An updated review of the epidemiology of swimming injuries

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Short title: Epidemiology of swimming injuries

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Objective: To carry out a systematic review to update the scientific evidence on the incidence and prevalence of injuries in the swimming discipline, as well as the location, type and mechanism of the injuries, and to assess whether studies are meeting methodological recommendations for data collection and injury surveillance.

Literature Survey: The databases of Pubmed and Sportdiscus were used to search for studies that describe the epidemiology of injuries in adult swimmers between 2010 to March 2020.

Methodology: Of the 864 articles identified, 14 studies were finally included in this review. The methodological quality of the studies was analysed with the Strobe scale and PRISMA guidelines were followed.

Synthesis: The results showed a high prevalence of shoulder, knee and lower back injuries among swimmers due to overuse. These injuries were mainly short-term tendon-muscles, there were reported data differences between genders.

Conclusions: Despite the publication of an injury surveillance single and multi-sport events document and a consensus on data collection and injury surveillance in swimming, there are huge methodological limitations that do not allow firm conclusions. As such, more epidemiological studies following guidelines for data collection and injury surveillance are needed to establish differences by gender, age group, and swimming stroke.

Keywords: swimming, risk factors, prevention, shoulder, tendinopathy.

An updated review of the epidemiology of swimming injuries

Swimming has become one of the most practised and popular sports worldwide[1,2] thanks to its peculiarity of being in an aquatic environment[3], and the multitude of benefits that it brings to the health[2,4,5]. Likewise, swimming is available to everyone regardless of age and sex, since the water hardly generates an impact on the bones and joints[2]. Nevertheless, its cyclical nature, combined with large training loads, high technical requirements and demands on strength to overcome an external load, mainly in the upper limb[6,7], might lead to joint and muscular overloads, increasing the risk of injury[8-10]. For example, an elite swimmer can swim an average of 6-10 km per day, 5 to 7 days a week, and often twice a day. This equates approximately 60 to 80 km and 30,000 strokes per week[11,12]. In particular, two reviews have described that the most common injuries in swimming occur mainly due to overuse in the knee, the lumbar/hip area, and especially in the shoulder of the swimmer[8,10]. Regarding the type of injury, it seems that the most predominant injuries are musculoskeletal and ligamentous[8,10].

There is no consensus on reporting injury rates, however, which does not allow us to compare the risk of injury in swimmers across studies. Injuries have a negative impact on the swimmer, evoking a high number of absences in training and/or competition[13-15], leading to chronic pain or even end up in a surgery[16,17] which can turn into a disability or withdrawal from the sport[15,18,19]. Furthermore, the pain may persist for years after withdrawal[19], and as a consequence, this is associated with a great social and economic cost for the athlete.

Notwithstanding, research on the prevalence of swimming injuries is precarious from a methodological level[8]. Swimming science does not allow the establishment of valid and reliable conclusions to develop effective programmes aimed at reducing the incidence and severity of injuries in this sport[8], as is the case in other sports, where injury registration guidelines have been already established[20-23].

The swimming literature has mainly focused on shoulder injuries, largely avoiding other less prevalent injuries that may be just as relevant. Likewise, most of the identified studies were descriptive or retrospective with low samples and using a questionnaires format[8]. For this reason, in 2016, the International Swimming Federation (FINA) published a consensus statement on the methodology of injury and illness surveillance in aquatic sports[24]. This document not only discusses medical care guidelines for swimmers at the elite level, but it also examines a wide array of different competitions and age levels[24]. As such, the aim of the document is to improve the quality of the data collected and the development of effective and individualised preventive measures. On the other hand, a previous document (2008) has been shown to be reliable in the injury surveillance for single-sport and multi-sport events, thus, its use allows comparison of the results between swimming studies[25].

Since the last reviews, there are several epidemiological studies that have been published in swimming in clubs[14,15,26-28] as well as in international championships[13,29,30,31] that could improve the quality of the existing information[8,10]. Therefore, it is important to check if the injury surveillance for single and multi-sport events and swimming guidelines established for the data collection have been followed[24,25] in order to respond to the suggestions established by Gaunt and Maffuli[8]. Doing so will allow rigorous compliance with the first step of the guidelines to develop effective prevention programmes for swimmers[32]. Therefore, the objectives of this study were to carry out a systematic review to update the scientific evidence on the incidence and prevalence of injuries in the swimming discipline, as well as the location, type and mechanism of the injuries; and to assess whether studies are meeting methodological recommendations for data collection and injury surveillance.

Method

To carry out this study, guidelines for reporting systematic reviews of observational studies in epidemiology (PRISMA guidelines) were followed[33]. PRISMA checklist can be found in Appendix 1.

Search strategy

Potential studies were identified by combined search processes, clearly planned and ordered. First, the following bibliographical databases were consulted: PubMed and Sportdiscus with the following search terms included in Boolean search strategies: (swim*[tiab] OR aquatic[tiab]) AND (injury[tiab] OR incidence[tiab] OR prevalence[tiab] OR epidemiology[tiab]) or in Spanish (natación[tiab] OR acuático[tiab]) AND (lesión[tiab] OR incidencia[tiab] OR prevalencia[tiab] OR epidemiología[tiab]). By using filter criteria of the respective databases, the search was limited to publication dates (from 01/01/2010 to 31/03/2020), species (humans), and English and Spanish languages. Finally, the reference lists of the studies recovered were hand-searched to identify potentially eligible studies not captured by the electronic searches.

Two reviewers independently (A.T. and H.G-G.): a) screened the title and abstract of each reference to locate potentially relevant studies, and once hard copies of the screened documents were obtained; b) reviewed them in detail to identify articles that met the selection criteria. A third external reviewer (A.L-V.) was consulted to resolve discrepancies between reviewers in the studies selection.

Study selection

To be included in the systematic review, the studies had to fulfil the following criteria: 1) studies must report either injury incidence rate or prevalence in swimmers; 2) swimmers had to be adults or compete at a high level of swimming; 3) preventive studies had to provide a control group to be included in this review; 4) the study had to be published in a peer-reviewed journal; and 5) it had to be written in English or Spanish. Literature reviews, abstracts, editorial commentaries and letters to the editors were excluded. Finally, some authors were contacted to provide missing data. Moreover, incomplete data, or data from an already included study, were excluded.

With the aim of guaranteeing the maximum possible objectivity, a codebook was produced that specified the standards followed in coding each of the studies characteristics. The moderator variables of the eligible studies were coded and grouped into three categories: 1) general study descriptors (e.g., authors, country of the sample, year of publication, and study design); 2) description of the study population (e.g., sample size, age, sex, stroke type and level of the swimmers); and 3) main epidemiologic findings (e.g., injury and exposure data, distribution of injuries by anatomic location, type of injury, injury severity and mechanism of the injuries). The datasets used and/or analysed during the current study are available from the corresponding author upon request.

