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REVIEW

Injuries in badminton: A review

Blessures en badminton: une revue

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KEYWORDS
Badminton;
Injury;
Trauma;
Epidemiology

Summary
Objectives. — The aim of this review is to provide an overview of the injury risks in badminton, by exploring and takes a global approach related to the eyes, and upper and lower limbs. This explain how the injury occurred and as well as medical and training recommendations for athletic population.
News. — Badminton injuries are around 1—5% of all sports injuries. It ranked six after soccer, basketball, volleyball, long-distance running and cycling.
Prospects and projects. — Such knowledge could help coaches and fitness trainers focus on the specific muscular activities required to prevent injuries. The relationship between scientists and coaches, particularly in terms of biomechanics and physiotherapy, will help improve performance and prevent injury.
Conclusion. — Badminton will be influenced by the evolution of intensity of the game. It is apparent that the movement patterns and movement demands are related to an increase in injuries and the generation of new injuries. Eye injury occurs when shuttlecock impact from an opponent's stroke. Wearing glasses can considerably reduce the risk of eye injury. Injuries to the arm and shoulder are due to faulty technique, while leg and back injuries are caused mainly by a lack of strength or mobility. The contribution of the trunk to the prevention of lower limb injuries suggests that specific attention should be paid to this area. Fatigue influences the way that lunges are performed, and the jump is received by making these tendons less powerful and more unstable. Training program increases body strength to prevent injuries.

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MOTS CLÉS
Badminton ;
Blessure ;
Traumatisme ;
Épidémiologie

Résumé
Objectifs. — L'objectif de cette revue est de fournir un aperçu sur les risques de blessures en badminton en explorant et en adoptant une approche globale des blessures des yeux, des membres supérieurs et inférieurs. Cela explique comment la blessure a eu lieu et de ce fait, propose des recommandations médicales et d'entraînement pour les sportifs.
Actualités. — Les blessures en badminton sont autour de 1—5 % des blessures sportives. Elles sont classées sixième après celles du football, du basketball, du volleyball, de la course à pied et du vélo.
Perspectives et projets. — Les connaissances pourraient aider les entraîneurs et les préparateurs physiques à se focaliser sur les activités musculaires spécifiques dans la prévention des blessures. La relation entre les scientifiques et les entraîneurs, notamment en biomécanique et en physiothérapie contribuera à améliorer les performances et prévenir les blessures.
Conclusion. — Le badminton sera influencé par l'évolution de l'intensité des échanges. Il est visible que les modèles et les exigences des mouvements vont augmenter le nombre de blessures et d'en générer de nouvelles. Une blessure oculaire survient suite à un coup de volant frappé par l'adversaire. Le port de lunette peut réduire considérablement le risque de blessure aux yeux. Les blessures au bras et à l'épaule sont dues à une mauvaise technique, tandis que les blessures aux jambes et au dos sont principalement causées par un manque de force ou de mobilité. La contribution du tronc dans la prévention des blessures des membres inférieurs suggère une attention toute particulière à cette zone. La fatigue influence la production des fentes et la réception des sauts rend les tendons moins puissants et plus instables. Les programmes ciblés d'entraînements augmentent la force du corps afin de prévenir les blessures.

1. Introduction

Q2 Badminton is originated in China and created in England and is one of the most popular sports in the world with 200 million adherents [1]. It is considered as the fastest racket game [2]. This sport has five events: men's and women's singles and doubles and mixed doubles. The decision to include badminton in the 1992 Olympics Game increased participation in the game. This sport can be practiced by anyone, regardless of age or experience [3]. During a tournament, badminton match are generally played with one to three matches over the course of 4 or 5 days.

Badminton is an individual non-contact sport that is considered very safe because it involves no physical impact with other players [4]. Quick changes of direction, jumps, lunges at the net and rapid arm movements in order to strike the shuttlecock from a variety of postural positions increase the risk of injury [5]. Existing studies have demonstrated the risk of injury in badminton to be 0.85 injuries per year [6], 1.6 to 2.9 injuries per 1000 hours of play [3], 2 to 5 injuries per 1000 players [7] and 1% to 5% of all sports injuries [8]. The way those injuries occur will be discussed in this review.

Participation in badminton training and tournaments was found to increase the risk of injury by 15 to 39% [9]. The injury rate was higher in training than in competition [10]. Non-contact trauma occurs frequently in badminton playing (35%) and a higher injury rate was found among athletes competing in badminton tournaments at the London Olympic Games in 2012 (11%) [9]. Study has reported a higher injury risk among recreational rather than elite players [11]. However, other studies have reported similar risks among these players [12].

