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Systematic review on badminton injuries: incidence, characteristics and risk factors

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ABSTRACT

Objectives As a high-intensity intermittent sport with short and repeated rapid accelerations, decelerations and changes of direction, badminton involves high joint and muscle loads. This review aims to identify relevant injury risk characteristics and factors that facilitate developing and implementing badminton-specific injury prevention programmes.

Design This systematic review of badminton injuries assessed the risk of bias, injury incidence, mechanism, location, type, severity, and risk factors.

Data sources PubMed, WoS, SURF, EBSCO, Ovid and SPORTDiscus.

Eligibility criteria Only English or German peer-reviewed articles presenting epidemiological data. All age groups, genders and levels of play were represented.

Results Examination of 19 studies with male (60%) and female players (41%) at different player levels (age: 10–50 years). The mean injury incidence was between 1 and 4 injuries/1000 hours, whereby the incidence in the studies that were only carried out with elite players tended to be at the upper end. Lower body injuries occurred most frequently (41%–92%), including strains (11%–64%), sprains (10%–61%), tendinopathy (6%–14%) and stress fractures (5%–11%). There was a high proportion of overuse injuries (25%–74%) and a predominance of mild and moderate injuries (73%–100%). The following risk factors can only be cautiously emphasised due to the heterogeneous results: The risk of injury increases with increasing level of play and a history of injury.

Conclusion Young players with a history of injury quickly moving to higher competition classes must be targeted with the highest injury prevention priority. Future studies should focus on improving the quality of studies by using comparable data collection methods.

WHAT IS ALREADY KNOWN

⇒ Both acute and overuse injuries are linked to repetitive movement patterns such as lunges, jumps, quick changes of direction and overhead strokes.

⇒ The range of injury incidence estimates reported in previous reviews is wide, whereby the variability between different performance levels, sex and age groups increases the uncertainty about the epidemiology in badminton.

WHAT THIS STUDY ADDS

⇒ The injury rate ranges between 1 and 4 injuries/1000 hours, with the lower extremities being mostly affected, and overuse injuries appear to be a relevant problem.

⇒ Due to the heterogeneous results in the studies, the following risk factors can only be emphasised with caution: The risk of injury appears to increase with increasing level of play and a history of injury.

⇒ The included studies differed considerably in terms of injury definitions, data collection methods and inclusion criteria, which makes a comprehensive conclusion difficult.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ With the help of knowledge about informative predictors (gender, age, training level, stress and strain parameters, etc.), injuries that occur during training and competition can be predicted using individualised models, allowing preventive measures to be introduced appropriately and at an early stage. This makes it possible to detect individual risk constellations for coaches and athletes.

INTRODUCTION

With a worldwide estimate of 220 million fans, badminton is one of the most popular sports.[1] Aside from China and India, popularised in England, badminton is the national sport of various Asian countries.[2] With a shuttle cock speed of up to 565 km/hour,[3] badminton can be regarded as the fastest racket sport.[4] Badminton is characterised by numerous actions in which short periods of high intensity with many accelerations, decelerations and direction changes alternate with longer periods of lower intensity during the rally breaks.[2 5 6] Complex interactions between technical, tactical, physiological and psychological skills are key.[7]

Although badminton is considered a non-contact sport, injuries are remarkably common in badminton.[8] The injury frequency is between 1 and 4 injuries/1000 hours, although some studies also indicate injury rates of up to 7 injuries/1000 hours. The range of injury incidence estimates reported in previous reviews is wide, even within the elite-player segment.[8] The epidemiological uncertainty in badminton is further challenged by methodological heterogeneity and differences in performance levels, study quality, sex and age groups.[8]

Both acute and overuse injuries are caused by typical repetitive movement patterns, such as lunges, jumps, quick direction changes and overhead strokes, as these movements exert high stress on both the lower and upper extremities.[8] Injuries rarely occur due to collisions with the doubles partner's racket or the double partner themselves.[8] Eye injuries occur more commonly in racket sports and have been the subject of many studies.[9] While there is a considerable body of work on injury epidemiology in badminton, the heterogeneity and amount of previous work precluded a meta-analytical work. Consequently, we opted for a narrative summary.

