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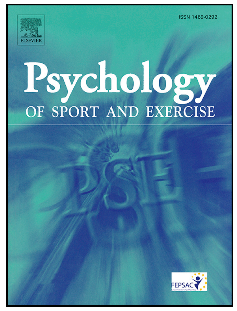

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Sleep Interventions for Performance, Mood and Sleep Outcomes in Athletes: A Systematic Review and Meta-Analysis

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Abstract

Sleep is fundamental to sports performance and other health outcomes such as mental wellbeing. This systematic review explored the effects of sleep interventions implemented among athletes on performance, sleep, and mood outcomes. Five databases were searched, returning 5,996 records for screening. Of these, 27 articles met the inclusion criteria (16 controlled deigns, 11 uncontrolled; athletes *n*=617; male *n*=432, female *n*=93, non-binary/other *n*=0 or not reported *n*=92). Narrative synthesis of all studies based on intervention type suggested that sleep hygiene, assisted sleep, and sleep extension interventions may be associated with improved sleep, performance, and mood outcomes. Twelve controlled trials were eligible for quantitative meta-analysis, investigating the effect of sleep interventions on athlete sleep, performance, and negative affect, compared to controls post-intervention. Utilizing random-effects meta-analyses, sleep interventions improved subjective sleep quality (*g*=0.62, 95% CI [0.21, 1.02]), reduced sleepiness (*g*=0.81, 95% CI [0.32, 1.30]) and decreased negative affect (*g*=0.63, 95% CI [0.27, 0.98]), but did not appear to influence subjective sleep duration. No effects were identified for objective sleep measures (e.g., actigraphy), or aerobic/anaerobic performance indices. While sleep interventions may offer some benefit to athletes, caution is warranted given limitations of the extant research relating to small, non-representative studies with methodological concerns.

Key Words

Sleep; Athletes; Mental Health; Intervention; Performance

Sleep Interventions for Performance, Mood and Sleep Outcomes in Athletes: A Systematic Review and Meta-Analysis

Sleep plays a crucial role in human health and is involved in a range of fundamental processes, including cognitive function, immunity, metabolism, and muscular recovery (Besedovsky et al., 2012; Krause et al., 2017). Further, there is a wealth of literature that links poor sleep with mental health concerns, including symptoms of depression, anxiety, anger, paranoia, hopelessness, loneliness, and psychological distress (Freeman et al., 2017; Ramsey et al., 2019; Zochil & Thorsteinsson, 2018). The importance of sleep is a growing area of interest within high-performance and youth-development sporting contexts and is regarded as a key contributor to optimal performance and recovery for athletes (Fullagar, 2017; Walsh et al., 2020). Equally, the field of elite sport is increasingly recognising the need for improved mental health support for athletes (Purcell et al., 2019; Reardon et al., 2019). Obtaining high-quality sleep may assist with recovery following strenuous physical activity, reducing inflammation and risk of injury, maintaining alertness and concentration during competition, and enhancing mental health (Bonnar et al., 2018; Kirschen et al., 2020; Silva et al., 2020; Watson et al., 2019).

Published systematic reviews have highlighted that sleep deprivation negatively impacts performance in sports (Kirschen et al., 2020). Equally, higher quality and extended sleep appear to improve athletic performance (Kirschen et al., 2020; Vitale, Owens, et al., 2019). However, despite the importance of obtaining adequate sleep, meta-analysis suggests that athletes largely do not achieve the recommended total sleep time (7 hours or more) or sleep efficiency (more than 85% of the time in bed spent asleep) (Roberts et al., 2019). Indeed, athletes in high-performance environments encounter a range of unique stressors that may negatively impact sleep, including frequent travel across time zones for competition, unfamiliar sleeping environments, early and late training and competition, pre-competition anxiety, muscle soreness, and injury (Fullagar, 2017; Halson & Juliff, 2017; Lastella et al., 2014).

The importance of effective sleep interventions is accentuated by increasing reports of sleep medication use in athletes, including medication with sleep-inducing side effects (Taylor et al., 2016). While evidence suggesting that overreliance and abuse of sleep medication is frequent in elite athletes, this is largely from anecdotal and clinical reports (Taylor et al., 2016). There are concerning case reports of benzodiazepine use for sleep enhancement in athletes leading to harmful outcomes, including addiction and withdrawal symptoms (Zamboni et al., 2019; Zandonai, et al., 2018). However, reported use of sleep medication among two large samples of athletes leading up to a sporting event has been low, with just 1.3% (Erlacher et al., 2011) and 2.6% (Martin et al., 2018). Elsewhere, 3% of American collegiate athletes reported non-prescription, and 18.7% reported prescription sleep aid use (NCAA, 2018). While more work is needed to accurately determine the prevalence and outcomes of sleep medication use in athletes, non-pharmacological sleep interventions could be an adaptive alternative to potential over-reliance on sleep medications.

In light of this emerging evidence base, a number of interventions have been designed to improve the quantity and quality of sleep among athletes. Common initiatives include sleep hygiene interventions, whereby behavioural and environmental recommendations are provided alongside psychoeducation about healthy sleep habits (Irish et al., 2015), sleep extension (aiming for 9-10 hours of sleep a night), and assisted sleep strategies such as the use of low-colour temperature light or auditory brainwave entrainment. One systematic review from Bonnar et al. (2018) explored the association between sleep interventions and performance in elite athletes. The authors concluded that sleep extension was likely the most beneficial strategy for improving performance compared with other interventions such as post-exercise recovery strategies.

There are several methods to measure sleep, both objectively and subjectively. The gold standard is polysomnography that objectively measures sleep through brain activity, eye movement, muscle movement, heart rate, and oxygen saturation (Roomkham et al., 2018). This technique allows for full sleep cycles to be measured in an accurate manner, but is expensive and obtrusive. More commonly, objective sleep is measured with wearable devices, such as actigraphy wristbands, that can monitor activity through movement (Driller et al., 2016). Research-grade actigraphy devices have been validated against polysomnography ratings (Depner et al., 2020), however, some may be prone to overestimation of sleep duration (Ancoli-Israel et al., 2015). Lastly, subjectively rated sleep measures are obtained through sleep estimation scales and sleep diaries, the latter involving individuals noting their bed and wake times, napping, sleepiness ratings, and use of sleep-affecting substances like alcohol or caffeine. These techniques provide estimates of several sleep outcomes including sleep duration (amount of time asleep during recording period), onset latency (time between lights out and time fallen asleep), sleep efficiency (percentage of time in bed spent asleep), sleep quality (self-rated quality of sleep period), and sleepiness (self-rated perception of tiredness following sleep period) (Shrivastava et al., 2014).

Presently, reviews amongst athletic cohorts have largely focussed on how sleep is related to performance, however, sleep interventions may contribute to additional positive outcomes. A gap exists for researchers to examine the extent to which sleep interventions actually influence an athlete's sleeping patterns, performance, and mental health or mood states. No such meta-analyses have been performed for sleep interventions in athletes. Therefore, the aim of this study was to conduct a systematic review and meta-analysis of sleep interventions in athletes, for sleep, performance, and mental health outcomes. Two research questions were proposed: (i) do sleep interventions (regardless of type) improve outcomes in athletes? and (ii) what types of sleep interventions, if any, are associated with improved outcomes in athletes?

Methods

This study was conducted in line with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009), though a protocol was not pre-registered.

Search Strategy

This project stemmed from a commissioned report on prevention and early intervention initiatives for sporting teams or groups of athletes (Purcell et al., 2020). The search was comprised of sport and athlete terms, intervention and study design terms, and mental health terms (including sleep). The search was implemented across five databases (Embase, Medline, PsycINFO, SPORTDiscus, and CENTRAL). The search was completed in April 2020 (full search strategy, including search terms, documented in Supplement 1). Given the magnitude of identified studies, three authors independently screened the titles and abstracts (i.e., were unaware of each other's decisions). Two authors double-screened the full texts independently. No disagreements regarding inclusion were identified as consensus was reached following integration of the full text.

Inclusion Criteria

Articles were included based upon the following criteria: (i) recruitment of athlete samples regardless of sleep problem status. Athlete samples were defined as sub-elite, semi-elite, collegiate, professional, international, and Olympic levels, including athletes in para sports. These athlete levels reflect a minimum performance standard that is not evident in community-level athletes and recreational athletes (Swann et al., 2015). Sleep problem status was not a criterion given the importance of both prevention and intervention studies; (ii) implementation of a sleep intervention OR intervention aimed at improving sleep. For example, a sleep hygiene intervention was classified as a sleep intervention, whereas a cryostimulation intervention that measured sleep outcomes was deemed an intervention aimed at improving sleep; (iii) articles reported an outcome for at least one of the following: sleep (e.g., polysomnography data, actigraphy data, sleep diary, self-reported quality), performance (e.g., sport-specific skills, aerobic or anaerobic measures), or mental health and mood states (e.g., well-being, affect, psychological symptoms), and (iv) were published in English. Screened articles were excluded if: (i) interventions were not yet implemented (i.e., protocol papers); or (ii) reported data were from community sport samples. or general populations. Given the early nature of the work, no restrictions were placed on sample sizes, publication date or article type (i.e., conference abstracts were included if there was no corresponding published article). For the meta-analysis, only controlled designs were included (i.e., studies with a control and intervention group). Cross-over designs were also included given this is a type of (randomised) controlled design. Other designs were included in the narrative synthesis.

