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Literature review

Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: A systematic review

Michael Michaelidis*, George A. Koumantakis

401 General Army Hospital, Athens, Greece

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ABSTRACT

Background: Anterior Cruciate Ligament (ACL) injury is frequently encountered in sports.
Purpose: To analyze the effects of ACL injury prevention programs on injury rates in female athletes between different sports.
Methods: A comprehensive literature search was performed in September 2012 using Pubmed Central, Science Direct, CINAHL, PEDro, Cochrane Library, SCOPUS, SPORTDiscus. The key words used were: 'anterior cruciate ligament', 'ACL', 'knee joint', 'knee injuries', 'female', 'athletes', 'neuromuscular', 'training', 'prevention'. The inclusion criteria applied were: (1) ACL injury prevention training programs for female athletes; (2) Athlete–exposure data reporting; (3) Effect of training on ACL incidence rates for female athletes.
Results: 13 studies met the inclusion criteria. Three training programs in soccer and one in handball led to reduced ACL injury incidence. In basketball no effective training intervention was found. In season training was more effective than preseason in ACL injury prevention. A combination of strength training, plyometrics, balance training, technique monitoring with feedback, produced the most favorable results.
Conclusion: Comparing the main components of ACL injury prevention programs for female athletes, some sports-dependent training specificity issues may need addressing in future studies, related primarily to the individual biomechanics of each sport but also their most effective method of delivery.

1. Introduction

Anterior cruciate ligament (ACL) tear, is one of the most common knee injuries in sports (McCarthy, Voos, Nguyen, Callaghan, & Hannafin, 2013; Yu & Garrett, 2007), usually occurring in a multitude of sports such as basketball, soccer, handball, alpine skiing and tennis (Bahr & Holme, 2003; Paszkewicz, Webb, Waters, Welch McCarty, & Van Lunen, 2012). Extrapolating the data of a study to the whole US collegiate population, an annual average of more than 2000 ACL injuries in 15 different sports has been reported (Hootman, Dick, & Agel, 2007).

A 2–8 times higher incidence of ACL injury in female compared to male athletes has been documented (Agel, Arendt, & Bershadsky, 2005; Arendt & Dick, 1995; Bjordal, Arnły, Hannestad, & Strandt, 1997; Hootman et al., 2007; Mountcastle, Posner, Kragh, & Taylor, 2007), therefore a significant amount of research is focusing on female participants of various ages and sports (Myer, Sugimoto, Thomas, & Hewett, 2013; Sugimoto, Myer, McKeon, & Hewett, 2012). A difference in ACL incidence rates has been reported for both sexes for different sports. Specifically, for females the injury rate-reported in number of injuries/1000 athlete-exposures (1 exposure = 1 game or practice) was 0.28 for soccer, 0.23 for basketball, relatively smaller for volleyball (0.09) and the highest for gymnastics (0.33) (Hootman et al., 2007).

Scientific studies support that females are at increased risk for an ACL injury due to sex specific anatomical and hormonal differences as well as sex disparities in neuromuscular (NM) factors (Alentorn-Geli et al., 2009; Griffin et al., 2006; Hewett, Myer, & Ford, 2006). Studies examining the relation of female hormones and increased risk of ACL injury in females have not yet concluded on the relative importance of this factor (Beynnon, 2008; Hewett, Zazulak, & Myer, 2007). Additionally, although studies have investigated the relation of sex specific anatomical differences in relation to an ACL injury, those differences remain non-modifiable (Alentorn-Geli et al., 2009; Hewett, Myer, et al., 2006; Uhorchak, Scoville, Williams, Arciero, St Pierre, & Taylor, 2003).

* Corresponding author. Grammou 10 Kallithea, Athens 17675, Greece. Tel.: +30 6942701526; fax: +30 2109560880.
E-mail address: spphysio@hotmail.com (M. Michaelidis).

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Neuromuscular (NM) control of knee joint stability as a risk factor has received particular attention, since between-gender differences in movement and muscle activation patterns have been purportedly related to an increased risk of ACL injury especially in females (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Chappell, Yu, Kirkendall, & Garrett, 2002; Ford, Myer, & Hewett, 2003; Ford, Myer, Toms, & Hewett, 2005; Hewett et al. 2005; McLean, Lipfert, & Van Den Bogert, 2004). Many studies have reported that female athletes perform several sporting maneuvers such as landing from a jump, cutting and pivoting with decreased hip and knee flexion, increased knee valgus, increased hip internal rotation, increased external rotation of the tibia and less knee joint stiffness resulting from high quadriceps to hamstrings activity compared with their male counterparts (Chappell et al., 2007; Chappell et al., 2002; Colby, Francisco, Yu, Kirkendall, Finch, & Garrett, 2000; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004; Huston & Wojtys, 1996; McLean, Huang, Su, & Van Den Bogert, 2004; Padua, Carcia, Arnold, & Granata, 2005; Pollard, Davis, & Hamill, 2004).

It has been shown that NM risk factors are modifiable through neuromuscular training, leading to improved sport performance also (Chappell & Limpisvasti, 2008; Chimera, Swanik, Swanik, & Straub, 2004; Herman, Weinhold, Guskiewicz, Garrett, Yu, & Padua, 2008; Lephart et al., 2005; Myer, Ford, Brent, & Hewett, 2006; Myer, Ford, Brent, & Hewett, 2007; Myer, Ford, Palumbo, & Hewett, 2005; Paterno, Myer, Ford, & Hewett, 2004), however the success of injury prevention programs incorporating aspects of NM training is variable (Sugimoto, Myer, McKeon, et al., 2012).

