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Preventive Training of Anterior Cruciate Ligament Injuries in Female Handball Players: a Systematic Review

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Abstract
Handball is a sport which involves the repetition of high-intensity movements and actions, such as single-leg landing and one-on-one actions, which are conducive to anterior cruciate ligament injury mechanism. Preventive training can modify the neuromuscular risk factors associated with the danger of this injury in women athletes. Determining their characteristics (duration, frequency, type of exercise, etc.) and components (strength, plyometrics, balance, etc.) is critical when designing specific and individualised training for players. The objectives of this study were to identify and categorise the common components of preventive training programmes for anterior cruciate ligament injury in women handball players and to describe and classify the exercises involved in each category. A systematic review was conducted following the guidelines of the PRISMA Statement in the Web of Science, Sport Discus, PubMed, Scopus, Cochrane and ScienceDirect databases. The inclusion criteria were: (a) participants were female handball players of any age, (b) there was a preventive training intervention, and (c) injury incidence was reported with the number of ACL injuries. Six studies were included and their methodological quality was assessed using the ROB 2.0 tool. The results show that most interventions included more than one training component with a median duration of 15 minutes and that the exercises which varied most across the programmes were plyometrics.

Keywords: anterior cruciate ligament, prevention, training, women's handball.

Introduction

Handball is one of the sports with the highest number of non-contact anterior cruciate ligament (ACL) injuries (De Loës et al., 2000; Myklebust et al., 1997). In 90% of cases, the injury is associated with cutting or single-leg landing from a jump (Olsen et al., 2004; Takahashi et al., 2019). These types of actions typically involve the valgus position of the knee in flexion and internal rotation of the tibia relative to the femur, which is the main mechanism of ACL injury (Koga, H., 2010). It is one of the most serious injuries, both because of the prolonged period required to return to competition and the long-term consequences (Lai et al., 2018).

The ACL injury rate in women handball players is 0.7-2.8 injuries per 1,000 hours of exposure (Myklebust et al., 1998), with an incidence two to five times greater than in their male counterparts (Montalvo et al., 2019). This difference is also found between the ages of 12 and 16, and women players are at greatest risk of sustaining this injury during adolescence (LaBella et al., 2014; Reckling et al., 2003).

Intrinsic and non-modifiable anatomical and hormonal risk factors, coupled with modifiable risk factors associated with neuromuscular control, are the most important aetiological contributions to ACL injury in women athletes (Griffin et al., 2006; Shultz et al., 2015). Since the injury is multifactorial in origin, the first prevention strategy should be to identify the modifiable risk factors (Fort-Vanmeerhaeghe & Romero, 2013).

Women athletes tend to present less knee and hip flexion (Bencke et al., 2018) and increased knee valgus (Hewett et al., 2005) in landing and cutting actions. The relative strength deficit in the lower limbs, particularly in the hamstrings (DiStefano et al., 2015) and a lower activation of the latter relative to the quadriceps in this type of action, increases anterior tibial traction forces and consequently generates greater stress on the ACL (Ahmad et al., 2006).

Preventive training recommends that consideration be given to the risk factors described (Gómez et al., 2019), mainly targeting abnormal biomechanical movement patterns and neuromuscular alterations and adapting to the training principles (Fort-Vanmeerhaeghe & Romero, 2013; Taylor et al., 2015). A lower risk of ACL injury has been demonstrated in women athletes following multifactorial and general preventive training (Myer et al., 2013; Petushek et al., 2019; Soomro et al., 2016; Sugimoto et al., 2016).

The objectives of this review were to identify and categorise the common components of preventive training programmes for anterior cruciate ligament injury in women handball players and to describe and classify the exercises comprising each category.

Method

The study followed the guidelines of the PRISMA Statement for systematic reviews to guarantee an appropriate structure and performance (Urrutia & Bonfill, 2010).

A literature search was conducted in the Web of Science (WOS), Sport Discus, PubMed, Scopus, Cochrane and ScienceDirect databases combining the following keywords: "*female*" or "*woman*" or "*girl*", "*handball*", "*exercise*" or "*training*" or "*prevention*" or "*intervention*" and "*ACL injury*" or "*anterior cruciate ligament injury*" or "*lower limb injury*" or "*knee injury*" (Table 1). All scientific articles published in Catalan, Spanish and English were considered using the following inclusion criteria: (a) the participants were female handball players of any age, (b) there was a sports training intervention, and (c) injury incidence was reported with the number of ACL injuries. Articles for which the full text was not available or were reviews were excluded.