Article Methodological Quality Appraisal

The Joanna Briggs Institute critical appraisal tool was used to assess study quality (Tufanaru et al., 2020). The checklist for quasi-experimental studies and the checklist for randomized controlled trials (RCTs) were utilised where appropriate. This checklist appraises methodological quality within studies to determine the extent of potential bias in the design. The checklists assess areas of study design, including randomisation and blinding procedures, identical group treatment, follow-up procedures, measurement reliability, and appropriate statistical analysis. Authors KG and CW critically appraised all studies independently before reviewing their evaluations. The authors then met to sequentially discuss any discrepancies between ratings on the methodological quality items. Consensus was achieved following collaborative consultation of the individual full-texts with the authors engaging in a detailed discussion of each study included within the review. For the five studies presented as an abstract only, there was insufficient information to accurately appraise the study, and thus, these were not assessed. No articles were excluded from the review based on this analysis, and we have interpreted quality as the proportion of items marked as 'yes' (i.e., higher proportions indicate better methodological quality).

Data Extraction

A template to extract study and sample characteristics of all articles included the study design, location, intervention type, sample size and gender, sport population, analysed outcomes, and key results. Data extraction for the meta-analysis began by screening articles for viable outcomes. A variable was suitable for meta-analysis if it had been measured in at least three articles, despite a recognised minimum of two (Valentine et al., 2010), as this allowed analysis of publication bias in the meta-analysis software.

Meta-analysis

Sleep outcomes were separated by objective and subjective measures, including sleep duration, onset latency, efficiency, quality, and sleepiness. Performance measures were separated by aerobic and anaerobic outcomes. Mood outcomes including stress, irritability, psychological strain, and psychological fatigue were pooled into an analysis of negative affect. All intervention types were included in the analyses, taking an inclusive approach given the investigative nature of this study and the early nature and limited scope of the literature base (Lorenc et al., 2016; Walsh et al., 2020). Although we acknowledge the differences across interventions, there is alignment across participants' characteristics, outcomes, and overarching intervention aiming to improve sleep. To determine the role of elite status, we ran separate sensitivity analyses (see Supplement 2.). Given the challenges and variation in defining 'elite', we adopted an approach that aligned with competitive level (Swann et al., 2015). With this approach, 'elite' included youth-elite/collegiate, professional, national, international, and Olympic athletes (Rice et al., 2019). Samples described as semi-professional, semi-elite, or sub-elite were excluded for this sensitivity analysis.

For the controlled trials, raw data were extracted from the articles (mean, *SD,* and *n*), where possible. The raw data were used to calculate a Hedge's *g* estimate, as this estimate corrects for small samples sizes. Hedge's *g* is preferable to Cohen's *d* as it uses the pooled pre-intervention standard deviation (*SD*) for the denominator, allowing a more precise estimate of effect size. Morris (2008) proposes the following formula for pre-test, post-test control comparisons; whereby $g = \text{K} \times [(M \text{ post intervention} - M \text{ pre intervention}) - (M \text{ post control} - M \text{ pre control}) / SD \text{ pre}]$, where $SD \text{ pre} = \sqrt{} \, [((n \text{ intervention} - 1) \times SD \text{ pre intervention}^2 + (n \text{ control} - 1) \times SD \text{ pre control}^2) / \; n \text{ intervention} + n \text{ control} - 2]$, and $\text{K} = 1 - [3 /(4 \times (n \text{ intervention} + n \text{ control} - 2) - 1)]$. When raw data were unavailable, effect size data was extracted (e.g., *r, F, t,* and *d* values). Those values that were able to be inputted into the software program directly were done so (*r, t, d*). For *F* values, the following equation from Thalheimer and Cook (2002), was used to calculate a *d* score, which was transformed into *g* using the formula $d \times \text{K}$; $d = \sqrt{} \, (F \times ((n \text{ intervention} + n \text{ control}) / (n \text{ intervention} \times n \text{ control})) \times ((n \text{ intervention} + n \text{ control}) / (n \text{ intervention} + n \text{ control} - 2)))$. When relevant data were presented in non-extractable formats (i.e., small graphs), we contacted the authors to request the data, however this did not yield any returned data. This occurred for one study only.

For cross-over studies, data were commonly reported as combined intervention and control groups, rather than Intervention A, Control B, Intervention B, and Control A. Though this is not the ideal way of reporting, Li and colleagues (2015) note that this method is acceptable when there is no missing data, as the mean of differences is equal to the difference in means. This method of reporting often results in a conservative effect estimate as it does not consider the paired nature of cross-over designs. Further, all cross-over articles included a washout period. Given this, the same Hedge's *g* calculation was implemented for raw data in these articles. Furthermore, we conducted sensitivity analyses, removing cross-over designs to explore the impact this choice may have had on the overall analysis.

Pooled effect sizes were estimated using Comprehensive Meta-Analysis (CMA) software, version 3.3.070 (Borenstein et al., 2014). The authors report the overall effect estimate as Hedge's *g*, adjusted for small sample sizes, as this is suggested to be a more precise estimate than Cohen's *d* (Morris, 2008). All analyses were estimated using the random-effects model to account for between- and within-study error.

Heterogeneity and Publication Bias

Violations of homogeneity were measured using the Q and I^2 statistics. The Q statistic tests the null hypothesis for no variation in true effect sizes between studies. This assumes homogeneity is violated when the statistic is below the $p = .05$ level, in other terms, indicating heterogeneity across studies. The degree of heterogeneity was interpreted using the I^2 statistic. This statistic reflects the percentage of variance in the observed effect due to variance in the true effect (Higgins & Green, 2008). In other terms, the I^2 represents the proportion of total variation across studies that is attributed to heterogeneity. Heterogeneity is considered as low (0 to 40%), moderate (30 to 60%), substantial (50% to 90%) or considerable (75 to 100%) (Higgins & Green, 2008). Duval and Tweedie's 'trim-and-fill' funnel plot method assessed publication bias (Duval & Tweedie, 2000). When there is asymmetry in a funnel plot, this suggests potential publication bias. An asymmetric plot is then balanced by the 'fill' of additional study points. This fill subsequently provides an altered estimate of the effect size. If publication bias exists, it was expected that the smallest studies would report the biggest effect sizes. Though it is considered best practice to have 10 studies for the most accurate detection of publication bias (Lau, Ioannidis, Terrin, Schmid, & Olkin, 2006), this method provides a more rigorous estimate than other computations for publication bias (Rothstein, Sutton, & Borenstein, 2005). Computations were made using the L_0 estimator.

Interpretation of Forest Plots

The left side of the forest plot indicates a greater change in outcome scores favouring the control group, whereas the right side indicates the effect estimate favours the intervention group. For negatively termed outcomes (e.g., negative affect), favouring indicates reduced scores (i.e., a decrease in negative outcomes). For positively termed outcomes (e.g., sleep quality), favouring indicates increased scores. The magnitude of Hedge's *g* can be interpreted as per Cohen's *d*, where effects are small (0.2), medium (0.5) or large (0.8) (Cohen, 1988).

Results

Literature Search

The database search returned 7,825 articles, of which 1,829 were duplicates (see Figure 1 for PRISMA flowchart). Title and abstract screening resulted in 389 articles to review in full. The full-text review returned 27 articles eligible for inclusion in the systematic review. Of these, 16 controlled designs were identified and 12 were suitable for meta-analysis (no extractable data (k = 1), no contributing variables (k = 1), conference abstracts (k = 2)).

Study Characteristics

For a review of article characteristics, see Table 1. The review encapsulates data from 617 athletes (female n = 93; 15%; not directly reported and/or assumed male n = 92). Samples largely represented athletes from the USA (k = 4; 15%), Germany (k = 3; 11%), New Zealand (k = 3; 11%), and Australia (k = 3; 11%). The most common intervention types were sleep hygiene (k = 10; 37%), followed by assisted sleep strategies (k = 7; 26%), sleep recovery (k = 5; 19%), sleep extension (k = 3; 11%), and combined strategies (k = 2; 7%). The most represented sport was soccer/football (k = 8, 30%), followed by basketball (k = 3; 11%), tennis (k = 3; 11%), rugby (k = 2; 7%), and baseball (k = 2; 7%). Randomised control trial designs were most utilised (parallel *k* = 7; cross-over *k* = 4), followed by single group pre-post designs (*k* = 10), non-randomised parallel groups (*k* = 4), and single-group repeated designs (*k* = 1). Information regarding the types of control groups can be found in Table 1 under intervention characteristics. Ten studies implemented interventions for one week or less and 15 studies conducted interventions for longer than 1 week. Two studies were unclear or varied in their intervention lengths. The average length was 4.9 weeks, and the median length was 2.0 weeks.

