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Sleep, Recovery, and Musculoskeletal Injury Risk in Strength and Racquet-Sport Athletes: A Narrative Review

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Abstract

Background. Sleep is widely regarded as an important component of athletic recovery, although its relationship with musculoskeletal injury appears to be more complex than is sometimes implied.

Aim. To critically review evidence linking sleep duration and quality with recovery, physical and technical performance, pain, and musculoskeletal injury in strength and racquet-sport athletes.

Material and methods. A targeted narrative search of PubMed was conducted in August 2026. Consensus statements, systematic reviews, meta-analyses, prospective cohorts, controlled sleep-manipulation studies, and sport-specific research were prioritized.

Results. Sleep loss may impair selected physical, cognitive, and sport-specific outcomes. Experimental studies also indicate alterations in skeletal-muscle protein synthesis, selected hormonal and inflammatory responses, and pain perception. Associations between insufficient sleep and injury are more consistent in adolescents than in adults. Sport-specific prospective evidence remains limited.

Conclusions. Sleep is a relevant and modifiable component of recovery. Current evidence, however, does not establish insufficient sleep as an independent risk factor for musculoskeletal injury in adult athletic populations.

Key words: *sleep; recovery; musculoskeletal injury; resistance training; strength sports; tennis; badminton; athletic performance*

1. **Introduction**

Recovery after training does not occur as a single, clearly defined physiological event. It unfolds over time, with neuromuscular, metabolic, psychological, and other physiological processes responding to the preceding training stimulus. Sleep has become an increasingly prominent part of this discussion in sports medicine because it occupies a substantial proportion of the daily recovery period and is relevant to both physical and cognitive

functioning. Sleep duration, quality, and timing are therefore commonly considered when athlete recovery and readiness are assessed. [1,2] Experimental work further indicates that pronounced sleep loss can influence skeletal-muscle protein synthesis [3,4] and pain perception. [5] These findings make sleep biologically relevant to recovery, although biological plausibility alone is insufficient to demonstrate that inadequate sleep leads to musculoskeletal injury. The number of hours slept is only one part of the issue. Sleep opportunity, efficiency, continuity, timing, regularity, perceived quality, daytime sleepiness, chronotype, and the compatibility between an athlete's schedule and individual circadian tendencies may all influence how sleep should be interpreted. [1,6] Two athletes can report the same nightly sleep duration and still have quite different sleep profiles. One may sleep continuously and follow a stable schedule, while another may wake repeatedly or shift bedtime substantially from one day to the next. Context also matters. A single short night is unlikely to have the same significance as several nights of accumulating restriction. Observational data suggest that some elite athletes regularly obtain less sleep than they believe they require. Sargent et al. reported a mean self-assessed sleep need of approximately 8.3 h, whereas habitual sleep duration averaged around 6.7 h. Only a small proportion of participants obtained sufficient sleep to meet their own perceived requirement. [7] Earlier actigraphy-based research adds another layer to this picture. Leeder et al. found lower sleep efficiency and greater fragmentation in elite athletes than in non-athletic controls, although total sleep duration itself did not differ significantly. [8] Sleep duration, therefore, does not always capture the full picture. The wider athlete literature also shows substantial variability. Vlahoyiannis et al. reviewed 81 studies involving more than 1,800 athletes and reported a mean total sleep time of approximately 7.2 h. [6] Yet the findings varied considerably. Age, sex, sporting expertise, type of sport, and seasonal context all appeared to influence sleep characteristics. Against that background, a single universal sleep threshold is difficult to justify. Training organization can further shape sleep opportunity. Sargent et al. observed that athletes slept less before training days than before rest days, while shorter sleep was accompanied by greater pre-training fatigue. [9] These findings suggest that scheduling itself can constrain the time available for sleep, although they provide no direct evidence that changing training times reduces injury. Competition creates another set of practical challenges. Evening events may be followed by meals, post-match recovery procedures, media responsibilities, travel, or persistent physiological and psychological arousal. International competition can also involve travel fatigue and, when several time zones are crossed, circadian disruption and jet lag. Current consensus guidance recognizes these factors as relevant to sleep, alertness, and performance, although evidence supporting many specific travel-management strategies remains limited. [10] Professional tennis provides a useful example. Players may face late matches, uncertain start times, frequent travel, and short intervals between matches. A 2026 study involving 20 professional tennis players identified notable subjective sleep-quality concerns and reported some differences between male and female participants. [11] The small, cross-sectional design limits interpretation, but the study confirms that sleep disturbance occurs within this sporting population. The possible consequences of inadequate sleep also depend on the demands of the sport. Powerlifting and Olympic weightlifting require very high force production, technical precision, intermuscular coordination, and repeated exposure to heavy external loads. Injury surveillance commonly identifies the lower back, knee, shoulder, elbow, and upper limb among affected regions, although estimates vary considerably between disciplines and according to the injury definition used. [12] Reduced readiness after inadequate sleep could plausibly interact with these demands. Whether this interaction meaningfully alters injury incidence has not yet been established. Racquet sports impose a different combination