Male badminton players were found to be more frequently injured than females [10,12,13]. However, when the higher participant rate of male players was considered, the incidence rate did not differ much between the genders [14]; 0.09 for males and 0.14 for females per person and per year [15]. Most badminton injuries can be classified as chronic overuse injuries (~74%) [16]. The lower limbs account for 58 to 76% of all badminton injuries, the upper limbs for 19 to 32%, and 11 to 16% of back injuries [16]. Eye injuries in sports have been linked to racket sports (42%) [17,18]. Based on this finding, the objective of this review is to summarize the existing literature of badminton injuries, their location, nature and causes. In addition, this explain how the injury occurred and as well as medical and training recommendations for athletic population.

2. Methods

We conducted a literature search for English language and non-English language papers on the following databases: PubMed, EBSCOhost, PsycINFO, ScienceDirect, Cairn and Web of Science. An additional search was performed on the Internet using Google Scholar and ResearchGate. Keywords and combinations of these words were used to carry out a comprehensive search of the databases: badminton injury, badminton knee, badminton eye, badminton legs, badminton trunk, racket sports injury, performance injury badminton, shoulder badminton, elbow badminton, muscle badminton and arm badminton. Database searches covered the period from 1974 to 2015.

3. Frequency, epidemiology and traumatology of injuries

Although it is widely accepted that warming up is vital for the attainment of optimum and safe performance [19], most players still only spend less than 15 minutes on warm-up

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activities. Only 20.0% of players spend 30 minutes or more before playing and players older than 30 years old spend less time warming up than younger players [19]. Studies have shown that badminton injuries constitute 4.1% of the total number of registered injuries in the literature of sport injury [8,20].

3.1. Temporal distribution of badminton injuries

Study was found that most injuries occur at the beginning of the season, in September, and in January, after the Christmas holidays [8] (Fig. 1). Most of July is spent to rest and holidays for the athletes. In addition, many tournaments begin in September in different countries, which may explain the increased risk of injury in this month. In the study of Kroner et al. (1990), around 75% of the badminton players included were recreational players [8]. To prepare the beginning of the season, greater care should be taken at these times. In addition, Achilles tendon rupture occurred during the winter months (October to March) for recreational players [21]. Athletes should engage in a high level of physical preparation, individual training programs (physical activities) and prophylactic intervention.

3.2. Injured players' characteristics

Age has been seen as a risk factor for sport injuries [22]. The mean age of players reported is 29.5 ± 8.9 years, for males 28.9 ± 8.5 (Table 1) and for females 30.5 ± 8.4 years (Table 2). The age bands most frequently injured are 20 to 29 years (52%), 30 to 39 years (13%), and 40 to 49 years (35%); specifically for males 20 to 29 years (52%), 30 to 39 years (20%), and 40 to 49 years (28%) and for females 20 to 29 years (52%), and 40 to 49 years (48%), according to the entire studies in this literature.

3.3. Distribution of badminton injuries

Even if training sessions are highly necessary to avoid further injuries, existing literature has shown that injuries could occur during the training, with a high frequency of occurrences at the end of training (48%), followed by the middle of training (41%) and the beginning of training (11%). This can be explained by a decline in force output and proprioception brought about by muscle fatigue at the end of training [23]. Furthermore, rapid changes in direction, jumps, lunges and the high repetition of 'stop-and-go' maneuvers [1] are required in badminton and these constitute a major source of muscle fatigue. Thus, according to the literature, the lower body extremities are involved in 49.7% of injuries, whereas the upper body extremities are involved in 42.3% of injuries (Fig. 2).

The head and eyes are injured in 2.0% of cases in different studies [8], [15]. Most injuries have been shown to occur to the joints and ligaments, such as sprains (35.8%) and strains (35.2%), followed by overuse injuries (i.e., tendons, tissue) (22.4%) and bone fractures (3.8%) (Fig. 2).

3.4. Identification of injury type

A sprain can be defined as a minor ligamentous injury that requires no surgery and causes no major time off from training or competition [11]. Ligamentous injury can be defined as major ligamentous damage that requires surgery and leads to major time off (more than one month) from training or competition [11]. A strain can be defined as muscular fiber, or tendon tears, including acute or chronic tendinopathy [11]. A fracture can be defined as bony damage that results in discontinuity of trabeculae, with radiographic confirmation [11].

4. Eye injury

It has been shown that the extent of eye injuries depends on the type of sports played in a particular country or area, with racket sports appearing to generate the most eye injuries in Europe and Asia [13,24]. All injuries were found to be unilateral [24]. In the United Kingdom and Australia, in particular, studies have shown that squash and badminton account for half of all sports-related eye injuries [25]. Whilst in Malaysia, badminton generates two-thirds of all ocular sports injuries [26]. The evolution of badminton playing with an increasing shuttlecock velocity during the last 30 years [27] can be associated with physical and ocular injuries [24]. Several research studies have examined the causes and types of eye injuries (Table 3).