Of note, interventions were generally not targeted to athletes with sleep disorders. No studies specifically recruited athletes with sleep problems/disorders, although two studies reported 35% of their sample had suspected sleep concerns at baseline (Bender et al. 2018; Tuomilehto et al. 2017). Beyond these two studies, none indicated that their sample had sleep disorders. It was implied in most articles that the aim was to enhance current sleep behaviour in athletes, rather than to treat a sleep disorder.

Narrative Synthesis

For an overview of key outcomes for each study, see Table 1. The authors intended to conduct subgroup analyses within the meta-analysis by intervention type, however this was not feasible as too few trials were available. The following narrative synthesis explores outcome patterns across all 27 studies based on intervention type. Further information regarding athlete level, measurements, and intervention details can be found in Table 1.

Sleep Hygiene

Sleep hygiene strategies were the most used interventions for athletes (*n* = 10). Samples represented several athlete levels, from semi-professional to international competitive athletes. Amongst these studies, interventions endorsed similar recommendations, including the effective use of napping; ensuring a quiet, cool, and dark bedroom environment; eliminating the bedroom clock; avoiding light-emitting technology devices prior to sleep; limiting caffeine, alcohol, or other stimulants before sleep. Six of 10 studies implemented uncontrolled designs (Bender et al., 2018; Driller et al., 2019; Harada et al., 2016; O'Donnell & Driller 2017; Tuomilehto et al., 2017; Van Ryswyk et al., 2017). All 10 articles reported at least one positive change in sleep-related outcomes, ranging from reduced subjective sleep difficulty scores (Bender et al., 2018), improved subjective sleep quality (Driller et al., 2019; Harada et al., 2016; Tuomilehto et al., 2017; Vitale, La Torre et al., 2019), objective sleep onset variance (Driller et al., 2019), objective sleep efficiency (Driller et al., 2019), objective and subjective sleep duration (Fullagar et al, 2016; O'Donnell & Driller, 2017; Van Ryswyk et al., 2017), and cortisol awakening responses (Bonato et al., 2020). However, one controlled article reported negative changes, where increased sleep duration and time in bed was coupled with reduced sleep efficiency (Caia et al., 2018).

Three articles examined performance and mood outcomes. Benefits to performance were found for sport-specific performance, (i.e., self-rated soccer performance) (Harada et al., 2016), rather than general indices of athleticism (e.g., psychomotor attention, heart rate, exertion) (Fullagar et al., 2016; Van Ryswyk et al., 2017). Mixed results were indicated for countermovement jump, where an experimental group showed a slight improvement but only 32 hours post-game (Fullagar et al., 2016). For mood and mental health outcomes, improvements were identified for irritation (Harada et al., 2016), fatigue, and vigour (Van Ryswyk et al., 2017). No changes were identified for psychological recovery or stress, although this was only assessed in one controlled study (Fullagar et al., 2016). Notably, Harada and colleagues (2016) implied that their sleep hygiene intervention led to better performance via improved mental health from a covariate analysis. The positive relationship between the implementation of intervention recommendations and soccer performance was boosted when accounting for scores on the General Health Questionnaire (a measure of common mental health concerns such as depression or anxiety) (Jackson, 2007).

Assisted Sleep

Assisted sleep was the second most common intervention type, with seven studies implementing this intervention. All were controlled designs. A range of different approaches were used, with four using far-infrared clothing (Letton, et al., 2018; Loturco et al., 2016; Mazzardo-Martins, et al., 2016; Nunes et al., 2020), and the remaining studies using red-light whole-body irradiation (Zhao et al., 2012), brain-wave entrainment (Abeln et al., 2014), and exposure to low-colour temperature lighting (Wada et al., 2013). Samples largely consisted of youth elite and university/collegiate athletes. Five of seven studies measured sleep outcomes and all five reported improvements, including increased sleep quality (Abeln et al., 2014; Letton et al., 2018; Mazzardo-Martins et al., 2016; Wada et al., 2013; Zhao et al., 2012) and latency (Letton et al., 2018; Mazzardo-Martins et al., 2016; Zhao et al., 2012). Two articles reported mood outcomes, showing improved motivational state (Abeln et al., 2014) and reduced anger and irritation (Wada et al., 2013). Four articles reported performance outcomes with mixed results. Two reported an increased running performance (Nunes et al., 2020; Zhao et al., 2012). No effects were identified for countermovement jump or squat jumps (Loturco et al., 2016; Nunes et al., 2020), though one article found heart rate responses were better under exercise stress following far-infrared exposure (Mazzardo-Martins et al., 2016).

Sleep Recovery

Five articles implemented sleep recovery interventions, with three using cryostimulation (two partial-body (Douzi, Dupuy, Theurot, Boucard, & Dugue, 2019; Grainger, Comfort, & Heffernan, 2020), one full-body (Schaal et al., 2015)), one examining cold water immersion (Krueger, Costello, Stenzel, Mester, & Wahl, 2020), and one utilising lower-body compression garments (Atkins, Lam, Scanlan, Beaven, & Driller, 2020). Samples spanned across international elite athletes, professional, and youth/collegiate athletes. Only one study utilised a single-group pre-post design (Douzi et al., 2019). Partial-body cryostimulation techniques had no significant effect on sleep (Douzi et al., 2019; Grainger et al., 2020). Alternatively, whole-body cryostimulation technique indicated protective effects following heightened training load, as sleep duration, efficiency and fatigue were poorer in the control phase but not the experimental phase (Schaal et al., 2015). Likewise, swim-trial speed reduced in the control phase but not intervention phase. Lower-body compression resulted in reduced fatigue and muscle soreness as well as increased sleep quality (reduced movement during sleep) in the experimental group but not the control group (Atkins et al., 2020). The cold-water immersion strategy did not show any improvements to sleep, performance or recovery (Krueger et al., 2020).

Sleep Extension

Three studies employed sleep extension with athletes, all in single-group pre-post designs (Mah, et al., 2009; Mahet al., 2011; Schwartz & Simon Jr, 2015), aiming for 9-10 hours of sleep per night. All studies utilised a single group pre-post design in collegiate/university level athletes. Athletes were able to extend their sleep in all studies, with daytime sleepiness and fatigue subsequently reduced. These articles examined sport-specific skills including tennis serve, hitting accuracy, and basketball shooting accuracy, as well as general athleticism including sprint time and self-rated performance. All three articles found improvements to performance indices following sleep extension. Two studies measured mood states, reporting improved anxiety, depression, anger, fatigue, and vigour scores (Mah et al., 2009; Mah et al., 2011).

Multicomponent Interventions

Two studies implemented mixed interventions, with one pre-post study combining sleep extension and low colour temperature in national level athletes (Bender et al., 2017), and the other controlled design combining cold-water immersion, full body compression and sleep hygiene interventions in a professional athlete sample (Duffield et al., 2014). The sleep extension and low colour light strategy only reported mood outcomes, with athletes reporting overall mood improvements across subscales including depression, vigour, and fatigue (Bender et al., 2017). The last strategy reported improvements to perceived muscle soreness and fatigued mood following the intervention phase compared to the control condition (Duffield et al., 2014).

Meta-analyses

Objective Sleep Outcomes

Sleep Duration. Five studies measured objective sleep duration (e.g., from actigraphy data) (Atkins et al., 2020; Caia et al., 2018; Fullagar et al., 2016; Schaal et al., 2015; Vitale, La Torre et al., 2019). No improvement following sleep intervention was identified compared to controls (g = 0.35, 95% CI [-0.42, 1.12]; see Figure 2a). There was no publication bias detected however, there was substantial heterogeneity, (p < .01; I^2 = 79.25), that became low after removal of the two cross-over studies (Q = 3.24, p = .20, I^2 = 38.25). Sensitivity analysis excluding these cross-over articles (Fullagar et al., 2016; Schaal et al., 2015) also reported no effect of intervention on objective sleep duration (g = -0.23, 95% CI [-0.78, 0.31]; k = 3).

Onset Latency. Four studies measured objective onset latency (Caia et al., 2018; Fullagar et al., 2016; Schaal et al., 2015; Vitale, La Torre et al., 2019). No effect was observed compared to controls (g = 0.36, 95% CI [-0.66, 1.38]; see Figure 2b). However, considerable heterogeneity was identified (Q = 19.31, p < .001, I^2= 84.47). Exploration of the studies indicated that one study imposed standard bed and wake times (Fullagar et al., 2016). This could have impacted onset latency as participants may have been told to go to bed before they were tired. In a sensitivity analysis removing this study, heterogeneity resolved (Q = 3.08, p = .22, I^2= 35.01), and objective onset latency improved favouring sleep interventions (g = 0.81, 95% CI [0.23, 1.40]). There was evidence of publication bias whereby one filled point reduced the effect estimate to g = 0.60. Without cross-over articles

(Fullagar et al., 2016; Schaal et al., 2015), objective onset latency also improved in the intervention arm (g = 0.60, 95% CI [0.04, 1.16], k = 2).