of stressors. Tennis involves repeated accelerations and decelerations, intermittent high-intensity activity, anticipation, decision-making, stroke precision, and substantial unilateral loading of the trunk and upper limb. Acute injuries often involve the lower extremity, whereas gradual-onset or overuse problems frequently involve the upper limb and trunk. [13] Badminton adds repeated lunges, rapid changes of direction, jumping, overhead actions, and very short reaction times. A recent systematic review and meta-analysis identified a substantial lower-limb injury burden and reported sprains and muscle injuries among commonly observed injury categories. [14] Several concepts therefore need to be separated. Performance impairment is not the same as delayed recovery. Delayed recovery does not necessarily imply pain, and pain should not be treated as synonymous with clinically defined injury. A decline in serving accuracy after sleep restriction is evidence of altered performance. Reduced muscle protein synthesis is a biological response. Greater pain sensitivity reflects altered symptom processing. None of these outcomes, considered alone, establishes a greater likelihood of structural musculoskeletal injury. The aim of this narrative review was to critically examine sleep, recovery, physical and sport-specific performance, pain, and musculoskeletal injury risk in athletes participating in strength and racquet sports. Particular emphasis was placed on distinguishing mechanistic evidence and performance outcomes from direct clinical injury data.

2. **Research Materials and Methods**

A targeted narrative search of PubMed was conducted in August 2026 using combinations of terms related to “sleep,” “sleep duration,” “sleep quality,” “sleep deprivation,” “sleep restriction,” “athletes,” “musculoskeletal injury,” “sports injury,” “recovery,” “pain,” “resistance exercise,” “strength,” “powerlifting,” “weightlifting,” “tennis,” and “badminton.” Reference lists from relevant reviews and consensus statements were also examined to identify additional publications directly related to the topic. Priority was given to expert consensus statements, systematic reviews and meta-analyses, prospective cohort studies addressing injury, controlled experimental studies in which sleep was manipulated, and primary sport-specific research. When specific numerical findings from individual investigations were discussed, original studies were preferred whenever available. Direct research examining sleep and injury in strength and racquet sports is scarce. For this reason, evidence from broader athletic populations and healthy adults was also included when it contributed to the interpretation of mechanisms, recovery, pain, or performance. Findings from those populations were not assumed to transfer directly to powerlifting, weightlifting, tennis, or badminton. The purpose of the review was to provide a critical narrative synthesis rather than a formal systematic review.

3. **Results**

3.1. **Sleep Characteristics in Athletic Populations**

The literature does not support the idea that athletes are uniformly sleep deprived. Some athletes experience recurrent short or irregular sleep, while others appear to maintain relatively adequate patterns. Sleep characteristics also vary substantially between sports, competitive levels, individuals, and phases of the training or competition cycle. [6,15] Part of that variation reflects the method used to assess sleep. Questionnaires and sleep diaries are practical and useful for identifying subjective complaints, but they do not measure sleep in the same way as actigraphy or polysomnography. An athlete may report an apparently acceptable amount of sleep while objective monitoring reveals fragmentation or reduced efficiency. The study by Leeder et al. illustrates this point well. Elite athletes showed lower sleep efficiency and greater fragmentation than non-athletic controls when assessed by wristwatch actigraphy, yet total sleep duration did not differ significantly between the groups.