Given that most ACL injuries occur in non-contact situations (Paszkewicz et al., 2012; Renstrom et al., 2008) usually during cutting or pivoting maneuvers (Arendt & Dick, 1995; Krosshaug et al., 2007; McLean, Huang, et al., 2004; McLean, Huang, & Van Den Bogert, 2005; McLean, Walker, Ford, Myer, Hewett, & van den Bogert, 2005; Olsen, Myklebust, Engebretsen, & Bahr, 2004) and single-leg landing (Arendt & Dick, 1995; Krosshaug et al. 2007; Olsen, Myklebust, et al., 2004), the different biomechanical demands of sports defined by the frequency of occurrence of such events, may also need to be taken into account. The difference in incidence rates in females between different sports (Hootman et al., 2007) may partly be explained by differences in the biomechanical demands of sports themselves (Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Munro, Herrington, & Comfort, 2012; Xie, Urabe, Ochiai, Kobayashi, & Maeda, 2013), different fatigue development in those sports (Chappell, Herman, Knight, Kirkendall, Garrett, & Yu, 2005; Delextrat, Gregory, & Cohen, 2010; Frisch, Urhausen, Seil, Croiser, Windal & Theisen, 2011), environmental factors (Alentorn-Geli et al., 2009; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2003), protective equipment used (Beynnon, 2008) and even whether athletes are considered as 'high' or 'low' risk for contracting an ACL injury through participation in a particular sport, based on the risk factor of increased knee abduction moment when performing a drop vertical jump (Myer et al. 2007).

Therefore, the success of injury prevention programs for the different sports was decided as the topic of this systematic review in order to analyze the content of successful programs and their method of delivery. Issues examined were the compliance level (Soligard et al., 2010; Sugimoto, Myer, Bush, Klugman, McKeon, & Hewett, 2012), the inclusion of multiple training components, training volume, incorporation of sports-specific drills (Myer et al., 2006) and whether these were also practiced in a field environment (McLean, 2008; Shultz, Schmitz, Benjaminse, Chaudhari, Collins, & Padua, 2012), and whether adequate feedback on sports-specific performance was provided to promote motor reprogramming (Benjaminse & Otten, 2011; Powers & Fischer, 2010).

2. Materials and methods

2.1. Study selection

The inclusion criteria for the randomized and non-randomized controlled studies used in this systematic review were the following:

(1) ACL injury prevention training programs for female athletes;
(2) Athlete–exposure data, expressed in hours. 1 athlete-exposure (1 A–E): 1 athlete participating in 1 practice or game & 1 A–E = 2 h (Hewett, Ford, & Myer, 2006; Hootman et al., 2007);
(3) Effect of training on ACL incidence rates for female athletes

The exclusion criteria were the following:

(1) Studies testing the effects of ACL injury prevention training programs only on male athletes.
(2) Studies only using video awareness or cognitive training techniques.
(3) Studies that focused on the effects of neuromuscular training following ACL reconstruction.

2.2. Search strategy

A systematic search was performed in September 2012 in the following electronic databases: Pubmed Central, Science Direct, CINAHL, PEDro, Cochrane Library, SCOPUS, SPORTDiscus. All databases were searched in the English language from the earliest records available, for studies including human subjects. The following key words were used: 'anterior cruciate ligament', 'ACL', 'knee joint', 'knee injuries', 'female', 'athletes', 'neuromuscular', 'training', 'prevention' (Table 1). The reference lists of the relevant studies were also reviewed to identify other potentially relevant studies. Additional sources for hand searching included sport injury textbooks (Olsen et al., 2004). The abstracts of the potentially relevant studies were reviewed. For studies with no available abstract, information was taken from the article title. If an abstract did not give adequate information as to whether the study met the inclusion criteria the full text of the study was reviewed.

2.3. Methodological quality evaluation of studies

Two reviewers (MM & GK) independently rated the methodological quality of included studies that were RCTs with the PEDro scale (Physiotherapy Evidence Database, 2012). Studies with a score

Table 1
Stepped PubMed host search strategy with the number of studies.

Step	Strategy	No.
#1	Anterior cruciate ligament[T/AB]	9809
#2	ACL [T/AB]	8331
#2	Knee joint [T/AB]	13449
#3	Knee injuries [T/AB]	1164
#4	(((#1) OR#2) OR#3) OR#4	26125
#5	Female[T/AB]	413407
#6	Athletes[T/AB]	22822
#7	(#5) OR#6	433276
#7	Neuromuscular [T/AB]	38100
#8	Training [T/AB]	218550
#9	Prevention [T/AB]	324143
#10	((#7) OR#8) OR#9	569577
#11	((#4) AND#7) AND#10 (Limits: Human, English)	342

[T/AB], Title and Abstract.

of ≥8/10 are considered of excellent quality, 5–7/10 of good quality, and ≤4/10 of poor quality. The PEDro scale is valid (de Morton, 2009) and has sufficient reliability for use in systematic reviews of physical therapy RCTs (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Inter-rater discrepancies were resolved by arbitration and consensus.

2.4. Data extraction

The following data were extracted from studies that met the inclusion criteria: (1) Sport, age, level and number of athletes tested in each study; (2) The number of ACL injuries as well as the mechanism of ACL injury (non-contact or contact); (3) The program training components as well as the duration of the training program tested in each study; (4) ACL injury incidence rates according to athlete–exposures; (5) Compliance level with administered exercise program, with compliance calculation based on the methodology followed by a recent study (Sugimoto, Myer, Bush, et al., 2012).

The outcome measure we chose to evaluate the effectiveness of a training program was the estimation of "ACL knee Injuries per 1000 h of exposure" (injury rate). Our study focused primarily on the effects of training on injury rate (Table 2). For mixed sports population studies the between-group injury rate significance was calculated by us. The Chi-square test was applied through the IBM SPSS Statistics program, version 19, extracting the number of non-contact ACL injuries and the athlete-exposures for each sport separately, provided by each corresponding author.

3. Results

From 458 records identified, 445 were excluded and hence 13 included in this systematic review (Fig. 1). Thirteen studies were reviewed and seven were scored according to the PEDro scale (Physiotherapy Evidence Database, 2012) yielding 1 study of excellent methodological quality (Pasanen et al., 2008), 4 studies (Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Olsen et al., 2005; Steffen et al., 2008; Waldén et al., 2012) of good quality and 2 studies (Gilchrist et al., 2008; Söderman et al., 2000) of poor quality. After reviewing the studies it was found that the effects of numerous forms of neuromuscular training on different sports were investigated. From the selected studies, seven studies focused on soccer players (Gilchrist et al. 2008; Heidt et al., 2000; Kiani et al., 2010; Mandelbaum et al., 2005; Söderman et al., 2000; Steffen et al., 2008; Waldén et al., 2012). Three studies tested the effects of training in a population of handball players (Myklebust et al., 2003; Olsen et al., 2005; Petersen et al., 2005). One study used floorball players (Pasanen et al., 2008) and two studies (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Pfeiffer, Shea, Roberts, Grandstrand, & Bond, 2006) used a mixed population of soccer, basketball and volleyball players (Table 2). Another mixed-population study (LaBella, Huxford, Grissom, Kim, Peng, & Christoffel, 2011) using soccer and basketball players was excluded from our review on the basis that there was no exposure information available for athletes in each sport. Similarly another study (Soligard et al. 2008) which focused on soccer players was also excluded due to the fact that it did not provide data on the number of ACL injuries sustained during the study.