Sleep Efficiency. Four studies examined objective sleep efficiency (Caia et al., 2018; Fullagar et al., 2016; Schaal et al., 2015; Vitale, La Torre et al., 2019). No changes were observed compared to controls (g = -0.18, 95% CI [-0.67, 0.31]; see Figure 2c). No evidence of substantial heterogeneity (Q = 4.85, p = .18, I^2 = 38.18) or publication bias was found. Sensitivity analysis removing cross-over designs (Fullagar et al., 2016; Schaal et al., 2015) also indicated no effect (g = -0.23, 95% CI [-1.13, 0.67]).

Subjective Sleep Outcomes

Sleep Duration. Three studies measured subjective sleep duration (e.g., from sleep diaries) (Abeln et al., 2014; Duffield et al., 2014; Zhao et al., 2012). No improvement was identified following intervention compared to controls (g = 0.11, 95% CI [-0.51, 0.73]; see Figure 3a). Homogeneity was upheld (Q = 2.35, p = .31, I^2 = 14.75), though there was evidence of publication bias, with two filled points reducing the non-significant estimate to g = -0.20. Sensitivity analysis removing one cross-over article (Duffield et al., 2014) indicated no effect (g = -0.05, 95% CI [-0.52, 0.62]; k = 2).

Sleep Quality. Six studies assessed subjective sleep quality from self-report measures and sleep diaries (Abeln et al., 2014; Grainger et al., 2020; Krueger et al., 2020; Schaal et al., 2015; Vitale, La Torre et al., 2019; Zhao et al., 2012). An improvement in sleep quality favoured the intervention groups compared to controls (g = 0.62, 95% CI [0.21, 1.02]; see Figure 3b). Homogeneity was maintained (Q = 2.35, p = .31, I^2 = 20.25), with no evidence of publication bias. Sensitivity analysis removing cross-over designs (Grainger et al., 2020; Schaal et al., 2015) also showed significant improvement in sleep quality following interventions, where the effect estimate increased (g = 0.75, 95% CI [0.30, 1.20], k = 4).

However, following the sensitivity analysis, publication bias became evident, adjusting the effect to resemble that of the original analysis (*g* = 0.63).

Sleepiness. Three studies measured subjective sleepiness outcomes (Abeln et al., 2014; Duffield et al., 2014; Schaal et al., 2015). The analysis reported a significant improvement in scores favouring the intervention groups compared to controls (*g* = 0.81, 95% CI [0.32, 1.30]; see Figure 3c). There was no identified publication bias or heterogeneity (Q = 0.95, p = .62, I^2 = 0.00). Sensitivity analysis was not feasible for this outcome as two of three studies were cross-over designs (Duffield et al., 2014; Schaal et al., 2015).

Performance Outcomes

Aerobic Performance. Five studies investigated aerobic performance in athletes (e.g., timed running outcomes) (Atkins et al., 2020; Caia et al., 2018; Fullagar et al., 2016; Nunes et al., 2020; Zhao et al., 2012). The meta-analysis found no significant effects following sleep interventions compared to controls (*g* = 0.31, 95% CI [-0.05, 0.67]; see Figure 4a). Homogeneity was upheld (Q = 1.32, p = .86, I^2 = 0.00), though there was evidence of publication bias, adjusting the effect estimate to *g* = 0.25. No changes to the analysis were observed when a cross-over article (Fullagar et al., 2016) was removed.

Anaerobic Performance. Five articles reported anaerobic performance outcomes, specifically, countermovement jump (Atkins et al., 2020; Duffield et al., 2014; Grainger et al., 2020; Krueger et al., 2020; Nunes et al., 2020). The analysis indicated no effect compared to controls (*g* = 0.14, 95% CI [-0.19, 0.48]; see Figure 4b). There was no significant heterogeneity (Q = 0.40, p = .98, I^2 = 0.00), or publication bias. Sensitivity analysis removing cross-over designs (Duffield et al., 2014; Grainger et al., 2020) did not alter the outcome, also resulting in no effect (*g* = 0.09, 95% CI [-0.38, 0.55]).

Mood Outcomes

Negative Affect. Five studies investigated the effect of sleep intervention on subjectively rated negative affect (Abeln et al., 2014; Duffield et al., 2014; Krueger et al., 2020; Schaal et al., 2015; Wada et al., 2013). The meta-analysis found a significant improvement in negative affect favouring the intervention groups compared to controls (g = 0.63, 95% CI [0.27, 0.98]; see Figure 4c). Homogeneity was upheld (Q = 3.43, p = .49, I^2 = 0.00), and no publication bias was detected. Sensitivity analysis excluding cross-over designs (Duffield et al., 2014; Schaal et al., 2015) also reported the same improvement, although the effect estimate slightly reduced (g = 0.54, 95% CI [0.11, 0.97]).

Sensitivity Analyses for Elite Status

Exploratory sensitivity analyses were conducted to explore the effect of elite status on outcomes. Full reporting of outcomes can be found in Supplement 2. One major change in results occurred, whereby the significant effect favouring experimental groups in sleep quality (g = 0.62, 95% CI [0.21, 1.02]; k = 6), became non-significant upon removal of two trials in semi-elite athletes (g = 0.38, 95% CI [-0.11, 0.90]; k = 4). Direction and significance of estimated effects remained unchanged in all other analyses following removal of non-elite athletes.

Quality Appraisal

Twenty-two of the 27 (81%) studies were assessed for study quality. Reporting of the required criteria was often unclear, and some studies may have met more criteria in their methodology than reflected in reporting. The appraisal score for the 22 studies ranged from 0.33 to 0.85. The average appraisal score was 0.63. Most studies (k = 17) ranged between 0.5-0.79, with four articles rating less than 0.5 and only one rating above 0.8. No study met all appraisal criteria. Quality appraisal scores for each study can be found in Table 1. While there was a range of approaches to statistical analysis varying between poor to more complex approaches, only two studies reported power analyses, which was required for this criterion.

For the 12 pre-post group designs, the average appraisal score was 0.66. Common areas where articles did not meet criteria included the lack of a control group or power analysis to satisfy appropriate statistical analysis. For the ten reviewable RCTs, the average appraisal score was 0.59. Most did not report on or use sufficient treatment blinding and group concealment procedures (i.e., allocation concealment, participant blinding, outcome assessor blinding). This may have impacted the meta-analysis whereby the estimated effects may be over-estimated. Complete quality appraisal information can be found in Supplement Tables 1a and 1b.

Discussion

The aim of this study was to conduct a systematic review and meta-analysis for sleep interventions targeted at athletes, and their association with sleep, performance, and mood outcomes.

Meta-analyses

Of the articles suitable for meta-analysis, examinable outcomes included objective and subjective sleep measures, aerobic and anaerobic performance, and negative affect. Significant results were identified in relation to subjective measures, including improvements to perceived sleep quality, reduced sleepiness, and decreased negative affect for athletes receiving sleep interventions compared to control groups. These results suggest that sleep interventions may enhance athletes' perception of their sleep. Interestingly, these subjective benefits were present when objective measures indicated no changes. Indeed, the meta-analysis indicated no changes for objective sleep duration or sleep efficiency following intervention. Of note, a recent meta-analysis also reported positive outcomes for subjective measures only (Chung et al., 2018). In the current review, it is possible that the identified improvements to subjective sleep outcomes are an artefact of un-blinded interventions. Specifically, if athletes know they are receiving a sleep intervention, they may expect to have better sleep and subsequently report this in their sleep diaries. Alternatively, studies in the subjective meta-analyses were different to those in the objective analyses, therefore we cannot rule out the possibility that the differences in interventions contributed to each effect. Another possible explanation for the lack of objective changes is that most samples were conducted in athletes who did not have pre-existing sleep concerns. Perhaps interventions were more effective on subjective sleep outcomes as athletes' objective sleep patterns had less scope to improve. Supporting this hypothesis, a meta-analysis from Murawski and colleagues (2018) revealed larger effects on sleep quality in intervention studies where baseline sleep health was worse. Future research could investigate whether sleep interventions may be beneficial in athletes with suspected sleeping conditions or concerns.

The only objective measure to indicate a positive effect estimate was onset latency. This became significant after sensitivity analysis to reduce heterogeneity removed a sleep hygiene study that implemented its procedures following a late-night match and imposed standardised sleep and wake times. This suggests that consideration of extraneous factors including game schedules, training load and travel are imperative to determine the best strategy to support an athlete's sleep. For instance, sleep hygiene strategies may not be best suited following periods where athletes need to wake at early hours for travel, but may be augmented with assisted sleep initiatives including audio devices or low colour lighting to enhance sleep in a shortened or designated timeframe (Abeln et al., 2014; Wada et al., 2013). Alternatively, after periods of high intensity training, sleep recovery interventions may be best suited to mitigate potential negative impacts on sleep (Schaal et al., 2015). Such factors may have a greater impact on the sleep quality of elite athletes, given the significant effect for sleep quality become non-significant when analysing only elite samples. It is possible that the sleep quality of elite athletes may be more resistant to change given exposure to these numerous extraneous factors that sub-elite or semi-professional athletes may not experience as regularly (e.g., travel).

