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SYSTEMATIC REVIEW

The Association Between Poor Sleep and the Incidence of Sport and Physical Training-Related Injuries in Adult Athletic Populations: A Systematic Review

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Abstract

Background The importance of achieving an adequate amount of sleep to optimize health and athletic performance is well recognized. Yet, a systematic evidence compilation of the risk for sport-related injury in adult athletic populations due to poor sleep does not exist.

Objective To examine the association between poor sleep and sport and physical training-related injuries in adult athletic populations.

Data Sources Electronic databases were searched using keywords relevant to sleep quantity and quality, and musculoskeletal injury and sport-related concussion (SRC).

Eligibility Criteria for Selecting Studies Studies were included in this systematic review if they were comprised of adult athletic populations, reported measures of sleep quantity or quality, followed participants prospectively for injury, and reported an association between sleep and incidence of sport or physical training-related injury.

Study Appraisal The methodological quality of each study was assessed using the Newcastle–Ottawa Scale for Cohort Studies.

Results From our review of 12 prospective cohort studies, we found limited evidence supporting an association between poor sleep and injury in adult athletic populations. Specifically, there is (a) insufficient evidence supporting the associations between poor sleep and increased risk of injury in specific groups of athletic adults, including professional or elite athletes, collegiate athletes, elite or collegiate dancers, and endurance sport athletes; and (b) limited evidence of an association between poor sleep and increased risk of SRC in collegiate athletes.

Conclusions The current evidence does not support poor sleep as an independent risk factor for increased risk of sport or physical training-related injuries in adult athletic populations. Given the methodological heterogeneity and limitations across previous studies, more prospective studies are required to determine the association between sleep and injury in this population.

Key Points

Enhancing the quality and quantity of sleep has been advocated as a useful strategy for improving the performance of adult athletic populations.

There is limited evidence to suggest that poor sleep quantity and quality result in an increased risk of sport and physical training-related injuries in adult athletic populations.

Future investigations may consider examining the role of sleep as a moderator of other potentially modifiable risk factors for sport-related injuries instead of as an isolated factor.

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1 Introduction

Injuries are common across a wide variety of physically active populations and pose a significant public health problem. According to the Centers for Disease Control and Prevention (CDC), roughly 8.6 million sports and recreation-related injury episodes occur annually in the United States [1]. In National Collegiate Athletic Association (NCAA) championship sports, an average of 210,674 injuries occurred annually during a 5-year reporting period (2009–10 through 2013–14), with American Football and football (soccer) accounting for the highest number of injuries for men and women, respectively [2]. Amongst collegiate athletes, most injuries are to the lower extremity [3], and sport-related concussions (SRC) account for roughly 6% of all injuries [4]. In addition, injuries occur frequently in professional athletes, [5, 6] and active-duty military personnel [7, 8]. In sport, injuries can have an immediate negative impact on the physical and mental health of young athletes [9], while long-term consequences include compromised team success [10], reduced activity levels [11], future impairments in quality of life [12] and increased risk of early-onset osteoarthritis [13]. Within the military, musculoskeletal injuries (MSK-I) have consistently been shown to be the leading cause of morbidity and lost duty days [14]. Consequently, identifying predictors of injury remains a top priority for sports medicine practitioners who are responsible for the care of athletes.

In recent years, there has been increased recognition [15–17] that poor sleep may be linked to athletic injury. Evidence from studies employing actigraphy [18, 19] and self-report [20, 21] indicates that collegiate athletes have insufficient sleep, while others have documented a high prevalence of poor sleep quality [22, 23], sleep complaints [24], daytime sleepiness [20, 23] and sleep disorders [25–27] in adult athletes. The reasons for poor sleep may include the reluctance to prioritize sleep over other athletic training demands and disruption of normal sleep patterns and circadian rhythms due to intense practice and competition schedules [28]. Further, physical pain and emotional stress incurred during practices or competitions may also limit the athlete's ability to achieve restorative sleep [29].

Sleep deprivation triggers intermediary mechanisms that may contribute to the incidence of injury. For example, testosterone and growth hormone (GH) are metabolic hormones involved in protein synthesis; yet sleep restriction after just 1 week leads to a significant reduction in testosterone levels in men [30]. Further, plasma concentrations of GH peak within 120 min of sleep onset, but when sleep is disrupted, GH levels are reduced [31]. In contrast, cortisol, a catabolic hormone, is released in higher concentrations following just 1 day of sleep disruption [32]. Together, these changes in hormonal secretion patterns with sleep disruption may impair skeletal muscle integrity, leading to injury. In addition, poor sleep quality negatively impacts anaerobic power [33, 34] and cardiorespiratory endurance [33], reduces maximal strength [35], delays muscle recovery [36, 37] and may alter the quality of dietary intake [38] to the extent that body composition is compromised. These alterations in sport performance and physique, coupled with increased reaction times [39], lapses in attention [40] and impaired visual tracking [40] that are associated with suboptimal sleep may hinder an athlete's ability to avoid injuries.

Accordingly, it is with good reason that position statements from the NCAA [16], the International Olympic Committee (IOC) [17] and the 4th International Congress on Soldiers' Physical Performance (ICSPP)[15] emphasize sleep education and assessment, good sleep hygiene, and treatment of sleep disorders using evidence-based approaches as strategies to improve the health and performance of elite athletes and military readiness in soldiers.

Consistent with the above position statements, a recent systematic review and meta-analysis found that adolescent athletes who chronically slept poorly were nearly 1.6 times more likely to suffer from a sport-related MSK-I [41], which may be attributable to poor sport performance or physiological changes in adolescents due to lack of sleep. However, a systematic evidence compilation of the risk for sport-related injury in adult athletic populations due to poor sleep does not exist. Accordingly, the purpose of the current paper was to evaluate existing scientific literature that examines the association between poor sleep and sport and physical training-related injuries in this group.

2 Methods

We performed a systematic review of the research literature to evaluate published, peer-reviewed studies examining the association between poor sleep and sport and physical training related injuries. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed to assess study methodology.

2.1 Article Selection

A research librarian (LS) performed a comprehensive search for relevant research articles published between January 1, 1970 and January 8, 2020 using the following online databases: CINAHL, ERIC, Medline, Ovid, PsycINFO, PubMed, SCOPUS, and SPORTDiscus. Search terms were: "sleep" AND "concussion" OR "mild traumatic brain injury" OR "traumatic brain injury" OR "injury" OR "musculoskeletal diseases" OR "musculoskeletal injury" OR "sprain" OR "strain" OR "fracture" OR "athletic injury" OR "dislocation" OR "tendonitis" OR "bursitis" OR "fasciitis" OR "joints" OR "risk assessment" OR "injury prevention" OR "attrition" OR "physical fitness" OR "exertion" OR "physical endurance" OR "physical education" OR "training" OR "exercise intervention" OR "physical exercise" OR "flexibility" OR "muscular strength" OR "muscular endurance" OR "muscular power" OR "aerobic fitness" OR "aerobic capacity" OR "aerobic power" OR "anaerobic fitness" OR "anaerobic capacity" OR "anaerobic power" OR "speed" OR "balance" OR "agility" OR "maximal oxygen consumption" OR "VO2max" OR "VO2peak" AND "military personnel" OR "Emergency Medical Technician" OR "athletes" OR "dancer" OR "emergency responder" OR "police" OR "firefighter" OR "soldier" OR "Army" OR "Navy".