4.1. Cause of eye injuries

Hensley and Paup (1979) have shown that when eye injuries occur by an opponent (65%), by a partner (26%), and self-inflicted (9%) [28]. Generally, 6% are related by shuttlecock, whilst 7% related by racket [15]. Patient records have indicated that eye injuries are generated during doubles matches (78%) [24] (Table 3). Indeed, existing studies have reported that doubles matches are associated with more injuries than singles matches [29]. Injuries in these matches occur when a player turns round to look at his or her partner [25] or when the shaft of the racket head becomes separated from the handle of one of the players [30]. In singles matches, injuries can be seen to occur when a player is close to the net and hit by a shuttlecock from the opponent's smash [28] (Table 3). In these cases, the high speeds involved are enough to cause injury when the shuttlecock hits the eye [24]. The shuttlecock head has a small diameter that fits the human orbits [24].

4.2. Types of related eye injuries

Modifications of racket properties and technology innovation have a great influence on shuttlecock velocity [2]. The speed at which shuttlecocks travel increases with the players' level of skill [31]. Studies have shown that when eye injuries occur, the right eye is involved in 52% of cases, the left in 48% of cases (Table 3). No instances have been recorded in which both eyes are involved [13]. Generally, the injuries are all unilateral with none of the players wearing eye protection [28]. Hyphemia is seen to be the most common eye injury [24,25], [28], with macular changes, traumatic cataracts, and glaucoma being the main causes of visual impairment in badminton injuries [26] (Table 3).

Thus, badminton players and coaches need to be aware of the risk associated with delivering powerful strokes in doubles matches by the opponent or partner. To prevent the occurrence of eye injuries (such as hyphemia), athletes should hold their racket to protect their head or use protective eyewear. The forward players should hold the racket in the front of the face while awaiting the smash [28]. The illusion that contact lenses [13] or glass lenses [28] offer partial protection should be dispelled, they merely complicate an injury. In some sports, there is already an awareness

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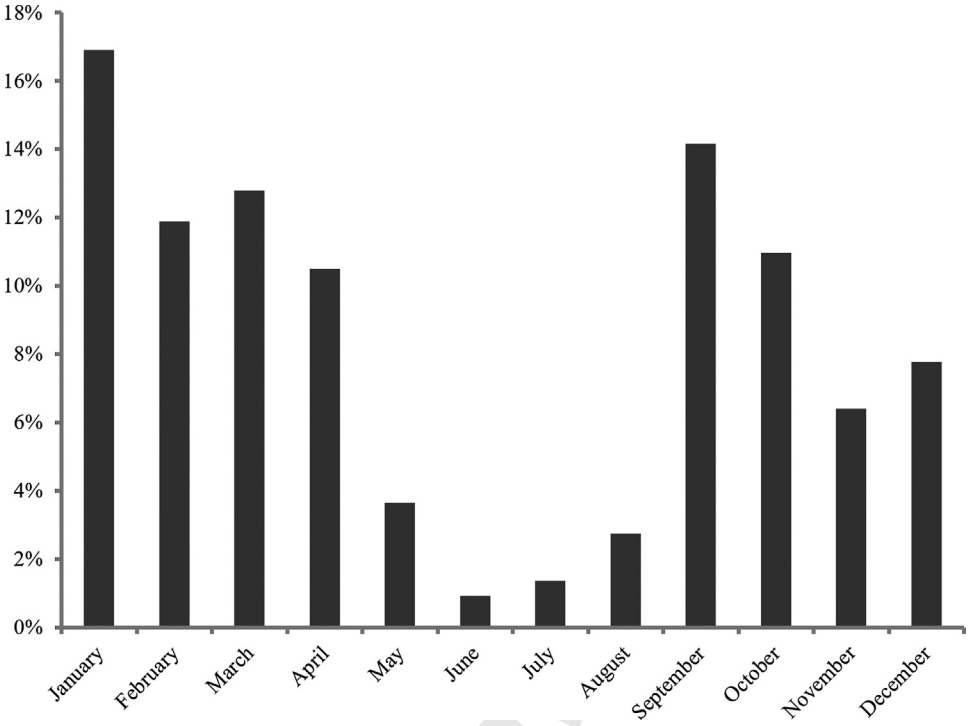

Figure 1 Percentage in each month according to the total number of injuries during one year.