There were 12 training programs investigated in these studies: SPORTSMETRICS (Hewett et al. 1999), Frappier Acceleration Training Program (FATP) (Heidt et al. 2000), Prevent Injury and Enhance Performance (PEP) (Gilchrist et al. 2008; Mandelbaum et al. 2005), Knee Ligament Injury Prevention (KLIP) (Pfeiffer et al. 2006), the "FIFA 11" (Steffen et al., 2008), SÖDERMAN (Söderman et al., 2000), MYKLEBUST (Myklebust et al. 2003), OLSEN (Olsen et al., 2005), PETERSEN (Petersen et al., 2005), PASANEN (Pasanen et al., 2008), WALDEN (Waldén et al., 2012) and the Harmoknee Preventive Training program (HPT) (Kiani et al., 2010), (Table 2). Some of the aforementioned studies tested the effects of a prevention program on ACL injury while others not only on ACL but also other sports-related injuries.

3.1. Prevention studies in soccer players

From the nine interventions which focused on soccer players, seven of them used a multi – component program (Gilchrist et al., 2008; Heidt et al., 2000; Hewett et al., 1999; Kiani et al., 2010; Mandelbaum et al., 2005; Steffen et al., 2008; Waldén et al., 2012), the SÖDERMAN training program used balance as a training mode alone (Söderman et al., 2000) while the KLIP was a plyometric based training program (Pfeiffer et al., 2006).

The three successful programs applied in female soccer players which resulted in statistically significant less ACL injuries for the intervention groups in contrast with the control groups were the PEP in one of the two studies that it was applied (Mandelbaum et al., 2005), the HPT (Kiani et al., 2010) and the WALDEN (Waldén et al., 2012). All were multicomponent in content, including strength, stretching, strengthening, plyometrics, agility training (Table 2). The HPT (Kiani et al., 2010) and the WALDEN (Waldén et al., 2012) also included core stability training and balance. Incorporation of sports-specific drills in a field environment was used in the three successful programs. The PEP program although successful in Mandelbaum et al., (2005) approached but did not reach significance when used in another study ($p = 0.066$), possibly due to the fact that it included athletes in their late teens (18–20 years) (Gilchrist et al. 2008), not readily amenable to the training effect as a recent systematic review has reported (Myer, Sugimoto, Thomas, & Hewett, 2013).

The training "volume" & compliance of the successful (Kiani et al., 2010; Mandelbaum et al., 2005; Waldén et al., 2012) as well as the unsuccessful studies are presented in Table 2. For the PEP (Mandelbaum et al., 2005) enrollment of participants may have biased results in a positive manner as subjects were not randomized (selection bias) and they voluntarily enrolled to the intervention program (motivation bias).

The "FIFA 11" (Steffen et al., 2008), the KLIP (Pfeiffer et al., 2006), the FATP (Heidt et al. 2000) and the SÖDERMAN (Söderman et al. 2000) training programs all resulted in non-significant effects on ACL injury incidence rates (Table 2). Finally, SPORTSMETRICS failed to significantly reduce the number of ACL injuries in the soccer population only, although significant results have been reported for the total population applied (Hewett et al. 1999).

Strength was included in the intervention programs except from the SÖDERMAN (Söderman et al. 2000) and the KLIP program (Pfeiffer et al. 2006). All but SÖDERMAN included plyometrics (Söderman et al. 2000). Flexibility training was conducted in the SPORTSMETRICS (Hewett et al. 1999), FATP (Heidt et al. 2000) and the PEP programs (Gilchrist et al. 2008; Mandelbaum et al. 2005). Balance training was part of the "FIFA 11", the HPT and the WALDEN programs (Kiani et al., 2010; Steffen et al., 2008; Waldén et al., 2012) and a main training method in SÖDERMAN program (Söderman et al., 2000). Agility exercises were performed in the FATP (Heidt et al., 2000), the PEP (Gilchrist et al., 2008; Mandelbaum et al., 2005) and the KLIP (Pfeiffer et al., 2006) training interventions. Core stability training was included in the "FIFA 11" (Steffen et al., 2008), the HPT (Kiani et al., 2010) and the WALDEN program (Waldén et al., 2012). The FATP (Heidt et al., 2000) was the only training program which used 'Acceleration–Speed Running' as part of its multi-component training program. Specifically, a treadmill was used with the ability to incline to 40° enabling the athletes to perform incline sprints at a high incline.

Table 2
Summary of studies examining ACL Injury Prevention Programs for the different sports.