[8] These findings should be viewed primarily as evidence that total sleep time alone may fail to capture potentially relevant differences in sleep characteristics, performance and injury were not assessed as outcomes. A broader perspective comes from Vlahoyiannis et al. More than 1,800 athletes were represented in their systematic review, with mean sleep duration of approximately 7.2 h and sleep efficiency of around 86%. [6] Those averages concealed substantial variation according to age, sex, level of expertise, sport, and seasonal context. In practice, this supports individualized interpretation rather than strict reliance on a single numerical threshold. Scheduling is one factor that can influence this pattern. Sargent et al. observed shorter sleep before training days, together with greater pre-training fatigue when sleep was reduced. [9] Although the study did not examine injury prevention, it provides direct evidence that training organization may restrict sleep opportunity. Competition may complicate sleep in other ways. Late finishes, post-event meals, treatment, travel, media responsibilities, and residual arousal may all postpone sleep onset. International travel introduces further complexity, particularly when circadian rhythms become misaligned. [10] The importance of these factors probably differs substantially between athletes and according to how frequently such disruptions occur. There are still relatively few sport-specific data in racquet sports. Marazziti et al. described subjective sleep-quality concerns in a small group of professional tennis players, with some differences between men and women. [11] Given the sample size and cross-sectional design, the study is more informative descriptively than in relation to causality. Evidence in badminton is similarly sparse. A 2025 systematic review identified only two eligible studies comprising 165 athletes. Poor sleep health was reported in roughly 28-36% of participants. Delayed sleep timing, greater training exposure, and academic stress were among the factors associated with poorer sleep in the included work. [16] With such a limited evidence base, prevalence and clinical consequences remain uncertain.

3.2. Acute and Repeated Sleep Loss and Athletic Performance

The relationship between sleep loss and performance is more consistently supported than the relationship between sleep and injury, although considerable heterogeneity remains. Fullagar et al. summarized evidence indicating that sleep loss may negatively affect selected physical, cognitive, and perceptual outcomes relevant to sport. [2] Not every task appears equally sensitive. Craven et al. later analyzed 69 publications and 227 performance outcomes. [17] Acute sleep loss was associated with an overall decline in exercise performance of approximately 7.6%. This pooled estimate should not be interpreted as a fixed response to one poor night. Heterogeneity was extremely high, and the magnitude of impairment varied according to the form of sleep loss, time of testing, population, and type of performance task. Negative effects were reported across endurance, strength, high-intensity exercise, anaerobic power, and skill domains. [17] Even so, the literature does not indicate that all aspects of performance deteriorate predictably whenever sleep is shortened. Total deprivation and severe experimental restriction are also much stronger interventions than the modest loss of sleep many athletes experience in routine practice. Repeated moderate restriction may be more relevant in real-world sport. One slightly short night may have little measurable effect in some athletes. The same degree of restriction, repeated for several nights during a demanding training block or tournament, may be more consequential. The evidence is therefore best summarized cautiously. Substantial or repeated sleep loss can impair selected performance domains, but susceptibility varies, and performance impairment should not be treated as equivalent to injury risk.

3.3. Neuromuscular Performance and Strength Sports

The effects of inadequate sleep on maximal strength are less consistent than commonly assumed. Knowles et al. reported mixed findings across the available literature. [18] Acute sleep deprivation often had little effect on isolated maximal-force measures, while repeated restriction appeared more likely to interfere with some multi-joint resistance-exercise tasks. A later systematic review reached a similar conclusion. [19] Some outcomes deteriorated, whereas others remained relatively unchanged. Differences in training status, exercise selection, timing of testing, and sleep-loss protocol probably explain part of the inconsistency. The distinction between laboratory tests and real strength-sport performance is important. A single-joint maximal-force test requires relatively little technical coordination. A squat, deadlift, bench press, clean, or snatch demands bracing, sequencing, attention, motor control, and coordination in addition to force production. Consequently, relatively preserved isolated strength does not necessarily imply that complex barbell performance is unaffected. Training readiness is broader still. Repetition capacity, bar velocity, power output, perceived effort, motivation, technical consistency, and tolerance of total training volume can all influence a training session. A lifter may complete a heavy single after a poor night's sleep but still experience greater difficulty maintaining quality across the remainder of the session. The link with injury is much less certain. Tung et al. reported injury incidences of approximately 2.4-3.3 injuries per 1,000 training hours in weightlifting and approximately 1.0-4.4 per 1,000 hours in powerlifting. [12] Frequently affected anatomical regions included the lower back, knee, shoulder, elbow, and hands or fingers. These figures characterize the injury burden of strength sports rather than identifying sleep as a specific risk factor. Within the literature identified for this review, few prospective studies directly examined repeated sleep measures alongside standardized injury surveillance in competitive powerlifters or weightlifters. Sleep may still contribute to a wider pattern of reduced readiness. Repeated restriction occurring at the same time as high relative intensity, accumulated fatigue, pain, or recent injury could plausibly influence how an athlete tolerates training. The extent to which sleep contributes independently from these accompanying factors remains uncertain.