To be included, studies were required to: (1) contain original data, (2) include participants aged 18–65 years, (3) report measures of sleep (quantity or quality), (4) track participants prospectively for subsequent sport or physical training-related MSK-I or SRC, and (5) report a measure of association (e.g., correlation coefficient, odds ratio, hazard ratio, risk ratio) or related metric with injury. Publications were excluded when: (1) populations were comprised of children or adolescents (17 years of age or younger), (2) injury data reported were exclusively general medical related (e.g., illness), or any classification where MSK-Is or SRCs were not of primary interest, (3) injuries were not the result of participation in sport or physical training-related activities, (4) publications were systematic reviews, literature reviews, cross-sectional studies, poster presentations, or conference abstracts, or (5) studies reported sleep-related measures as an outcome, rather than a risk factor for future injury incidence. Two investigators (DD and PL) independently screened titles and abstracts for relevance based on the inclusion criteria for this systematic review. The full texts of articles were screened when study eligibility could not be determined by title and abstract alone. Following initial screening, the two investigators met and any disagreements about article selection were resolved through discussion and consensus.

2.2 Quality Assessment

The same investigators (DD and PL) independently assessed each study for methodological quality using the Newcastle–Ottawa Scale (NOS) for cohort studies [33–35, 42]. The assessment tool was comprised of three sections: selection (4 items); comparability (1 item); and outcome (3 items). For the selection category, individual items included: (1) representativeness of the expressed cohort, (2) selection of the non-exposed cohort, (3) ascertainment of exposure, and (4) demonstration that outcome of interest was not present at start of study. The comparability category was comprised of one item, which was the comparability of cohorts on the basis of the design or analysis controlled for confounders. The outcome category included three items: (1) assessment of outcomes, (2) adequate follow-up time, and (3) adequacy of follow-up of cohorts.

For scoring, a study could be awarded one star for each item within the selection and outcome categories, whereas a maximum of two stars could be given for the comparability category. The awarding of stars for the comparability category is centered on the presence of "primary" and "other" confounders, which were predetermined by the reviewers. For the present review, a study was awarded one star for controlling for previous history of injury and a second star for including any other potential confounders (e.g., age, sex, and sport). The maximum total score for the NOS is nine stars.

After initial scoring, the investigators met to compare scores and any disagreements were resolved through discussion and consensus. Once determined, studies were rated on overall methodological quality using recommended Agency for Healthcare Research and Quality (AHRQ) standards [43, 44]. Designated ratings included: (a) good quality (3 or 4 stars in selection category AND 1 or 2 stars in comparability category AND 2 or 3 stars in outcome/exposure category); (b) fair quality (2 stars in selection category AND 1 or 2 stars in comparability category AND 2 or 3 stars in outcome/exposure category); or (c) poor quality (0 or 1 star in selection category OR 0 stars in comparability category OR 0 or 1 stars in outcome/exposure category).

The Oxford Centre for Evidence-Based Medicine Levels of Evidence tool [45] was used to assess the level of evidence for each study based on the question, "What will happen if we do not add a therapy (prognosis)?" We chose this question since our primary interest was to review studies designed to examine the association between sleep metrics and future incidence of injury.

2.3 Assessment of Evidence Summary

The overall strength of evidence for the association between sleep and sport and physical training-related injuries was assessed using criteria adapted from Bulzacchelli et al. [46] and determined to be:

- Strong evidence: Consistent findings reported from two or more multivariate analyses in good-quality studies
- Moderate evidence: Consistent findings reported from multivariate analyses in one good-quality study and at least one fair-quality study
- Limited evidence: Findings reported from multivariate analysis in one good-quality study or consistent findings reported from two or more multivariate analyses in fair-quality studies
- Conflicting evidence: Inconsistent findings from multivariate analyses in good or fair-quality studies

- Insufficient evidence: No evidence from multivariate analyses in good-quality studies, evidence from only one or no multivariate analysis in fair-quality studies

Given the methodological heterogeneity across the studies reviewed, specifically in regard to study populations and injury definitions, we chose to evaluate the strength of evidence for each unique population separately. In addition, a separate appraisal was performed for the association between poor sleep and incidence of sports-related concussion (SRC). Further, this approach was chosen since limiting the review to one distinct population only (e.g., elite or professional athletes) would significantly lessen the breadth of our findings. Nonetheless, we still assessed the overall strength of evidence for all reviewed studies with the aim of providing a comprehensive appraisal for the relationship between poor sleep and injury across all adult athletic populations.

2.4 Data Extraction

One investigator (DD) independently extracted data using a standardized set of abbreviations and reporting methods. The following information was abstracted from each study and entered into a data spreadsheet: reference and year of study, study design, sample size and participant characteristics, follow-up period for incidence of injury, injury type and definition, time period for sleep assessment, sleep measure and definition of "poor" sleep, and statistical measures of association (univariate analysis, multivariate analysis with adjustments, and "other" forms of reported outcomes). Regarding statistical measures, it is important to briefly note the differences between risk ratios (RR), odds ratios (OR) and hazard ratios (HR) since these were the most common statistics reported in the reviewed studies. Applied to the present review, the RR is the ratio of risk of an injury in the exposed group, or those presenting with "poor" sleep, versus the risk of injury in the non-exposed ("normal" sleep) group. In comparison, the OR is the probability or odds an injury will occur in the "poor" sleep group versus the odds of injury in those categorized as having "normal" sleep measures. For both measures, a value of 1.0 indicates that both groups have similar risk or odds for injury. Values > 1.0 indicate greater risk or odds of injury in the "poor" sleep group compared to the "normal" group, whereas values < 1.0 indicate a decreased risk or odds for injury in those presenting with "poor" sleep [47]. It has been reported that when the outcome (injury) is uncommon (< 10%), the OR and RR will be similar. In contrast, HRs can be used when risk changes over time. Consequently, the HR can change as the unit of time increases (e.g., days–weeks–full season). [47, 48].

3 Results

3.1 Search Findings and Study Selection

The electronic search yielded 3248 articles (CINAHL = 347, ERIC = 52, Medline = 143, Ovid = 161, PsycINFO = 283, PubMed = 569, SCOPUS = 1313, SPORTDiscus = 380). Three additional articles from other sources were identified as potentially relevant. A total of 1658 duplicate records were removed, and a further 1526 irrelevant articles were excluded based on title and abstract; 67 full-text articles were screened and 55 were removed, leaving 12 articles for inclusion in this review. Primary reasons for exclusion, in order were (a) study design was not prospective (e.g., cross-sectional, review); (b) unfitting primary injury outcome (e.g., illness, delayed onset muscle soreness, dermatological); (c) statistical analyses did not include measures of association or other related metric (e.g., interaction); and (d) population of interest was adolescents. The full results of the search are presented in Fig. 1.