Reference	Comparison groups	Prevention program	Training 'volume' & overall compliance rate	Hours of exposure	Non-contact ACL injuries (& injury rate)	Total ACL injuries (& injury rate)	Between-group significance
SOCCER STUDIES							
Heidt et al. (2000)[a]	I: $n = 42$ C: $n = 258$	FATP MC: cardiovascular conditioning, plyometrics, strengthening, agility, sport-specific drills, flexibility	75 min/session 3 d/wk TOTAL: 7 wks (preseason ONLY) COMPLIANCE information not given	7896 48,504	– –	1 (0.13) 8 (0.16)	$p > 0,05$ NS
Söderman, Werner, Pietilä, Engström, and Alfredson (2000)[a]	I: $n = 62$ C: $n = 78$	SÖDERMAN Balance-Proprioception Training (with balance board). Performed at home	10–15 min/session for 30 sessions; then 3 d/wk rest of the season TOTAL: 6 months High drop-out rate COMPLIANCE: 31.3% (Low to moderate)	8246 9262	– –	4 (0.49) 1 (0.11)	$p > 0,05$ NS
Mandelbaum et al. (2005)	I: $n = 1885$ C: $n = 3818$	PEP MC: warm-up, stretching, strengthening, plyometrics, agility	20 min/session 2–3 times/wk TOTAL: 12 wks per season (3 seasons) Compliance could not be calculated	135,720 274,896	6 (0.04) 67 (0.24)		$p < 0.0001$
Steffen, Myklebust, Olsen, Holme, and Bahr (2008)	I: $n = 1073$ C: $n = 947$	"FIFA 11" MC: core stability, balance, dynamic stabilization (plyometrics), eccentric hamstrings strengthening	15 min/session for 15 sessions; then 1 d/wk rest of the season TOTAL: 7.5 months COMPLIANCE: 10.7% (Low)	66,423 65,725	3 (0.05) 2 (0.03)	4 (0.06) 5 (0.08)	$p = 0.73$ NS
Gilchrist et al. (2008)	I: $n = 583$ C: $n = 852$	PEP MC: warm-up, stretching, strengthening, plyometrics, agility	20 min/session 3 times/wk TOTAL: 4–5 months Compliance could not be calculated	35,220 52,919	2 (0.06) 10 (0.18)	7 (0.20) 18 (0.34)	Non-contact ACL: $p = 0.066$ NS ACL injuries: $p = 0.198$ NS
Kiani, Hellquist, Ahlqvist, Gedeborg, Michaëlsson, and Byberg (2010)	I: $n = 777$ C: $n = 729$	HPT MC: warm up, muscle activation, balance, strength, core stability	20–25 min/session 2 d/wk for 2 months preseason & 1 d/wk in season TOTAL: 9 months COMPLIANCE: 70.4 % (High)	66,981 66,505	0 5 (0.08)	– –	$p = 0.025$[c]
Waldén, Atroshi, Magnusson, Wagner, and Hägglund (2012)	I: $n = 2479$ C: $n = 2085$	WALDEN MC: core stability, strength, balance, jump-landing technique (plyometrics) with knee alignment feedback	15 min/session 2 d/wk TOTAL: 7 months COMPLIANCE: 26.3%[b] (Low)	149,214 129,084	5 (0,03) 8 (0.06)	7 (0.05) 14 (0.11)	Non-contact ACL (compliant players): $p = 0.049$ ACL injuries: $p = 0.02$
Hewett et al. (1999)	Mixed population study-Soccer: I: $n = 97$ C: $n = 193$	SPORTSMETRICS MC: flexibility, plyometrics, weight training, technique analysis and feedback	60–90 min/session 3 alternating d/wk TOTAL: 6 wks (preseason ONLY) COMPLIANCE: 45.2% (Moderate)	9034 18,034	0 2 (0.11)	0 2 (0.11)	Non-contact ACL: $p = 0.32$ NS[c]
Pfeiffer et al. (2006)	Mixed population study-Soccer: I: $n = 189$ C: $n = 244$	KLIP Plyometrics, agility training	20 min/session 2 d/wk Performed at beginning or end of training TOTAL: 4–5 months Compliance: Average number of 23 sessions/athlete	11,826 18,714	0 1 (0.05)	– –	$p = 0.43$ NS[c]
HANDBALL STUDIES							
Myklebust, Engebretsen, Braekken, Skjølberg, Olsen, and Bahr (2003)	I: $n = 855$ C: $n = 942$	MYKLEBUST Balance and proprioceptive single and double leg training. More sports-specific drills incorporated in the 2nd year of program (floor running & planting, 180° turns,	15 min/session 3 times/wk (5–7 wks preseason) & 1 time/wk in-season TOTAL: 5 months COMPLIANCE: 1st year – 12.3% 2nd year – 13.7% (Low)	359,497 208,936	10 (0.03) 18 (0.09)	23 (0.06) 29 (0.14)	Entire cohort: $p = 0.15$ NS Elite division – for compliant players: $p = 0.01$

(continued on next page)

Table 2 (*continued*)

Reference	Comparison groups	Prevention program	Training 'volume' & overall compliance rate	Hours of exposure	Non-contact ACL injuries (& injury rate)	Total ACL injuries (& injury rate)	Between-group significance
		landing exercises, squatting, ball passing on unstable surfaces), with feedback from training partner on movement quality & 1 physiotherapist/team to supervise program					
Olsen, Myklebust, Engebretsen, Holme, and Bahr (2005)	I: $n = 808$ C: $n = 778$	OLSEN Warm up, balance, technique, strength & power training (plyometrics)	15–20 min/session for 15 sessions; then, 1 d/wk rest of season TOTAL: 5 months Compliance could not be calculated	93,812[a] 87,483[a] [a]for girls & boys	1 (0.01) 5 (0.06)	3 (0.03) 9 (0.10)	Non-contact ACL injuries: $p = 0.085$ NS[c] ACL injuries: $p = 0.064$ NS[c]
Petersen et al. (2005)	I: $n = 134$ C: $n = 142$	PETERSEN Balance – Proprioception (with balance board), plyometrics, education	10 min/session 3 d/wk (8 wks pre-season) & 1 d/wk (competition period in season) TOTAL: 8 wks Compliance NOT MONITORED	25,000 23,809	0 5 (0.21)	1 (0.04) 5 (0.21)	$p > 0.05$ NS
FLOORBALL STUDY							
Pasanen et al. (2008)	I: $n = 256$ C: $n = 201$	PASANEN MC: running techniques, balance & body control exercises, plyometrics, strengthening, stretching	20–30 min/session 2–3 d/wk intensive training (start of season & December) & 1 d/wk maintenance (rest of season) TOTAL: 6 months Compliance: Average number of 31 sessions/team	32,327 25,019	3 (0.09) 3 (0.12)	6 (0.19) 4 (0.16)	Non-contact ACL injuries: $p = 0.75$ NS[c] ACL injuries: $p = 0.82$ NS[c]
BASKETBALL STUDIES							
Hewett et al. (1999)	Mixed population study-Basketball: I: $n = 84$ C: $n = 189$	SPORTSMETRICS MC	As above (soccer studies)	9534 20,740	0 3 (0.14)	2 (0.21) 3 (0.14)	Non-contact ACL: $p = 0.24$ NS[c]
Pfeiffer et al. (2006)	Mixed population study-Basketball: I: $n = 191$ C: $n = 319$	KLIP Plyo-based	As above for training volume (soccer studies) Compliance:Average number of 18 sessions/athlete	12,604 36,152	3 (0.24) 2 (0.06)	– –	$p = 0.08$ NS[c]
VOLLEYBALL STUDIES							
Hewett et al. (1999)	Mixed population study-Volleyball: I: $n = 185$ C: $n = 81$	SPORTSMETRICS MC	As above (soccer studies)	Not given	0 0	0 0	–
Pfeiffer et al. (2006)	Mixed population study-Volleyball: I: $n = 197$ C: $n = 299$	KLIP Plyo-based	As above for training volume (soccer studies) Compliance:Average number of 22 sessions/athlete	11,478 22,458	0 0		–