3.4. Sport-Specific Performance in Tennis and Badminton

In racquet sports, performance depends heavily on functions that may not be captured by simple measures of maximal physical capacity. Technical precision, anticipation, reaction, decision-making, and the ability to adjust rapidly to an opponent are central to successful play. Reyner and Horne examined serving accuracy after partial sleep restriction in performance tennis players. [20] After a restricted condition involving approximately 5 h of sleep, serving accuracy was lower than after normal sleep. In a separate experiment, 80 mg of caffeine did not restore serving accuracy to the level observed under normal-sleep conditions. The study was small and focused on one component of performance. Even so, it provides direct experimental evidence that restricted sleep can affect a technically demanding tennis skill. Schwartz and Simon considered the reverse situation. Twelve collegiate varsity tennis players increased mean sleep duration from approximately 7.14 to 8.85 h during a period of sleep extension. Serving accuracy improved from 35.7% to 41.8%, while daytime sleepiness decreased. [21] The findings are compatible with the possibility that increasing sleep opportunity may benefit selected technical outcomes, particularly when habitual sleep is insufficient. The design, however, was non-randomized and lacked an independent control group. Familiarization, learning, expectations, or changes in routine may therefore have contributed to the observed improvement. Neither study assessed injury. Reduced serving accuracy after sleep

restriction is best interpreted as a performance outcome. A pathway involving impaired attention or motor control and subsequent injury exposure is plausible, but it has not been demonstrated prospectively. Badminton provides another example of the uncertainty in this field. Skare et al. studied 153 elite junior athletes. [22] Around 28% demonstrated poor sleep behavior and 27% reported current musculoskeletal symptoms. After adjustment, poor sleepers did not have significantly greater odds of symptoms, the reported odds ratio was 1.23 with a 95% confidence interval of 0.52-2.90. The wide interval means that considerable uncertainty remains. At the same time, the finding does not support a simple deterministic relationship between poor sleep and musculoskeletal symptoms. Badminton itself involves repeated lunges, jumps, rapid accelerations and decelerations, multidirectional movement, and frequent overhead actions. Lower-limb injuries represent a substantial part of the reported injury burden. [14] The epidemiological evidence identified for this review has not established inadequate sleep as an independent predictor of these injuries.

3.5. Sleep and Skeletal-Muscle Protein Metabolism

One of the more plausible biological links between sleep and recovery involves skeletal-muscle protein turnover. Adaptation to training depends partly on muscle protein remodeling, and experimental evidence indicates that severe sleep restriction can interfere with this process. Saner et al. studied 24 healthy young men exposed to five consecutive nights with only 4 h of time in bed. [3] Myofibrillar protein synthesis was lower during sleep restriction than during normal sleep. High-intensity interval exercise modified this response, suggesting an interaction between exercise and restricted sleep at the level of muscle protein metabolism. From a mechanistic perspective, the finding is relevant. Several nights of substantial sleep restriction altered a process involved in skeletal-muscle adaptation. The study did not, however, involve competitive strength or racquet-sport athletes, and no clinical injury outcome was measured. Lamon et al. reported a related effect after one night of total sleep deprivation. [4] In 13 healthy young adults, postprandial muscle protein synthesis during the following day was approximately 18% lower. Cortisol was higher and testosterone lower during the measured period. Again, the physiological effect is clear, but its direct clinical meaning is limited. Total sleep deprivation is very different from a moderately shortened night, and a short-term reduction in protein synthesis cannot be translated directly into a defined increase in muscle strain or tendon injury. Dáttilo et al. provide an instructive contrast. [23] After exercise-induced muscle damage followed by 48 h of sleep deprivation, several hormonal and inflammatory responses changed, including IL-6. Recovery of voluntary muscle strength, however, was not delayed. This discrepancy matters. A biomarker may change even when a functional outcome remains relatively stable. Mechanistic findings should therefore not be treated automatically as surrogates for clinically meaningful recovery. Chennaoui et al. reviewed several potential mechanisms through which sleep could contribute to recovery from exercise-induced muscle injury, including inflammatory, endocrine, metabolic, and neural pathways. [24] These mechanisms are biologically plausible and useful for understanding the field, but they remain proposed pathways rather than established mediators of injury in athletes.