The country where the study was conducted, participant age, the sample analysed, the frequency of weekly sessions and session duration were recorded for data extraction purposes. The description of all the exercises performed in each one of the preventive training sessions in the studies was also recorded and classified in five categories:

1) Agility: exercises designed to foster a full-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006).
2) Running: exercises intended to develop motor-locomotor pattern based on movement and technique (Jeffreys, I., 2019).
3) Balance: exercises that involved maintaining a single- or two-legged position specifically designed to challenge stability and improve proprioceptive awareness (Crossley et al., 2020).
4) Strength: exercises designed to improve muscle capacity by using body weight, free weights, resistance bands or resistance machines (Crossley et al., 2020).
5) Plyometric: exercises that included powerful dynamic movements such as jumping, landing or bouncing (Crossley et al., 2020). The plyometric exercises were classified into three levels based on the movement's intensity (increase in horizontal velocity or vertical height) and complexity.

Each exercise could only be classified in one category, although a training programme might consist of one or more categories.

Table 1
Search strategy and key.

Database	Equation
Web of Science (WOS)	#1 TS=(female* OR women OR girl*) #2 TS=(handball) #3 TS=(exercise* OR training OR prevent* OR intervention) #5 TS=(ACL injury* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*) #1 AND #2 AND #3 AND #5
Sport Discus	(female* OR women OR girl*) AND handball AND (exercise* OR training OR prevent* OR intervention) AND (ACL injury* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*)
PubMed	((((female*[Title/Abstract] OR women[Title/Abstract] OR girl*[Title/Abstract]) AND (handball[Title/Abstract])) AND (exercise*[Title/Abstract] OR training[Title/Abstract] OR prevent*[Title/Abstract] OR intervention[Title/Abstract])) AND (ACL injur*[Title/Abstract] OR anterior cruciate ligament injur*[Title/Abstract] OR lower limb injury*[Title/Abstract] OR knee injury*[Title/Abstract])
Scopus	(TITLE-ABS-KEY (female* OR women OR girl*) AND TITLE-ABS-KEY (handball) AND TITLE-ABS-KEY (exercis* OR training OR prevent* OR intervention) AND TITLE-ABS-KEY (acl AND injury* OR anterior AND cruciate AND ligament AND injury* OR lower AND limb AND injury* OR knee AND injury*))
Cochrane	(female* OR women OR girl*) in Title Abstract Keyword AND handball in Title Abstract Keyword AND (exercis* OR training OR prevent* OR intervention) in Title Abstract Keyword AND (ACL injur* OR anterior cruciate ligament injury* OR lower limb injury* OR knee injury*) in Title Abstract Keyword
ScienceDirect	(females OR women OR girls) AND (ACL injury OR anterior cruciate ligament injury) AND (exercise OR training OR prevention) AND handball