Injury Rate (=ACL knee Injuries per 1000 h of exposure) was the outcome measure of interest.
Abbreviations: FATP: Frappier Acceleration Training Program, HPT: Harmoknee Prevention Training Program, I: Intervention/C: Control (Groups), KLIP: Knee Ligament Injury Prevention, MC: multicomponent (program), mins: minutes/d: days/wks: weeks, NS: non-significant, PEP: Prevent Injury and Enhance Performance.

[a] Only total ACL injuries reported in those studies, with the non-contact ACL injuries not reported separately.
[b] Calculated by authors of this systematic review, from data presented within studies based on a formula presented in Sugimoto, Myer, Bush, et al., 2012.
[c] Calculated by authors of this systematic review, from data presented within studies.

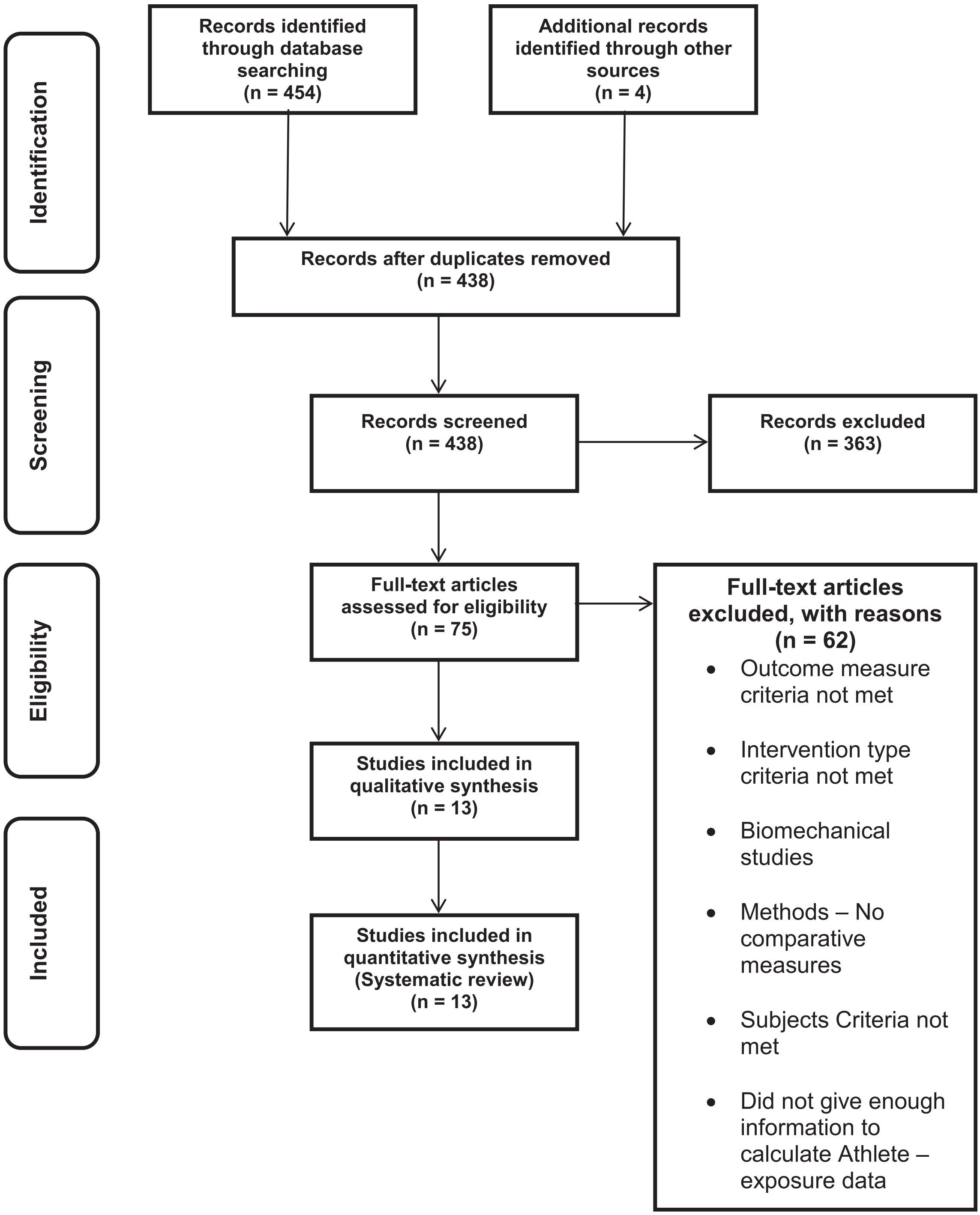

Fig. 1. Flow chart of literature review.

The "FIFA 11" (Steffen et al. 2008) and the WALDEN (Waldén et al., 2012) used low intensity running, the SPORTSMETRICS (Hewett et al., 1999) used running exercises. The PEP (Gilchrist et al. 2008; Mandelbaum et al. 2005) and HPT (Kiani et al. 2010) programs both included a warm up part consisting of running drills before the execution of the main part of the prevention program. Education or feedback on correct technique was included in all the studies except for one program (Söderman et al., 2000).