Quality assessment

Two reviewers independently assessed the reporting quality of included studies using an adapted version of the "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) statement[34]. All included studies were rated on 11 specific criteria which were derived from items 5, 6, 7, 8, 9, 12, 14 and 15 of the original checklist. The STROBE scale was considered as a suitable starting point for assessing the quality of observational studies[34]. This 11-item checklist provides guidance on the reporting of observational studies in order to facilitate critical appraisal and interpretation of results. The observational studies were considered as having a low risk of bias if they were determined as high quality (score of ≥7/11) or a high risk of bias if they were low quality (≤6/11)[34].

In order to assess the inter-coder reliability of the coding process, two researchers coded all studies randomly (including methodological quality assessment). For the quantitative moderator variables, intra-class correlation coefficients (ICC) were calculated, while for the qualitative moderator variables, Cohen's kappa coefficients were applied. On average, the ICC was 0.87 (range: 0.77 – 1.0) and the kappa coefficient was 0.92 (range: 0.83 - 1.0), which can be considered highly satisfactory[35]. The inconsistencies between the two coders were resolved by consensus, and when these were due to ambiguity in the coding book, this was corrected. As previously mentioned, any disagreement was resolved by mutual consent in consultation with a third reviewer.

Results

After the search process, 805 were deleted due to duplication or not meeting inclusion criteria based on review of the title and abstract. The remaining 59 articles were selected for their complete review. Finally, 45 articles were excluded due to not meeting some of the established inclusion criteria and thus 14 articles were included in the present review[13-15,26-31, 36-40]. The article selection process can be found in Figure 1.

Please insert Figure 1 near here

Descriptive characteristics of the studies

The main characteristics of each of the integrated studies are presented in Table 1. The studies selected were carried out between 2010 and 2019. Three studies were carried out in the United States of America (USA), two in Japan, one in Brazil, one in Finland, one in Denmark, four in World Championships and two in Olympic Games. The total sample size was larger than 6.000 swimmers. Thirteen out of fourteen included both male and females, and only one study included only female swimmers[39].

Twelve articles provided information about the location of injuries and eight articles about the type of injuries. One article studied only the prevalence of spine/low back injuries[38].

******Please insert Table 1 near here******

Quality of the selected studies

With regards to the reporting quality of the studies, the mean score obtained with the STROBE quality scale was 7 (minimum: 5, maximum: 9), showing high quality, low bias in most of the studies included in the review. All studies reported participation locations, and most of the relevant dates about recruitment, follow-up and data collection. However, very few of the studies included data about methods of follow-up, verified injuries by a medical professional and indicated the number of participants with missing data. The detailed data are presented in Table 2.

Furthermore, it is quite relevant to show that five papers provided retrospective data. It has been assumed than retrospective studies have more bias since the study operations, data collected, data entry, and data quality assurance, were not planned ahead of time, thus some data could be lost[41].

******Please insert Table 2 near here******

Injury incidence

Only six studies[15,27-30,40] included incidence values in their research. Nevertheless, almost all the studies presented a different value. Chase et al.[27] revealed that university swimmers suffer 3.04 injuries/1000hours of exposure or 5.55 injuries per 1000 athlete exposure (AE), with the incidence greater in females than males (3.32 injuries/1000 hours of exposure or 6.06 injuries 1000 AE vs 2.74 injuries/1000 hours of exposure or 4.97 injuries 1000 AE, respectively). On the other hand, Ristololainen et al.[15] found lower values of incidence than Chase et al.[27] in elite swimmers with 2.6 injuries/1000 hours of exposure. In the same line, Kerr et al.[28] also showed a lower incidence in university swimmers, both females (1.48 injuries/1000 AE) and males (1.63 injuries/1000 AE). Finally, Mountjoy et al.[30,40] reflected the incidence in World Championships with values of 31.9 injuries/1000 athletes and 6,1 injuries per 100 registered athletes, respectively, while Dijkstra et al.[29], in a 25m pool World Championship, revealed much lower incidence (3,5 injuries per 100 registered athletes). In the 2009 World Championship[30], as in the rest of the studies, the incidence was higher in females (34.8 injuries per 1000 athletes) than males (21.8 injuries per 1000 athletes).

Injury location

All studies reported information about the localisation of injuries, except for Folkvardsen et al.[38]. Most of the studies pointed out that shoulder or shoulder/clavicle injuries were the most common injury location in swimmers, except for two studies[14,39]. Those studies showed that the most common location of injuries was the lower back followed by shoulder injuries, although Nagano et al.[39] only included overuse injuries. In this sense, all studies included back/lower - back/upper - back/trunk (different methodological classifications) as one of the most frequent injuries in swimmers. On the other hand, most of the studies in World Championships[29,30,40] and Olympic Games[31], revealed that wrist/hand injuries were very common in these competitions. Regarding lower extremities, knee and ankle are the regions more affected by the injuries in swimmers. More detailed information can be found in Table 3.

Please insert Table 3 near here

Comparing gender-location injuries, only four studies established a difference between male and female swimmers[26,27,28,36]. Shoulder injuries were the most common in both male and female in all studies. Spine/trunk/back was the second most usual injury in one study, both male and female[28], and in the male sample of Chase et al.[27]. In the female sample of Chase et al.[27], ankle and knee injuries were more frequent than back injuries. Otherwise, De Almeida et al.[36] found that the knee was the second region most affected by injuries in both male and female, followed by lower back and ankle/foot, respectively.

Finally, one study[38] further classified reported lower-back injuries in elite swimmers by spinal level, and the L5-S1 region was the most affected (more than 30% of injuries), followed by L4-L5 (25.3%), L1-L2 (19.8%) and L2-L3/L3-L4 (15.4% each one).

Injury type

Seven studies analysed the type of injuries suffered by swimmers[27,28,30,31,36,37,40]. Strain/-tendinopathy injuries seem to be the most usual injuries in swimmers. However, this statement should be analysed with caution due to the different classifications used in each study. Moreover, contusions also showed a higher prevalence (6%-17.4%) in all studies included. For instance, Chase et al.[27] and Kerr et al.[28] found that strain and tendonitis were the most usual type of injury in university swimmers followed by sprain. Concerning International Championships, Mountjoy et al.[30] combined strain and sprain injuries as the most common type of injury (33%), thus, it cannot be compared to other studies in the same way. Engebretsen et al.[37], showed that more than 20% were strain injuries followed by sprain (16%) and tendinosis (12%), similar to Mountjoy et al.[40] which registered 18.5% of tendinosis, followed by sprain (12.3%) and strain (6.2%). Contrary to these findings, Soligard et al.[31], in the 2016 Olympic games, showed sprain/ligament ruptures were more frequent (26.1%) than tendinosis/tendinopathy (17.4%).