3.2 Quality Assessment

The NOS quality assessment scores and the Oxford Centre for Evidence-Based Medicine (OCEBM) level of evidence for all included studies are shown in Table 1. The mean NOS score for all 12 studies was 4.41 stars (range: 3–8). Two studies were found to be of good quality, two were fair quality, and eight were of poor quality. Results revealed specific methodological limitations for each NOS category that were consistent across multiple studies. Within the selection category, only three studies received a star for being rated as representative of the adult athletic community as the remaining nine were comprised of participants from a select group (e.g., small cohort of professional athletes from one sport). Likewise, two studies measured sleep objectively (star) via actigraphy, one study measured sleep objectively and through self-report (star), while the remaining nine assessed sleep using self-report measures (no star). For the comparability category, five studies controlled for potential confounders in the statistical analysis, whereas the remaining seven were awarded no stars for conducting univariate analyses only. Within the outcome category, six studies were awarded a star for using medical records or direct injury diagnosis by a health care professional for determining injury incidence, while the other half used self-report measures only. In contrast, all 12 studies were awarded a star for following cohorts for an appropriate length of time for injury occurrence and 75% (8 of 12) reported no or minimal loss of participants to follow-up (star). No articles were excluded on the basis of methodological quality.

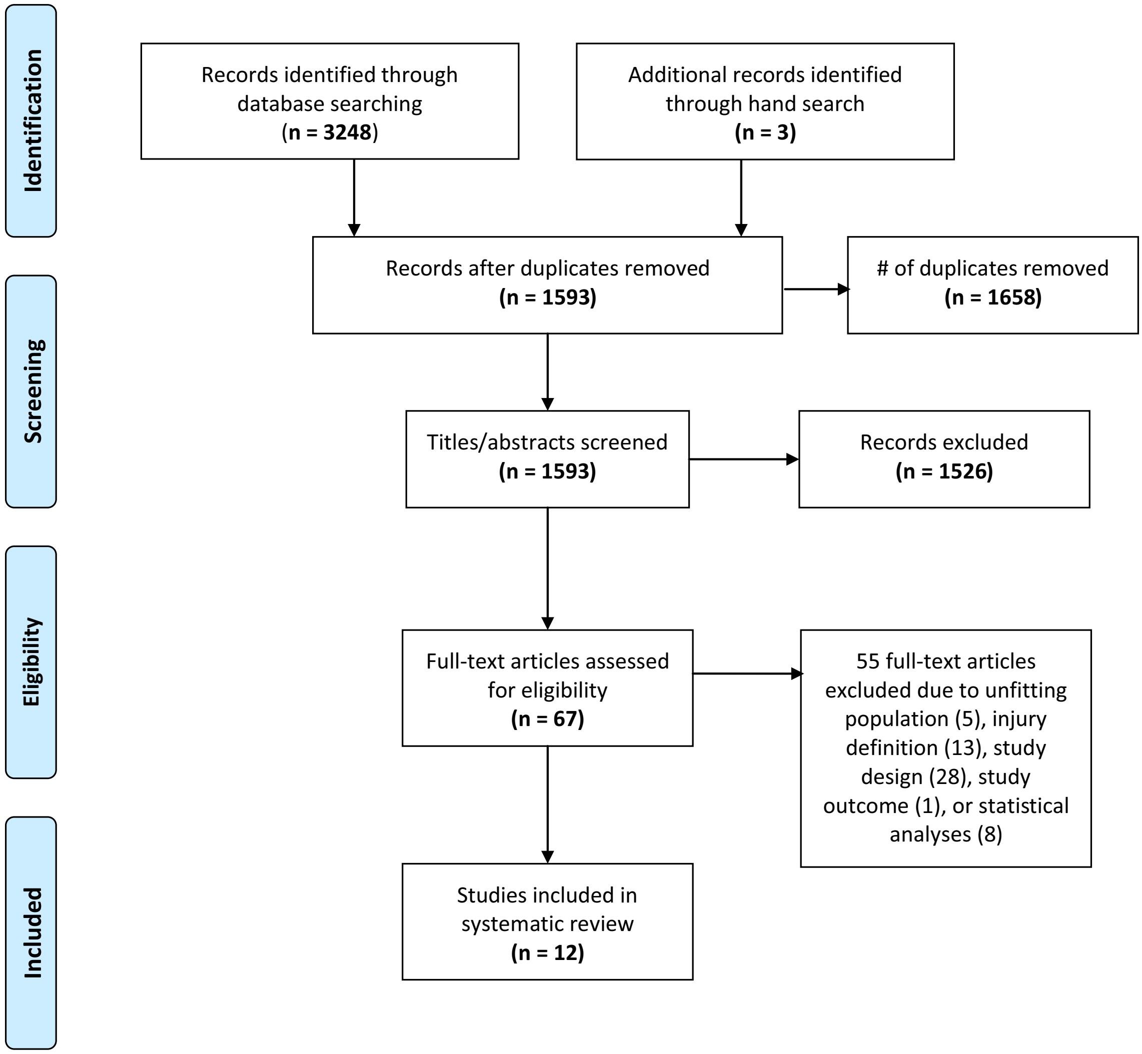

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram of search strategy

3.3 Participant Characteristics

The characteristics of the participants investigated in the included articles are presented in Table 2. Participants monitored in each study competed in the following sports: endurance sports (i.e., running, triathlon, swimming, cycling, and rowing) ($N=1$), rugby ($N=1$), cross-country running ($N=1$), Australian Rules football ($N=1$), American Football (N = 2), Irish/contemporary dance ($N=2$), soccer ($N=2$) and mixed martial arts ($N=1$). An additional study assessed athletes who were competing across 13 different collegiate sports (i.e., American Football, cross-country/track and field, swimming/diving, softball, baseball, gymnastics, golf, volleyball, tennis, basketball, cheerleading and cricket). The sample sizes for each study ranged from 8 to 384 athletes. Five studies examined men and women, while seven studies examined men only.

3.4 Injury Characterization

In the five studies reporting MSK-1 injuries that relied on medical records or diagnosis by a health care provider, the injuries were characterized based on severity (e.g., days of time loss) ($N=4$), location (N = 3), and mechanism (e.g., contact vs. non-contact, overuse) ($N=5$). An additional study reported SRCs. Of the six remaining studies, participants were instructed to self-report an injury as any physical complaint that caused reduced time from training or time loss ($N=4$) or asked to report the number of "injuries" sustained during the season and the resulting practices/games missed ($N=2$). In addition, two studies asked participants to report the type, mechanism or location of an injury.