The time needed for training was 10–25 min for all the programs, except from the SPORTSMETRICS (Hewett et al. 1999) and the FATP (Heidt et al. 2000) which needed 60–90 and 75 min respectively. The SÖDERMAN, PEP, KLIP, and the WALDEN were administered during the season (Gilchrist et al., 2008; Mandelbaum et al., 2005; Pfeiffer et al., 2006; Söderman et al., 2000; Waldén et al., 2012) while SPORTSMETRICS and FATP during the off season (Heidt et al., 2000; Hewett et al., 1999). Training in the "FIFA 11" and HPT was implemented in the preseason also (Kiani et al. 2010; Steffen et al. 2008). The subjects in most of the programs were high school and collegiate athletes in their mid teens (14–18 years) with only one study (Gilchrist et al., 2008) including athletes in their late teens (18–20 years) and one (Söderman et al., 2000) early adults (over 20 years).

3.2. Prevention studies in handball players

The MYKLEBUST was the only program which presented with statistically significant results, in female handball players (training details reported in Table 2). Specifically, there was a trend towards reduction in ACL injuries, however results were statistically significant only for compliant players from the elite division.

The OLSEN program failed to have a significant effect on ACL injury incidence rates, however their results were promising with the trained group experiencing significantly less ACL, posterior cruciate ligament (PCL) and medial collateral ligament (MCL) injuries compared with the control group (Olsen et al., 2005). Finally, in the PETERSEN program, the ACL injury risk was 80% less in favor of the intervention group however the reduction was not significant (Petersen et al., 2005).

The time needed for training varied from 10 to 20 min. Athletes started training in the preseason then continued in season. Education or feedback on correct technique was included in all three programs. Subjects in the Olsen et al. (2005) and Petersen et al. (2005) studies were non elite athletes while the athletes in the Myklebust et al. (2003) study were both elite and non elite. The athletes in the study of Olsen et al. (2005) were in their mid teens (14–18 years) while those in the study of Petersen et al. (2005) were in their late teens (18–20 years). Participants in the Myklebust et al. (2003) study were early adults (over 20 years old).

3.3. Prevention study in floorball players

Only one study was focused on floorball athletes and used a multi component training program (Pasanen et al. 2008). Running exercises, balance and body control exercises, plyometrics, strengthening exercises and stretching for players with limited flexibility were included. Education and feedback on proper technique was also part of the training program. A training session needed 20–30 min to complete. Training started in the preseason and continued in-season. Athletes participating in the study were early adults (over 20 years old) of both elite and non elite level. Although the reduction of ACL injuries was not significant, significantly fewer non-contact leg injuries in general occurred in the intervention group.

3.4. Prevention studies in basketball/volleyball players

Basketball and Volleyball players followed the SPORTSMETRICS and the KLIP training programs (Hewett et al. 1999; Pfeiffer et al. 2006). The SPORTSMETRICS (Hewett et al. 1999) was a multi component program, while the KLIP (Pfeiffer et al. 2006) a plyometric based training program supplemented by agility training and instruction on correct technique. SPORTSMETRICS included aspects of strength training, flexibility, plyometrics as well as education and feedback on correct technique (Hewett et al. 1999). Running exercises were also performed as a warm up before the execution of the main part of the training program.

The time needed for training was 20 min (Pfeiffer et al., 2006) and 60–90 min (Hewett et al., 1999) respectively. KLIP was performed in season (Pfeiffer et al. 2006) while the SPORTSMETRICS was conducted in the preseason (Hewett et al. 1999). Participants in both studies were non elite athletes in their mid teens (14–18 years). Both programs failed to have a significant reduction of ACL injuries in basketball athletes. For the volleyball players, no ACL injuries were noted either in the control or the intervention group in both studies (Hewett et al., 1999; Pfeiffer et al., 2006).

4. Discussion

From all the training interventions used for decreasing the incidence of an ACL injury irrespective of which sport they focused on, four programs showed significant improvements in reducing the incidence of ACL injury (Kiani et al. 2010; Mandelbaum et al., 2005; Myklebust et al., 2003; Waldén et al., 2012) with the study of Myklebust et al., (2003) showing significant reduction only for compliant players in the elite division.

Observing the injury rates of the 13 studies included in our review, a low incidence of ACL injuries were reported in general for their control groups (receiving no intervention), with a range of 0.06–0.21 in 11 of the studies and only 2 studies reporting higher injury rates (0.24 for Mandelbaum et al. 2005; 0.34 for Gilchrist et al. 2008). Therefore, the reported injury rates between the intervention and control groups of those studies were not significantly different in most instances. To overcome the similarity in injury rates reported between control and intervention groups, either larger groups might need to be used or as a study has argued (Myer et al., 2007) to perform identification of 'high-risk' athletes in injury prevention studies that may be more amenable to prevention training programs than the general sporting population in order for significant injury prevention results to emerge or adaptations in the training protocols towards further sports-specific refinements and more appropriate methods of delivery are required.

A well-rounded injury prevention protocol should focus on multiple components of training: plyometrics, dynamic stabilization, strength training for the trunk, upper and lower body as well as sport specific agility training paired with education and feedback on correct technique. The duration and the time period of delivery (preseason/in season or both) of the training program still remain unclear. All analyzed protocols avoid fatigue development during preventive training sessions, which may account for the average duration of 20 min of preventive training, to weave a negative impact on the ideal movement execution and feedback delivery, however in a game situation this may not be realistic. It has been noted that better conditioned soccer athletes display improved neuromuscular joint control for longer time periods in a game relative to less conditioned athletes, with the latter displaying longer reflex latencies and decreased activation in muscles around the knee joint (Alentorn-Geli et al., 2009). Therefore, subjects might also need to be reaching a certain fatigue level which would still provide a positive injury prevention training stimulus.

As far as the training program specificity and its method of delivery the following considerations may prove useful additions to the existing training programs. Since excessive knee valgus moments and angles present in the specific maneuvers of different sports are considered to stress the medial passive and active stabilizing knee structures and also predispose to ACL injury (Hewett et al., 2005; Myer, Ford, Khoury, Succop, & Hewett, 2011; Sigward, Ota, & Powers, 2008), specific NM training of the whole lower limb kinetic chain for individual sports and in their specific conditions of play may be required.