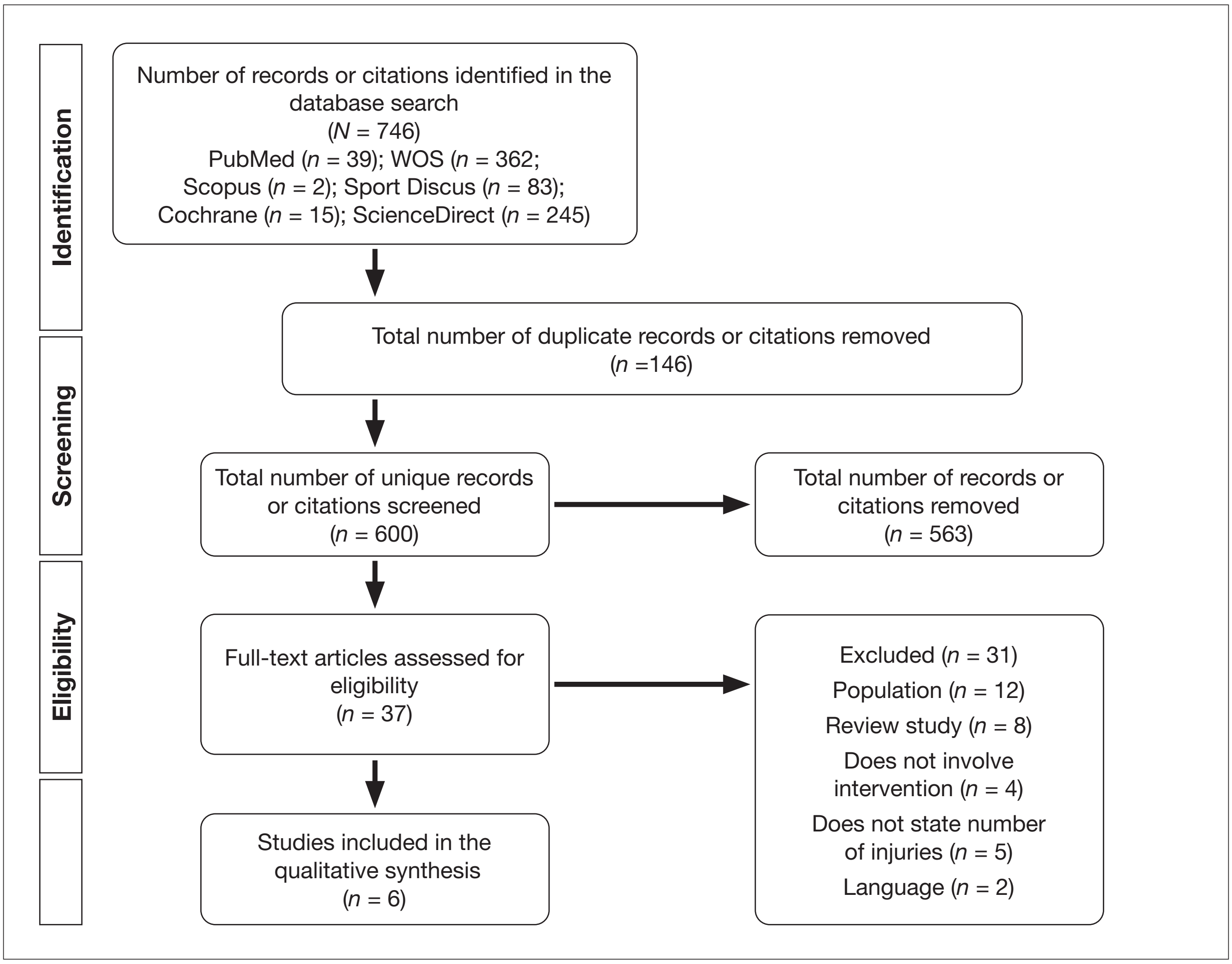

Figure 1
Study selection flowchart.

Table 2
Scores of the studies reviewed with ROB 2.0.

Study	D1	D2	D3	D4	D5	General
Achenbach et al. (2018)	+	+	+	+	+	+
Myklebust et al. (2003)	−	+	+	+	+	−
Olsen et al. (2005)	+	+	+	+	+	+
Petersen et al. (2005)	−	+	+	+	+	−
Wedderkopp et al. (1999)	+	+	+	+	+	+
Zebis et al. (2016)	+	+	+	+	+	+

Note. D1 = randomisation process; D2 = deviations from scheduled interventions; D3 = outcome data; D4 = outcome measurement; D5 = result reporting

Risk of bias assessment

Two reviewers (MC and SM) independently assessed the methodological quality of the articles included using the ROB 2.0 tool, which consists of five domains and an overall criterion. The five domains are: (a) bias arising from the randomisation process, (b) bias due to deviations from intended interventions, (c) bias due to missing outcome data, (d) bias in measurement of the outcome, and (e) bias in reporting results (Sterne et al., 2019).

To facilitate understanding, the results of the data extracted were grouped by the characteristics of the population analysed (country, age and sample) and by the components, duration and exercises of the training programmes.

Results

Selection of studies

The initial yield of articles for this review was 746 original papers. After duplicates (n = 146) had been discarded and following screening by title and abstract (n = 563) and the application of the inclusion criteria n = 31) (Figure 1), three studies which did not fully meet the inclusion criteria (the participants were male and female and the sample was handball and football) were included as they fitted the objective of the review. Finally, six studies were included for analysis (Urrutia & Bonfill, 2010).