Finally, Folkvardsen et al.[38] provided information about the type of lower back injuries. Disc degeneration (52.7%) was the most common type of spine injury, followed by bulges (26.4%) and herniations (20.9%) in elite swimmers.

Mechanism of injuries

Five studies showed that overuse injuries occurred more frequently than contact/traumatic injuries[15,27,28,29,31], while one study found a higher prevalence of traumatic injuries[37]. However, traumatic injuries were more common than overuse injuries in male samples of two studies[27,28]. Regarding gender differences, overuse injuries where more frequent in female in two studies[27,28].

Severity of injuries

Only one study included any severity classification, measured by duration of time needed for recovery, in their studies. In the Ristolainen et al.[15] study, minor injuries (> 1 week) were the most common injuries (63.5%), in both male and female. Besides, major injuries (> 3 weeks) showed a low percentage of prevalence (11.5%).

Injuries by stroke type

One study provided information about injuries by stroke type[29]. Both males and females suffered more injuries (>45%) when the four swimming strokes (butterfly, backstroke, breaststroke, and freestyle) where combined in a sequential order (individual medley) during training and/or race. The second stroke with more injuries in males was the butterfly, followed by freestyle, backstroke and breaststroke. In females, backstroke had a higher prevalence than males, followed by butterfly and breaststroke with the same prevalence as males, and freestyle with lower prevalence than males.

Discussion

The main finding of this review is that, to date, the methodological recommendations for data collection and injury surveillance in swimming are not being followed[24,25]. Only 6 studies included these methodologies in their research[13,14,29,30,31,40]. As a whole, several definitions of injury or pain, and different classifications of location, type, mechanism and severity of injuries are used, as well as the incidence values provided (1000 hours exposure/100 athlete exposure, 10.000 athlete exposure, injuries per athlete, competition starts, etc). As a consequence, this lack of guidelines in methodology hindered ways to compare all those results to establish preventive measures depending on category, age, gender, swimming stroke and/or level, that might allow reducing the number and severity of the most prevalent injuries in swimming.

Secondly, shoulder, back and knee injuries are the main locations of injuries. Regarding the type of injury, it seems that overuse muscle/tendon injuries (cramps/strains/tendinopathies) are the most common.

Injury incidence

The incidence of injuries (2.6-3.0 injuries per 1000 hours of exposure / 1.5-5.5 injuries per-1000 AE / 3.2-6.1 per-100 registered athletes) shows that swimming is a sport with a relatively low risk of injury compared to other sports with great involvement of the upper body[31,37]. This is mainly due to the characteristics of the environment in which the sport takes place, without impacts, without interference with other rivals or teammates and without any implement, which greatly reduces the probability of injury[42,43].

The incidence of injuries seems to be higher in competitions than in training, although the prevalence is much higher in training. However, the pressure to which athletes are exposed during the competition[44], the intensity and the overload of events in the competition[13,30,31,37,40], and the limited recovery time between the events greatly increase the risk of injury[43].

A high percentage of the studies included in this review indicate a higher incidence of injuries in women swimmers than in men. This may be due to anatomical, biomechanical, physiological and psychological differences compared to men[45-48]. For instance, the shorter length of arms and legs in women makes it necessary to perform a greater number of strokes at the same distance, thus generating greater stress on the joints[47]. Likewise, lower levels of strength in women[49], as well as the energetic differences observed in competition between genders[45,47], could generate greater fatigue in women and with it, an increased risk of injury. However, the scarcity of studies that analyse the influence of different risk factors by gender make it difficult to draw firmer conclusions. Hence, the importance of carrying out specific studies in order to establish preventive programmes aimed at women and men individually.

Injury location

Regarding injury location, and in line with previous reviews[3,8,9], the shoulder is the body region most affected by injuries, assuming between 16 and 76% of all injuries. The main risk factor for shoulder injuries is the repetitive cyclical movement of the glenohumeral joint, with a positive correlation with training time and distance[12]. Likewise, these repetitive and continuous movements generate great fatigue[3] and friction between the different structures of the joint that leads to inflammation and pain[50]. As such, the fatigue caused in the agonist musculature may cause a biomechanical alteration in the movement of the shoulder that can trigger an injury[3,12]. It is also worth noting the previous clinical history of pain, a limitation of motion range, excessive shoulder laxity and/or unilateral/bilateral dominance as determinants of the injury[8,10,12,51-53].

Shoulder prevalence varies slightly according to gender (men: 23.8-50.6% and women: 33.3% -41.3%), being slightly higher in men in most of the studies[27,29,36]. Although women have a lower average height and a shorter stroke[45], it is likely that greater muscle development in men and altered biomechanics in women[45,54] increase the risk of shoulder injury in men.

As for knee injuries, the second most injured body region (3.1-17.7%), are mainly caused by overuse[8]. Likewise, it should be noted that breaststroke swimmers have a greater number of knee injuries compared to other strokes[55] and up to 75% of breaststrokers report medial knee pain throughout their career[56]. The repetition of certain technical gestures such as the breaststroke kick[55,57], the frequency and technical intensity of the kick[55], a different propulsive pattern[58], decompensation of the kick angle, a mechanical imbalance of the joint[55,59], or the degree of flexion during pushing from the wall[60], would affect the movement pattern of the knee and increase the risk of injury and pain. Likewise, it has been proven that an increased Q angle is related to knee pain[57]. Hence, the importance of teaching the technical performance of the kick and knowing how to detect possible propulsive irregularities at the biomechanical level in swimmers.

Regarding gender differences, there is no clear trend in this review. Although the literature does not clarify the main risk factors by gender, it could be speculated that the differences in the Q angle[57], as well as the greater propulsive force generated during the kick or the push on the wall after "flip turns"[61], could increase the risk of injury in men.

Moreover, the lower back is consolidated as a region with a high risk of swimming injury[3,8,10], showing a higher prevalence in the butterfly stroke (33-50 % of lower back injuries)[62]. All competitive swimming strokes require that the lumbar spine should be maintained in hyperextension to achieve a streamlined body position while performing trunk rotations, which can generate an excessive load on the lumbar area[3,63]. This pain is directly related to the intensity, duration and distance of the training, the technique of the undulating strokes and the use of auxiliary material[64], the position of the cervical region[65] and the head during breathing[66], along with the "flip turns" typical of changes in direction[3]. In line with previous studies[67,68], lower vertebral discs (L4-L5-S1) were more affected by swimming. The fact that lower vertebral discs are the most load-bearing structures and that they are the axis of rotation during swimming could explain this high incidence compared to other vertebral areas. Consequently, teaching, correcting and maintaining good swimming technique, as well as strengthening the lumbopelvic complex area 4, could help reduce the risk of injury and pain to the lumbar area in swimmers[69,70].