Table 1 Male players characteristics on the different studies. NS: no specify.

Study	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Experience (years)
Boesen et al. [6]	25.9 ± 3.2	76.4 ± 6.4	183.5 ± 6.6	22.7 ± 1.0	18.8 ± 4.1
Fahlström et al. [7]	32.9 ± NS	NS	NS	NS	24.5 ± NS
Fahlström et al. [16]	43.1 ± 7.0	NS	NS	NS	22.1 ± 10.9
Fahlström et al. [53]	24.4 ± 4.3	76.9 ± 8.8	183.0 ± 6.6	22.9 ± 1.4	15.6 ± 4.4
Fahlström et al. [72]	44.7 ± 6.1	NS	NS	25.0 ± 3.2	29.8 ± 4.3
Fahlström et al. [38]	23.5 ± 4.3	NS	NS	NS	14.2 ± 4.9
Fu [73]	20.1 ± 1.9	71.1 ± 7.6	179.1 ± 3.4	NS	10.7 ± 2.5
Fu et al. [74]	20.1 ± 1.9	71.1 ± 7.6	179.1 ± 3.4	10.7 ± 2.5	NS
Hensley and Paup [15]	33 ± 13.1	73.8 ± 9.2	177.8 ± 7.3	NS	13.4 ± 10.1
Huang et al. [48]	24.9 ± 5.2	75.0 ± 11.9	178.0 ± 8.7	13.6 ± 2.6	11.6 ± 5.3
Koenig et al. [71]	25.0 ± 3.5	73.5 ± 9.2	179.1 ± 14.0	22.5 1.7	17.9 ± 4.3

Table 2 Female players characteristics on the different studies. NS: no specify.

Study	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Experience (years)
Fahlström et al. [7]	25.8 ± NS	NS	NS	NS	22.2 ± NS
Fahlström et al. [16]	44.3 ± 12.1	NS	NS	NS	26.8 ± 13.9
Fahlström et al. [53]	21.9 ± 4.1	64.0 ± 4.9	170.1 ± 3.7	22.1 ± 1.3	13.3 ± 4.3
Fahlström et al. [72]	42.7 ± 5.4	NS	NS	25.9 ± 4.8	29.1 ± 3.1
Hensley and Paup [15]	27 ± 8.2	57.2 ± 6.2	165.1 ± 7.2	NS	9.5 ± 8.4
Huang et al. [48]	21.4 ± 2.9	54.6 ± 5.1	166.8 ± 4.5	19.6 ± 2.1	7.3 ± 2.3

of the risk of eye injuries [13]. However, the lack of knowledge is responsible for athletes failing to use eye protection [13]. The value of ocular protection in sport has already been demonstrated [32]. Eye injuries in sports can easily be prevented with the proper use of protective eyewear [33]. Protective polycarbonate spectacles are available for wearing on the court; these are designed to deflect blows [13]. They merely complicate an injury [13]. While vision loss is uncommon, these injuries can lead to permanently diminished visual function.

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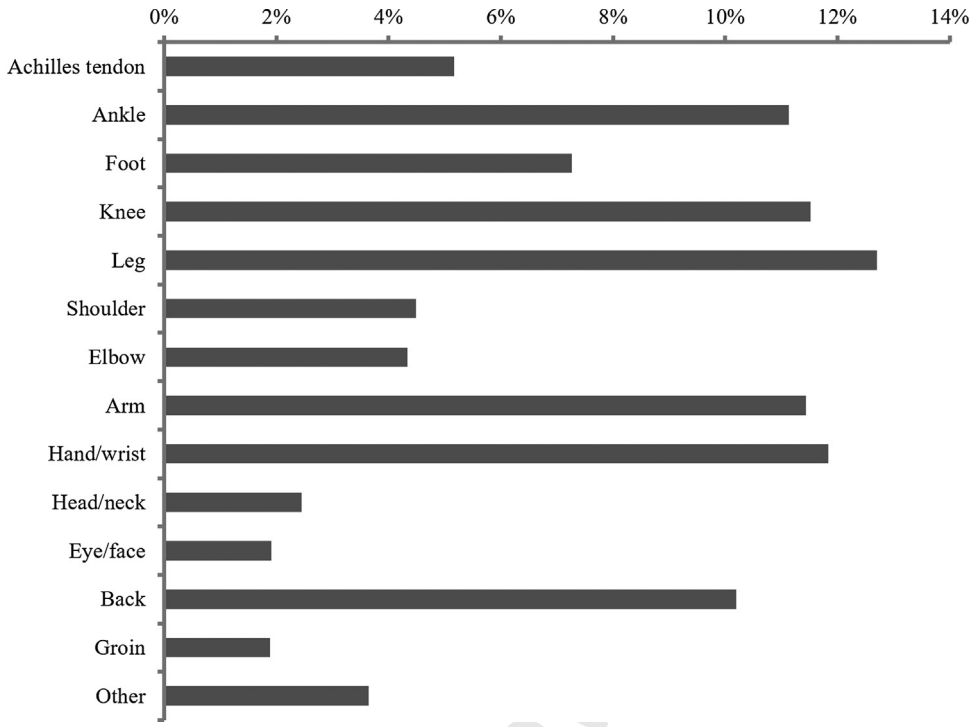

Figure 2 Body sites distribution of badminton injuries.