We did not find sufficient evidence regarding the effects of sleep interventions on mental health outcomes. This is a relevant given (i) knowledge that poor sleep is often both a prodromal indicator and secondary symptom of mental ill-health (Fang et al., 2019) and (ii) there is strong meta-analytic evidence that enhancing sleep via intervention is associated with subsequent improvements across various mental health outcomes (Scott et al., 2021). While the meta-analysis results here suggested that sleep interventions may reduce levels of negative affect, this was a pooled group of outcomes (including stress, irritability, psychological strain and psychological fatigue), rather than clinical mental ill-health symptomatology. Given overlap between negative affect and mental ill-health, we propose that expansion of this area is vital, given increasing awareness that athlete cohorts experience high rates of mental health symptoms (Gouttebarge et al., 2019; Reardon et al., 2019). Sleep interventions, especially sleep hygiene and sleep extension initiatives, represent a relatively inexpensive and accessible option for sporting organisations to implement to support the holistic wellbeing of their athletes. Given that there are limited strategies in place that assist in mental health prevention or promotion in sport (Chang et al., 2020), future research should aim to explore the feasibility and efficacy of sleep interventions as a mental health prevention strategy. None of the studies examined samples with diagnosed mental health conditions, and thus it would be advantageous to understand if such interventions strategies are efficacious in these populations.

Narrative Synthesis

As these results combined both controlled and uncontrolled research designs (excluding assisted sleep studies that were all controlled), the below discussion is speculative and not definitive as it is possible that results reported in uncontrolled designs were caused by extraneous variables. When synthesising results based on intervention type, it appeared that sleep hygiene, assisted sleep and sleep extension reported the most consistently beneficial impacts on subjective sleep variables and mood outcomes. For performance variables (e.g. sport-specific skills), assisted and extended sleep strategies appeared favourable. This aligns and builds upon the findings from Bonnar et al. (2018), who concluded sleep extension was most beneficial for performance. Sleep recovery appeared to have mixed impacts on sleep and performance outcomes, with more protective benefits occurring following increased training load. Not surprisingly, sleep recovery interventions also showed protective effects for physical recovery including muscle soreness. It is logical to infer that improved sleep may lead to improved mood and performance rather than vice-versa. Interventions that did not impact sleep often did not show improvements to other variables. Likewise, those that were able to show increased sleep quality or duration also reported improvements to mood (e.g., motivational state; Abeln et al., 2014), performance (e.g., distance run; Zhao et al., 2013), and recovery (e.g., heart-rate response; Mazzardo-Martins et al., 2016). Future research should explore causal, covariate and mediation analyses to determine how outcome variables may influence the others. For translation into practice, there is an opportunity to shift away from a ‘one-size-fits all’ approach by providing athletes with options regarding strategies that best suit them. Future research should investigate whether tailored or individualised intervention strategies are more effective than packaged or set interventions.

Limitations and Future Directions

This study is the first to present meta-analytic findings for sleep interventions in athletes, however key limitations within both the review procedures, and studies included, exist. With regard to our methodology, the review is limited by not conducting a pre-registered protocol. Future meta-analyses which are pre-registered and include more targeted procedures are warranted.

The interpretation of the meta-analytic findings is limited to ‘sleep interventions’ broadly given the inclusive approach taken, as it was not feasible to conduct subgroup analyses for different intervention types. It may be the case that certain intervention types skewed the data in cases where one type was more efficacious than another. When future research trials are available, we recommend conducting subgroup analyses for intervention type. The number of studies, and at times participants within studies, were relatively small. It is understandable that sample *n*’s may be limited by the size of a sporting club, however researchers should endeavour to implement interventions in larger cohorts. Further, we reported adjusted effect sizes for small samples, using a *g* estimate rather than the *d* statistic. Publication bias and heterogeneity analyses were also conducted to ensure rigorous reporting. Sensitivity analyses also demonstrated no detrimental impacts occurring from including cross-over designs in the analysis. Encouragingly, all four cross-over articles included a washout period, spanning from 24 hours for an acute study (Duffield et al., 2014), to four weeks for a long-term intervention (Grainger et al., 2020). All used appropriate paired or repeated analyses (Duffield et al., 2014; Fullagar et al., 2016; Grainger et al., 2020; Schaal et al., 2015), though only one examined an order effect (Schaal et al., 2015).

There was low methodological quality across a large proportion of the studies included, with 18% of appraised studies meeting less than 50% of appraisal criteria, and 95% meeting less than 80% of criteria. Given this, there is evidence for risk of bias in all the identified studies. Due to smaller samples, power analysis was deemed necessary to contextualise the results, however only two of 22 assessed articles reported power analyses. Further, intention-to-treat analyses were not conducted when participants were unable to complete study protocol or provided missing data. The appraisal indicated necessity for implementation of more controlled designs that properly conduct blinding procedures for participants, treatment deliverers, and outcome assessors where possible.

Our narrative synthesis combined all studies including controlled and pre-post designs. Further controlled trials for different sleep intervention types are necessary to confirm the outcomes reported above. This will provide greater clarity regarding the efficacy of each intervention type for the outcome domains and subsequently allow stronger recommendations to sporting organisations. Of note, there were no RCTs for any sleep extension designs.

There was a lack of representation for para-athletes as no interventions were delivered to this population. It is critical that future research examines sleep interventions developed and delivered to para-athletes, as they may face additional barriers to sleep quality, including travel to locations that lack adaptive facilities and poorer sleeping conditions (Swartz et al., 2019). There was also an underrepresentation of female athletes in the reported studies, with over four times the number of male athletes compared to female athletes. This is an ongoing concern in sports science research that needs immediate improvement (Costello et al., 2014). Sleep interventions may have differing effects across sexes as observational studies have indicated that male and female athletes have differing sleep profiles (Carter et al., 2020). Further relating to samples included within these studies, we emphasise that none specifically recruited athletes with sleep problems/disorders. While it is likely that each sample varied in terms of observed sleep quality at baseline, we suggest ceiling effects may be present and that many of the examined interventions may be more effective for individuals specifically struggling with their sleep. Future trials which selectively recruit individuals with sleep deficits beyond certain thresholds will be valuable for developing a true understanding of efficacy.

Finally, there was an additional lack of reporting regarding intervention adherence, particularly for sleep hygiene interventions. More detailed reporting of intervention adherence will direct sporting bodies and practitioners to identify which recommendations are easily adopted by and valuable for athletes.

Conclusion

This study was the first to conduct a systematic review and meta-analysis examining the effects of sleep interventions on athlete sleep, performance, and mood outcomes. The findings suggest that these interventions may show improvements in subjective measures of sleepiness, sleep quality and negative affect. They may also improve objective onset latency however no other objective sleep or performance effects were identified. The narrative synthesis suggests sleep hygiene, assisted sleep and sleep extension interventions may be associated with improved sleep, mood, and some performance outcomes, though require further evaluation using randomised-controlled designs. These outcomes appear promising, though confidence in the findings is limited by low methodological quality across included studies. For this reason, we are hesitant to provide applied recommendations and instead recommend further work in this burgeoning area of research.

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Table 1

Article Characteristics and Key Results by Intervention Type

Article	Study design; Article type	Intervention characteristics	Sample *n* (% female), age	Sport; location	Analysed outcomes	Key results	Quality
Sleep Hygiene							
Bender et al. 2018	Sub-study = randomised single group pre-post; Original research article	Individualised sleep hygiene; 2-week baseline, followed by clinical sleep interview to formulate advise, follow-up average 21 weeks post	Total *n*=44 (% female NR), Age *M*=24.0	Mixed sports (National; *n*=23); Canada	Sleep difficulty	Overall, athletes showed a significant reduction to their sleep difficulty score. When separated by baseline sleep difficulties, athletes with mild or no issues showed no changes.	.56
Bonato et al. 2020[a]	RCT; Letter to the editor	45-minute session and leaflet; implemented recommendations following late night practice match. CG = treatment as usual	Intervention *n*=17 (0% female), Age *M*=26; Control *n*=12 (0% female), Age M=25	Soccer (5th Division); Italy	Salivary cortisol and cortisol awakening response	The EG had a lower cortisol awakening response than the CG. Authors propose that this indicates more restorative sleep and reduced stress response following sleep hygiene strategies.	.54
Caia et al. 2018	Parallel groups (median split); Original research article	2-week baseline followed by 2x30-minute sleep hygiene sessions over two weeks. 2-week follow up one month post-session.	Intervention *n*=12 (0% female), Age *M*=26.7; Control *n*=12 (0% female), Age *M*=25.2	Rugby League (National); Australia	Sleep outcomes (actigraphy & self-report diary; bed time, wake time, duration, latency, time in bed, efficiency)	The EG reported earlier bedtimes and later wake times, hence longer time in bed and increased sleep duration. However, sleep efficiency reduced in week two. Sleep behaviours at one month follow-up were no different from baseline.	.78