Adequate injury prevention programming based on epidemiological data, addressing injury characteristics and risk factors, is crucial for the sustainable and successful long-term development of (elite) athletes. Collecting epidemiological data is a crucial first part of 'prevention sequencing', described by van Mechelen *et al*[10] and updated and expanded by Finch[11] as the 'TRIPP framework'. This model comprises six consecutive steps: identifying the problem, analysing the causes, developing prevention strategies, testing the prevention strategies, putting the prevention strategies into practice and evaluating the implementation. The Translating Research into Injury Prevention Practice (TRIPP) framework particularly emphasises implementing and evaluating prevention strategies in the real world. Based on this cycle and with the aim of injury prevention in badminton, this review analyses the first two pillars of injury prevention according to Finch based on the existing literature. Therefore, sound epidemiological data on the frequency and characteristics of injuries in badminton, such as mechanism, location and type, as well as severity, are important prerequisites for developing, assessing and implementing effective injury prevention programs.[10] Against this background, this systematic review aims to analyse and summarise available epidemiological data on badminton injuries to arrive at comprehensive conclusions, including possible high-risk constellations and valid considerations for developing injury prevention programmes and the direction of future research in injury programme implementation.

METHODS

Search strategy and inclusion criteria

We conducted the review according to the registered protocol (PROSPERO ID: CRD42024557604) and reported according to the Synthesis Without Meta-Analysis[12] in systematic reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses[13] guidance. Meta-analysis was not appropriate because the measurement tools were too dissimilar across studies.

Two researchers (BS and HS) independently conducted the literature search. Six medicine-related and sport-related databases (PubMed, Web of Science, SURF, EBSCO, Ovid and SPORTDiscus) were screened. The final search was completed on 16 September 2024. We combined the following search terms (operators) with Boolean conjunctions (OR/AND) and applied on one search level: ("badminton") AND (injur* OR epidemiolog*) AND (prevalence OR incidence).

Tracking of cited articles and hand-searching relevant primary and review articles were also completed. Unpublished and ongoing trials were searched via the US National Institutes of Health (https://clinicaltrials.gov/) and WHO International Clinical Trial Registry Platform (https://trialsearch.who.int/Default.aspx). Duplicates were removed, and the remaining studies underwent manual screening. Three screening levels were applied: (1) title, (2) abstract and (3) full text. Irrelevant articles were excluded. Two independent researchers (BS and HS) made a final inclusion/exclusion decision. Therefore, the following inclusion criteria based on the PICOS approach (population (P), intervention (I), comparators (C), main outcome (O) and study design (S)) were used. However, as we did not search for any intervention studies with a comparison or control group, 'intervention (I)' and 'comparators (C)' were omitted. No limit was set for the search with regard to the publication date to provide the most comprehensive summary of injury patterns experienced in badminton.

Studies were eligible for inclusion if they fulfilled the following criteria: (1) original research articles published as a full-text paper in English or German in an independent peer-reviewed journal published before September 2024, (2) observe athletes of any age of both sexes and regardless of their competition level (recreational to elite), (3) observe any outcome related to injuries of the following: incidence (number of new injuries that occurred to the population during a specific duration of time), prevalence (proportion of the population who have an injury at a specific time), mechanism, location, type, severity and risk factors.

Studies were excluded if they (1) were any type of review article, case study or conference abstract, (2) articles dealing with Paralympic sports, (3) studies on the general epidemiology of sports injuries, including badminton, that did not present specific injury percentages for each sport and (4) items that solely addressed some type of specific badminton injury, for example, articles reporting only shoulder injuries in badminton. We have excluded this type of study because it does not provide comprehensive figures on incidence and prevalence, only the figures for a specific type of injury.

Assessment of methodological quality

Both authors independently assessed the risk of bias (ROB) of the eligible studies using a checklist ('Risk of

Bias Assessment Tool'), which was developed by Lopes *et al*[14] for the assessment of ROB in incidence or prevalence studies with different research designs, specifically for the investigation of musculoskeletal injuries. This tool consists of 11 criteria, such as the existence of an injury definition, a description of the population, the follow-up process or the data collection mode, which must be answered with 'yes' or 'no' (see online supplemental material, appendix A).[14 15] An item was rated as negative if no clear item information was provided or if it was unclear whether the ROB criteria for the item were met. Any ROB disagreements between the two raters (BS and HS) were resolved in a consensus meeting. The total ROB score for each trial was calculated by counting the number of positively scored items, expressed as a percentage of all items. A score of ≥75% was considered high quality, 75%–60% was considered moderate quality, and ≤60% was considered low quality (for the results of the ROB assessment, see online supplemental material, appendix B).

Data extraction

The data were extracted by two authors (HS and BS) using a structured data extraction table. These data extraction table included information on authors, year, country, study design, surveillance period, population (sample size, sex, age, level of performance, weekly badminton training hours), injury definition, data collection method, injury incidence and prevalence (eg, injuries per athlete, injuries per 1000 hours of training exposure), injury location (eg, upper limbs), injury type (eg, sprains and fractures), injury severity (eg, days lost to injury), and injury nature (eg, acute/overuse). Due to the heterogeneity and low number of studies, a meaningful meta-analytical integration was not possible. We, therefore, opted for a qualitative summary. This summary was developed based on the data extraction table as deliberate consensus within the author team.