3.6. Endocrine and Inflammatory Responses

Sleep deprivation can alter selected hormonal and inflammatory variables. Lamon et al. reported changes in cortisol and testosterone, [4] while Dáttilo et al. observed differences involving cortisol, IGF-1, and IL-6. [23] These responses are strongly context dependent. A night without sleep is not simply an extreme version of sleeping somewhat less than usual. Nutritional intake, preceding exercise, timing of blood sampling, age, sex, and baseline sleep characteristics can all modify the observed endocrine response. This is relevant to strength

sports, where cortisol and testosterone are sometimes treated as convenient markers of readiness. Current evidence does not support using an acute change in either hormone as a stand-alone predictor of musculoskeletal injury. [18] Inflammatory variables present a similar interpretive problem. Exercise itself alters inflammatory signaling as part of normal adaptation. A change in circulating IL-6 following sleep deprivation is therefore an intermediate physiological finding rather than evidence of pathological inflammation or impending tissue injury. [23] The endocrine and inflammatory literature is most useful in demonstrating biological plausibility. A direct dose-response relationship between hours of lost sleep and musculoskeletal injury has not been established.

3.7. Sleep, Pain Perception, and Musculoskeletal Symptoms

Pain may represent one of the more clinically relevant links between sleep and perceived recovery. Athletes frequently make training decisions partly on the basis of soreness or discomfort, and some injury-surveillance systems include painful conditions that alter participation even in the absence of a clearly defined structural lesion. Schrimpf et al. examined experimental studies of sleep deprivation and pain perception in healthy participants. [5] Their meta-analysis found increased pain sensitivity following sleep deprivation in between-group analyses. Methodological differences across studies were substantial, and the clinical significance of the effect remained uncertain. This distinction is important. Greater pain sensitivity does not necessarily indicate greater tissue damage. The same exercise-related soreness may simply feel more intense after poor sleep. The relationship may also operate in the opposite direction. Runge et al. found prospective evidence suggesting that baseline sleep problems were associated with later chronic musculoskeletal pain. [25] Evidence for the reverse pathway, from musculoskeletal pain to subsequent sleep problems, was also present, although it was less consistent across follow-up periods. These studies were not restricted to athletes, which limits direct extrapolation to competitive sport. For an athlete with persistent symptoms, sleep disturbance may therefore form part of the overall clinical picture without being the original cause of the problem. Poor sleep may amplify symptom perception, whereas pain may subsequently impair sleep quality or continuity. Pain, soreness, time-loss injury, medical-attention injury, and confirmed tissue damage should therefore remain conceptually distinct.

3.8. Direct Evidence Linking Sleep and Sports Injury

The injury literature differs considerably between adolescents and adults. Milewski et al. retrospectively examined 112 adolescent athletes. Those reporting less than 8 h of sleep per night had approximately 1.7 times the likelihood of having recorded an injury compared with athletes reporting at least 8 h. [26] Because sleep exposure was self-reported and the design retrospective, the result represents an association rather than evidence of causation. Gao et al. subsequently pooled seven adolescent studies. [27] Chronic poor sleep was associated with greater odds of sports or musculoskeletal injury, with an odds ratio of 1.58 and a 95% confidence interval of 1.05-2.37. Prospective work by von Rosen et al. offered further support, although within a broader framework. Sleeping more than 8 h on weekdays was associated with lower injury odds in adolescent elite athletes. [28] Later longitudinal work from the same group considered sleep together with changes in training volume, training intensity, and other biopsychosocial factors. [29] That broader interpretation is probably more appropriate than treating sleep as a single dominant exposure. The adolescent literature suggests that sleep may contribute to injury risk, but it does not indicate that 8 h represents a precise biological boundary between risk and safety. The adult literature is considerably less consistent. Dobrosielski et al. reviewed 12 prospective cohort studies and concluded that poor sleep had not been established as an independent risk factor for sport- or physical-training-related injury in adult athletic populations. [30] Lytle et al. provided a more recent perspective using actigraphy-

based studies. [31] Four of seven studies examining injury found an association between poorer sleep metrics and injury occurrence, while three did not. Overall, the relationship remained inconclusive. The contrast with performance outcomes is important. Performance can be measured repeatedly and may change within hours after a sleep intervention. Injury is less frequent, has multiple determinants, and requires larger cohorts and longer follow-up. The adult evidence therefore supports a cautious conclusion. Poor sleep may be relevant to performance and recovery, but it has not been established as an independent risk factor for musculoskeletal injury.