The overall methodological quality of the six studies included is summarised in Table 2.

Study characteristics

In most of the studies included (4/6 = 66 %) the participants were adolescent (under 18 years of age) women handball players. In the study by Zebis et al. (2016), participants could be handball or football players, whereas the studies by Achenbach et al. (2018) and Olsen et al. (2005) included both male and female participants (Table 3).

The study by Zebis et al. (2016) used the same training programme as Olsen et al. (2005). The study by Wedderkopp et al. (1999) did not say what exercises were used in the training programme.

Training programme components

Balance was included in all the training programmes, followed by plyometrics (5/6 = 83 %), while half of the studies analysed (3/6 = 50 %) worked on agility and strength. Combining components in preventive training was most common in the studies reviewed (5/6 = 83 %). Only Wedderkopp et al. (1999) used balance as the sole programme component (Table 3).

Table 3
Study characteristics.

Study	Population			Training programme							
	Country	Age (years)	Sample analysed	Frequency[a]	Duration (min)	No. of exercises	Components				
							R	B	S	A	P
Achenbach et al. (2018)	Germany	IG: 14,9 ± 0,9[b] CG:: 15,1±1,0[b]	*N* = 174 IG: *n* = 98 CG: *n* = 76	PRE: 2/3 SEAS: 1	15	5	✗	✓	✓	✗	✓
Myklebust et al. (2003)	Norway	21 - 22	Season 1: *n* = 855 (58 teams) Season 2: *n* = 850 (52 teams)	PRE: 3 SEAS: 1	15	3	✗	✓	✗	✓	✓
Olsen et al. (2005)	Norway	IG: 16,3± 0,6[b] CG:: 16,2± 0,6[b]	*N* = 1586 IG: *n* = 808 CG: *n* = 778	PRE: 3 SEAS: 1	15 - 20	4	✓	✓	✓	✓	✓
Petersen et al. (2005)	Germany	IG: 19,8 CG:: 19,4	*N* = 276 IG: *n* = 134 (10 teams) CG: *n* = 142 (10 teams)	PRE: 3 SEAS: 1	10	4	✗	✓	✗	✗	✓
Wedderkopp et al. (1999)	Denmark	16 - 18	*N* = 237 IG: *n* = 111 CG: *n* = 126	SEAS: all	10 - 15	3	✗	✓	✗	✗	✗
Zebis et al. (2016)	Denmark	IG: 15,9 ± 0,4[c] CG::15,6± 0,5[c]	*N* = 40 IG: *n* = 20 CG: *n* = 20	PRE: 3 (12 weeks)	15	3	✓	✓	✓	✓	✓

Note. R: running; B: balance; S: strength; A: agility; P: plyometric; IG: intervention group; CG: control group; PRE: preseason; SEAS: season.
[a]In sessions per week. [b]The study included men and women. [c]The study included football and handball.

Table 4
Training programme exercises.

Running	Agility	Strength	
Running forward[c, f]	Plant and cut[c, f]	Lower body	Nordic hamstring[a, c, f]
Running backwards[c, f]	Run and plant[b]		Squat to 80° knee flexion[c, f]
Running with knees up and heel kicks[c, f]	Run and plant with ball[b]	Trunk	Plank[a]
Sideways crossing legs (carioca)[c, f]			Side plank[a]
Sideways running with arms up (parade)[c, f]			
Running forward with trunk rotations[c, f]			
Running forward with intermittent stops[c, f]			
Running speed[c, f]			

