported that female athletes landed with less knee flexion and less time to peak knee flexion than male athletes.34,119-121 One study in male athletes with a relatively high quality score of 7 out of 8 showed increased ranges of knee motion during a double-legged vertical jump but not during a single-legged vertical jump.81 The difference may be caused by the use of more bilateral instead of unilateral plyometric exercises. Therefore, it is suggested that the type of plyometric exercises should match the type of landing that needs to be improved.

Plyometric and resistance training did not reduce VGRF in double-legged landings.80,84 However, one study showed conflicting results, where plyometric training resulted in a reduction of landing forces.79 These results need to be interpreted with caution considering the small sample sizes. Furthermore, VGRF in the dominant leg was decreased during a single-legged vertical jump after balance training.83 Plyometric training did not decrease VGRF.84 This may suggest that balance and dynamic stabilization exercises are important to decrease VGRF during a single-legged vertical jump, because these exercises contained force-dissipation techniques. The instruction to reduce landing forces may also be of importance, because this was done only for the balance group. Due to a lack of evidence, it can only be concluded that balance exercises and specific instructions appear to reduce VGRF in a single-legged vertical jump. All studies were conducted with female athletes, so conclusions cannot be drawn for male athletes.

Kinematic and Kinetic Variables During Drop Jump Movement
Intervention programs, in general focusing on neuromuscular control, showed improved knee valgus angles and moments in female athletes during a single and a double-legged drop jump.85,89-91,93-95 However, five studies did not report improvement
in knee valgus angles and moments.\textsuperscript{86,88,92,96,97} This may be due to the fact that the effective programs instructed the subjects to maintain good technique during all the sessions. In contrast is the study of Nagano et al.\textsuperscript{92} that also contained feedback but did not show significant results, although this may be due to the small sample size (eight athletes). However, the reduction of knee valgus angle and moment may not only have been the result of the instructions used, because the studies that showed nonsignificant results did demonstrate a trend towards improvement of this risk factor. That they did not reach significance may be caused by the fact that they contained a small sample size or too few participants that had room for improvement because many participants already had a good jumping technique. In contrast with the results of these studies, it appears that sessions of short duration were important for compliance. Short-duration programs with sessions no longer than 25 min had a compliance of more than 75 \%,\textsuperscript{86,88,89,96,97} while the compliance was less than 75 \% in the effective programs with long-duration sessions.\textsuperscript{85,90,94} These results suggest that a program should consist of neuromuscular control training with feedback/instructions during the sessions, and it is important to have short duration sessions to ensure compliance with the program.

There is conflicting evidence on the effects of prevention programs for improving knee flexion angles during a double-legged drop jump. A prevention training program with strength and plyometric exercises did not show improvement in soccer players,\textsuperscript{97} while prevention programs with balance and plyometric exercises showed improvement in knee flexion angles in volleyball, soccer, and basketball players.\textsuperscript{86,90,91} This difference may be caused by the small sample size, which may have limited the ability to detect significant improvement. On the other hand, balance training alone did not improve knee flexion angles.\textsuperscript{91} This may be because of the specificity of the exercises, considering that the balance training contained mainly single-legged exercises while the test is double-legged. Overall, it can be suggested that a program should contain plyometric exercises that are specific for the task, e.g. specific double-legged exercises for improving kinematics during a double-legged jump. Furthermore, knee flexion angles during a single-legged drop jump were improved after jump and balance training and after balance training alone.\textsuperscript{91,92} Plyometric training and neuromuscular control training did not influence knee flexion angles.\textsuperscript{91,96} In general, the intervention programs contained double-legged instead of single-legged exercises and did not contain specific balance exercises, while single-leg landing needs more balance skill than double-legged landing. These results suggest that the exercises have to be specific for the task that needs to be improved.
Only one study examined landing technique in general. The poor landing group showed greater enhancement in landing technique than all other groups. For future studies it may be important to indicate which players have a poor landing technique, because the intervention program has a larger effect on this group. High school children showed greater enhancement in landing technique than prehigh school children. Therefore, it is suggested that there is a need for customized programs for children in several age groups.

**Kinematic and Kinetic Variables During Jump Stop Movement**

In contrast to strength training, neuromuscular control and progressive jump training reduced knee valgus angles and moments. However, strength training with additional feedback and a feedback intervention alone showed a reduction in knee valgus angles and moments. In addition, one study that included the effect of neuromuscular control training also contained augmented feedback, and another study contained video feedback. In summary, it can be recommended that feedback should be added to a neuromuscular control training program to reduce knee valgus angles and moments.

Feedback-inclusive interventions showed increased knee flexion angles in male athletes and knee flexion angles and moments in female athletes. Strength training and neuromuscular control training alone did not improve knee flexion angles and moments. This may be caused by the addition of a feedback component that is used in the effective programs, while ineffective programs did not contain a kind of feedback or instructions. In addition, adding specific stop jump exercises seems worthwhile, because these exercises were only present in the effective programs.