3.9. Interaction Between Sleep and Training Load

Sleep does not occur independently of training. That is likely to be one reason why its isolated relationship with injury has been difficult to determine. A short night before a low-load technical session is not necessarily comparable with a short night during a period of maximal lifting intensity. In the same way, inadequate sleep after a relatively easy tennis practice differs from restricted sleep following a prolonged evening match and subsequent travel. The work of von Rosen et al. is useful here because sleep was interpreted together with training and other biopsychosocial variables. [29] The quantitative findings come from adolescents and should not be transferred directly to adult strength or racquet-sport athletes, but the conceptual model remains relevant. Strength athletes may experience phases in which high intensity, accumulated fatigue, pain, body-mass manipulation, and psychological stress overlap. If an injury occurs during such a period, assigning the event to sleep alone would be difficult to justify. Tennis presents a similar problem. Match duration, court surface, environmental conditions, travel, late finishes, and congested scheduling can occur simultaneously. Poor sleep may therefore be one element of a wider cluster of exposures. For this reason, sleep is probably best viewed as one part of a changing recovery environment rather than as a single isolated injury determinant.

4. Discussion

The available literature gives a reasonably coherent overall picture, although it is not a simple one. Sleep clearly matters for recovery and performance. Its independent role in musculoskeletal injury, particularly among adults, remains much less certain. For performance outcomes, the evidence is comparatively strong. Substantial sleep loss can impair selected physical, cognitive, and sport-specific tasks. [2,17] The magnitude of the effect varies considerably, and resistance exercise seems less uniformly affected than some endurance or skill-based outcomes. [18,19] The tennis literature illustrates why outcome specificity matters. Serving accuracy deteriorated after sleep restriction and improved during sleep extension. [20,21] These findings are meaningful for technical performance, but they offer no direct evidence regarding subsequent injury incidence. Mechanistic research requires the same degree of caution. Sleep restriction can reduce skeletal-muscle protein synthesis, [3,4] and severe deprivation can alter selected hormonal and inflammatory responses. [4,23] These findings demonstrate physiological effects, but their translation into clinically relevant injury outcomes remains uncertain. Dáttilo et al. provide a particularly useful example. [23] Several inflammatory and hormonal variables changed, yet voluntary muscle-strength recovery was not delayed. Biological change and functional impairment do not always move in parallel. Pain further complicates the picture. Sleep deprivation can increase pain sensitivity, [5] and prospective evidence suggests that chronic musculoskeletal pain and sleep disturbance may influence one another over time. [25] The sleep-to-pain direction appears more consistently supported than the reverse pathway, although both have been reported. In athletes, this interaction may affect soreness, perceived recovery, and symptom reporting. Greater pain sensitivity is not equivalent to greater tissue damage. An athlete may feel worse

after poor sleep without having sustained a new injury. Conversely, pain from an existing musculoskeletal problem may make subsequent sleep more difficult. This bidirectional relationship limits the interpretation of cross-sectional findings. The injury literature is most consistent in adolescents. [26-29] Even in this group, most data are observational. The widely cited 8-h threshold should therefore be interpreted as a category used in several studies rather than as a universally validated injury-prevention target. The situation in adults is less convincing. Dobrosielski et al. did not identify strong evidence that poor sleep independently predicts sport- or physical-training-related injury, [30] and the newer actigraphy-based review reached a similarly cautious conclusion. [31] The absence of a consistent independent association should not be interpreted as evidence that sleep is irrelevant to athlete health or recovery. Rather, current research has not isolated its contribution to injury risk with sufficient consistency. Sleep may interact with workload, pain, prior injury, nutrition, psychological stress, and competition scheduling in ways that are difficult to separate.

4.1. Practical Implications for Strength Athletes

For strength athletes, sleep may be considered as one component of a broader assessment of recovery and training readiness. The available evidence suggests that inadequate sleep can affect selected strength and resistance-exercise outcomes, although responses vary considerably between tasks and sleep-loss protocols. [1,18,19] One moderately short night may have little measurable consequence for some athletes, whereas repeated sleep restriction may be more relevant when accompanied by increasing fatigue or deterioration in training performance. Nevertheless, the available evidence does not define a sleep-duration threshold at which strength training becomes unsafe. Longitudinal patterns may therefore provide more useful context than an isolated nightly value. Sleep duration and perceived sleep quality can be considered alongside training performance, fatigue, pain, and other recovery-related information. Current evidence, however, does not support sleep measures alone as established independent predictors of sport- or training-related injury in adult athletic populations. [30,31] In practice, information on recent sleep may therefore be interpreted alongside other indicators of recovery rather than used in isolation. Whether modifying training specifically in response to poor sleep reduces musculoskeletal injury risk has not been established. [1,30,31] An additional limitation is that experimental studies frequently use total or marked sleep deprivation, whereas the effects of more moderate partial sleep restriction may be less consistent. The strength outcomes examined across studies also differ substantially in their technical and neuromuscular demands. [1,18,19] More sport-specific prospective research is needed before precise sleep-based recommendations for injury-risk management can be made.