Unlike shoulder and knee injuries, it seems clear that injuries to the lower back are more prevalent in men. A greater hydrostatic lift and a smaller sinking force in women, which would reduce hyperextension of the lumbar area[71,72], the higher percentage of fat and lower relative body weight in the trunk[72], as well as its greater resistance in the trunk extensors[73] that would help reduce water resistance[72] reduces the risk of a lower back injury in women.

Injury type

The most prevalent type of injury in swimmers, strain/tendinopathy, is closely associated with the location and mechanism of the previously mentioned injuries, since they appear mainly due to repetitive movements in joint areas such as shoulder, knee, intervertebral and hip[3,8,10]. Although there are methodological limitations, no groupings can be established by specific injuries, previous studies reveal the main strain/tendinopathy injuries in swimming. For instance, the cyclical movement of the stroke generates some deterioration on the shoulder that could destabilise the phase of the arm and hand, leading to impingement of the supraspinatus and the long head of the biceps[10,12]. Likewise, subacromial or intra-articular shock generated at the end of the aerial recovery phase of the stroke [74] and during the underwater phase[75] is also common.

On the other hand, the repetitive movement of the kick, especially in the breaststroke, causes great strain on the ligaments and tendons of the knee joint[3,55]. Furthermore, it was pointed out in a previous review that a large number of knee pathologies are associated with strain/sprain injuries, such as: medial collateral ligament sprain, patellofemoral pain syndrome, patellar tendinopathy and/or adductor longus/brevis muscle strains[3]. All of those previously mentioned pathologies are a result of knee valgus during the breaststroke kick[58-61], the low angles of hip abduction in the kick[58] and/or repetitive quadriceps contractions associated with flutter and dolphin kicks, and from patellofemoral joint contact pressure during the wall push-off and start[60].

Concerning the lower back area, the literature refers more to subtypes of spinal disorders such as scoliosis, hyperlordosis, hyperkyphosis, than more specific injuries such as spondylolysis, spondylolisthesis, lumbago and/or lumbosciatica[10,64,66,67,76]. The need to maintain a position as aerodynamic as possible through hyperextension, together with the constant rotation of the trunk, generates a great overload in the lower back area that could lead to different tendon, ligament or muscle pathologies[3,10,66]. This position degenerates in pathologies of the intervertebral disc, bulges and herniations[38,67,68], as well as joint inflammation[77].

Severity of injuries

One study included in this review provided information on the severity of injuries, which shows that injuries are predominantly short-term (< 7 days). The fact that a large percentage of injuries are due to overuse and not trauma[24,31,37,40] as reported in previous reviews[8,10], could make recovery faster because these injuries would require only rest in some cases. Injuries such as fractures, ruptures or muscle tears, which require long recovery periods, are rare in swimming, so most of the swimming injuries allow to return to practice in short periods of time[30,31,37,40].

Injuries by stroke type

Unfortunately, only one study in this review reported swim-stroke injuries[29]. Medley swimmers had a much higher prevalence of injuries in both genders, so the combination of several strokes that imply different swimming techniques could increase the risk of injury due to abrupt biomechanical changes, together with the combination of the risk factors of each stroke[3,42].

With regards to individual stroke type, butterfly and specially backstroke were those that had a higher prevalence of injuries. This fact may be caused because these strokes, especially butterfly, require spinal hyperextension positions and hyperextension plus abduction arm movements[10,25,78]. If we combine these risk factors with limited ranges of motion in some swimmers, we have a combination of potentially risky actions[79,80].

Limitations

The main limitation of this review is that the different methodologies used in injury definitions, data collection and injury surveillance did not allow a direct comparison between the studies. Likewise, few studies provided relevant information regarding severity, swimming stroke, mechanism of injury and/or age group. It may decrease validity and reliability when it comes to carrying out effective and individualised preventive programmes. Finally, it is important to highlight that studies comparing and explaining the different risk patterns by gender are minimal, when there is evidence of the anatomical, biomechanical and physiological gender differences[45-48].

Conclusions

The latest epidemiological studies in swimming show a high prevalence of short-term muscle/tendon injuries to the shoulder, knee and lower back in adult swimmers. The aforementioned studies provided insufficient information regarding the injury pattern due to methodological limitations. Future studies should follow the guideline recommendations in data collection and injury surveillance in swimming.

This review identifies current limitations in understanding of injury type and risk factors. We recommend future epidemiological studies follow the methodological recommendations established in recent years. Criteria should include the anatomical location, type (acute, overuse, or traumatic), and severity of injuries. Details on population studied should include gender, level, age group, and primary swimming stroke. These common data reporting practices would allow for developing injury specific preventive programs in the predominant stroke of each swimmer and may reduce risk of the most prevalent injuries.

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Tables Caption

Table 1. Characteristics of the studies reviewed in the meta-analysis.

Table 2. Analysis of the selected studies' methodological quality (n = 14).

Table 3. Injury location and type of injury of the studies included in the review.

Figure Caption

Figure 1. Flow chart of the selection of studies in the systematic review.

Appendix Caption

Appendix 1. PRISMA checklist.

Table 1. Characteristics of the studies reviewed in the meta-analysis.