5. Upper limb injury

Badminton is a sport that requires a large number of overhead strokes (30%) with clear drop shots and smash shots [27]. Studies have shown that female players play a higher percentage of shots from the back of the court [34] and that the upper extremity injuries that occur are unique to racket sports [35]. A retrospective study found that the incidence rate of injuries is 5.04 per 1000 hours of play, and that the shoulder [11] is the most frequently affected location, followed by the hand (Table 4).

5.1. Shoulder pain

Badminton requires a considerable amount of over-shoulder motion, with the shoulder in abduction or external rotation [16]. It has been reported that shoulder pain occurs frequently, as does impingement of the rotator cuff caused by anterior instability of the shoulder joint [36]. A large proportion of badminton players continue to play with an ongoing injury to the shoulder (17—28%) [37]. Studies have observed no differences between male and female players [38]. During the World Mixed Team Championship in 2003, shoulder pain on the dominant side was reported by 52% of players, with 37% of players reporting previous shoulder pain and 20% ongoing pain [38]. With regard to badminton players in Hong Kong, shoulder injuries accounted for 19% of all injuries [11]. Similarly, a Swedish study found that 52% of players had existing or present pain in the dominant shoulder, with 16% of them experiencing ongoing pain [16]. Injury does not prevent a player from playing; however, it does affect the quality of his or her performance [37].

Stroke repetition that is suggestive of an overuse epiphyseal injury to the shoulder may occur as the result of a repetitive explosive action [39]. It has been noted that the repetitive movement from the cocking to the follow-through phases generates a stress to the epiphyseal plate. In fact, a study has shown that the rotator cuff in badminton players on the dominant arm is stronger than that of the non-dominant arm [37]. The ratio between eccentric antagonist and concentric agonist strength is important when analyzing shoulder symptoms experienced by badminton players [40]. During the cocking phase, the ratios of strength were found to be 2.15:1 for the dominant side and 1.71:1 for the non-dominant side; whereas the ratios were 0.97:1 for the dominant side and 1.08:1 for the non-dominant side during the deceleration phase [40].

Rehabilitation for these players should include muscle-strengthening exercises (i.e., shoulder stabilizers and rotator cuff muscles), and exercises to avoid loss of motion [16]. The ratio between eccentric antagonist and concentric agonist strength is important when analyzing shoulder symptoms experienced by badminton players [40].

5.2. Elbow injuries

Tennis elbow and golfer's elbow are the most commonly reported diagnoses related to the elbow in badminton players [3] (Table 4). Tennis elbow is mainly caused by lateral epicondylitis [41] whereas golfer's elbow is caused by medial epicondylitis [42]. Training errors are one of most common causes of overuse injuries [42]. Players who have hitting technique problems are at an increased risk of injury [43]. Poor technique can often be related to an incorrect grip or the holding of the racket too tightly by the beginner.

5.3. Hand injuries

Players were found to rarely use a 'wrist snap' [44]; however, they can use it to increase the power of the smash. The grip, the intensive practice of the badminton game and the

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Table 3 Different eye injuries on badminton. NS: no specify.