		CG = treatment as usual					
Driller et al. 2019	Single group pre-post; Original research article	50-minute group sleep hygiene session & 30-minute individual session, three week baseline, three week post-intervention	Total *n*=9 (0% female), Age *M*=23	Cricket (International); New Zealand	Sleep outcomes (actigraphy; total sleep time, time in bed, efficiency, latency, wake after sleep onset, wakeful episodes, onset variance, etc.), subjective sleep outcomes (sleep behaviour, sleepiness, sleep quality)	Sleepiness, sleep quality, sleep efficiency, sleep latency and sleep onset variance improved following the intervention. All other variables showed small, non-significant or unclear changes.	.78
Fullagar et al. 2016	Cross-over; Original research article	Sleep hygiene strategy (dim light, cool room, eye masks, ear plugs, set bed and wake times) implemented for one night following later night practice match, one week washout; CG = treatment as usual	Total *n*=14 (0% female), Age=NR	Soccer (Semi-professional); Germany	Sleep outcomes (actigraphy, sleep diary), perceived restfulness, general recovery; Performance outcomes (heart rate, exertion, training load, distance run, peak speed, CMJ, etc.) Psychological recovery (fatigue, emotional and mental recovery)	Sleep duration was significantly longer for the EG than CG following the match, though no subjective differences in sleep quality were observed. No effects were found for physical performance, recovery, or stress.	.46
Harada et al. 2016	Single group pre-post; Original research article	Sleep hygiene leaflet, encouraging eight recommendations for one month. Data collected pre-, post- and 3-months post-intervention	Total *n*=84 (0% female), Age range: 18-22	Soccer (University); Japan	Sleep quality, performance, mood (GHQ)	Sleep quality increased and irritation decreased following the intervention. Soccer performance showed an initial improvement after the intervention. Higher intervention implementation was positively correlated with better performance.	.78

O'Donnell & Driller 2017	Single group pre-post; Original research article	1-hour session covering five recommendations. One week baseline, One week post-monitoring	Total *n*=26 (100% female), Age *M*=23	Netball (International/National); New Zealand	Sleep outcomes (actigraphy; total sleep time, time in bed, efficiency, latency, wake after sleep onset, wakeful episodes, onset variance, etc.)	There were significant improvements in total sleep time, wake variance and wake episodes following the sleep hygiene intervention. No other significant effects were observed.	.78
Tuomilehto et al. 2017	Pre-post sub-study; Original research article	Athletes provided general sleep hygiene tips. Athletes with suspected sleep disorder received personalised counselling. 12-month follow up	Total n=107 (*n*=23 received sleep counselling; 0% female), Age *M*=25.4 [b]	Ice Hockey (Professional); Finland	Self-reported sleep quality	40 athletes completed 1-year follow-up (though 14 of the 23 athletes with suspected sleep conditions completed follow-up), with 83% of athletes reporting benefitting from the sleep treatment. Athletes reported improved sleep quality following sleep hygiene and individualised treatment plans.	.56
Van Ryswyk et al. 2017	Single group pre-post; Original research article	Two 1-hour hygiene sessions & weekly individual progress updates over six weeks	Total *n*=25 (0% female), Age *M*=23.7	Australian Football (National); Australia	Sleep outcomes (diary & actigraphy), sleepiness (ESS), sleep quality (PSQI); Mood (POMS); Psychomotor vigilance & attention	Total sleep time and efficiency improved following the hygiene session for diary measures but not actigraphy. Significant mood improvements were observed for fatigue and vigour. No changes were observed for psychomotor vigilance and attention.	.33
Vitale, La Torre et al. 2019[a]	RCT; Original research article	45-minute session and leaflet; implemented recommendations following late night practice match. CG = treatment as usual	Intervention *n*=17 (0% female), Age *M*=26; Control *n*=12 (0% female), Age *M*=25	Soccer (5th Division); Italy	Sleep outcomes (actigraphy & diary), sleep quality (1-10)	Significant improvements were observed for sleep latency and subjective sleep quality in the EG as compared with the CG. No effects were found in other sleep indices.	.54
Assisted sleep							

Article	Study design; Article type	Intervention characteristics	Sample *n* (% female), age	Sport; location	Analysed outcomes	Key results	Quality
Abeln et al. 2014	Parallel groups; Original research article	Brain-wave entrainment (audio in pillows); 2-week baseline, 8-week intervention period. CG = sports students used placebo pillows	Intervention *n*=15 (0% female), Age *M*=16.28; Control *n*=15 (40% female), Age *M*=22	Soccer (Youth elite vs Sport Students); Germany	Sleep diary outcomes (total sleep time, time in bed, wake time, waking periods), sleep quality; mood outcomes (strain, calmness, motivational state, self-confidence etc.). Physical state (energy, fitness, health)	Sleep diary outcomes suggested better sleep and awakening quality for the EG including higher ratings of sleep quality. EG showed an increased motivational state. Physical state showed no changes.	.44
Letton et al. 2018	Parallel groups; Conference abstract	Far-infrared shirts worn overnight; length NR; CG = placebo shirts	NR	Baseball (youth elite); NR	Sleep outcomes (quality, latency, disturbance)	Compared to the CG, the EG showed improved sleep quality, latency and disturbances following intervention.	N/A
Locturo et al. 2016	RCT; Original research article	Far-infrared clothing; 6-week baseline, clothes worn overnight following intense exercise session; CG = placebo shirts	Intervention *n*=10 (0% female) Age *M*=19.4 Control *n*=11 (0% female), Age *M*=19.6	Soccer (Youth elite); Brazil	Performance (squat jump, CMJ, strength), delayed onset muscle soreness.	The CG reported increased muscle soreness at 24, 48 and 72 hours, whereas the EG only reported at 24 and 48 hours. No differences were observed for other variables	.85
Mazzardo-Martins et al. 2016	RCT; Conference abstract	Far-infrared shirts worn overnight for six weeks; CG = placebo shirts	Intervention *n*=15 (% female NR), Control *n*=15 (% female NR), Age range: 16-22	Baseball (Youth elite); United States of America	Oxygen consumption, heart rate under exercise stress, sleep quality (PSQI), sleep latency	The use of infrared shirts significantly improved participant's sleep quality and sleep latency. Improved heart rate responses under exercise stress were found in the EG.	N/A

Nunes et al. 2020	RCT (double-blind); Original research article	Far-infrared pants worn overnight for two weeks following one week baseline; CG = placebo pants	Intervention *n*=10 (% female NR), Age M=24.3; Control *n*=8 (% female NR), Age *M*=25.5	Futsal (Professional); Brazil	Performance (CMJ, squat jump, sprints), biochemical stress markers; DOMS	No significant differences in skeletal muscle performance between groups were observed. There were also no effects found for muscle soreness. The EG had higher tumor necrosis factor alpha levels after the intervention as compared to the CG.	.77
Wada et al. 2013	Parallel groups; Original research article	Low colour temperature light, incandescent light bulbs in bedroom; four week intervention period; CG 1= treatment as usual, CG 2=protein-rich breakfast and sun exposure	Intervention *n*=21 (0% female), Control 1 *n*=20 (0% female), Control 2 *n*=22 (0% female), Age *M* (all)=20.3	Soccer (University); Japan	Sleep outcomes (diary, melatonin), sleep quality; Mood (Irritation; GHQ)	There was a significant correlation between implementation (hours under incandescent light) and sleep quality. Anger/irritation reduced in the EG while there were no changes in either CGs. Melatonin levels were higher than both CGs.	.78
Zhao et al. 2013	RCT; Original research article	Red light whole body irradiation, 30 minutes/night for two weeks; CG=placebo non-light whole body treatment	Intervention *n*=10 (100% female) Age M=19.3; Control *n*=10 (100% female), Age *M*=17.9	Basketball (semi-professional); China	Sleep outcomes (quality, latency, duration; PSQI), melatonin, Performance (12-minute run)	The EG demonstrated greater improvements in overall PSQI scores, sleep quality, duration, latency, and serum melatonin levels. There was a significant increase in distance run for the EG.	.62
Sleep recovery							
Article	**Study design; Article type**	**Intervention characteristics**	**Sample *n* (% female), age**	**Sport; location**	**Analysed outcomes**	**Key results**	**Quality**
Atkins et al. 2020	RCT; Original	Lower-body compression garment worn ~15	Intervention *n*=15 (0% female);	Basketball (University	Sleep duration (actigraphy), perceived fatigue,	EG reported reduced fatigue and muscle soreness compared to CG. No effect was found for other performance outcomes.	.62