Reference (Country/Year study)	Design (type of study/weeks of follow-up/data collection)	Sample Characteristics	Level of swimmers	Exposure	Prevalence of Injuries	Swimming Injury surveillance
Baker et al. 2019 (USA/-)	R/-/Q	N = 499 ♂= 205; ♀ = 294 55.3 ± 13.7 Years old (20-86)	Master	1. 67 ± 25min/day and 2.5 days/week. 2. 13.3 ± 11.5 years of practice.	- 160 injuries	-
Chase et al. 2013 (USA/-)	P/1 year/CA	N= 34 (19.5 ± 1.4 years old) (18-23) ♂= 16; ♀= 18 ♂ 19.6 Years old (18-23) ♀ 19.3 Years old (18-22)	NCAA Division I level University	1. 6-7 days/week, 10.180hours training. 2. 11.0 ± 3.4 years of practice: - ♂ 4752.9 hours training - 10.9 ± 4.3 years of practice. - ♀ 5427.8 hours training - 11.1 ± 2.6 years of practice.	- 31 injuries - 3.04 injuries/1000hours - 5.55 injuries 1000 Athlete exposure(AE) ♂ 13 injuries - 2.74 injuries/1000 hours 4.97 injuries 1000 AE ♀ 18 injuries - 3.32 injuries/1000hours 6.06 injuries 1000 AE	-
de Almeida et al. 2015 (Brazil/ 2010)	R/1 year/Q	N= 257 (20.1 ± 3.8 Years Old) ♂= 117 (19.4 ± 3.9 Years Old) ♀ = 140 (20.6 ± 3.7 Years Old)	National International	1. Not given. 2. 57.1 ± 29.9km/week - 13.2 ± 4.7 years of practice: ♂ 59.7 ± 32.5km/week - 13.6 ± 4.7 years of practice. ♀ 53.9 ± 26.4km/week - 12.6 ± 4.8 years of practice.	- 54 (21%) showed pain in the last year/ 37 (68.5%) training/17 (31.5%) competition ♂ 29 (20.7%) showed pain in the last year/ 18 (62.1%) training/11 (37.9%) competition ♀ 25 (21.4%) showed pain in the last year/ 19 (72%) training/6 (28%) competition - 144 (56%) had an injury in the last year/ 131 (91%) training/13 (9%) competition. ♂ 81 (57.9%) had an injury in the last year/ 73 (90.1%) training/8 (9.9%) competition. ♀ 63 (53.8%) had an injury in the last year/ 58 (92.1%) training/5 (7.9%) competition.	-
Dijkstra et al. 2016 (Qatar/WC 25m 2014)	P/1 week/CA	N = 974	Elite/ World Championship	1. Not given. 2. Not given.	- 34 injuries - 3.5 injuries per 100 registered athletes. ♂ 21 injuries. ♀ 13 injuries.	Yes (a)
Engebretsen et al. 2013 (Great Britain/OG 2012)	P/1 week/CA	N = 931 ♂= 481; ♀= 450	Elite Olympic games	1. Not given. 2. Not given.	- 50 injuries/ 13 competition (31%)/ 29 training (67%).* ♂ 24 injuries. ♀ 26 injuries.	-
Folkvardsen et al. 2016 (Denmark/-)	D/-/CA	N=100 (18.7 years old) (16-25) ♂= 60 (18.9 years old) ♀= 40 (18.5 years old)	Elite	1. 47.4km/week - 20.3hours/week ♂ 46.8km/week - 20hours/week ♀ 48.2km/week - 20.8hours/week 2. Not given.	- 91 spine injuries. - 52% low back pain.	-
Kerr et al. 2015 (USA/2009-2014)	P/5 seasons/CA	N = 295 ♂= 124; ♀= 171	NCAA level University	1. Not given. 2. Not given.	- 295 injuries. ♂ 124 injuries - 1.48 injuries 1000 AE/ 110 injuries training - 1.43 injuries 1000 AE /14 injuries competition - 1.96 injuries 1000 AE. ♀ 171 injuries - 1.63 injuries 1000 AE/ 157 injuries training - 1.62 injuries 1000 AE /14 injuries competition - 1.70 injuries 1000 AE.	-

Matsuura et al. 2019 (Japan/2002-2008)	P/7 years/ CA	N = 217 ♂= 121; ♀= 96 ♂ 21.2 ± 2 years old ♀ 21.3 ± 3 years old	Elite	1. Not given. 2. Not given.	- 94 injuries.	Yes (b)
Mountjoy et al. 2010 (Italy/WC 2009)	P/1 week/CA	N = 1502 ♂= 872; ♀= 630	Elite World Championship	1. Not given. 2. Not given.	- 48 injuries - 31.9 injuries per 1000 athletes. ♂ 19 injuries (13 training/6 competition)-21.8 injuries per 1000 athletes. ♀ 22 injuries (13 training/9 competition)-34.8 injuries per 1000 athletes.	Yes (b)
Mountjoy et al. 2015 (Spain/WC 2013)	R/4weeks/Q P/1 week/CA	N= 464 (21.9 ± 3.8 years old) retrospective. ♂= 250; ♀= 214 N= 1071 (21.5 ± 3.8 years old) prospective. ♂= 608; ♀= 463	Elite World Championship	1. 3102 (1652/1450) number of starts (male/female) 2. Not given.	- 23.5% (21.6% male/25.7% female) athletes reported a physical complaint in the 4 weeks prior WC. - 65 injuries - 6.1 per 100 registered athletes/46 training injuries - 4.3 per 100 registered athletes/16 competition injuries-0.5 per 100 starts. ♂ 31 injuries. ♀ 34 injuries.	Yes (b)
Nagano et al. 2019 (Japan/-)	P/24 weeks/Q and CA	♀ = 29 (19.9 ± 1.3 years old)	University	1. Not given. 2. 7.7 ± 1.2 years of practice	-	-
Prien et al. 2017 (Russia/WC 2015)	R/4weeks/Q P/1 week/CA	N=576 (21.3 years old) ♂= 669; ♀= 525	Elite World Championship	1. Not given. 2. Not given.	- 73 injuries 4 weeks prior WC. - 9 injuries/2 time-loss injuries.	Yes (b)
Ristolainen et al. 2010 (Finland/2006)	R/1 year/Q	N=154 (18.7 ± 2.9 years old; 15-35 years old). ♂= 71; ♀= 183	Elite	1. Not given. 2. 1500.8km/year - 9.9 ± 3.1 years of practice	- 210 injuries/2.6 injuries per 1000 hours exposure.	-
Soligard et al. 2017 (Brazil/OG 2016)	P/1 week/CA	N= 906. ♂= 490; ♀ = 416	Elite/Olympic games	1. Not given. 2. Not given.	- 23 injuries (17 training-5 competition-1 unknown). ♂ 11 injuries. ♀ 12 injuries.	Yes (a)

-: Not information available; CA: clinical assessment; D: descriptive; P: prospective study; Q: questionnaire/survey; R: retrospective study.

*Note. * Information missing in 8 injuries; OG: Olympic Games; WC: World Championship. 1. = Activity exposure; 2. = Years of experience.*

a) Mountjoy M, Junge A, Alonso JM, Clarsen B, Pluim BM, Shrier I, van den Hoogenband C, Marks S, Gerrard D, Heyns P, Kaneoka K, Dijkstra HP, Khan KM. Consensus statement on the methodology of injury and illness surveillance in FINA (aquatic sports). British Journal of Sports Medicine. 2016;50(10):590-596.

b) Junge A, Engebretsen L, Alonso JM, Renström P, Mountjoy M, Aubry M, Dvorak, J. Injury surveillance in multi-sport events: the International Olympic Committee approach. British Journal of Sports Medicine. 2008;42(6): 413-421.