Study	Players	Main injury (%)	Causes (%)
Chandran [26]	63 novices	Hyphaemia (78), traumatic mydriasis (54), commotion retinae (19), haematoma of lid (14), corneal abrasion (13), vitreous haemorrhage (13), subconjunctival haemorrhage (6), laceration of lids (3)	Struck by racket (9), struck by shuttlecock (54), double play (44), single play (19)
Jones [18]	45 males and 7 females (range 11-68)	Skin lacerations (19.2), blowout fracture of orbit (9.6), macroscopic hyphaemia (59.6), raised intraocular pressure (23), iris tears or dialysis (9.6), significant angle recession (15.4), cataract (1.9), vitreous haemorrhage (13.5), commotion retinae (23), retinal break (7.7), choroidal rupture (1.9), penetrating injury (5.8)	Struck by shuttlecock (73.1), instrument (19.2), opponents (7.7)
Kelly [28]	4 males and 2 females	Corneoscleral perforation (16), uveal prolapse (16), glass intraocular (16), hyphaemia (50), sphincter pupillae tear (16), retinal dialysis and detachment (16), choroidal rupture involving macula (16), angle recession glaucoma (33), vitreous haemorrhage (16), optic atrophy (16)	Struck by racket (16), struck by shuttlecock (84)
Zamora and Harvey [24]	14 males and 9 females	Iridocyclitis/iritis (48), secondary glaucoma (26), hyphaemia (22), posterior vitreous detachment (13), eyelid contusion (9), corneal abrasion (9), corneal oedema (9), cystoid macular oedema (4), peripheral intraretinal haemorrhage (4), lid laceration (4), commotio retina (4), vitreous haemorrhage (4), berlin's oedema (4), subconjunctival haemorrhage (4), bulbar congestion, conjunctivitis (4), iridoplegia (4), macular hole (4), retinal detachment (4)	Struck by racket (26), struck by shuttlecock (74)

repetitive hyperextension movements of the wrist are risk factors for scaphoid fractures [45], even without axial load (Table 4). The scaphoid bone is a connecting rod between the two carpal rows and may be exposed to shearing and torsional forces by excessive and repetitive movement of wrist flexion and extension [46].

5.4. Trunk function to prevent injury

Studies have shown that badminton players hold a racket in their dominant hand, which limits their arm position and leads to an asymmetric posture through lateral trunk flexion, especially during overhead strokes [47]. In general, core stability is essential to the control of movements of the trunk and distal segments [48].

Trunk sway greatly contributes to a change of direction in the knee adduction movement. The badminton-specific movement in the upper extremity and trunk motion during an overhead stroke may affect the hip and knee joint kinematics and kinetics [49]. During an overhead stroke in the left rear court, players have to laterally bend their trunk to their left side as their arm comes through [50]. Deficits in neuromuscular control of the trunk may contribute to lower extremity joint instability and injury [50]. Neuromuscular training should be carried out to increase trunk and hip control, thus preventing injury to the lower limb [51].

Stroke repetition and hitting technique problems can increase the risk of arm injuries. Most players continue to play through the pain, but the discomfort affects their quality of play. The badminton-specific movement engages the trunk, which makes a specific contribution during a stroke, forming a link between lower limb movement and upper limb stroke.

6. Lower limb injury

Injuries are common in badminton, and overuse injuries are frequent, particularly those localized to the lower extremities [7]; in studies, these accounted for 58% of the injuries [6] (Table 5).

6.1. Achilles tendon rupture

The most severe overuse injuries were found to be tendon related, including Achilles tendinopathy [6], and patella tendinopathies [12]. Indeed, Hess [52] has shown a relatively high incidence of acute Achilles tendon ruptures. Such injuries are a major problem among athletes [53].

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Table 4 Different upper limb injury on badminton. NS: No specify.

Study	Players	Main injury (%)	Causes (%)
Shoulder			
Boyd and Batt [39]	1 elite junior (15 years)	Stress fracture of the proximal humeral epiphysis	Overuse
Fahlström et al. [38]	96 males and 92 females	On-going shoulder pain (20)	Overuse
Fahlström et al. [16]	73 inexperienced and 49 professional players	Pain (65)	Overuse
Goh et al. [76]	34 males and 24 females (range 13-16)	Sprain (2), fracture (2)	Acute
Jafari et al. [75]	23 males and 7 females professional	Muscle tendon (18.8), joint ligaments (3.1), bone (3.1)	NS
Elbow			
Jafari et al. [75]	23 males and 7 females professional	Muscle tendon (12.5), joint ligaments (9.4), bone (3.1)	NS
Wrist			
Jafari et al. [75]	23 males and 7 females professional	Muscle tendon (65.6), joint ligaments (43.8), bone (12.5)	NS
Finger			
Brutus and Chahidi [45]	1 inexperienced (23 years)	Scaphoid fracture	Stress fracture
Fukuda et al. [77]	1 females (14 years)	Stress fracture of the second metacarpal bone	Overuse

Badminton is a sport where tendons are placed under a heavy strain [6]. Existing studies of badminton players and fencers have used magnetic resonance imaging to show that the cross sectional area of the patella tendon on the dominant leg is up to 28% greater than that of the non-dominant patella tendon [54]. Chronic Achilles tendon pain associated with structural tendon changes is often located in the middle portion of the tendon [55].