Recent biomechanical research findings show a different response to unilateral drop jump tasks between female basketball and soccer athletes, with basketball players exhibiting increased frontal plane knee angles than soccer players (Munro et al., 2012). The authors could not solely attribute knee frontal plane angle differences between the 2 sporting populations to anthropometry (Munro et al., 2012). However, a possible interaction between certain ACL load-increasing basketball sporting drills with the anthropometry and lack of adequate training specificity, could be possibly predisposing basketball players to increased internal ACL loading (Myer et al., 2007; Padua, Bell, & Clark, 2012), and subsequent injury. Also, differences in the utilized NM strategies were identified between female basketball and soccer players' landing and cutting tasks (Cowley et al., 2006). The authors suggested that sport specific NM training should be focusing on jumping and landing tasks for basketball based on ground reaction force and stance time data and on unanticipated cutting for soccer but also for basketball athletes, based on increased knee valgus moments and angles data (Cowley et al., 2006). In another more recent study conducted in female basketball athletes, it was similarly reported that the stop phase of a sidestep cutting maneuver had an increased risk for ACL injury, due to aberrant ratios of hamstrings to quadriceps NM activation (Xie et al., 2013), underlying the necessity of an appropriate NM approach to decrease ACL Injury risk (Myer et al., 2011).

Improvements in frontal plane alignment of knee valgus angles (Kato, Urabe, & Kawamura, 2008) and knee valgus moments (Myer et al., 2007) towards more normal values have been reported with relevant NM training. A recent review examining whether NM motor control learning can be transferred from laboratory conditions to the competitive field raised the issue whether current explicit learning techniques (feedback-education-instruction on technique) may not be sufficient to promote unexpected and automatic movements (Benjaminse & Otten, 2011). Movement execution under relatively uncontrolled conditions requires complicated motor control adaptations, promoted with implicit learning techniques focusing on the successful performance of an overall movement sequence rather than focusing on the individual movements required to achieve this sequence, offering protection against injury in unanticipated situations (Benjaminse & Otten, 2011). Other authors also present findings that skill acquisition training brings about decreases in corticomotor excitability, suggesting that subcortical neural sites (striatal and cerebellar circuits) gradually become more relevant in the automatic co-ordination of task-specific movements (Powers & Fischer, 2010), thus reducing the reaction time of the neuromuscular system to the control of deleterious loads to the knee.

Compliance seems to be a major issue and is mandatory to be monitored for the delivered training program to bring about the desired protective transformations in reaction times, fatigue resistance and instilment of the correct movement execution patterns for each sport. A recent study calculated the compliance of 6 of the 13 trials included in our systematic review (Sugimoto, Myer, Bush, et al., 2012). According to the instructions of that study, we further calculated compliance for 1 more trial (Waldén et al., 2012) not included in that systematic review. Low compliance is noted for most studies.

4.1. Soccer – key components

In soccer the PEP, the HPT and the WALDEN training programs showed significant improvements in reducing the incidence of ACL injury (Kiani et al. 2010; Mandelbaum et al., 2005; Waldén et al., 2012). The PEP training program in another study although not significant, noted a lower percentage of non-contact ACL injuries compared with the control group (70% decrease) (Gilchrist et al. 2008). Common elements of the three programs (Kiani et al., 2010; Mandelbaum et al., 2005; Waldén et al., 2012) were plyometric exercises, dynamic stabilization, education - feedback on correct technique, strengthening exercises with the use of body-weight exercises focused on trunk, upper and lower body muscles. Strength training along with plyometrics, dynamic stabilization and education - feedback on correct technique has been previously supported to be vital parts for every ACL injury prevention training program to become successful (Myer et al., 2013). In this review it becomes more apparent that a prevention training program focusing on soccer athletes should include agility training mimicking the high risk positions for ACL injury which exist in soccer such as cutting maneuvers (Arendt & Dick, 1995; Krosshaug et al., 2007; McLean, Huang, et al., 2004, McLean, Huang, et al., 2005; McLean et al., 2005; Olsen, Myklebust, et al., 2004). Agility training was used in both HPT and PEP protocol with positive results (Kiani et al. 2010; Mandelbaum et al., 2005). Agility exercises such as shuttle run, diagonal run, bounding run as well as zigzag running with pressure technique should always be supplemented by feedback driven technique so that the players learn instinctively to avoid the high risk positions. Limited feedback in the KLIP protocol which used plyometrics and agility exercises might have been a contributing factor in failing to reduce the number of ACL injuries in soccer athletes (Pfeiffer et al. 2006).

Pre-practice warm up type training protocols appear to be effective in producing the desirable results and reducing the number of ACL injuries (Kiani et al. 2010; Mandelbaum et al. 2005; Waldén et al., 2012). From the three effective training protocols, the PEP and the WALDEN (Mandelbaum et al., 2005; Waldén et al., 2012) were both performed in–season while the HPT (Kiani et al., 2010) started in the preseason (2 days/week) and continued during the season (1 day/week). Athletes trained with the "FIFA 11" protocol used effective training components but began training for a limited amount of time (15 consecutive sessions) which may not be enough time for neuromuscular changes to occur and continued their training for 1 day/week. It has been supported that a prevention program needs to be performed more than once a week for at least six weeks to become successful (Hewett, Ford, et al., 2006). SPORTSMETRICS (Hewett et al. 1999) and FATP (Heidt et al. 2000), although consistent with the recommendations of the previous authors (Hewett, Ford, et al., 2006) failed to reduce the number of ACL injuries. SPORTSMETRICS, although effective at significantly reducing the number of non contact ACL injuries in its overall population (basketball, soccer and volleyball players), when analyzing its effects on soccer athletes alone, the positive results could not be reproduced. This may also be due to the separation of the entire population of the study in smaller samples (refer to Table 2) and indeed those subsamples were relatively smaller compared to other studies. Therefore, to reach a more definitive conclusion on the effectiveness of the SPORTSMETRICS, which is one of the most comprehensive multicomponent programs, for different sports it has to be applied in larger sporting populations.