Table 2. Analysis of the selected studies' methodological quality (*n* = 14).

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Baker et al. 2019	+	+	+	-	-	-	-	-	+	-	+	5
Chase et al. 2013	+	+	+	+	-	+	-	+	+	-	+	8
de Almeida et al. 2015	+	+	+	-	-	-	+	-	+	-	+	6
Dijkstra et al. 2016	+	+	+	-	-	+	+	+	-	-	+	7
Engebretsen et al. 2013	+	+	+	-	+	-	-	-	-	-	+	5
Folkvardsen et al. 2016	+	+	+	-	+	-	-	+	+	-	+	7
Kerr et al. 2015	+	+	+	+	+	-	+	-	+	-	+	8
Matsuura et al. 2019	+	+	-	-	+	+	-	+	+	+	+	9
Mountjoy et al. 2010	+	+	+	-	-	-	+	-	+	-	+	6
Mountjoy et al. 2015	+	+	+	-	-	+	-	-	+	-	+	6
Nagano et al. 2019	+	+	+	+	-	-	+	-	+	+	+	7
Prien et al. 2017	+	+	+	-	+	+	-	+	+	-	+	7
Ristolainen et al. 2010	+	+	-	-	+	+	+	-	+	+	+	9
Soligard et al. 2017	+	+	+	-	+	+	+	+	+	-	+	8

Note. The numbers of the columns corresponded to the following items of the STROBE scale. Materials and methods:

1. *Describes the setting or participating locations.*
2. *Describes relevant dates (period of recruitment, exposure, follow-up, data collection).*
3. *Provides statement concerning institutional review board approval and consent.*
4. *Gives the inclusion and exclusion criteria.*
5. *Describes injury history.*
6. *Describes methods of follow-up.*

Data sources/measurement

7. *Provides a definition of injury.*
8. *Verifies injury by an independent medical professional.*
9. *Classifies injury (severity, location and type of injury).*
10. *Indicates the number of participants with missing data and explain how this was addressed.*
11. *Measures and presents exposure data.*

Table 3. Injury location and type of injury of the studies included in the review.

References	Location of injury			Type of injury			Mechanism of injury
	Both Genders	Men	Women	Both Genders	Men	Women	
Baker et al. 2019	Shoulder: 121 (76%) Knee: 10 (6%) Ankle: 9 (6%) Other: 20 (13%)						
Chase et al. 2013	Shoulder: 12 (38.7%)/ Back: 5 (16.1%) Knee: 4 (12.9%) Ankle: 4 (12.9%) Upper leg: 3 (9.7%) Groin: 2 (6.5%) Neck: 1 (3.2%)	Shoulder: 6 (46.2%) Back: 3 (23%) Groin:2 (15.4%) Knee:1 (7.7%) Upper leg:1 (7.7%) Ankle:0 Neck: 0	Shoulder: 6 (33.3%) Ankle:4 (22.2) Knee:3 (16.7%) Back: 2 (11.1%) Upper leg:2 (11.1%) Neck: 1 (5.6%) Groin:0	Tendonitis: 18 (58%) Strain: 11 (35.5%) Sprain: 2 (6.5%)	Tendonitis: 6 (46.2%) Strain: 6 (46.1%) Sprain: 1 (7.7%)	Tendonitis: 12 (66.6%) Strain: 5 (27.8%) Sprain: 1 (5.6%)	58.1% overuse injuries/ 41.9% traumatic injuries ♂ 46.2% overuse injuries/ 53.8% traumatic injuries ♀ 66.7% overuse injuries/ 33.3% traumatic injuries
de Almeida et al. 2015	Shoulder: 67 (46.5%) Knee: 23 (16%) Lower back: 9 (6.2%) Neck/cervical: 9 (6.2%) Ankle/foot: 7 (4.9%) Hip/Thigh: 6 (4.2%) Elbow/wrist/hand: 4 (2.8%) Others: 16 (11.1%)	Shoulder: 41 (50.6%) Knee: 12 (14.8%) Lower back: 9 (11.1%) Neck/cervical: 5 (6.2%) Ankle/foot: 3 (2.1%) Hip/Thigh: 2 (2.5%) Elbow/wrist/hand: 1 (1.2%) Others: 8 (9.9%)	Shoulder: 26 (41.3%) Knee: 11 (17.5%) Ankle/foot: 5 (7.9%) Neck/cervical: 4 (6.3%) Hip/Thigh: 4 (6.3%) Elbow/wrist/hand: 3 (4.8%) Lower back: 0 (0%) Others: 8 (12.7%)	Tendinopathy: 61 (58.7%) Muscular lesion: 8 (7.7%) Dislocation: 4 (3.8%) Arthritis/Synovitis/Bursitis: 4 (3.8%) Ligament rupture: 3 (2.9%) Meniscal/Cartilage: 2 (6.7%) Sprain: 2 (1.9%) Others: 15 (14.5%)	Tendinopathy: 34 (55.7%) Muscular lesion: 6 (9.8%) Meniscal/Cartilage: 5 (8.2%) Dislocation: 4 (6.7%) Arthritis/Synovitis/Bursitis: 1 (1.6%) Ligament rupture: 1 (1.6%) Sprain: 0 (0%) Others: 10 (16.4%)	Tendinopathy: 27 (62.9%) Arthritis/Synovitis/Bursitis: 3 (7%) Muscular lesion: 2 (4.6%) Meniscal/Cartilage: 2 (4.6%) Ligament rupture: 2 (4.6% Sprain: 2 (4.6%) Dislocation: 0 (0%) Others: 5 (11.7%)	
Dijkstra et al. 2016	Shoulder: 10 (29.4%) Knee: 6 (17.7%) Foot/ankle: 4 (11.8%) Hand/fingers: 2 (5.9%) Groin: 2 (5.9%) Back: 4 (11.7%) Head: 2 (5.9%) Chest: 1 (2.9%) Wrist: 1 (2.9%) Elbow: 1 (2.9%) Hip: 1 (2.9%)	Shoulder: 5 (23.8%) Knee: 5 (23.8%) Foot/ankle: 3 (14.3%) Hand/fingers: 2 (9.5%) Groin: 2 (9.5%) Back: 2 (9.5%) Head: 1 (4.8%) Chest: 1 (4.8%) Wrist: 0 (0%) Elbow: 0 (0%) Hip: 0 (0%)	Shoulder: 5 (38.5%) Back: 2 (15.4%) Knee: 1 (7.7%) Foot/ankle: 1 (7.7%) Head: 1 (7.7%) Wrist: 1 (7.7%) Elbow: 1 (7.7%) Hip: 1 (7.7%) Groin: 0 (0%) Hand/fingers: 0 (0%) Chest: 0 (0%)				♂ 5 (23.8%) overuse injuries/ 16 (76.2%) traumatic injuries ♀ 7 (53.8%) overuse injuries/ 6 (46.2%) traumatic injuries
Engebretsen et al. 2013	Shoulder/clavicle: 8 (16%) Upper back: 6 (12%) Ankle: 3 (6%) Foot and toe: 3 (6%) Thigh: 3 (6%) Lower leg: 3 (6%) Achilles tendon: 3 (6%) Face: 3 (6%) Fingers: 3 (6%) Lower back: 2 (4%) Knee: 2 (4%)			Strain: 11 (22%) Sprain: 8 (16%) Contusion/hematoma/bruise: 6 (12%) Tendinosis: 6 (12%) Laceration/abrasion/skin lesion: 5 (10%) Arthritis/bursitis/synovitis: 2 (4) Fracture: 1 (2%)			Contact injuries: 18 (36%) Overuse: 14 (28%) Others: 11 (12%) NA: 11 (12%)