RESULTS

Literature search analysis

Search results

A total of 998 potentially relevant articles were found (figure 1). In the first step, 337 duplicates were removed, leaving 661 articles. Of these, 610 were removed after a title and abstract screening. This left 51 publications whose full texts were analysed for the previously established criteria. Of these, 30 articles were excluded, leaving 21 publications that could finally be included in the systematic review.

Study characteristics

All studies were observational, with 16 included studies having a retrospective design[16–31] and the remaining 5 having a prospective design.[32–36] The 21 included studies analysed populations in 11 different countries (Denmark,[18 22 36] France,[26 31 33] Hong Kong,[28] Iran,[19] Japan,[23 29 35] Malaysia,[24 27 32] Austria,[21] Sweden,[16] the USA,[17 25] China[31] and India[30]) and 2 cross-national studies.[20 34] One study compared the epidemiology of badminton injuries in disabled and non-disabled players in Malaysia, with only the non-disabled players' data included in the systematic review.[24] There are numerous differences between the studies regarding age, sex and level of play (for more details, see online supplemental material, appendix B). In addition, several studies categorised their data (at least partially) by sex,[17 18 22 34–36] age,[18 20–22 26 28 29 35] level of play[36] and origin (Asian/non-Asian)[20 31] (for the individual participant characteristics, see online supplemental material, appendix B).

The performance level of the athletes ranged from beginners to elite players. The players from nine studies[16–18 22 25 26 30 31 36] are at different levels of play (recreational to elite). Only elite players are considered in five studies.[20 28 32–34] Players who are at a national level were analysed in six publications.[21 23 24 27 29 35] Zhou *et al*[29] investigated the injury rate of athletes of primary school age. Various standardised criteria generally allow athletes to be divided into classes (elite, competitive, recreational and exerciser).[37] The intention of the athlete, the training volume as a quantitative characteristic or the level of competition can be used for this. However, none of the badminton publications explicitly refer to such a categorisation. There is only a correlation to the separately specified training volume (for elite players, the indicated training amounts per week are notably higher than for recreational players).

Seven studies[16–18 21 22 25 36] were conducted before the year 2000. The average publication date was 2010 (1979–2022).

ROB assessment

Only 5 of the 21 studies scored ≥75% and were categorised as high-quality studies.[18 23 32 35 36] 16 studies scored between 60% and 75% and were categorised as moderate.[16 17 20–22 24–31 33 34] Only one study had a score ≤60% and was, therefore, categorised as a low-quality study[19] (see online supplemental material, appendix B).

Injury definition and data collection methods

The definition of injury and the data collection methods differed considerably between the included studies (see online supplemental material appendix C). In four studies, injury was defined by admission to the local hospital.[16 18 22 26] In contrast, one study considered data from all injuries entered into a database from a visit to one of approximately 100 representative US hospitals.[25] Three studies did not provide a proper definition.[17 19 28] The remaining studies considered a player injured if his performance was negatively affected by the injury during a match[17 23 27 29 32 33 36] and/or he/she required medical attention to continue playing[23 24 29 30 32–35] and/or a reduction/abstinence from subsequent training was necessary[20 23 24 29 35] and/or affected the availability for selection of a player[32] or included any physical discomfort suffered by a player during a badminton match or