4.2. Practical Implications for Tennis and Badminton

In racquet sports, the practical effects of inadequate sleep may appear first through technical inconsistency rather than loss of maximal physical capacity. The available tennis data support this possibility. [20,21] Recent sleep should therefore be considered when an athlete unexpectedly reports unusual fatigue or demonstrates poorer technical consistency. At present, however, sleep extension should not be described as a proven strategy for reducing musculoskeletal injury. Tournament scheduling provides a practical reason to protect sleep opportunity. Late matches, post-match recovery procedures, travel, and early obligations can all reduce the amount of time available for sleep. Where possible, minimizing avoidable delays to bedtime is consistent with current sleep and travel guidance for athletes. [1,10] Badminton introduces another issue, particularly among younger athletes: the need to balance training with educational responsibilities. Academic stress and delayed sleep timing may

contribute to poor sleep behavior in this group. [16] These practical constraints may be more relevant than highly detailed interpretation of consumer-device sleep-stage estimates.

4.3. Sleep Extension, Napping, and Sleep Hygiene

When habitual sleep is insufficient, increasing sleep opportunity is a reasonable strategy. Systematic reviews suggest that sleep extension and napping are among the more promising interventions for improving selected athletic-performance outcomes. [32-34] The literature is still relatively small and heterogeneous. Cunha et al. identified improvements in selected physical and cognitive outcomes following sleep interventions, although the studies varied considerably in design, population, intervention type, and endpoint. [32] Silva et al. found only a limited number of eligible sleep-extension studies in athletes. [33] Some outcomes improved, but certainty varied between endpoints. Sleep extension is therefore better described as potentially useful than universally effective. Napping may help provide additional sleep opportunity when nocturnal sleep is restricted or when competition takes place later in the day. Its effect depends on timing, duration, preceding sleep, and the interval between waking and subsequent performance. [1,32,34] Sleep-hygiene advice usually focuses on preserving sleep opportunity, maintaining an appropriate sleep environment, and avoiding behaviors that unnecessarily delay bedtime. [1] Education alone has not consistently produced large improvements in performance. [32,34] Persistent insomnia symptoms, excessive daytime sleepiness, suspected sleep-disordered breathing, or other clinically important complaints require more than generic sleep-hygiene recommendations. Duffield et al. evaluated a combined recovery intervention in tennis that included sleep-hygiene recommendations, cold-water immersion, and compression garments. [35] Several recovery-related outcomes differed between conditions, but the individual contribution of sleep hygiene cannot be separated from the other components of the protocol.

4.4. Individualization of Sleep Recommendations

Consensus recommendations favor an individualized approach. [1] Age, habitual sleep, perceived sleep need, daytime functioning, competition schedules, travel, and possible sleep disorders all matter. Population-based sleep recommendations remain useful as general reference points. They should not, however, be converted into precise athletic injury thresholds without supporting evidence. Sleep regularity may also be relevant. Large changes in bedtime and wake time could plausibly affect circadian alignment and recovery, but evidence defining an optimal level of regularity specifically for injury prevention in strength or racquet sports remains limited. Wearable devices can help identify broad within-athlete trends in sleep timing and estimated duration. They should not be treated as equivalent to polysomnography. [1,6] In practice, a pattern observed over several weeks is likely to be more useful than interpreting a single night's estimated sleep stages. The actigraphy literature also shows that more objective measurement does not automatically solve the problem of injury prediction. [31] Better exposure assessment improves methodology, but the underlying relationship remains complex.