Table 1 Oxford Center for Evidence-Based Medicine Level of Evidence (OCEM LOE) and Newcastle–Ottawa Scale (NOS) Assessment

Reference	OCEM LOE, study design	Total stars, AHRQ	Representativeness of the exposed cohort	Selection of Nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Follow-up was long enough for outcomes to occur	Adequacy of follow-up of cohorts
Burke et al. [49]	3, cohort study	6, fair	c	a*	a*,c	b	b*†	a*	a*	b*
Cahalan et al. [54]	3, cohort study	3, poor	c	a*	c	b	c	c	a*	b*
Cahalan et al. [55]	3, cohort study	3, poor	c	a*	c	b	c	c	a*	b*
Dennis et al. [51]	3, cohort study	4, poor	c	a*	a*	b	c	a*	a*	c
Hayes et al. [52]	3, cohort study	7, good	b*	a*	c	a*	a*,b*†	c	a*	b*
Johnston et al. [57]	3, cohort study	5, fair	a*	a*	c	b	b*†	c	a*	b*
Jones et al. [53]	3, cohort study	4, poor	c	a*	c	b	c	a*	a*	b*
Kilic et al. [56]	3, cohort study	3, poor	c	a*	c	b	b*†	c	a*	c
Laux et al. [58]	3, cohort study	4, poor	c	a*	c	b	c	a*	a*	b*
Peacock et al. [59]	3, cohort study	3, poor	c	a*	a*	b	c	d	a*	d
Raikes et al. [60]	3, cohort study	8, good	b*	a*	c	a*	a*,b*†	a*	a*	a*
Sampson et al. [50]	3, cohort study	3, poor	c	a*	c	b	c	a*	a*	d

AHRQ; Agency for Healthcare Research and Quality, a; good quality, b; fair quality, c: poor quality

*This grade merits a star per NOS criteria

† Multiple confounders controlled for in multivariate analyses

Table 2 Characteristics of the participants in each included study

Reference	Sport	Playing level	Participants (n)	Sex (n)	Age, y (mean ± SD)
Burke et al. [49]	American Football	Collegiate	94	M	19.6 ± 1.7
Cahalan et al. [54]	Dance	Professional/student Competitive	84	M: n = 18 F: n = 66	MTA: 20 (19, 22)[a] LTA: 20 (19, 23.5)[a]
Cahalan et al. [55]	Dance	Collegiate	50	M: n = 2 F: n = 48	ID: 21.5 ± 1.7 CD: 21.0 ± 3.1
Dennis et al. [51]	Australian Rules football	Elite	22	M	23.8 ± 3.2
Hayes et al. [52]	Cross-country	Collegiate	97	M: n = 40 F: n = 57	M:19.0 ± 0.2; F:19.2 ± 0.2
Johnston et al. [57]	Endurance sports	Elite/recreational	95	M: n = 61 F: n = 34	42.2 ± 10.0
Jones et al. [53]	Rugby	Elite	51	M	22.9 ± 4.1
Kilic et al. [56]	Soccer	Professional	384	M	27.0 ± 5.0
Laux et al. [58]	Soccer	Professional	22	M	25.8 ± 5.0
Peacock et al. [59]	Mixed martial arts	Professional	8	M	27.7 ± 3.4
Raikes et al. [60]	Varsity sports[b]	Collegiate	190	M: n = 103 F: n = 87	SRC—no: 20.6 (19.6–21.3)[c] SRC—yes: 20.0 (19.4–20.9)[c]
Sampson et al. [50]	American Football	Collegiate	42	M	20.5 ± 1.2

M: male, F: female, MTA: more time absent, LTA: less time absent, ID: Irish dance, CD: contemporary dance, SRC: sport-related concussion

[a]Median (interquartile range)

[b]Athletes competed in 13 Division I sports

[c]Confidence intervals

3.5 Injury Follow-Up Period

The duration of the study follow-up ranged from an 11-week pre-season to 16 months excluding summer break. Four studies [49–52] followed participants for incidence of injury during one competitive season, two [49, 50] of which were comprised of collegiate American Football players with a season length of 17 weeks. The other two studies were comprised of elite Australian Rules football players [51] or collegiate cross-country runners [52] and did not specify the exact number of weeks for each competitive season, though Hayes et al. [52] did report that injury surveys were completed in August (end of pre-season) and November (end of post-season). One study [53] examined the incidence of injuries in elite rugby players during an 11-week pre-season. Four other studies specified a follow-up period of one year, two of which [54, 55] were comprised of collegiate or professional dancers, while one each included professional soccer players [56] or endurance athletes [57]. In the other study of professional soccer players [58], athletes were followed for 16 months, though time characterized as summer break was excluded. Peacock et al. [59] followed professional MMA fighters for incidence of injury during a 6-week fight camp. In the only study [60] that examined SRCs as the sole injury outcome, athletes were followed for injury for at least one year following their completion of self-reported sleep measures.

3.6 Sleep Measures

Of the three studies that assessed sleep objectively with actigraphy, one monitored sleep continuously for the duration of a 6-week fight camp [59] while the other two [49, 51] measured sleep at regular intervals throughout the examination period. Specifically, Burke et al. [49] had collegiate American Football players wear actigraphs in 2-week increments for an entire 17-week season while Dennis et al. [51] monitored elite the sleep of Australian Rules football players the three nights before, night of, and night after games for one full competitive season. Characterization of sleep via self-report varied across the included articles. Three studies [49, 52, 60], each comprised of collegiate athletes (American Football, cross-country, or multiple sports), required participants to complete sleep assessments at baseline only or prior to the start of their competitive seasons. Four studies [50, 53, 54, 57] assessed sleep weekly, with two recording sleep once per week in either professional dancers [54] or endurance sports athletes [57] throughout a 1-year follow-up period. Jones et al. [53] assessed sleep biweekly in elite rugby players during an 11-week pre-season period while Sampson et al. [50] had collegiate American Football players self-report sleep quality three times per week during an entire 17-week competitive season. Two studies, comprised of collegiate dancers [55] and professional soccer players [58], assessed sleep monthly during a 1-year or 16-month (excluding summer break) follow-up period. Finally, Kilic et al. [56] asked professional soccer players to self-report sleep disturbances at baseline (prior 4 weeks), 6 and 12 months during a 1-year follow-up period. In regard to measures of self-reported sleep, participants were asked to report sleep quantity ($N=3$), sleep quality ($N=5$) or both quantity and quality of sleep ($N=2$). The mechanism of self-report included sleep diary ($N=3$), Likert scales ($N=2$), or validated questionnaires ($N=5$). The summary of specific article characteristics is presented in Table 3.

3.7 Evidence Summary

3.7.1 Sleep and Injury in Professional or Elite Athletes

Five studies [51, 53, 56, 58, 59] measured the association between sleep and injury in professional or elite athlete populations with only one [58] reporting a significant association between poor sleep and injury. Laux et al. [58] reported a significant univariate association (OR = 0.53; 95% CI: 0.33–0.86; $P=0.010$) between low sleep quality, as measured by the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) Sleep Quality scale, and increased risk of time loss injury in a study of 22 German professional soccer players. Results from the other four studies revealed no significant associations between objective or self-reported measures of sleep in sports comprised of elite Australian Rules football players [51], elite rugby players [53], professional soccer players [56], and professional MMA competitors [59]. Consequently, the evidence supporting the association between poor sleep and injury in professional or elite athletes is insufficient.