In female athletes, a feedback intervention affected the VGRF while strength training did not. In male athletes, a neuromuscular control program with verbal feedback on incorrect technique improved the VGRF. Based on the limited number of studies, it can only be assumed that VGRF may be reduced by inclusion of feedback in the intervention.

The PTSF was examined in three studies. Again feedback interventions were effective in reducing PTSF. The quality of one of those studies was relatively high (7 out of 10), while the other was low (3 out of 10). In conclusion, preliminary evidence is available that verbal and video feedback intervention decreases the PTSF. Furthermore, strength training did not seem to reduce PTSF.
Kinematic and Kinetic Variables During Side-Cutting Maneuver

A pediatric program and a traditional prevention program did not show reduction in knee valgus moments and PTSF in children with a mean age of 10 years.\textsuperscript{105} Apparently, children within this age do not react the same as older children.\textsuperscript{87} In addition, a preventive training program did not improve kinematic and kinetic variables of the knee in children.\textsuperscript{81,88} Even a specific pediatric program showed a reduction in knee internal rotation angles.\textsuperscript{105} Children aged 10 years also demonstrated movement patterns associated with greater injury risks like increased knee valgus and less knee flexion.\textsuperscript{122,123} The study of Parsons and Alexander\textsuperscript{104} reported increased knee flexion angles after video and verbal feedback during a jump stop movement. In summary, it seems that this particular age group needs a specified program for reducing risk factors.

In older populations, knee flexion angles did not improve after agility training of 15 min per session\textsuperscript{106} or after neuromuscular control training of 20 min per session.\textsuperscript{107} This may be due to the short durations of the sessions. Furthermore, the difference may be caused by the exercises because the agility training did not involve specific side-cut maneuvers and only gave instructions for increasing knee flexion angles during the first session.\textsuperscript{106} Additionally, the other study did not present the exercises for neuromuscular control training and did not contain instructions or feedback.\textsuperscript{107} The lack of evidence makes it difficult to draw a conclusion from this work.

The VGRF was also not improved after agility training.\textsuperscript{106} The VGRF was measured by a side-cut maneuver, while the agility training did not involve exercises that contained a side-cut maneuver. This may explain the absence of a significant improvement. However, there is a lack of evidence to draw a conclusion.

Strength and Muscle Activation

Neuromuscular control, resistance, balance, and plyometric training seem to improve the $H:Q$ ratio in female athletes.\textsuperscript{79,82,83,109,111} The inclusion of hamstring-isolated resistance exercises seems important.\textsuperscript{124} Only one prevention program did not contain hamstring-isolated strengthening exercises, but contained plyometric exercises.\textsuperscript{79} Moreover, the focus of this plyometric program was on proper technique that may contribute to strength increases of the hamstrings, given that the exercises stretched the hamstring muscles and may lead to greater force production.\textsuperscript{125} Thus, exercises that improve the imbalance between hamstring and quadriceps muscles, like plyometric training and hamstring-isolated resistance training, seem to be necessary. Furthermore, in male athletes, two slightly different neuromuscular control
programs improved the quadriceps strength more than hamstring strength by a decreased DCR, which may increase the anterior tibia shearing of the ACL.\textsuperscript{108,109} To increase the DCR, it may be important to add more hamstring-specific exercises. The 11+ program did increase the CSR and the fast/slow speed ratio in only the nondominant leg. This may be because the athletes that were included in this study participated in soccer. In soccer, the nondominant leg typically serves as the stabilizing leg. The difference between the effect on DCR and CSR may be caused by the analyzed eccentric hamstring torque in DCR and the concentric hamstring torque in CSR. It is more functional to improve the DCR and eccentric actions are more forceful than concentric actions.\textsuperscript{126,127} However, more research is necessary to draw a conclusion about improving the H : Q ratio in male athletes.

A neuromuscular control program increased the activity of the medial hamstrings in the prelanding phase,\textsuperscript{107} which is thought to be beneficial for stabilizing the knee.\textsuperscript{128} However, the methodological quality of this study was low (3 out of 8).\textsuperscript{107} During the landing phase, the medial hamstring activity was increased after a neuromuscular control program and agility training.\textsuperscript{106,107} Female athletes have lower medial hamstring activation during a side-cut than male athletes,\textsuperscript{129} so it may be that female athletes have enough room for improvement in medial hamstring activity. Besides, decreased time to peak reactivity of the medial hamstrings after plyometric training was shown during a jump task.\textsuperscript{80} The hamstring activity was also increased after jump and balance training.\textsuperscript{92} Resistance training alone does not seem to improve hamstring activation at all.\textsuperscript{80} In conclusion, a neuromuscular training program may increase the hamstring activation.