	Neck/cervical spine: 2 (4%) Head: 1 (2%) Groin: 1 (2%) Elbow: 1 (2%) Wrist: 1 (2%) Thumb: 1 (2%) Not available: 4 (8%)			Fasciitis/Aponeurosis: 1 (2%) Others: 10 (20%)			
Folkvardsen et al. 2016	Spine injuries (91%) Low back pain (52%) L1/L2: 18 (19.8%) L2/L3: 14 (15.4%) L3/L4: 14 (15.4%) L4/L5: 23 (25.3%) L5/S1: 28 (30.8%)			Disc degeneration: 48 (52.7%) Bulges: 24 (26.4%) Herniations: 19 (20.9%)			
Kerr et al. 2015	Shoulder/Clavicle: 106 (35.9%) Trunk: 50 (17.0%) Knee: 30 (10.2%) Hip/groin: 16 (5.4%) Foot: 16 (5.4%) Hand/wrist: 15 (5.1%) Thigh/upper leg: 12 (4.1%) Arm/Elbow: 10 (3.4%) Head/Face: 9 (3%) Lower leg: 8 (2.7%) Ankle: 7 (2.4%) Neck: 2 (0.7%) Others: 14 (4.7%)	Shoulder/Clavicle: 53 (34.7%) Trunk: 20 (16.1%) Knee: 11 (8.9%) Hand/wrist: 11 (8.9%) Foot: 7 (5.7%) Arm/Elbow: 6 (4.8%) Hip/groin: 6 (4.8%) Thigh/upper leg: 6 (4.8%) Head/Face: 5 (4%) Lower leg: 2 (1.6%) Ankle: 2 (1.6%) Neck: 0 (0%) Others: 5 (4%)	Shoulder/Clavicle: 63 (36.8%) Trunk: 30 (17.5%) Knee:19 (11.1%) Hip/groin: 10 (5.9%) Foot: 9 (5.3%) Thigh/upper leg: 6 (3.5%) Lower leg: 6 (3.5%) Ankle: 5 (2.9%) Head/Face: 4 (2.3%) Arm/Elbow: 4 (2.3%) Hand/wrist: 4 (2.3%) Neck: 2 (1.2%) Others: 9 (5.3%)	Strain: 50 (17.3%) Tendonitis: 44 (15.2%) Impingement: 37 (12.8%) Sprain: 15 (5.2%) Spasm: 9 (3.1%) Inflammation: 8 (2.8%) Contusion: 7 (2.4%) Concussion: 6 (2.1%) Subluxation: 6 (2.1%) Sacroiliac joint dysfunction: 6 (2.1%) Fracture: 3 (1%) Others: 98 (33.9%)	Strain: 21 (21.8%) Impingement: 18 (14.5%) Tendonitis: 17 (13.7%) Sprain: 6 (4.8%) Spasm: 5 (4%) Concussion: 5 (4%) Contusion: 4 (3.2%) Fracture: 3 (2.4%) Inflammation: 2 (1.6%) Subluxation: 1 (0.8%) Sacroiliac joint dysfunction: 0 (0%) Others: 36 (29%)	Strain: 29 (17%) Tendonitis: 27 (15.8%) Impingement: 19 (11.1%) Sprain: 9 (5.3%) Sacroiliac joint dysfunction: 6 (3.5%) Inflammation: 6 (3.5%) Subluxation: 5 (2.9%) Spasm: 4 (2.3%) Contusion: 3 (1.8%) Concussion: 1 (0.6%) Fracture: 0 (0%) Others: 62 (36.2%)	♂ 55 (44.4%) overuse injuries/ 58 (46.7%) traumatic injuries [27 (21.7%) contact injuries/ 31 (25%) noncontact injuries]/11 (8.8%) others ♀ 109 (63.7%) overuse injuries/46 (26.9%) traumatic injuries [17 (9.9%) contact injuries/ 29 (17%) noncontact injuries]/16 (9.4%) other
Matsuura et al. 2019	Lumbar: 51 (54.3%) Shoulder: 22 (23.4%) Knee:10 (10.6%) Ankle: 8 (3.7%) Others: 3 (3.2%)						
Mountjoy et al. 2010	Shoulder: 9 (18.8%) Wrist/hand: 9 (18.8%) Lower back: 5 (10.4%) Head/face: 5 (10.4%) Hip/groin: 5 (10.4%) Multiple: 5 (10.4%) Cervical spine/neck: 3 (6.2%) Knee: 3 (6.2%) Others trunk: 2 (4.2%) Thigh/lower leg: 1 (2.1%) Ankle/foot: 1 (2.1%) Arm/elbow: 0 (0%)			Sprain/strain: 16 (33.3%) Skin lesion: 6 (12.5%) Contusion: 6 (12.5%) Tendinosis: 5 (10.4%) Subluxation/Dislocation: 3 (6.25%) Enthesopathy/fasciitis: 2 (4.2%) Muscle cramps: 1 (2.1%) Concussion: 1 (2.1%) Inflammation/bursitis: 1 (2.1%) Fracture: 1 (2.1%) Impingement: 1 (2.1%) Others: 5 (10.4%)			