3.7.2 Sleep and Injury in Collegiate Athletes

Three studies [49, 50, 52] examined the association between sleep and injury in collegiate athletes. Hayes et al. [52] reported a significant univariate association (RR = 0.90; 95% CI: 0.81–1.00; $P=0.04$) between higher sleep quality scores, as measured by the PROMIS SD questionnaire, and decreased incidence of in-season injury in male and female collegiate cross-country runners. Findings from two studies comprised of collegiate American Football players revealed no associations between self-reported measures of sleep [49, 50] or sleep duration assessed via actigraphy [49], and injury. Therefore, there is insufficient evidence supporting an association between subjective or objective measures of sleep and injury in collegiate athletes.

3.7.3 Sleep and Injury in Dancers

Two studies examined the association between self-reported sleep and injury in male and female dancers [54, 55]. One study reported a univariate association between self-reported sleep duration and any physical complaint/injury that led to dance time loss; elite dancers reporting insufficient sleep were 2.54 times more likely to self-report > 14 days of absence from dancing because of pain/injury or absence during three or more months over a 1-year follow-up [54]. In a study comprising collegiate dancers, Cahalan et al. [55] reported a negative association (r = − 0.375, $P=0.007$) between self-reported sleep quality, as determined by the percentage of weeks where sleep was rated as "good" or "very good", and number of self-reported days that dancers were limited or unable to participate in dance activities. Accordingly, the evidence supporting the association between poor sleep and injury in professional, competitive, or student dancers is insufficient.

3.7.4 Sleep and Injury in Endurance Sport Athletes

Evidence that there is an association between poor sleep and injury in male and female endurance sporting participants is insufficient. One study comprised of male and female triathletes, swimmers, cyclists, and rowers reported a multivariate association between 14-day lag sleep quantity and incidence of injury that limited or resulted in time loss from training [57]. Athletes self-reporting a 14-day lag sleep quantity < 7 h/day were 1.51 times more likely to be injured than those reporting sleep quantity of 7 h/day. Further, findings revealed an association (HR = 0.63, 95% CI: 0.45–0.87; $P<0.01$) between a 14-day lag sleep quantity of > 7 h/day and incidence of new injury compared to the reference of 7 h/day [57].

3.7.5 Sleep and Sport-Related Concussion in Collegiate Athletes

Evidence that self-reported measures of sleep can predict incidence of SRC in collegiate athletes is limited. One study reported multivariate associations between insomnia and excessive daytime sleepiness reported at baseline, and incidence of SRC in male and female collegiate athletes from 13 different sports [60]. Athletes self-reporting clinically moderate-to-severe insomnia severity or excessive daytime sleepiness two or more times per month were 3.1 and 2.9 times more likely to suffer a SRC during a minimum of a one-year follow-up period, respectively, than those with lower insomnia or daytime sleepiness scores [60]. In sum, the evidence to support an association between poor sleep and sport and physical training-related injuries across numerous adult athletic populations is limited.

Table 3 Summary of study findings

Reference	Injury definition; recording; follow-up period	Sleep monitoring	Sleep assessments	Crude association	Association with adjustments	Other forms of outcomes reported	Strength of association
Burke et al. [49]	Injury resulting in time loss of at least one practice or game; recorded by sports medicine staff; follow-up: 17-week competitive season	Self-reported sleep at baseline (pre-season); actigraphs worn in 2-week increments for 17-week season	PSQI (sleep duration)[a]	–	OR = 1.00 (95% CI: 0.99–1.01, p = 0.356)[b]	–	≠
			PSQI total score[a]	–	OR = 1.04 (95% CI: 0.83–1.30, p = 0.759)[b]	–	≠
			ISI total score[a]	–	OR = 1.03 (95% CI: 0.93–1.14, p = 0.541)[b]	–	≠
			ESS total score[a]	–	OR = 1.04 (95% CI: 0.92–1.17, p = 0.535)[b]	–	≠
			SMAM total score[a]	–	OR = 1.01 (95% CI: 0.92–1.10, p = 0.913)[b]	–	≠
			Actigraphy (sleep duration)[a]	–	OR = 1.01 (95% CI: 0.99–1.02, p = 0.358)[b]	–	≠
Cahalan et al. [54]	Any physical complaint that caused time loss; self-reported each month; follow-up: 12 months	Self-reported sleep duration each month	Sleep survey; duration categorized as sufficient, intermediate, or insufficient	OR = 2.54 (95% CI: 1.03–6.27, p = 0.043)[c]	–	–	+
Cahalan et al. [55]	"Any pain or injury that impacted upon ability to dance"; Self-reported weekly; Follow-up: 12 months	Self-reported sleep quality weekly	Likert scale from 1 to 5 (1 = very good; 5 = very poor)	rs = − 0.375, p = 0.0007[d]	–	–	+
Dennis et al. [51]	Injury resulting in time loss[e]; recorded weekly by physiotherapist; follow-up: 1 competitive season	Actigraphs worn 3 nights before, night of and night after game for one full season	Actigraphy: average measures (sleep duration, rest duration, sleep efficiency) from preceding 2 weeks compared to week of injury	–	–	GLM[f]: sleep duration x sleep efficiency x injury (F(1,20) = 0.254, p = 0.620)	≠
Hayes et al. [52]	New in-season injury not present at pre-season; self-reported at end of pre-season and end of season; Follow-up: 1 competitive season	Self-reported at end of pre-season	PROMIS SD[g] total score (higher score = better sleep quality)	RR = 0.90 (95% CI: 0.81–1.00, p = 0.04)	OR = 0.93 (95% CI: 0.83–1.04, p = 0.18)[h]	–	+
Johnston et al. [57]	Any MSK complaint due to sport participation resulting in inability to train fully or time loss; self-reported weekly; follow-up: 1 year	Self-reported sleep quantity recorded per week/weekend day	Sleep quantity (h/day); 7- and 14-day time lag implemented	–	HR = 1.51 (95% CI: 2.02–1.13, p < 0.01)[i,j]; HR = 0.63 (95% CI: 0.45–0.87, p < 0.01)[j,k]	–	+ +

Table 3 (continued)