4.2. Handball – key components

In handball the existence of effective ACL injury prevention protocols was limited with only one study (Myklebust et al. 2003) managing to significantly reduce the incidence of ACL injury and only for players in the elite division. The study of Petersen et al. (2005) used a similar protocol with Myklebust et al. (2003) and achieved a non significant 80% reduction in ACL injury risk. Both interventions included balance training, plyometrics as well as education on proper technique in their multi-component program. However, Myklebust et al. (2003) before the second intervention season modified their training protocol based on feedback from players and coaches. The inclusion of agility training focusing on correct technique while running and planting, as well as jump landing with correct technique made the program more specific to handball and more challenging. This modification seems to have accounted for the positive results of the study (Myklebust et al. 2003). The study of Petersen et al. (2005) may have reached significance if a similar approach was followed.

Both programs (Myklebust et al. 2003; Petersen et al. 2005) that produced positive results began in the preseason for 3 days/week and continued during the season with less frequency. In contrast, the study of Olsen et al. (2005) which failed to reduce the incidence of ACL injuries used similar training components and started training for 15 continuous training sessions initially and after 1 day/week for the competitive season. As mentioned already, six weeks is the minimum duration of training may be one of the contributing factors for a prevention program to become successful (Hewett, Ford, et al., 2006).

4.3. Basketball/volleyball – key components

None of the two studies that focused on basketball players significantly decreased the ACL injury incidence in this subgroup of players (Hewett et al., 1999; Pfeiffer et al., 2006). An ACL injury prevention protocol focused on basketball players should mainly consist of high intensity plyometrics, supplemented by agility training and education on correct technique. Strength training for correcting muscular imbalances which may predispose athletes to an increased risk for an ACL injury might be useful. Although, plyometrics were part of both programs, no positive results were documented. Athletes in the program of Hewett et al. (1999) were trained in the preseason while athletes in the study of Pfeiffer et al., (2006) during the in-season. More specifically, athletes trained according to Hewett et al. (1999) followed an intervention consisting of flexibility, plyometrics, strength training as well as education on correct technique. On the other hand, the Pfeiffer et al., (2006) program although having used plyometrics supplemented with some agility drills, provided limited feedback on correct technique. Feedback may be particularly important for sports with landing and cutting maneuvers and athletes training with plyometrics, in order to learn to land correctly. Pfeiffer et al. (2006) suggest the lack of effect of their program on ACL injury reduction due to the absence of strength training. However other factors may have also adversely affected their results. The Pfeiffer et al., (2006) training program was designed to be performed either in the beginning or the end of the training session. The performance and technique after training may have been negatively affected by the accumulated fatigue from practice. In addition, the total duration of training (9 weeks), however administered only in the preseason might not have been enough for plyometrics to maintain the desirable neuromuscular changes throughout the in-season. It would be interesting to assess the effects of plyometrics in a longer duration training program. Similarly the study of Hewett et al. (1999) was also performed for only 6 weeks.

It is interesting that for the volleyball players, no ACL injuries were noted either in the control or the intervention groups in both relevant studies (Hewett et al., 1999; Pfeiffer et al., 2006). This finding may be attributed to the biomechanics of volleyball not exposing athletes to injury, as there is a low incidence rate of ACL injury in volleyball from epidemiologic studies (Hootman et al., 2007).

4.4. Limitations

A number of limitations exist in our review. Several articles were excluded on the basis of the outcome measure used to assess the effects of the prevention training program ("Estimation of ACL knee injury per 1000 h of exposures"). Additionally, the studies we analyzed varied in methodological quality, with only seven of them being RCTs. From those seven RCTs only one good quality RCT (Waldén et al., 2012) was found effective at reducing the incidence of ACL injuries while the rest of the studies with positive results were non-RCTs (Kiani et al. 2010; Mandelbaum et al. 2005; Myklebust et al. 2003). Based on the included studies in our review the strength of recommendation grade for the current evidence is level 1b.

Our review's main focus was to compare the effects of ACL knee injury prevention programs between different sports, keeping in mind that there may be different biomechanical predisposing factors to injury involved between different sports. However, there was a relevant sparsity of studies, with relevant publications focusing mainly on soccer while very few studies focused on other sports (handball, basketball, floorball, volleyball). Similarly, the use of multi component programs without being sport specific made it difficult to make clear recommendations for the effectiveness of prevention programs between different sports.

4.5. Future recommendations

RCTs with high methodological quality on a variety of female sporting populations, of different age groups and athletic level should be conducted, to elucidate further the effectiveness of specific exercise interventions in the prevention of serious knee injury. As low compliance had a negative influence on several studies' results, it would be beneficial for an injury prevention program to be evaluated in regard to its effect on athletic performance (Shultz et al., 2012). A program which not only prevents injuries but also improves performance can most likely achieve a higher compliance rate (Noyes & Barber Westin, 2012). Also, in two studies with positive results (Kiani et al. 2010; Myklebust et al., 2003) and another two with promising results (Olsen et al., 2005; Pasanen et al., 2008), the integration of preventive programs in training was initiated preseason, an issue to consider in future studies. Moreover a training program, which begins at preseason and continues in a modified, shorter format in-season, keeping training intensity high, will enable athletes maintain NM changes throughout the season. More studies are required to investigate the exact amount of time needed for neuromuscular changes to occur and be maintained throughout the competitive season. Future studies should also test the effects of injury prevention programs on athletes from specific 'high ACL risk sports', not just on a mixed population of athletes (Sugimoto, Myer, McKeon, et al., 2012; Sugimoto, Myer, Bush, et al., 2012). This will give a clear understanding of the intricacies that may be present for an ACL injury prevention program to become successful in relation to the specific functional requirements of individual sports.

5. Conclusion

This review examined the effects of ACL injury prevention programs on injury rates in different sporting female populations, analyzing further the main components that may be crucial for such programs to be effective. Specifically a successful training program for ACL injury prevention should start in the preseason for at least 6 weeks and continue in-season with less frequency (1–2 times a week). Training components such as strength training, plyometrics along with balance, proprioception and education–feedback on correct technique are all vital. However a training protocol for soccer and handball athletes needs to give extra emphasis on sport specific agility drills, while a program focused on jumping sports such as basketball should involve a lot of high intensity plyometrics along with feedback due to the different maneuvers and functional biomechanics of each sport.

Conflict of interest

All authors declare that we have read and understood the Physical Therapy in Sport policy on declaration of interests and we have no relevant interests to declare.

Ethical Approval

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