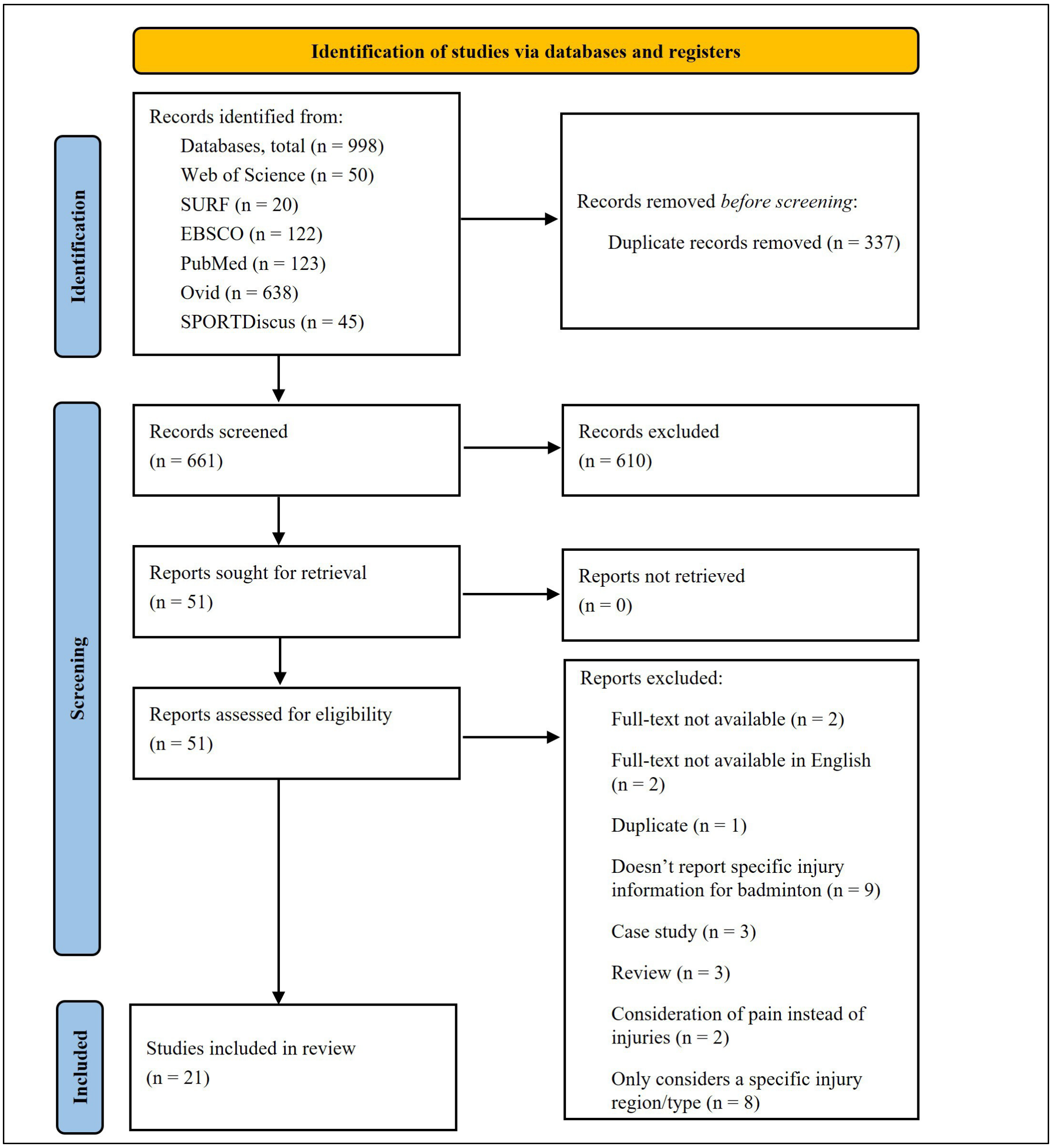

Figure 1 Flow chart of study screening and selection.

training session, regardless of the need for medical treatment or time lost from badminton activities.[31] The methods of data collection also varied substantially: 4 studies required injury reporting by the coach or medical staff,[28 32 34 35] 2 studies instructed players to self-report injuries,[33 36] 10 retrospective studies obtained data from questionnaires completed by players about their injury history,[17 19–21 23 24 27 29–31] 1 study used data from medical records[25] and 4 studies analysed admissions to the local hospital emergency department.[16 18 22 26]

Injury incidence

Injury incidence mainly ranged between 1 and 4 injuries/1000 hours of exposure time, or 0.09 injuries/player/year[17] and 1.09 injuries/player/year[32] (see online supplemental material, appendix C). However, there are some notable outliers: Marchena-Rodriguez *et al*[34] reported fewer than one injury per 1000 hours of exposure (0.13 injuries/1000 hours) in senior elite players with an average age of 50.2 years. With an average incidence rate of 5.04 injuries/1000 hours, the study by Yung *et al*[28] showed relatively high incidence values, whereby the rate for the oldest players ('elite senior athletes' with an average age of 24.2 years) was even higher at 7.4 injuries/1000 hours.

Kaldau *et al*[20] concluded that 48% of all 164 study participants (U19 players at the Badminton World Federation (BWF) World Junior Badminton Championships 2018) suffered from at least one significant injury in their badminton career to date. Jafari *et al*[19] stated that 70% of the 32 athletes analysed had already suffered at least one injury in their badminton career. Nhan *et al*[25] found that 2.5% of all injuries registered in a database of around 100 US hospitals were caused while playing badminton. In the publication by Krøner *et al*,[22] badminton injuries accounted for 4.1% of all sports injuries admitted to the Danish hospital during the 1-year observation period. According to Fahlström *et al*,[16] 1.2% of all sports injuries were registered in the Swedish hospital over 5 years.