Reference	Injury definition; recording; follow-up period	Sleep monitoring	Sleep assessments	Crude association	Association with adjustments	Other forms of outcomes reported	Strength of association
Jones et al. [53]	Time-loss injury[l]; recorded by physiotherapist; follow-up: 11-week pre-season	Self-reported sleep quantity and quality biweekly (days 1 and 4)	Total sleep hours and Likert scale from 1 to 5 (1 = very poor; 5 = great) to measure sleep quality	All injuries: RR = 2.5 (90% CI: 1.1–5.6, p = 0.071)[m]; Mod-severity: RR = 6.7 (90% CI: 1.1–40.4, p = 0.081)[m]; Low and mod-severity: RR = 2.7 (90% CI: 1.1–6.5, p = 0.067)[m]; non-contact injury: RR = 2.2 (90% CI: 1.0–5.2, p = 0.113)[m]	–	–	≠
Kilic et al. [56]	Time-loss MSK-I of > 28 days; self-reported at baseline (previous 4 k), 6 and 12 months; follow-up: 1 year	Self-reported sleep disturbances at baseline (previous 4 week), 6 and 12 months	4 questions based on the PROMIS, scored on 5-point scale ("not at all" to "very much")	RR = 0.58 (95% CI: 0.32–1.04)[n]	RR = 0.56 (95% CI: 0.25–1.00)[n,o]; RR = 0.60 (95% CI: 0.30–1.31)[n,p]	–	≠
Laux et al. [58]	Injury resulting in time loss of 1 or more training sessions or games; recorded by medical staff; follow-up: 16 mo excluding summer break	Self-reported sleep quality on a monthly basis	RESTQ-Sport (higher score = better sleep quality)	OR = 0.53 (95% CI: 0.33–0.86, p = 0.010)	–	–	+
Peacock et al. [59]	Number of injuries and number of missed sessions due to injury; method of recording not reported; Follow-up: 6-week fight camp	Actigraphs worn continuously for 6 weeks	Total sleep time	r = 0.155, p = 0.741	–	–	≠
			Sleep latency	r = − 0.457, p = 0.303	–	–	≠
			Sleep efficiency	r = − 0.628, p = 0.131	–	–	≠
			Onset variances	r = 0.682, p = 0.091	–	–	≠
Raikes et al. [60]	Incidence of SRC; injury data extracted from medical records; follow-up: at least 1 year	Self-reported sleep at baseline	PSQI (sleep duration)[q]	RR = 0.52 (95% CI: 0.23–1.35, p = 0.289)	–	–	≠
			ISI[r]	RR = 3.13 (95% CI: 1.32–7.42, p = 0.015)	OR = 3.05 (95% CI: 0.93–9.22, p = 0.054)[u]	–	+ +
			FSS[s]	RR = 1.02 (95% CI: 0.39–2.69, p = 1.0)	–	–	≠
			NHANES Sleepiness[t]	RR = 2.86 (95% CI: 0.68–11.98, p = 0.037)	OR = 4.79 (95% CI: 1.25–31.62, p = 0.046)[u]	–	+ +

Table 3 (continued)

Reference	Injury definition; recording; follow-up period	Sleep monitoring	Sleep assessments	Crude association	Association with adjustments	Other forms of outcomes reported	Strength of association
Sampson et al. [50]	All non-contact injuries irrespective of time loss; recorded by athletic training staff, follow-up: one full season (17-wk)	Self-reported sleep quality 3 × per week	Likert scale from 1 to 5 (1 = slept terrible; 5 = excellent sleep)	–	–	No clear effect on likelihood of injury with "better" (> + 1SD) or "worse" (< -1SD) sleep	≠

PSQI: Pittsburgh Sleep Quality Index; ISI: Insomnia Severity Scale; ESS: Epworth Sleepiness Scale; SMAM: Sleep Medicine Associates of Maryland Sleep Apnea Risk Questionnaire; OR: Odds Ratio; rs: Spearman's rho; GLM: General Linear Model; RR: Relative Risk; PROMIS SD: Patient Reported Outcomes Measurement Information System Sleep Disturbance; RESTQ: Recovery-stress Questionnaire for Athletes; FSS: Fatigue Severity Scale; NHANES: National Health and Nutrition Examination Survey; SD: Standard Deviation; + +: significant multivariate association between poor/low sleep quality/quantity and increased risk of injury; +: significant univariate association between poor/low sleep quality/quantity and increased risk of injury; ≠: no significant association

[a]continuous scores

[b]adjusted for age and body mass index

[c]association between baseline sleep and membership in the "more time absent" group

[d]relationship between percentage of weeks during which sleep was rated "good or very good" sleep and number of days dancers reported being unable to dance or dance impeded

[e]injuries classified as moderate severity (missed 1–2 weeks of training and 1–2 games) or high severity (2 + weeks of training and 2 + games)

[f]additional results for repeated measures ANOVA: sleep duration x injury ($F(1,20) = 0.554$, $p = 0.469$), sleep efficiency x injury ($F(1,20) = 0.346$, $p = 0.563$)

[g]total sleep score encompassed sleep quality, sleep problems, refreshing sleep, restless sleep, ability to fall asleep, and effort to fall asleep

[h]adjusted for large mileage difference and pre-season injury

[i]14-day lag sleep quantity < 7 h/day (reference7 h/day)

[j]adjusted for endurance athlete subgroup, 7-day lag psychological/lifestyle subjective health complaints (SHCs), 7-day total SHC, 7-day lag gastrointestinal SHCs, and 7-day lag cardiorespiratory SHCs

[k]14-day lag sleep quantity > 7 h/day (reference 7 h/day)

[l]Injury severity determined by days of time loss: low (0–7 days), moderate (8–28 days), high (> 28 days)

[m]sleep < 8.1 h

[n]reference group (no reported sleep disturbance)

[o]adjusted for age

[p]adjusted for age and life events

[q]PSQI total sleep < 8 h (reference ≥ 8 h)

[r]ISI ≥ 15 (reference < 15)

[s]FSS ≥ 36 (reference < 36)

[t]2 + times per month (reference 0–1 times per month)

[u]adjusted for high SRC prevalence sport participation and ISI score ≥ 15 or daytime sleepiness 2 + times per month

4 Discussion

The importance of achieving an adequate amount of restorative sleep to optimize health and performance of athletes [16, 17] and readiness of military personnel [15] is well recognized. The primary aim of this systematic review was to examine the association between poor sleep and sport and physical training-related injuries in adult athletic populations. From our review of 12 prospective cohort studies, we found limited evidence supporting an association between poor sleep and injury in adult athletic populations. More specifically, findings revealed that there is (a) insufficient evidence supporting the associations between poor sleep and increased risk of injury in specific groups of athletic adults, including professional or elite athletes, collegiate athletes, elite or collegiate dancers, and endurance sport athletes; and (b) limited evidence of an association between poor sleep and increased risk of SRC in collegiate athletes. The present review is informative for sports medicine clinicians who might otherwise consider adding sleep into Periodic Health Examination (PHE) batteries for injury risk prediction [61].

4.1 Association Between Sleep and Injury

Six of the 12 studies reported significant associations between markers of poor sleep quality or quantity and increased risk of sport or physical training-related injury. However, only two of these studies reported multivariate associations between poor sleep and injury as the other four did not control for covariates, which limits the strength of evidence. Given the multifactorial etiology of sport-related injury in athletic populations, the use of a multivariate statistical model has been recognized as the preferred method to investigate potential risk factors for injury [62, 63]. Notably, these two studies employed markedly different injury outcomes with one each using MSK-I or SRC only. The two studies [52, 60] considered of good quality according to NOS criteria were conducted in collegiate athletes. Interpretation of the collective results must proceed with careful consideration of the strengths and weaknesses of each study.