Balance		Plyometric	
Stable surface	Single leg, eyes closed and perturbation[a]	Static landing	Two-legged landing after hop[b]
	Single leg and ball use (throw, pass-reception or bounce)[d]		Two-legged landing after hop and throw[c, f]
Unstable surface (balance mat, wobble board, BOSU balance trainer, etc.)	Both legs[b]		Two-legged landing after throw from a 30-40 cm box[b]
	Both legs and squat[b, c, f]		Landing on one leg from a 30-40 cm box[b]
	Both legs and perturbation[b, c, d, f]	Controlled landing then subsequent action	Jumps (forward-backward, side-to-side, 180° turn)[b, d]
	Both legs and ball use (throw, pass-reception or bounce)[b, c, d, f]		Repetitive jumps5.7 with perturbation[b]
	Both legs and ball use (reception with jump)[b]		Forward jump from box to a mat and forward jump from mat to box[d]
	Single leg and squat[b, c, f]		Jump from floor to mat with throwing exercises, then side-to-side jumps[d]
	Single leg and perturbation[b, c, f]		Jump from box to mat with throwing exercises, then side-to-side jumps[d]
	Single leg and ball use (throw, pass-reception or bounce)[b, c, d, f]		Jump from box to mat with eyes closed, then side-to-side jumps[d]
	Single leg, ball use (throw, pass-reception or bounce) and perturbation[b]		Lateral jumps (skater)[a]
	Single leg, ball use (throw, pass-reception or bounce) and eyes closed[b, d]	Reducing ground contact time	Front lunges[a, c, f]
			Multi-directional hops[a]
	Single leg, ball use (throw, pass-reception or bounce), eyes closed and precision target[d]		Forward hops[c, f]

[a]Achenbach et al. (2018). [b]Myklebust et al. (2003). [c]Olsen et al. (2005). [d] Petersen et al. (2005). [e]Wedderkopp et al. (1999). [f]Zebis et al. (2016).

Training programme duration

The duration of the workouts varied between 10 and 20 minutes (Table 3). If a programme had a time interval, the maximum value of the range was recorded. Most of the programmes analysed lasted 15 minutes (4/6 = 66 %).

Training programme exercises

The training programmes included three to five exercises in each session.

The agility exercises did not specify how they were performed, although they did include plant and cut movements combined with throwing actions.

Running exercises were part of the warm-up and were intended to improve running technique.

The most commonly used balance exercises were on unstable surfaces (wobble board, balance mat, BOSU balance trainer, etc.) with single- or two-leg support and using a ball for throwing, passing, catching or bouncing (Table 4).

All the balance exercises were conducted progressively: different internal perturbations (player's limbs in motion) and external perturbations (handling a ball to perform technical actions related to throwing or unbalancing the partner) were included and sensory afferents were reduced to restrict vision.

Nordic Hamstring was the only exercise common to the training programmes that included strength as a component.

Finally, the exercises classified as plyometric were the most varied, as they included jumping across different planes and axes with perturbations and landings, on one and both legs and also from different heights (Table 4).

The most common work time for each exercise was 30 seconds.

Discussion

Five of the six interventions included more than one training component (Achenbach et al., 2018; Myklebust et al., 2003; Olsen et al., 2005; Petersen et al., 2005; Zebis et al., 2016), while balance was the sole component in one study (Wedderkopp et al., 1999).

It also transpired that the average duration of the training sessions was 15 minutes, which included between three and five exercises per session, and the exercises that varied most across the programmes were plyometrics.

Training programme components

The most frequent combination was balance training with plyometric training (5/6 = 83 %). This was not consistent with the reviews by Petushek et al. (2019), Yoo et al. (2010) and Taylor et al. (2015), who conclude that strength training combined with plyometric training is the best combination for lowering the risk of ACL injury in adolescent girls.

Strength training was under-represented in the studies reviewed (3/6 = 50 %). Myer et al. (2004) and Lloyd and Oliver (2012) emphasised the priority of developing this capacity in growth stages, especially in girls, to offset the anthropometric and hormonal changes that take place during peak height velocity (PHV). Fort-Vanmeerhaeghe et al. (2016) argue that the aim is to create a stable structure prior to plyometric or more sport-specific work to reduce the neuromuscular risk factors described above since, unlike in boys, no correlations have been demonstrated between height, weight and neuromuscular performance in the maturation phase in girls (Hewett et al., 2016).

Balance work was used in all the studies in the review (Table 3) and in most cases (5/6 = 83 %) it was combined with another component. This is consistent with the results of the reviews by Yoo et al. (2010) and Sugimoto et al. (2015) in women athletes, which showed that balance work does not yield results by itself but does do so in combination with other components.