Nine studies documented the number of injuries sustained by players in competition.[20 24 26–28 32 33 35 36] The remaining studies combined the injury data from training and competition to derive a global picture. The distribution of injury rates between training and competition appeared to differ in various studies. Numerous studies reported a higher prevalence during training (training vs competition: 65%–86.6% vs 1.7%–31%),[20 24 27 32] but also publications that presented a higher rate of injuries during the competition (training vs competition: 6.2% vs 93.8% or rather 2.8 vs 5.9–11.6 injuries/1000 hours).[26 28 33] Yung *et al*[28] explained that the significantly higher injury incidence during competition is due to higher physical and psychological stress.

Only one study explicitly differentiated between high-level players (27 randomly selected Danish teams in the 1st–4th league) and recreational players (lowest teams from 22 of the 27 clubs). According to Jørgensen and Winge,[36] the proportion of overuse injuries in the incidence of elite players is higher than in recreational players, which the authors say is 'a natural consequence of the greater number of badminton hours per year'. The anatomical sites of injuries also differ: Elite players are likelier to suffer injuries 'below' the knee (58% in elite players vs 45% in recreational players). In contrast, recreational players are more frequently affected at the knee, groin and upper arm levels. The authors explained this by the higher demands on speed, mobility and power of the well-trained and technically better elite players. The incidences in the five studies that only looked at elite player level tended to be at the upper end of the incidences (3.4–5 injuries/1000 hours with one exception: 0.13 injuries/1000 hours,[34] however, mean age of 50 years) in publications with players at national level or with mixed subject groups.

Comparing sex differences, no clear trends could be identified[16]: Some studies reported a slightly higher incidence rate among female players (3.5 injuries/1000 hours (female and elite) vs 3.3 injuries/1000 hours (male, elite))[33] and 2.9 injuries/1000 hours (female and national level) vs 1.6 injuries/1000 hours (male and national level)[35] while other studies found more injuries among men (42% (female, club level) vs 58% (male, club level)[18] and 46.2% (female, national level) vs 53.8% (male, national level)).[24]

Some studies explicitly emphasised the influence of age on injury occurrence. Miyake *et al*[35] reported significantly more injuries with increasing age (from the youngest male group aged 13.4±0.7 to the oldest group aged 20.0±1.2; the same applied to the female group), justified by stating that the mechanical strain of playing increases with increasing skill, which in turn 'grows' with players age. Herbaut *et al*[31] also explicitly emphasise that players over 26 were more prone to injury than those under-25. According to Mohd Jamali *et al*,[24] a more aggressive style of play and a lack of experience mean that players under 20 sustain most injuries. This reasoning is confirmed by Saragaglia *et al*,[26] who investigated an age range of 10–18 years, the most injured age group in their study and accounts for 37% of all athletes aged 10–66 years observed in the publication. Shariff *et al*[27] observed that 58.8% of all injured patients were younger than 20. According to Zhou *et al*,[29] pain and injuries, especially overuse injuries, had an upward trend with increasing age. However, only athletes between the ages of 7 and 12 were considered in this study.

In the study by Guermont *et al*,[33] most injuries occurred in January (n=6, 17.1%) and August (n=7, 20%). The authors explained this because these months are the periods after a longer break and, therefore, the return-to-play (RTP) periods. Krøner *et al*[22] also confirmed the increased injury rate in phases after a longer break.

The high injury rate in the two different 'basic disciplines' (singles and doubles/mixed) was only addressed in two studies: There appear to be tendencies towards a slightly higher injury rate in singles players.[17 19] However, the localisation of the injury varied considerably.

Mechanisms of injury

Guermont *et al*[33] described the smash as the stroke with the highest risk of upper body injury (n=6, 46.1%). According to the authors, this is why doubles players have higher rates of upper body injuries, as more attacking strokes, such as the smash, are executed in doubles. The lunge was the footwork movement with the highest risk to the lower body (n=6, 31.6%). Hensley and Paup[17] stated that the predominant cause of injury is intrinsic (eg, during the movement towards the ball or during the smash itself). Injuries caused by rackets and shuttles contact accounted for only 7% and 6% of all injuries, respectively. In the study by Krøner *et al*,[22] 8.1% of all injuries were caused by extrinsic factors such as collision with the partner or being struck by the racket or shuttle. All studies that reported at least one injury caused by direct or indirect contact with teammates or equipment[17 22 26] examined the injury rate in a high proportion of beginners and recreational players. However, this was not usually defined by numbers. None of the five studies with only elite players reported contact injuries.