In the investigation conducted by Hayes et al. [52], collegiate cross-country runners were queried about the occurrence and severity of MSK-Is sustained during the preceding season. Sleep quality was assessed during the pre-season using the short form Patient Reported Outcomes Measurement Information System (PROMIS) Sleep Disturbance (SD) questionnaire [64]. The risk of suffering an MSK-I was less among those who reported better quality sleep, but this association was no longer significant after controlling for differences in mileage and presence of a pre-season injury. Raikes et al. [60] recorded the incidence of SRCs amongst a large cohort of NCAA athletes competing across 13 Division 1 varsity sports. The authors then examined the association between incidence of SRC and self-reported sleep-related outcomes that were assessed prior to the competitive season. After adjusting for high SRC prevalence, sport participation and insomnia severity, daytime sleepiness was associated with an approximate 4.8 greater odds of sustaining an SRC. The two studies shared several strengths, including the inclusion of large samples of men and women, adequate follow-up period (i.e., one competitive season/full year) for an injury to occur, and adjustment for prior history of injury and other relevant confounders. Unlike Hayes et al. [52], who relied on self-reported injury data, Raikes and colleagues [60] confirmed the occurrence of SRC through the extraction of medical records.

Of the four additional studies [54, 55, 57] reporting a significant association between poor/low sleep quality/quantity and increased risk of injury, only one was considered to be of fair quality. Johnston and colleagues [57] asked endurance sports athletes (i.e., runners, triathletes, swimmers, cyclists and rowers) to self-report new MSK-Is resulting from participation in the sport and sleep quantity per day in weekly electronic online diaries. To determine whether sleep quantity contributed to the onset of a new injury, a 7-day and 14-day lag time was implemented, such that only sleep data from the 2 weeks prior to the onset of a new injury would be used in subsequent analysis. The authors found that compared to a reference of 7 h, a 14-day lag sleep quantity <7 h/day increased the risk of new injury by 51%, independent of the endurance athlete subgroup and various 7-day lag psychological/lifestyle subjective health complaints. While this study included a diverse sample that included men and women, an adequate follow-up period (i.e., full year), and adjustment for potential confounders, it was deemed of fair quality since it relied on self-report for assessment of sleep and injury occurrence and did not list exclusion criteria specific to pre-existing injury. Thus, it failed to demonstrate with certainty that the outcome of interest (i.e., sport-related injury) was not present at the start of the study.

The three remaining studies [54, 55, 58] were deemed to be of poor quality. Cahalan et al. [54] found that male and female dancers who reported being absent from dancing for greater than 14 days due to injury (i.e., "More time absent") were 2.54 more likely to report insufficient sleep than those who were "less time absent". In a subsequent year-long investigation [55], the investigators reported an inverse relation between the percentage of weeks during which sleep was rated "good" or "very good" and the number of days that a dancer reported being unable to dance, or impeded in his/her dancing. Finally, Laux et al. [58] found that low values on the sleep quality subscale of the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) were associated with higher subsequent risk of MSK-I among a small group of male professional soccer players over the course of a season; however, the actual implications of this finding are unclear, given that the RESTQ-Sport is not a valid or reliable measure of sleep quality [65]. Furthermore, a significant limitation of these studies, along with four of the remaining studies that did not report a significant association between poor sleep and sport-related injury [50, 51, 53, 59], were that they failed to adjust for potential confounders that might influence injury risk.

4.2 Measurement of Injury

Key variations in the outcome assessment across studies included differences in the definition of injury and methods used to determine injury occurrence (i.e., self-report or medical records). Inconsistencies in injury definition have been noted as a significant limitation in prior injury prevention research [66]. A strength of the current review is that six of the 12 studies we reviewed used medical staff to record injuries, and all but one of these studies used the "time loss" definition. Still, differences in what represents time loss existed between the studies. Whereas Burke et al. [49] defined time loss more broadly as "complete restriction from one or more practices or games", Jones et al. [53] established severity categories based on the number of days missed from scheduled training (i.e., low: 0–7 days missed, moderate: 8–28 days missed and high: > 28 days missed. Similarly, Cahalan et al. [54] separated dancers into "more time absent" vs. "less time absent", based on whether they missed more or less than 14 days due to injury, respectively. With regard to the five studies using self-reported injury data, time periods for collection included weekly [55, 57], monthly [54], at six months [56], and at the completion of the pre- and competitive seasons only [52]. Worth noting is that prior concerns have been raised as to the accuracy of self-reported injury details, in particular over increasing lengths of time [67, 68]. Lastly, one study in this review did not specify the method for injury data collection [59].

Additional methodological and reporting differences that may limit comparisons and thus warrant mention include diversity in the classification (e.g., MSK-I, SRC), onset (acute, chronic), and mechanism (contact, non-contact) of injuries irrespective of time loss. For example, six studies [50–52, 54, 56, 57] included only injuries to the musculoskeletal system whereas Raikes et al. [60] examined SRCs only. Three other studies used a broader definition of injury and included SRCs in the total injury tally, though MSK-Is comprised the majority of all injuries in each [49, 55, 58]. Of these, only Laux et al. [58] reported SRCs as an independent injury as both Cahalan et al. [55] and Burke et al. [49] combined SRCs with other injury types (e.g., whiplash, neck injuries). Worth noting is that according to the most recent data from the NCAA Injury Surveillance Program, American Football has the largest annual estimate of reported SRCs among 25 NCAA sports. [69] Despite the inclusion of SRCs in the total injury count of these three studies, only Raikes et al. [60] examined SRCs as an injury outcome, with results revealing that insomnia and daytime sleepiness were independent risk factors for SRCs. Given the inherent differences between concussions, defined partially as a "complex pathophysiological process affecting the brain, induced by biomechanical forces" [70], and injuries to the musculoskeletal system, caution should be taken when comparing findings across studies. Consequently, additional prospective studies that measure sleep and its association with SRCs are warranted. In regard to the reporting of injury onset, only three studies [51–53] included whether injuries were of acute or chronic origin though none examined these as separate injury outcomes. Similarly, only two studies clearly reported the mechanism of injury specific to contact or non-contact [51, 53], with one including non-contact injuries as a separate outcome [53]. In another study, Sampson et al. [50] examined non-contact injuries only. Notably, all three studies were comprised of athletes participating in collision sports (e.g., rugby, American Football). It is reasonable to suggest that these latter two injury characteristics, albeit limited to the few studies in which they reported, were influenced by population heterogeneity, another finding of this present review. In fact, studies included samples drawn from collision (five studies), contact (two studies) and non-contact sports or activities (four studies), with an additional study comprising athletes from 13 different sports that included all three groupings.