Badminton development has increased the number of hours per person and per day [56], increasing the risk of injuries as well. The cause of Achilles tendon ruptures is based on mechanical and degenerative factors [57] and the weight of the player [58]. The Achilles tendon is most loaded during badminton [6], because of the abrupt repetitive jumping and sprinting movements involved [59]. Studies have shown that Achilles tendon rupture occurs in the middle or at the end of a match or training session in 87% of cases [58]. One reason for this is that players tend to tire at this stage of play. Tiredness can lead to poor muscle coordination and increased tension in the Achilles tendon with acceleration and deceleration [58]. The occurrence of Achilles tendon injuries in athletes has been shown to increase with age [60]. Athletes with acute Achilles tendon ruptures reported previous Achilles tendon pain in 15 to 21% of cases [21].

Ultrasound is used in rehabilitation and to diagnose Achilles tendon ruptures and other tendon pathology [61]. This technique has been supplemented by the color Doppler technique for finding and treating hyperemia in tendinopathy in the Achilles tendon [62]. Surgical techniques and rehabilitation programs should lead to a decrease in complications [63], whilst treatment by Kinesio taping is aimed at decreasing tenderness and pain [64]. The majority of players play with orthoses (inserts in the shoes) [56]. However, it has not yet been established that orthoses prevent Achilles tendinopathy or achillodynia [56].

6.2. Anterior cruciate ligament injuries and prevention

Most anterior cruciate ligament (ACL) injuries occur during sports activity (Table 5). According to existing research, up to 70% of all incidents are non-contact injuries [49], whilst ACL injuries account for 37% of all injuries requiring surgically treatment [65]. The greater activation of the knee extensor is a predictor of knee injury, because of increased tension on the ACL [49].

Players need to move from back to front and side to side rapidly; they also need to return to the center of the court to prepare for the next shot by performing footwork that is unique to badminton [49]. The injury patterns recorded appear to be the result of frequently performed movements. In badminton, ACL injuries were found to be the result of two injury mechanisms (Table 5). First, the knee opposite the racket-hand side is at risk of injury during a single-leg landing after an overhead stroke. This usually occurs in the backhand side of the court (48%) [47]. The knee of the racket hand side is susceptible to injury because of plant-and-cut movements during side or backward stepping in the forehand side of the court (38%). ACL injury can also be explained by a greater increase in the knee valgus angle and movement during single-leg landing following back-steps to the backhand-side rear than with back-steps to the forehand-side rear [49]. Landing requires high levels of neuromuscular control to maintain stability and performance [66].

In order to prevent ACL injuries, it is important to study the biomechanics of players' movements and to put physiological knowledge into action with respect to knee joints [49]. Adequate muscular training of the lower extremities is necessary to prevent badminton injuries [7].

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Table 5 Different lower limb injury on badminton. NS: No specify.

Study	Players	Main injury (%)	Causes (%)
Leg			
Goh et al. [76]	34 males and 24 females (range 13-16)	Sprain (40), fracture (3), contusion (5) apophysistis (10), bursitis (3), tendinopathy (7), stress fracture (5), patellofemoral joint syndrome (2)	Acute and overuse
Shariff et al. [3]	190 players	Patellar tendinopathy (42.7), muscle strain (11.8) meniscus or ligamentous injuries (10.9)	NS
Yung et al. [11]	14 males and 16 females elite players (range 13-28)	Strains (64), sprains (14), facet injury (14)	NS
Knee			
Boesen et al. [78]	96 semi-professional	Dominant tendon pain (23), non-dominant tendon pain (13)	NS
Chard and Lachmann [41]	74 males and 54 females college (4: 15 and under years, 60: 16-25 years, 64: 26 and over)	Collateral ligament (28), cruciate ligament (12.5), meniscal injury (25)	NS
Couppé et al. [54]	7 professionals	Tendinopathy	Overuse and repetitive load
Fahlström et al. [7]	67 males and 11 females (range 11-52)	Knee injuries (16.7)	Overuse
Huang et al. [48]	17 injured players	Knee pain (100)	NS
Jafari et al. [75]	23 males and 7 females professional	Muscle tendon (56.2), joint ligaments (28.1), bone (9.4)	NS
Kimura et al. [47]	6 males and 15 females	Anterior cruciate ligament	Single leg landing (48), plant-and-cut (38)
Koenig et al. [70]	50 males and 22 females professional	Painful knee tendons (62.5)	Overuse
Kroner et al. [8]	136 males and 72 females (range 7-72)	Joint ligament (58.5), muscle injuries strains/tears (19.8)	Falling (62), struck by shuttlecock or racket (8)
Achilles tendon			
Boesen et al. [78]	96 semi-professional	Dominant tendon pain (15), non-dominant tendon pain (8)	NS
Boesen et al. [56]	50 males and 22 females professional	Dominant tendon pain (18), non-dominant tendon pain (16)	NS
Fahlström et al. [7]	67 males and 11 females (range 11-52)	Achilles tendon rupture (34.6)	Overuse
Fahlström et al. [71]	25 males and 7 females professional	Achilles tendon pain (22)	Overuse
Fahlström et al. [53]	41 males and 25 females	Overuse injury (5), bursitis (6), Achilles tendinitis (4)	Overuse
Houshian et al. [59]	192 males and 54	Achilles tendon rupture (46.29)	Overuse
Hoy et al. [5]	1650 males and 970 females (520 males, 293 females under 18 years; 243 males, 179 females between 18 and 25; 887 males, 498 females above 25 years)	Sprain (2), tear (0.4), rupture Achilles tendon (0.5), fracture (0.2)	NS