11 studies provided specific information on whether the injuries were acute or overuse injuries.[16 20 21 23 24 27 29 32 33 35 36] Five of these 11 studies observed that acute injuries were more common than overuse injuries.[20 23 24 29 32] The study by Fahlström *et al*[16] reported that 74% of all patients had no symptoms or pain at the injury site before the injury, which suggests a higher proportion of acute injuries. In contrast, five publications cited overuse injuries as the more common cause of injury,[21 27 33 35 36] with Miyake *et al*[35] concluding that the ratio of overuse to trauma injuries is three times higher for both training and competition. The frequency of recorded acute injuries ranges from 26%[36] to 73%[32] and overuse injuries from

25%[32] to 74%.[36] In three studies, no distinction was made between acute and overuse injuries[17 19 28] and four studies only considered acute injuries that required hospitalisation.[18 22 25 26]

Fahlström *et al*[16] stated that 26% of all players had either experienced symptoms at the injured site before the injury or had even had an injury at the same site. Yung *et al*[28] observed that as many as 51% (128/253) of all injuries were recurrent. Research by Liu *et al*[23] also demonstrated that a previous ankle injury often results in a recurrent injury at the same foot and knee site. However, it is possible that the rate of recurrent injuries was even higher, as they were only recorded if they occurred during the study's observation period and not afterwards.

Location and type of injury

All studies provided information on the anatomical distribution of the injuries that occurred and presented the percentage distribution across the upper and lower body and other body parts (see online supplemental material, appendix D). Only one study did not list any figures; it only named the lower extremities the most affected.[18] In all 21 included studies, the largest percentage of injuries was observed for the lower extremities. This ranged from 92.3% in Fahlström *et al*[16] to 41% in Nhan *et al*.[25] In 12 studies, the upper extremities were the second most frequently injured body region.[17 19 21–24 26 27 30 31 33 36] In contrast, the results of five studies showed that the second most frequently injured area was the back or trunk.[20 25 29 32 35]

Høy *et al*[18] found only 3 cases of eye injuries among 2060 club players, all requiring no further treatment. Therefore, they do not recommend wearing protective eyewear during the game. Jørgensen and Winge[36] found only 2 eye injury cases out of 229 reported injuries. In the study by Krøner *et al*,[22] 2.3% of all injuries involved the eyes. Hensley and Paup[17] reported 7% of eye injuries. 81% of all cases were caused by the shuttle hit by the opponent, not by a racket hit by themselves or their doubles partner.

Krøner *et al*[22] found no difference with regard to the anatomical side of the injuries. In the study by Guermont *et al*,[33] all injuries to the upper extremities occurred exclusively on the dominant side.

13 of the 19 studies provided information on the type of injury sustained during the respective observation period (see online supplemental fmaterial, appendix D).[16–18 20 22 24–26 30 32–34 36] Of these, eight studies cited strains or sprains as the most common acute injury type.[18 20 24–26 30 32 36] These ranged from 12%[36] to 64%.[28 32] Muscle injuries in general,[22 26 33 34] rupture of the Achilles tendon,[16 18 36] fractures,[20 25 26 36] tendon and ligament injuries[22 34] and skin injuries[17 25 33] were also cited as common types of injury. Tendinopathies[20 32] and stress fractures[20 32] were the most frequently reported overuse injuries. Four publications did not specify the exact type of injury, only the localisation of the injury,[21 27–29] and three studies did not provide a more precise injury diagnosis.[19 23 35]

Severity of injury and RTP

Nine studies provided information on the injuries' severity (see online supplemental material, appendix D). Two of these categorised injury severity using the Abbreviated Injury Scale (AIS),[16 18] which grades injuries from one (minor) to six (maximum, untreatable). Six studies categorised injury severity by elapsed time to RTP,[27 31–35] using different periods such as <1 day, 1–3 days, 4–7 days, 8–28 days and >28 days to classify injury severity. Two studies reported the percentage of injuries that were severe enough to require medical attention and treatment.[17 22] Except for the studies by Jørgensen and Winge[36] (mean injury time: 48.4 days) and Kaldau *et al*[20] (median injury time: 90 days), all studies that consider the time to RTP reported a greater proportion of lost time less than 28 days. The studies that use the AIS scale for categorisation also described most injuries (73%–100%) as minor or moderate rather than severe.