4.3 Ascertainment of Sleep

This review has also identified numerous methods through which sleep characteristics were ascertained. Wrist-worn actigraphs measure movement patterns which are then translated to sleep–wake scores based on computerized algorithms. In general, the validity and reliability of actigraphy in normal individuals with relatively good sleep patterns is reasonable [55], and therefore, may represent the most cost-effective method to objectively assess sleep quantity and quality in athletic groups. However, just three of the studies we reviewed utilized this technology. Dennis et al. [51] found that sleep efficiency amongst Australian Rules football players ($N = 22$) was less than what has been typically recommended for young adults. Further, Burke and colleagues [49] reported an average sleep duration of only six hours in a group ($N = 88$) of collegiate American Football players. However, neither of these studies reported a significant effect of sleep duration nor efficiency on injury. In addition, no associations between total sleep time or sleep quality characteristics (i.e., latency, efficiency or onset variances) as determined by actigraphy, and onset of injuries were found among eight professional mixed martial artists participating in a 6-week fight camp [59]. It has been recommended that actigraphy wear time be extended to at least five nights and that actigraphy monitoring be accompanied by subjective methodologies to increase reliability and provide more robust data on sleep than derived by body movement alone [33]. That being said, we note that compliance for wearing the watches was low in the Burke et al. study [49], potentially reducing the reliability of these data. Further, none of the above studies utilized a subjective measurement of sleep in concert with actigraphy. In a recent investigation published following the time period of the literature search for the present review, Silva et al. [71] examined the association between several sleep variables measured with actigraphy and injury in 23 elite male soccer players. Athletes were followed for incidence of injury over a 6-month period and results revealed a moderate negative correlation between sleep efficiency and several injury characteristics, including injury severity, greater time loss following injury, and the total number of injuries. An additional finding was that higher sleep latency was correlated with a greater number of injuries. However, actigraphy measures were only captured for 10 consecutive days during the pre-season and thus sleep was not assessed throughout the entirety of the injury follow-up period. Consequently, this may limit the interpretation of these findings as it is reasonable to suggest that sleep characteristics would likely fluctuate during a 6-month period of in-season competition. This methodological concern, albeit with the objective and not subjective (self-report) ascertainment of sleep, is consistent with investigations included in the present review that did not measure sleep throughout the entirety of the injury follow-up period [52, 60].

Subjective methods for ascertaining sleep characteristics varied widely between the studies and fell into two general categories: (1) self-reported sleep quantity or quality, and (2) completion of sleep questionnaires. While acknowledging that previous studies have reported lower sleep quantity and poorer sleep quality in athletes compared to non-athletes, our results revealed no clear trends regarding what aspect of sleep might explain increased injury in athletes. For example, whereas Johnston et al. [57] reported an increased risk of injury among endurance athletes who reported less than seven hours of sleep per night, Hayes et al. [52] found no independent association between self-reported sleep quality and in-season injury amongst collegiate cross-country runners. In contrast, the findings from Raikes et al. [60], who measured insomnia using the Insomnia Severity Index (ISI) questionnaire and daytime sleepiness using the NHANES Sleep module, suggest that daytime sleepiness, resulting from poor quality sleep and insomnia, may contribute to increased incidence of SRC in college athletes. We note further that the frequency with which sleep characteristics were assessed throughout the studies varied widely. Importantly, models of athletic injury etiology have described the dynamic nature of risk factors and the potential influence these changes may have in determining injury risk in sport environments [72]. As such, it is reasonable to assume that sleep behaviors change over the course of an athletic season, and therefore, pre-season assessment of sleep may not accurately depict sleep characteristics later in the year when travel and competitive demands are increased. This might explain why Hayes et al. [52] and Burke et al. [49] failed to demonstrate a significant association between self-reported sleep quality at baseline and the onset of injury in cross-country runners and collegiate American Football players, whereas the more frequent approach used by Johnston et al. [57] of assessing sleep quantity using a 7-day and 14-day lag time yielded a significant association between less sleep and increased injury risk amongst adult athletes competing in endurance sports. Consequently, future studies that examine the relation between subjective measures of sleep and injury should be designed to assess sleep longitudinally throughout the entirety of the injury follow-up period. However, we note that Raikes et al. [60] assessed insomnia and daytime sleepiness during the pre-season only, which predicted SRC during the competitive seasons of collegiate athletes.

4.4 Limitations

This systematic review is not without limitations. First, some studies may have been missed from the current literature search. Although we purposely used an expansive list of search terms that included language encompassing multiple components of health and performance-related measures of fitness to complement those specific to sport and physical activity, as well as a broad list of populations that included military, our search did not yield any prospective studies conducted in military cohorts. Worth noting is that of the 55 full-text articles that were excluded upon review, roughly 20 were comprised of military populations. The most common reason for exclusion was study design as most were cross-sectional reports and thus, no determination that poor sleep preceded injury incidence could be made. Given the recognition of sleep as a vital component in the health, performance, and overall preparedness of military members [15], future prospective studies in this population are warranted. Second, we considered only studies that included multivariate findings in our level of evidence determination. Consequently, four studies we reviewed that reported univariate associations between sleep and injury were not included. However, our level of evidence summary was adapted from previous systematic reviews [46, 73], and is aligned with the preferred methodological approach for studies investigating injury risk factors [62, 63]. Third, there was considerable variability in the methodology of the included studies. As previously discussed, studies differed in type of sport (e.g., endurance sports, collision sports), playing or performance level (e.g., collegiate/competitive student/professional dance) injury definition and other reported injury characteristics, and measures used to evaluate sleep (e.g., subjective questionnaires, actigraphy), including the frequency of these assessments. Importantly, none of the sleep questionnaires utilized across the 12 studies have been previously validated in athletic populations, and the RESTQ-Sport, used by Laux et al. [58] is not a valid or reliable measure of sleep quality [65]. Moreover, given this methodological heterogeneity, comparing findings across studies should be done with caution. However, we did evaluate the strength of evidence for each unique population separately, as well as studies only examining the incidence of SRC. To our knowledge, we are the first to systematically review the published literature on the association between sleep and sport and physical-training-related injuries in adult athletic populations. Therefore, we believe our findings should be useful to both researchers and practitioners interested in evidence-based risk factors for sport and physical training-related injuries.

5 Conclusion and Future Directions

The primary finding of this review is that the collective evidence supporting poor sleep as a risk factor for sport and physical training-related injuries in adult athletic populations is limited. Of the 12 reviewed studies, few examined this association using multivariate statistical models, and only one was specific to SRC. Consequently, additional research is warranted for both injury classifications (MSK-I and SRCs). In addition, while it remains unclear which method of sleep ascertainment (e.g., actigraphy, self-report, questionnaires) is most suitable for evaluating the sleep-injury relationship, we stress the importance of employing sleep questionnaires in future research studies that have previously been validated in adult athletic populations. Of note, the recently developed [74] Athlete Sleep Behavior Questionnaire (ASBQ), a valid and reliable means to evaluate the sleep behaviors of elite athletes, is moderately associated with total sleep time as determined by wrist-worn actigraphy. In addition, our review did not yield any prospective investigations conducted in military populations. This was surprising since poor sleep has been recognized as a problem in military populations, in particular during periods of deployment [75, 76], and MSK-I is the primary cause of limited duty days and decreased deployability rates [77] in these cohorts. Accordingly, there is a need for future research to examine the relationship between measures of sleep and injury in military populations. Lastly, recent conceptual work has suggested the need to examine sport injury from a complex systems approach, which considers the importance of multidirectional interactions between factors and their potential influence on risk profiling and subsequent injury occurrence [78]. As such, the authors have suggested that future research may want to explore the use of advanced statistical methods (e.g., machine learning) to improve sport injury prediction. When applied to the findings of this current review, investigators may consider examining the role of sleep as a moderator of other potentially modifiable risk factors for MSK-Is and SRCs instead of as an isolated factor.

Declarations

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