Landing stabilisation exercises geared towards optimising muscle activation to ensure proper jump technique and alignment (soft landing and aligned knees) had been included by definition in the plyometric component. Other studies, such as those by Brunner et al. (2019) and Petushek et al. (2019), classified them as technical exercises. Brunner et al. (2019) attached less importance to them because the sports they reviewed (football and floorball) did not include jumping as a common action. By contrast, in handball, jumping and jump receptions, particularly on one leg, are one of the specific actions which, together with one-on-one actions, most trigger a set of mechanisms that can result in ACL injury (Myklebust et al., 1997; Olsen et al., 2004; Takahashi et al., 2019). For this reason, the progression of plyometric work should focus on landing technique to gradually step up intensity and variability, for example by involving various planes and axes, including perturbations with external stimuli or a mobile one, combining expected and unexpected actions to improve feedforward capacity, increasing the intensity of the muscle stretching and shortening cycle, combining elastic and reactive actions and progressively introducing a fatigued state (Bedoya et al., 2015; Ford et al., 2011; Fort-Vanmeerhaeghe et al., 2016).

Training programme duration

Most of the studies lasted approximately 15 minutes (Table 3). The results of the review by Taylor et al. (2015) did not reveal any clear trend which would make it possible to recommend duration parameters for training programmes. By contrast, Padua et al. (2018) showed that ACL injury rates diminished in training programmes lasting approximately 15 minutes or longer.

Training programme exercises

Only the reviews by Padua et al. (2018) and Arundale et al. (2018) provide a detailed description of the exercises included in the ACL injury prevention programmes.

Nordic Hamstring is the exercise proposed by the three studies that include strength in their training programme. It is essential to perform strength work and activation of the hamstring musculature in positions close to maximum knee extension, as this helps to prevent anterior translation of the tibia and protects the ACL (Sugimoto et al., 2015).

The planks recommended by Achenbach et al. (2018) in their training programme are designed to enhance neuromuscular control of this area, as strength deficits and poor trunk control in exercises involving rapid changes of position during cutting, planting and landing movements compromise dynamic stability and lead to increased knee abduction load (Zazulak et al., 2007). The non-contact ACL injury mechanism in women athletes has been shown to involve lateral trunk lean with the body moving on one leg and will therefore be one of the patterns to be corrected when agility tasks are performed (Hewett et al., 2009; Olsen et al., 2004).

Altering the state of balance through the perturbations proposed in the training programmes is designed to improve awareness of the position, movement and muscular regulation of the knee joint in response to a stimulus, i.e. to stimulate the proprioceptive receptors to promote muscular coactivation and improve activation time (Padua et al., 2018).

Even so, Fort-Vanmeerhaeghe et al. (2016) suggest that balance exercises should target specificity and dynamism in sports movements, since when players sustain the ACL injury they are usually in motion, for example, cutting or landing after a jump.

Learning to land is probably more important than learning to jump, since a player may have to absorb a load of between 5.7 and 8.9 times her body weight depending on flight trajectory and time and jump speed (Mothersole et al., 2014). Achenbach et al. (2018), Myklebust et al. (2003) and Petersen et al. (2005) include drills that combine landing skills with other movements. Exercises aimed at reducing ground contact time should be performed once the previous levels have been achieved, while guaranteeing quality of movement.

Most of the plyometric exercise proposals are general, meaning that greater specificity is needed to enable the player to recognise the movement patterns that may be conducive to the ACL injury mechanism (Fort-Vanmeerhaeghe et al., 2016).

Based on the available evidence, it is recommended that multi-component training programmes aimed at reducing the risk of ACL injury should include feedback on technique and movement quality and also include agility, balance, strength and plyometric exercises.

Conclusions

Training programmes for preventing ACL injury in women handball players are performed two to three times a week for approximately 15 minutes. They are categorised into five components: running, agility, strength, balance and plyometrics. The same programme may consist of one or more components. The most frequent combination was plyometric training with balance training, and balance training was the common component in all the training programmes.

Exercises in the running category are designed to improve running technique; agility exercises include planting and cutting combined with movement actions; strength exercises focus on the lower limbs and trunk; balance exercises are on stable and unstable surfaces, with single- or two-leg support and using a ball; finally, plyometric exercises are performed on various planes and axes with perturbations and landings on one or two legs and also from different heights.

Limitations

One of the main problems was the small number of studies, high variability in terms of components and their combination and the lack of individualisation of the contents of the training programmes based on player characteristics.

Only outcomes in women handball players were analysed in all the articles, except the papers by Achenbach et al. (2018) and Olsen et al. (2005) which also included male participants. The women players analysed in the study by Zebis et al. (2016) played either football or handball.

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