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Table 5 (*Continued*)

Study	Players	Main injury (%)	Causes (%)
Lee and Yoo [64]	1 inexperienced (22 years)	Achilles tendon pain	Overuse
Malliaras et al. [62]	24 recreational and 12 elite males, 13 recreational and 12 elite females	Parallel tendons pain (8), spindle-shaped tendons pain (21)	Overuse
Ankle			
Fahlström et al. [7]	67 males and 11 females (range 11-52)	Spains/fractures (29.5)	Overuse
Jafari et al. [75]	23 males and 7 females professional	Muscle tendon (31.2), joint ligaments (21.9), bone (12.5)	NS
Kroner et al. [8]	136 males and 72 females (range 7-72)	Joint ligament (58.5), muscle injuries strains/tears (19.8)	Falling (62), struck by shuttlecock or racket (8)

6.3. Impact of the lunge on the knee

Lunge motions require a high level of knee dynamic stability; thus, they place a high physical demand on the lower limbs [67]. Two types of lunges exist according to the axe of the foot, the standard one and the ''break-foot lunge'' [68]. The repetition of lunges on the same leg can lead to players adopting an asymmetric posture [47]. The intensive braking phase of the dominant leg during the net stroke can increase the stress on the Achilles tendon by 6 to 12 times the player's body weight and by 5 times for the knee patellar tendon [64]. Core stability plays a key role in preventing knee joint injury [50]. The contraction of the core muscles provides a stable base for the movement of the lower extremities [48]. With unbalanced core muscle strength, players are at a higher risk of knee injury [69]. Thus, the trunk position affects the recruitment of the knee flexors [70]. During the performance of forehand and backhand backward lunges, the trunk movement affects the knee joint kinematics [49]. The skill level of players affects their lunge performance [67] (Table 5). The combination of greater knee flexion and a smaller root mean square of knee extensor in the injured player was seen to be the compensatory strategy required to complete the task and avoid injury [48].

7. Conclusion

This review takes a global approach to badminton-related injuries related to the eyes, and upper and lower limbs. Each of these factors may play an important role in the prevention of injuries to badminton players. Future badminton research is likely to continue to be heavily influenced by the evolution of temporal and notational structure. It is apparent that the movement patterns and movement demands of badminton are related to an increase in injuries and the generation of new injuries. Furthermore, it would be of interest to compare badminton with other racket sports.

8. Summary

Studies that have reported on eye injuries have determined the nature of these injuries and the way they occur. They have also suggested possible preventive measures. The main reason for eye injury is shuttlecock impact from an opponent's stroke; thus, by wearing glasses, badminton players can considerably reduce the risk of eye injury. Injuries to the arm and shoulder in badminton are largely due to faulty technique, while leg and back injuries are caused mainly by a lack of strength or mobility. The contribution of the trunk to the prevention of lower limb injuries suggests that specific attention should be paid to this area.

In general, the patellar tendon is put under serious stress in badminton [6]. Studies have shown that a substantial number of elite badminton players have patellar tendon pain and 'jumper's knee' [71]. Male badminton players have a significantly higher incidence of painful patellar tendons [71].

Rapid changes in the direction of movement, jumps and lunges can all result in injuries to the Achilles tendon and anterior cruciate ligament. Tendons are put under high pressure during each movement and, in general, injuries occur at the end of a training session or tournament. Fatigue influences the way that lunges are performed and the way that the jump is received by making these tendons less powerful and more unstable.

Such knowledge could help coaches and fitness trainers focus on the specific muscular activities required to prevent injuries. For example, they could design a training program that increases body strength to prevent injuries to badminton players. The relationship between coaches and scientists, particularly in terms of biomechanics and physiotherapy, will help improve performance and prevent injury.

Disclosure of interest

The authors declare that they have no competing interest.

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