Six studies showed improvement in strength of the lower extremity muscles in female athletes.\textsuperscript{80,83,96,98,99} As expected, specific strength training did increase strength in all tested muscles.\textsuperscript{99} However, it did not alter the biomechanics, so resistance training alone may not be sufficient to reduce the risk of ACL injury. This was confirmed by another study that showed undesired increase in strengthening after resistance training.\textsuperscript{98} Two other studies with plyometric interventions also showed an undesired increase in strengthening.\textsuperscript{80,96} This may be a result of the use of isometric strength testing,\textsuperscript{96,98,99} because this may not allow for any interpretation of what may be occurring within the dynamic state of the task. This is confirmed by a study that found weak correlations between isometric strength and kinematic changes.\textsuperscript{130} Only one study showed increased hamstring strength, which was desired, after a plyometric and balance program.\textsuperscript{83} This improvement may be caused by the use of isolated hamstring exercises because the ineffective programs did not contain more than one isolated hamstring exercise. This is equivalent to the results of improving the H : Q
ratio. In summary, it is suggested that isolated hamstring exercises are important for improving the strength of hamstrings. Furthermore, in male athletes, resistance training involving one stable open-chain exercise and two unstable closed chain exercises showed improvement in hamstring peak torque only at 80°. Both types of exercises seemed to be important for enhancing the hamstring peak torque at a more closed position. Nevertheless, these findings are based on only one study, therefore it is suggested that male athletes should implement both types of exercises.

**Balance**

Neuromuscular control training enhanced balance in female athletes aged 13–17 years. This study had a relatively high quality score and contained multiple components, so it is not clear which component or components were responsible for the improvement. Children (mean age 10 years) seem to improve their balance by increased anterior–posterior stability and decreased anterior–posterior time-to-stabilization after a traditional program. This is in contrast with a specific pediatric program that did not show improvement, which could be explained by the specificity of the exercises. The traditional program contained exercises that included very similar movements as used in the tests and it was performed three times more than the pediatric program. In summary, it seems that prevention programs need to be specific for the task that has to be improved.

**LIMITATIONS AND FUTURE RESEARCH**

This systematic review provides a comprehensive overview of the current literature regarding the effects of interventions on modifiable, potential risk factors for knee injury in team ball sports. However, there are some limitations that need to be addressed.

First, this systematic review focused on variables that are proposed as risk factors for knee injuries. The literature shows little agreement on the degree to which the variables account for the risk of knee injury. Over time there are more and other concepts of risk factors, resulting in a lack of consensus for baseline risks. This is important to consider when formulating conclusions based on this systematic review.

Second, this systematic review showed the effects of prevention programs by risk factor. However, it is important to address prevention of knee injuries from a
multifactorial viewpoint because several factors are involved in such injuries. This can only be done if it is known which exercises/programs affect which factors. Third, most of the interventions contain combinations of exercises like plyometric, agility, and balance exercises. This may limit the efficiency of these interventions and makes it difficult to conclude which component(s) modifies the risk factor.

In addition, this systematic review focused on the effects of interventions on modifiable risk factors. However, there is a disparity between positive study results and actual reduction of injury rates. Therefore, there may be a missing link between the discussed research outcomes in this review and the effective and efficient implementation of injury prevention programs. An effective transfer from a training/lab session to the field during training or a game where control of complicated motor actions is required is warranted before any firm conclusions can be drawn regarding the effectiveness of knee injury reduction. Nonetheless, this work provides insight into how to reduce specific potential, modifiable risk factors, which is important for developing individualized prevention programs.

Subsequently, future studies should be able to examine the effects of these prevention programs on injury rate.

Last, the characteristics of the subjects diverged with respect to sex, playing level, age, and type of sport. This makes it difficult to compare the results and to put forward clear recommendations. For example, it is important to improve the knee valgus angles and moments in male athletes because they have a higher absolute rate of injury than female athletes. Further research should focus on promising interventions for specific populations that affect potential, modifiable risk factors for knee injury.

CONCLUSION AND PRACTICAL IMPLICATIONS

Various training components are required to modify each of the included risk factors in female athletes. In general, it appears that programs should use short sessions (maximum of 25 min) rather than long sessions for program compliance to be satisfactory. The most powerful component for reducing knee valgus is neuromuscular control training that consists of plyometric and agility exercises with addition of a feedback component (verbal or video). To enhance knee flexion angles and moments, the most promising program is neuromuscular control training that consists of plyometric and resistance exercises and an additional feedback component. It is apparent that the prevention program should contain specific exercises for the task
that needs to be improved. More research is needed to provide evidence for reducing the VGRF and PTSF and for improving balance. However, the addition of a feedback component (video or verbal) appears promising. The most powerful approach for improving the H : Q ratio and hamstring strength is isolated hamstring resistance exercise. To improve hamstring activity, there is a need for activity of the muscle with specific exercises and duration of the programs. Further research is needed to determine which interventions can improve the knee kinematic and kinetic variables, hamstring activation, H : Q ratio, and strength in male athletes and in children. Focusing on younger populations (9–11 years) is likely to be a promising approach to identify influential risk factors. Although a specific intervention program seems necessary for children, more research should be executed to determine the type of training components necessary to reduce the risk of knee injury in this population.

In conclusion, there is a need for the development of specific prevention programs. A risk profile must be created to set up individual and specific intervention programs.

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Chapter 4

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