Mountjoy et al. 2015	Shoulder: 19 (29.2%) Trunk: 6 (9.2%) Hand/Fingers: 4 (6.2%) Head/face: 3 (4.6%) Wrist: 3 (4.6%) Knee: 2 (3.1%) Foot/toe: 2 (3.1%). Arm: 2 (3.1%) Hip/groin/thigh: 1 (1.5%) Lower leg/ankle: 1 (1.5%)/ Cervical spine/neck: 1 (1.5%) NA: 21 (32.3%)	Tendinosis: 12 (18.5%) Sprain: 8 (12.3%) Laceration: 6 (9.2%) Strain: 4 (6.2%) Contusion: 4 (6.2%) Muscle cramps/spasm: 2 (3.1%) Impingement: 2 (3.1%) Arthritis/bursitis: 1 (1.5%) Fracture: 1 (1.5%) Concussion: 0 (0%) Others: 25 (38.5%)	
Nagano et al. 2019	* Only overuse injuries Lower back: 27.6% Shoulder: 16% Knee: 9.9% Ankle: 9.0% Hip/Thigh: 5.2% Pelvis/glute: 3.1% Foot: 2.8% Elbow/Upper arm: 2.2% Wrist/forearm: 1.3% Shank: 1% Finger: 0.3% Unknown: 1%		47.8% overuse injuries
Ristolainen et al. 2010	Upper arm/shoulder: 75 (35.7%) Knee: 34 (16.2%) Back (low back/upper back): 33 (15.7%) Forearm (elbow/palm/ wrist/fingers: 20 (9.5%) Ankle: 12 (5.7%) Foot (toes/heel/Achilles/ sole): 7 (3.3%) Hip/groin/gluteal/pelvis: 6 (2.9%) Thigh: 6 (2.9%) Head/neck/face/eye/tooth: 5 (2.4%) Calf: 5 (2.4%) Thorax/abdomen: 1 (0.5%) NA: 6 (2.9%)		93 acute injuries (1.10 injuries per 1000 exposure hours)/ 117 overuse injuries (1.48 injuries per 1000 exposure hours)
Soligard et al. 2017	Shoulder/clavicle: 7 (30.5%) Hand: 3 (13.1%) Knee: 3 (13.1%) Lumbar spine/lower back: 2 (8.7%) Ankle: 1 (4.3%) Elbow: 1 (4.3%) Face: 1 (4.3%)	Sprain/ligamentous rupture: 6 (26.1%) Contusion/haematoma/bruise : 4 (17.4%) Tendinosis/tendinopathy: 4 (17.4%) Impingement: 2 (8.7%)	Contact injuries: 4 Equipment failure: 1 Non-contact/trauma: 3 Overuse: 9 NA: 2 Others: 4

Finger: 1 (4.3%) Foot/toe: 1 (4.3%) Head: 1 (4.3%) Lower leg: 1 (4.3%) Thigh: 1 (4.3%)	Strain/muscle rupture/tear: 2 (8.7%) Lesion of meniscus or cartilage: 2 (8.7%) Laceration/abrasion/skin injury: 1 (4.3%) Others: 2 (8.7%)

♂: male; ♀: female, *NA: Not available.*

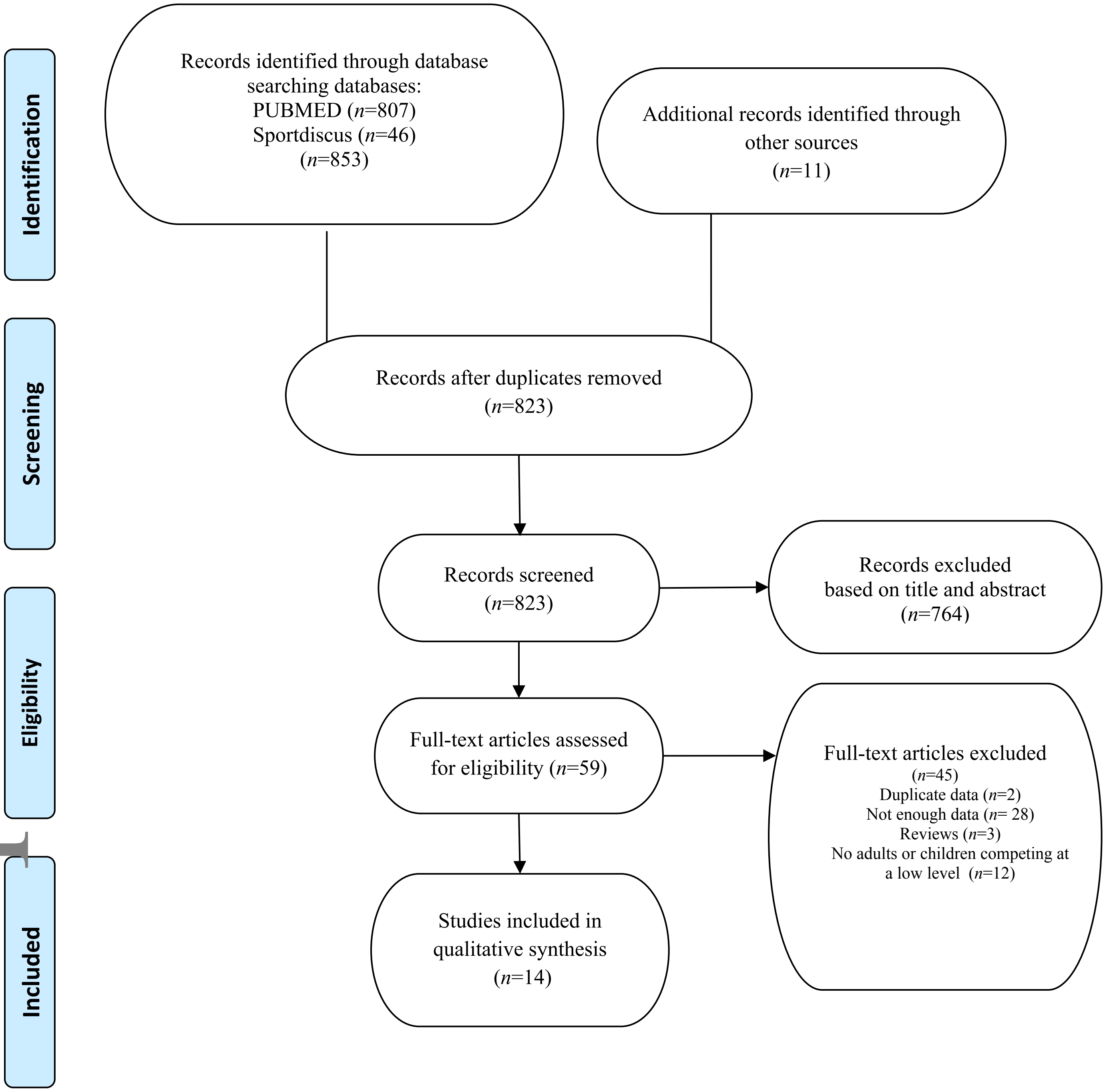

Figure 1. Flow chart of the selection of studies in the systematic review.