SUMMARY AND POTENTIAL FOR INJURY PREVENTION

The injury incidence was mainly between 1 and 4 injuries/1000 hours. Some studies with higher and lower rates exist. Our results are comparable with the injury rate results of other racket sports, such as tennis, where injury incidences range between 0.04 and 3.0 injuries/1000 hours were found.[38] The dominance of lower body injuries compared with upper body injuries is similar to other racket sports. Most upper body injuries in tennis tend to be overuse injuries, while injuries of the lower body are more likely to be caused by trauma.[38] As there seems to be no clear consensus on the distinction between acute and overuse injuries in badminton, a direct comparison with other sports remains challenging. Different injury frequencies have been identified in tennis, although neither of the two types of injury (acute/overuse) appears to dominate.[38]

If we compare the injury rates in badminton with those of other non-contact individual sports such as gymnastics, we find comparable injury rates of 1–4 injuries/1000 hours with few outliers.[39] For professional golfers, an injury rate of three injuries per player was found retrospectively over an observation period of two golf seasons.[40] For the amateur golfer, two injuries per player have been observed.[40] A total of 637 injuries were identified in 703 players. However, this study did not indicate that injury incidence was adjusted per 1000 hours of play. In repetitive endurance sports, such as long-distance running, the incidence was between 2.5 and 5.8 injuries/1000 hours, with 50%–75% being overuse injuries due to the constant repetition of the same movement.[41]

The second of the six pillars of prevention research, according to Finch,[11] entails the identification of the injury mechanism and possible risk factors, the complex interaction of which is responsible for sports injuries. Due to the heterogeneous findings in the studies described here, the following risk factors can only be cautiously emphasised: The risk of injury appears to increase as the level of play rises, and a history of injury also appears to be associated with an increased risk of reinjury. This finding is based on the results of Jørgensen and Winge,[36] who explicitly found a higher proportion of overuse injuries in elite players, as well as the fact that the injury rates in the five studies that only examined the level of elite players were generally at the upper end of the incidence rates. Three publications[16 23 28] specifically show an increased injury rate after an injury to either the same site or a different body site related to the original injury.

Furthermore, the lower extremities are particularly affected, and overuse injuries appear to be a relevant problem. Coaches and medical staff should be aware of these risk factors and pay particular attention to young professional athletes with a history of injury. Especially during athletic development, young players move to high-competition classes and promptly increase their training workload. The association between the occurrence of injuries and training load has been observed in numerous studies.[42] It is, therefore, often important to ensure that the total load of young players is adapted to their training history to counteract the problem of too much progress being desired in too short a time without the body being prepared for the increased demands. This means that adapting to the progression of intensity, duration and frequency of training to the individual's performance and fatigue level is of crucial importance.[43]

This point is underlined by the high proportion of overuse injuries, which require a systematic injury prevention programme that considers mobilisation, strength training and other aspects of the treatment and prevention of overuse injuries.[42 44] It, therefore, seems useful for coaches to record the acute training load to get an idea of whether the training volume, frequency or intensity needs to be reduced. On the one hand, excessive and rapid increases in training loads account for many injuries.[45] Piggott and Newton[46] showed that 40% of injuries were associated with a rapid change (>10%) in the weekly training load in the preceding week. On the other hand, evidence suggests that appropriate physical training benefits by developing physical qualities that protect against injury.[45] It has been shown that a greater amount of short, high-intensity acceleration training and game-specific aerobic activities can equip athletes with the appropriate physical qualities to perform at a high level and protect against injury.[45]

Another approach to monitoring the load would be regularly completing a questionnaire, such as the 'Short Recovery and Stress Scale'.[47 48] This instrument assesses the emotional, physiological, mental and overall aspects of recovery and stress.[48] This is also important in the off-training lives of young people with a lot of potential stress in their private lives and at school. Although the degree of physical maturity is not explicitly addressed in any of these studies, particular attention should be paid to this due to the 'injury age' of under 20 years emphasised in some studies. Adolescence is a time of physical, psychosocial and cognitive development and physical and psychological instability in which hormonal, musculoskeletal and neurocognitive changes of adolescence drive factors for sports-related injuries.[49] Changes in the muscle skeleton and subsequent physiological characteristics affect the increased risk of sports-related injuries.[49] Training methods adapted to the development stage could help reduce injuries and growth-related overload conditions.[50] Repetitive mechanical loads that require rapid deceleration and a quick change of direction should be reduced in favour of more technically oriented movement exercises.[51]

Injury history is also a major risk factor for future (re) injury to the body region in question.[52 53] This may be due to residual deficits in the previously injured joint or muscle, such as proprioceptive deficits, altered muscular recruitment patterns or altered biomechanics,[54] which make the athlete more susceptible to reinjury.[53] There is a strong positive correlation between the exposure time and the total number of injuries.[55] This results in a direct relation between an athlete's past career time and an existing injury history. For this reason, an injury history often affects older players, for whom a balanced and individualised training plan is very important.