	research article	hours overnight; CG=loose fitting clothing	Control *n*=15 (0% female), Age M (all)=22.5	); New Zealand	Performance outcomes (muscle soreness, CMJ, sprint test, agility)	There were no statistically significant changes in sleep quality or duration.	
Douzi et al. 2019	Single group, repeated design; Original research article	Partial body cryostimulation at varied lengths (90, 2x 90, and 180 seconds) at -180˚C 1x/week for four weeks; Following training sessions	Total *n*=9 (0% female), Age *M*=24.8	Soccer (Profession al); France	Heart rate, temperature, sleep quality (actigraphy & subjective)	There were no statistically significant changes in sleep efficiency or subjective sleep quality after 180-second cryotherapy exposure. However, athletes experienced reduced movement during sleep following 180-second exposure.	.78
Grainger, Comfort & Heffernan, 2020	Counterbalan ced sequential with washout; Original research article	Partial body cryostimulation for 2-min at -120˚C 1x/week for 9-12 weeks. 4-week washout, no-partial body cryostimulation	Total *n*=18 (0% female), Age *M*=25.4	Rugby Union (Profession al); United Kingdom	Self-reported sleep quality, muscle soreness, energy, mood, and appetite; Training load; Performance (CMJ)	No statistically significant effects were identified for any outcomes.	.62
Krueger et al. 2020	RCT; Original research article	Cold water immersion, 5-min at -6˚C, 1x/day for four days CG = passive recovery	Total *n*=18 (0% female), Age *M*=16.6	Field hockey (Youth elite); Germany	Performance (during game exertion, distance, time on, heart rate; CMJ); Perceived stress, perceived recovery, sleep quality	No effects on in-game performance parameters, perceived recovery, stress, or sleep quality were found.	.54
Schaal et al. 2015	Cross-over (randomised) ; Original research article	Whole-body cryostimulation for 3-mins at -110˚C, 1x/day for two weeks, nine day washout, crossover;	Total *n*=10 (100% female), Age=20.4	Synchronis ed Swimming (Elite); France	Performance (swim trial); Physiological performance response (heart rate, cortisol, blood lactate); Sleep outcomes (actigraphy; time in bed,	During intensified training, sleep duration, efficiency, latency, and perceived fatigue all worsened in the CG, but remained similar to baseline in the EG. Slower swim speed and poorer physiological responses (heart rate,	.46

		in-season, following intensified training			duration, latency, wake time, efficiency; self-reported quality); Psychological outcomes (self-reported fatigue)	cortisol, blood lactate) were also observed in the CG.	
Sleep extension							
Article	**Study design; Article type**	**Intervention characteristics**	**Sample *n* (% female), age**	**Sport; location**	**Analysed outcomes**	**Key results**	**Quality**
Mah et al. 2009	Single group pre-post; Conference abstract	2-3 week baseline, sleep extension aiming for 10 hours/night for 5-6 weeks	Total *n*=5 (100% female), Age range: 18-21	Tennis (University); United States of America	Performance (training statistics), Mood (POMS), Sleep outcomes (ESS, diary and actigraphy)	Athletes recorded improved performance on sprinting drills, hitting accuracy & depth, and self-rated performance following sleep extension. Sleepiness and POMS fatigue scores also improved.	N/A
Mah et al. 2011	Single group pre-post; Original research article	2-4 week baseline, sleep extension aiming for 10 hours/night for 5-7 weeks	Total *n*=11 (0% female), Age *M*=19.4	Basketball (University); United States of America	Performance (training statistics), Psychomotor vigilance (reaction time), Sleep outcomes (ESS, diary, actigraphy), Mood (POMS)	Total sleep time increased as assessed by both actigraphy & sleep journals. All athletic performance measures showed improvements following sleep extension (shooting accuracy, sprint time, self-reported performance ratings), and most psychomotor task performance scores improved. Sleepiness and mood (all POMS subscales) also showed significant improvements.	.56
Schwartz & Simon 2015	Single group pre-post; Original research article	1-week baseline, 1-week sleep extension aiming for 9 hours/night	Total *n*=12 (58% female), Age *M*=20.2	Tennis (University); United States of America	Performance (tennis serve), Sleep duration (diary), sleepiness (ESS, SSS)	Players extended their sleep duration during the intervention period. Sleepiness (ESS & SSS) and tennis serve accuracy significantly improved.	.78
Multi-component interventions							
Article	**Study design; Article type**	**Intervention characteristics**	**Sample *n* (% female), age**	**Sport; location**	**Analysed outcomes**	**Key results**	**Quality**

Bender et al. 2017	Single group pre-post; Conference abstract	Combined sleep extension and low colour temperature (no electronics one hour before bed); 3.5 week intervention	Curlers *n*=15 (53% female), Age *M*=30.7; Rowers *n*=11 (100% female), Age *M*=26.0	Curling and Rowing (National); Canada	Mood (POMS; tension-anxiety, depression, fatigue, vigour, total disturbance)	For rowers, there was reduced depressive mood and total mood disturbance following intervention. For curlers, there was reduced fatigue and total mood disturbance, and increased vigour.	N/A
Duffield et al. 2014	Cross-over (paired-randomised); Original research article	Combined 15-min cold-water immersion, 3-hour full body compression garment, sleep hygiene recommendations. Following 90-min training session. One-day washout, crossover. CG = stretching	Total *n*=8 (0% female), Age *M*=20.9;	Tennis (Profession al); Australia	Performance (technical, physical and physiological), sleep outcomes, perceptual responses (mood, fatigue, soreness)	Authors reported large effect sizes though non-significant results for increased total stroke count, time in play, shots per minute, sleep duration and decreased fatigue. No changes in CMJ were found. Heart rate and perceived muscle soreness were significantly lower following recovery intervention.	.54

Note. *NR (not reported), EG (experimental group), CG (control group), CMJ (countermovement jump), SJ (squat jump), DOMS (delayed onset muscle soreness), ESS (Epworth sleepiness scale), SSS (Stanford Sleepiness Scale), PSQI (Pittsburgh Sleep Quality Index), GHQ (General Health Questionnaire), POMS (Profile of Mood States).

[a] Same sample.

Figure 1

PRISMA Flow Chart

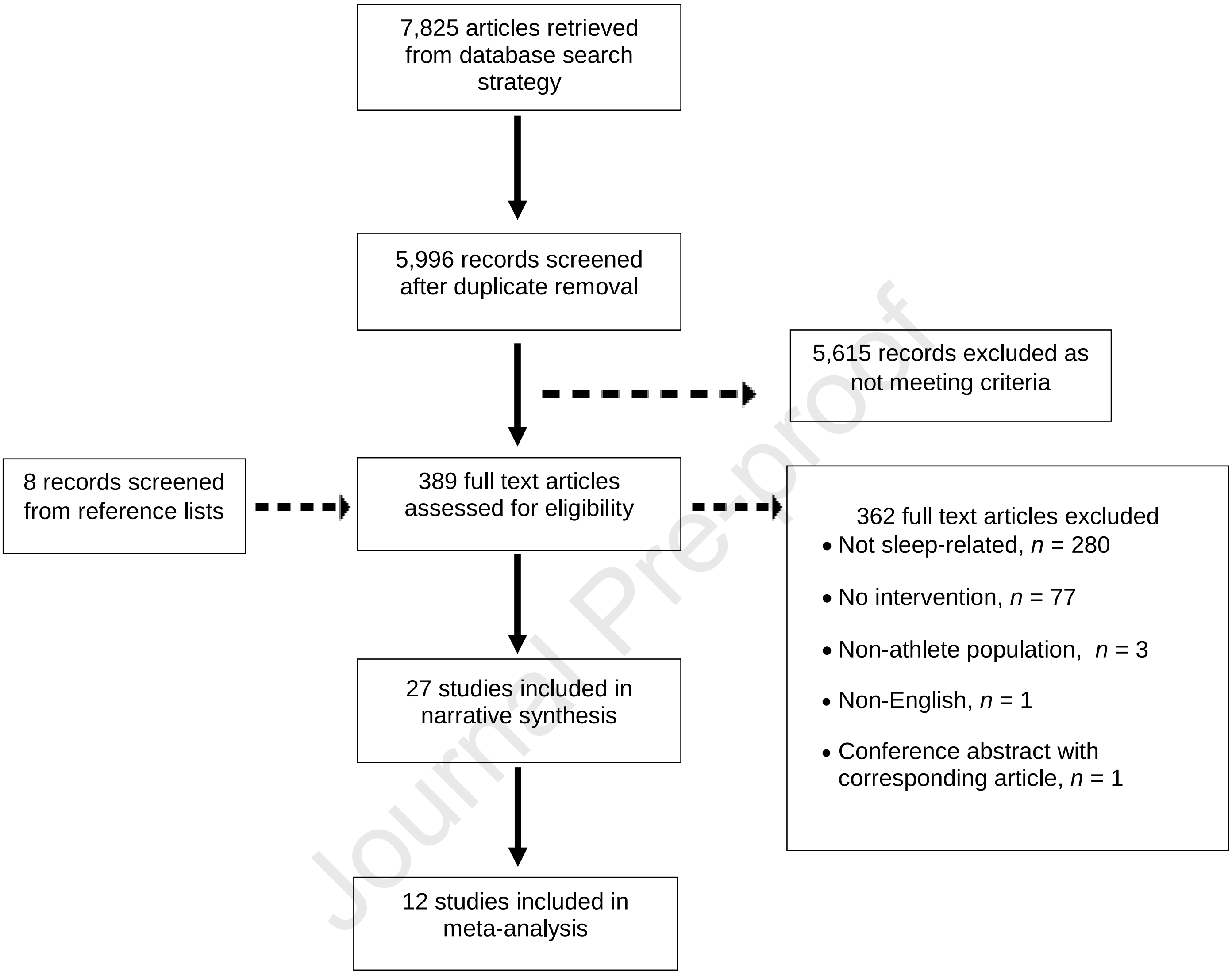
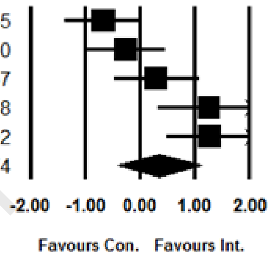