4.5. Limitations of the Existing Evidence

Several methodological problems explain why a plausible biological relationship has not translated into a consistent estimate of injury risk. Sleep is defined differently between studies. One investigation may use duration, another a questionnaire score, and another actigraphy-derived variables. These approaches do not necessarily describe the same exposure. Injury definitions vary just as much. Pain that modifies training may be grouped together with time-loss injury or medically diagnosed structural injury. These endpoints are not equivalent. Reverse causation remains an important concern. Pain may disturb sleep. Injury can alter training

volume, medication use, psychological state, and daily routine. Unless sleep is measured prospectively before injury, the direction of the relationship remains uncertain. Training and competition exposure can also confound the association. Athletes who train or compete more frequently may simultaneously have less time for sleep and more opportunities to become injured. Experimental work has a different limitation. Total sleep deprivation and repeated 4-h sleep opportunities are useful for identifying mechanisms, but they may not resemble the partial, variable sleep restriction that athletes more commonly experience. Dose-response relationships are poorly defined as well. It remains unclear whether absolute sleep duration or deviation from an athlete's usual pattern is the more relevant exposure. Women remain underrepresented in several experimental areas of sleep research, which limits conclusions about possible sex-related differences. Finally, the sports emphasized in this review remain under-studied. Injury epidemiology is reasonably well described in powerlifting, weightlifting, tennis, and badminton, but the sport-specific prospective sleep-injury evidence identified in this review is limited. Extrapolation therefore needs to remain explicit. A laboratory study demonstrating reduced muscle protein synthesis after severe deprivation can support a mechanistic hypothesis. It cannot be treated as direct evidence that a competitive powerlifter or tennis player faces a defined increase in injury risk after a short night.

4.6. Directions for Future Research

Future work should prioritize large, prospective, sport-specific cohorts in which sleep is assessed repeatedly rather than at a single time point. In powerlifting, Olympic weightlifting, tennis, and badminton, sleep should ideally be monitored alongside training exposure, previous injury, pain, competition, travel, nutrition, and psychological stress. Time-varying analyses may be especially useful. Instead of classifying an athlete once as a “good” or “poor” sleeper, researchers could examine whether meaningful deviations from that athlete's normal sleep pattern precede changes in performance, symptoms, or injury. More consistent injury definitions are also needed. Acute traumatic injuries, gradual-onset conditions, pain without time loss, and medically confirmed injuries should be analyzed separately. Randomized sleep-extension trials can provide stronger causal evidence for performance and recovery outcomes. Injury prevention will be more difficult to demonstrate because injuries are less frequent and require larger samples and longer follow-up periods. Strength-sport studies should move beyond isolated maximal-force testing. Bar velocity, repetition performance, technical consistency, perceived exertion, and tolerance of training volume may provide a more useful picture of readiness. In racquet sports, future studies could combine sleep assessment with stroke accuracy, reaction time, decision-making, match load, movement demands, and prospective injury surveillance. Such designs would help determine which sleep-related changes are genuinely relevant to competition and whether any of them precede clinically meaningful injury.

5. Conclusions

Sleep is an important and modifiable component of athletic recovery. Substantial or repeated sleep loss can impair selected aspects of physical performance and sport-specific skill. Experimental research also demonstrates alterations in skeletal-muscle protein synthesis, selected hormonal and inflammatory responses, and pain perception. These findings provide plausible pathways through which inadequate sleep may influence recovery. Their translation into clinically defined musculoskeletal injury, however, remains uncertain. Associations between sleep and injury are more consistent in adolescent athletes, although the available evidence remains predominantly observational and does not identify a universal sleep threshold for injury prevention. In adults, prospective evidence is more heterogeneous. Poor sleep has not been established as an independent risk factor for sport- or physical-training-related injury, and recent actigraphy-based evidence remains inconclusive.

Within the literature identified for this review, sport-specific prospective evidence directly linking sleep with injury in powerlifting and Olympic weightlifting remains limited. The same applies to tennis and badminton. Existing studies in these disciplines provide useful information on performance, symptoms, sleep characteristics, and injury epidemiology, but evidence that improving sleep reduces musculoskeletal injury incidence is currently insufficient. Sleep should therefore be considered within a broader recovery framework that also includes previous injury, training and competition exposure, pain, nutrition, psychological stress, travel, scheduling, and individual recovery needs. Increasing sleep opportunity is reasonable when habitual sleep is insufficient, but rigid nightly duration thresholds should not be presented as established injury-prevention targets. Future prospective, sport-specific studies using repeated sleep assessment and standardized injury surveillance are needed to determine whether sleep provides independent predictive information and whether improving sleep can meaningfully reduce musculoskeletal injury incidence.

Disclosure

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