LIMITATIONS

A meta-analysis was not conducted in our systematic review due to significant differences in methodologies, populations and interventions among the included studies. This heterogeneity made it challenging to combine the results quantitatively in a meaningful way. As a related issue, insufficient studies were identified to perform a statistically robust meta-analysis.

This paper combines the two types of systematic review, the 'Systematic Review of Incidence[56 57]' and the 'Systematic Review of Aetiology'.[57 58] The heterogeneity of the included studies in terms of study design, indication of incidence and indication of risk factors did not allow for the distinction between those two perspectives. We, therefore, could not consider the two methodological approaches and the needs of the two principles separately. Still, we had to combine them to obtain a well-rounded overall picture.

A comparison of injury rates between different studies within badminton and between different sports is thus limited and would be facilitated by the consensual use of proper injury definitions and the standardisation of incidence reporting. The BWF published a consensus statement on injury definitions and data collection methods to standardise future injury surveys in 2022.[59] This resulted in the definition of injury developed by the World Federation: 'Any physical injury sustained by a player during a match or training regardless if further diagnostic tests were done or if playing time was lost',[59] which can be used in future studies. Depending on the injury definition and data collection method used, studies tend to underestimate the real injury rate: Underestimation may occur, for example, when only injuries requiring medical treatment are recorded or when studies are conducted with self-reporting past injuries (recall bias and social desirability). This may also apply to the lower outlier who reported less than one injury/1000 hours. In this case, the injury definition was that an injury was only counted as such if it was reported to medical staff by the player concerned or if medical assistance was required.[34] In contrast, other studies may have overestimated injuries, particularly those in which players reported all types of pain and discomfort that may be due to a training effect rather than an actual injury. Yung *et al*[28] stated a high incidence, although they did not define the term 'injury' directly. This makes it impossible to understand the range of injuries recorded, as the definition was interpreted very broadly. As described above, a standardised definition would be important for the future.

The quality of the studies in the checklist adapted from Lopes *et al*[14] averaged 71% and is, therefore, of moderate quality. Because most publications were retrospective studies, there was a risk of a notable recall bias. In addition, some studies did not provide any information on the distribution of risk between training and competition and/or on changes over the year, which also led to a deduction of points in the quality assessment. As many studies did not record the hours of training and competition, there was also a lack of standardised information on injury incidence as injuries per 1000 hours of exposure, which means that the study results are not comparable between all studies. This highlights the impact that injury definitions and data collection methods can have on injury outcomes and emphasises the need to introduce consistent guidelines for future epidemiological studies in badminton to make the results more meaningful. In addition, many of the results of this work are based on only a few studies, which at the same time only have a small number of cases. It is, therefore, important to interpret the results with this background knowledge.

Data on specific risk factors should be considered when developing injury prevention programmes. In badminton, however, scientific information on risk factors is limited. In particular, methodologically sound prospective longitudinal studies are lacking. Only 5 of the 19 studies included here were prospective, while the others collected retrospective data. These five prospective studies had an average quality of 80% and were, therefore, of high quality with a low ROB.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The mean injury rate in all studies was between 1 and 4 injuries per 1000 hours of exposure, and the incidences tended to be at the upper end in the studies conducted with elite players only. Lower body injuries occurred most frequently, including strains, sprains, tendinopathies and stress fractures, with a high proportion of overuse injuries. All studies considering the time to RTP reported a greater proportion of less than 28 days of lost time. The studies that used the AIS scale for categorisation also described the majority of all injuries as minor or moderate rather than severe. Due to the heterogeneous findings in the studies presented here, the risk factors described (high level of play, injury history, pronounced susceptibility of the lower extremities and many overuse injuries) can only be emphasised with caution.

The studies included in this review differ substantially regarding injury definitions and data collection methods. More research should be carried out in the field of risk factors to obtain more information on the epidemiology of badminton and avoid injuries more frequently in the future. Better data (large, multicentre prospective cohort studies) methodologically based on published consensus statements are needed to stabilise the tentative findings. In addition, studies in which injury rates are recorded strictly according to different characteristics (eg, gender, level and training frequency) are particularly useful. This further development of the epidemiological report would also help injury monitoring and injury prevention in elite sports since 'Top shape and injuries are close neighbours'.[60]

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