Figure 2

Objective Sleep Forest Plots

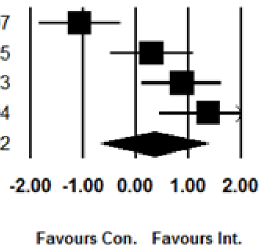
a) Objective sleep duration

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Atkins et al. 2020	Sleep Recovery	Sleep Duration	30	-0.675	0.366	-1.391	0.042	0.065
Vitale et al. 2019	Sleep Hygiene	Sleep Duration	29	-0.272	0.368	-0.994	0.450	0.460
Caia et al. 2017	Sleep Hygiene	Sleep Duration	24	0.295	0.396	-0.482	1.072	0.457
Schaal et al. 2015	Sleep Recovery	Sleep Duration	10	1.252	0.472	0.327	2.177	0.008
Fullagar et al. 2016	Sleep Hygiene	Sleep Duration	14	1.270	0.404	0.477	2.062	0.002
				0.348	0.391	-0.419	1.115	0.374



b) Objective onset latency

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Fullagar et al. 2016	Sleep Hygiene	Onset Latency	14	-1.063	0.393	-1.834	-0.292	0.007
Caia et al. 2017	Sleep Hygiene	Onset Latency	24	0.303	0.397	-0.475	1.080	0.445
Vitale et al. 2019	Sleep Hygiene	Onset Latency	29	0.876	0.384	0.123	1.629	0.023
Schaal et al. 2015	Sleep Recovery	Onset Latency	10	1.382	0.481	0.440	2.325	0.004
				0.359	0.522	-0.664	1.381	0.492



c) Objective sleep efficiency

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Caia et al. 2017	Sleep Hygiene	Sleep Efficiency	24	-0.702	0.407	-1.499	0.096	0.085
Fullagar et al. 2016	Sleep Hygiene	Sleep Efficiency	14	-0.521	0.373	-1.253	0.211	0.163
Vitale et al. 2019	Sleep Hygiene	Sleep Efficiency	29	0.216	0.368	-0.505	0.936	0.558
Schaal et al. 2015	Sleep Recovery	Sleep Efficiency	10	0.296	0.431	-0.549	1.140	0.493
				-0.183	0.250	-0.673	0.308	0.466

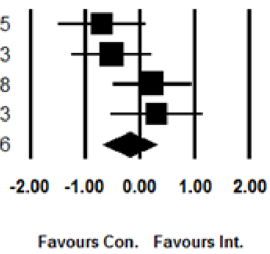


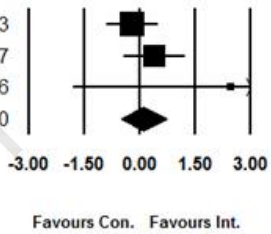
Figure 3

Subjective Sleep Forest Plots

a) Subjective sleep duration

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Abeln et al. 2014	Assisted Sleep	Sleep Duration	30	-0.195	0.356	-0.893	0.503	0.583
Zhao et al. 2012	Assisted Sleep	Sleep Duration	20	0.399	0.433	-0.450	1.247	0.357
Duffield et al. 2014	Combined	Sleep Duration	8	2.458	2.165	-1.785	6.702	0.256
				0.109	0.316	-0.511	0.729	0.730

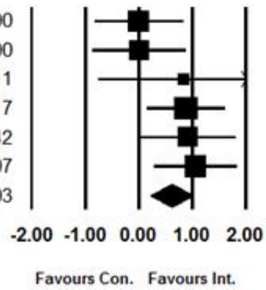
Hedges's g and 95% CI



b) Subjective sleep quality

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Schaal et al. 2015	Sleep Recovery	Sleep Quality	10	0.000	0.428	-0.839	0.839	1.000
Krueger et al. 2020	Sleep Recovery	Sleep Quality	18	0.000	0.449	-0.880	0.880	1.000
Grainger et al. 2020	Sleep Recovery	Sleep Quality	18	0.829	0.817	-0.773	2.430	0.311
Abeln et al. 2014	Assisted Sleep	Sleep Quality	30	0.887	0.373	0.155	1.619	0.017
Zhao et al. 2012	Assisted Sleep	Sleep Quality	20	0.918	0.452	0.032	1.804	0.042
Vitale et al. 2019	Sleep Hygiene	Sleep Quality	29	1.059	0.392	0.291	1.828	0.007
				0.616	0.206	0.213	1.019	0.003

Hedges's g and 95% CI



c) Subjective sleepiness

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Schaal et al. 2015	Sleep Recovery	Sleepiness	10	0.479	0.435	-0.374	1.331	0.271
Duffield et al. 2014	Combined	Sleepiness	8	0.846	0.496	-0.126	1.817	0.088
Abeln et al. 2014	Assisted Sleep	Sleepiness	30	1.039	0.380	0.295	1.784	0.006
				0.809	0.248	0.323	1.295	0.001

Hedges's g and 95% CI

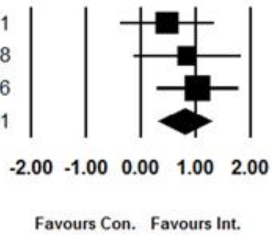


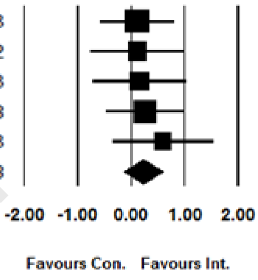
Figure 4

Performance and Negative Affect Forest Plots

a) Aerobic performance

Study name	Intervention Type	Outcome	N	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Atkins et al. 2020	Sleep Recovery	Sprint	30	0.116	0.356	-0.581	0.813	0.743
Nunes et al. 2020	Assisted Sleep	Sprint	18	0.119	0.452	-0.767	1.005	0.792
Krueger et al. 2020	Sleep Recovery	Sprint	18	0.160	0.450	-0.722	1.041	0.723
Fullagar et al. 2016	Sleep Hygiene	Distance Run	14	0.255	0.369	-0.467	0.978	0.488
Zhao et al. 2012	Assisted Sleep	Distance Run	20	0.592	0.486	-0.361	1.545	0.223
				0.228	0.185	-0.134	0.589	0.218

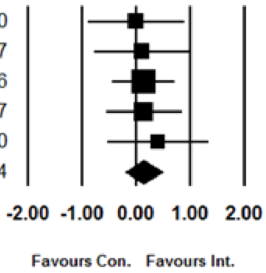
Hedges's g and 95% CI



b) Anaerobic performance

Study name	Intervention Type	Outcome	N	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Nunes et al. 2020	Assisted Sleep	CMJ	18	-0.000	0.452	-0.885	0.885	1.000
Krueger et al. 2020	Sleep Recovery	CMJ	18	0.098	0.449	-0.782	0.979	0.827
Grainger et al. 2020	Sleep Recovery	CMJ	18	0.137	0.289	-0.430	0.704	0.636
Atkins et al. 2020	Sleep Recovery	CMJ	30	0.139	0.356	-0.559	0.836	0.697
Duffield et al. 2014	Combined	CMJ	8	0.402	0.478	-0.535	1.339	0.400
				0.146	0.171	-0.190	0.482	0.394

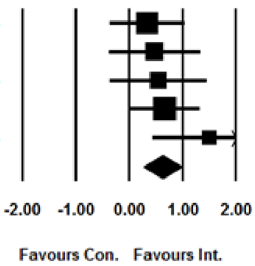
Hedges's g and 95% CI



c) Negative affect

Study name	Intervention Type	Outcome	n	Hedges's g	Standard error	Lower limit	Upper limit	p-Value
Abeln et al. 2014	Assisted Sleep	Perceived strain	30	0.338	0.358	-0.363	1.040	0.345
Schaal et al. 2015	Sleep Recovery	Psychological fatigue	10	0.479	0.435	-0.374	1.331	0.271
Krueger et al. 2020	Sleep Recovery	Perceived stress	18	0.544	0.458	-0.354	1.441	0.235
Wada et al. 2013	Assisted Sleep	Irritability	43	0.670	0.328	0.027	1.313	0.041
Duffield et al. 2014	Combined	Psychological fatigue	8	1.503	0.542	0.440	2.566	0.006
				0.625	0.181	0.271	0.980	0.001

Hedges's g and 95% CI



Highlights

- The effects of sleep interventions on performance, sleep, and mood were explored.
- Sleep hygiene, assisted sleep, and sleep extension interventions appear beneficial.
- Subjective sleep quality, sleepiness, and negative affect all showed improvement.
- Conclusions are hindered by low study quality and small non-representative samples.
- Sleep interventions may improve a range of performance and well-being outcomes.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: