Article title:

Benefits of Daytime Napping Opportunity on Physical and Cognitive Performances in Physically Active Participants: A Systematic Review

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Abstract

Background

Evidence suggests that athletes often experience chronic sleep disturbance. Napping is widely recommended as a safe and non-invasive intervention to counteract the negative effects of partial sleep deprivation. However, systematic reviews on the benefits of napping have yet to be undertaken.

Objective

(i) To evaluate the effectiveness of diurnal napping opportunities on athletes' physical and cognitive performance and (ii) to outline how aspects of the study design (i.e., nap duration, exercise protocol, participants' fitness level and previous sleep quantity) can influence the potential effects of napping through a systematic appraisal of the literature.

Methods

This systematic review was conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. PubMed, Web of Science and SCOPUS databases were searched up to June 2020 for relevant studies investigating the effect of napping on physical and cognitive performances in physically active participants. Fourteen strong-quality and four moderate-quality (mean QualSyst score = 75.75 ± 5.7%) studies met our inclusion criteria and were included in the final sample (total participants: 158 physically active and 168 athletes).

Results

Most studies (n = 15) confirmed the beneficial effects of napping and showed that diurnal napping improved short-term physical performance (n = 10), endurance performance (n = 3) and specific skills performance (n = 2). Two studies showed no significant napping effect and only one study showed reduced sprint performance following diurnal napping. Moreover, napping improved reaction time (n = 3), attention (n = 2) and short-term memory (n = 1) performances. Importantly, “replacement naps” improved both physical and cognitive performance regardless of the type of exercise. However, “prophylactic naps” improved only jump, strength, running repeated-sprint, attention and reaction time performances. In addition, this systematic review revealed that longer nap opportunities (i.e., 90 min) resulted in better improvement of physical and cognitive performance and lower induced fatigue.

Conclusions

A diurnal nap seems to be an advantageous intervention to enhance recovery process and counteract the negative effect of partial sleep deprivation on physical and cognitive performance. Particularly, to optimize physical performances of athletes experiencing chronic lack of sleep, findings from the included individual studies suggest 90 min as the optimal nap duration. Diurnal napping may be beneficial for athletes but this benefit should be viewed with caution due to the quality of the evidence, risk of bias and the limited evidence about napping interventions.

Key Points

A diurnal nap could enhance the recovery process and counteract sleep deprivation’s negative effects before and/or following competition and/or training.

Diurnal napping improved short-term memory, attention, reaction time, repeated-sprint, jumping, endurance and specific skills performances, with greater improvement following longer naps for attention, reaction time and repeated-sprint tests.

The effect of naps is strongly affected by (i) athletes’ objective and subjective rating of sleep quality and duration during the nap and previous nights and (ii) exercise type.

A possible suggestion to coaches, sports scientists and medical staff in technical-based sports is to use morning training scheduled time for technical practice of various individual skills and to introduce NAPO in mid-afternoon (i.e., 13:00–14:00 h). This may consolidate learning processes and lead to better mastery of sport skills. Especially for athletes undergoing chronic lack of sleep, 90 min might be the optimal nap duration to avoid sleep inertia and to optimize physical and cognitive performance. In addition, the duration of at least 1 h between the nap's end and the start of exercise is recommended to allow the athlete to be fully awake and avoid sleep inertia.

1 Introduction

Athletes, coaches, sport scientists and medical staff are facing the challenge to ensure that the required intensity and duration of training do not cause injury, over-reaching, or overtraining. The key is to find the perfect balance between training load and the appropriate recovery to allow improvement [1]. In this way, sleep is widely considered to be essential for optimal performance, general health and recovery [2, 3]. While at least 7 h of sleep is recommended for healthy adults [4, 5], research suggests that athletes need 9–10 h of total sleep time (TST) for optimal waking functioning [6]. Nonetheless, despite the clear need for athletes to obtain adequate sleep, all indications are that sleep disturbances are frequent among athletes [7, 8]. A recent systematic review and meta-analysis concluded that elite athletes' sleep may be more disturbed than normal due to several reasons. Jetlag, altitude, early morning training, increases in training load and traveling to sport meetings might involve getting up early in the morning or retiring late at night [9]. In the same vein, various sport-specific factors as well as societal factors disturbing athletes' sleep have been highlighted lately in a narrative review [10]. Further, it has been reported that elite athletes generally show a high overall prevalence of insomnia symptoms consisting of longer sleep latencies, non-restorative sleep and excessive daytime fatigue [7]. According to Lastella et al. [11], 68% of athletes reported experiencing poorer than normal sleep on the night prior to competition, resulting in an average of TST of 5 h 51 min. In addition, it has been shown, from data collected in 70 nationally ranked athletes from seven different sports, that the athletes averaged 6.5 h of TST per night on training days [12]. In addition, Mah et al. [13] reported that 42.4% of the 628 sampled collegiate student-athletes indicated experiencing poor sleep quality, with 39.1% obtaining less than 7 h of sleep per night. Moreover, a sleep efficiency (SE) of at least 85% is recommended for healthy adults to promote health [14]. However, evidence suggests that SE was lower (3–4%) the night following night competition compared with previous nights [9].

Furthermore, sleep deprivation has been widely reported to affect mood [15], alertness, reaction time [15, 16], short-term memory [17], endurance [18,19,20,21], and short-term maximal intensity [15, 20, 22] performances. Thus, it seems essential for athletes to find a way to counteract lack of sleep. It has been shown that prolonged night-time sleep can improve athletic performance [6]. However, this alternative is sometimes difficult to implement because of early morning training. In this context, napping is a safe and non-invasive intervention and could be an efficient countermeasure to alleviate the consequences of nocturnal sleep deprivation [23]. In addition, since 9–10 h are recommended for athletes for optimal functioning, a diurnal nap could be taken even following a normal sleep night (i.e., 7 h) to achieve better performances. Nevertheless, studies investigating the effect of naps on physical and cognitive performance showed inconclusive results. Several studies reported that repeated-sprint [23, 24], jumping [25, 26], endurance [19, 27], reaction time [25, 28], attention [26, 29] and short-term memory [17] performances were improved by daytime napping. However, in other reports, a diurnal nap did not affect [17, 28, 30, 31] or even impaired performance, potentially due to sleep inertia [32].

In view of these statements, it is important for sport scientists, medical staff and coaches to examine the impact of diurnal napping on physical and cognitive performances. To the best of the authors' knowledge, a systematic review evaluating the effect of napping on physical and cognitive performance is lacking. Hence, the primary aim of the present systematic review was to bridge this gap in knowledge by synthesizing data from selected studies and providing a critical analysis of their results and methodology. In addition, a secondary aim was to outline how aspects of the study design (i.e., nap duration and timing, exercise protocol and timing, participants' fitness level and previous sleep quantity) can influence the potential effects of napping on physical and cognitive performance. The recommendations based on the current findings will have the capacity to inform napping guidelines to optimize exercise performance and recovery practices in athletes and coaches.

2 Methods

2.1 Systematic Review Protocol

This systematic review was conducted and reported in accordance with the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement, which is an evidence-based protocol describing a set of items for reporting in systematic reviews and meta-analyses (see Electronic Supplementary Material online for PRISMA checklist) [33].

2.2 Data Sources and Search Strategy

A comprehensive systematic search of studies was performed electronically in the following electronic scholarly databases: PubMed, Web of Science and Scopus. Data collection was completed on June 2020. The following combination of keywords was used when searching: [(nap) OR napping)] AND [(((((physically active) OR physical activity) OR athletes))] AND [((((((((((((((agility) OR balance) OR speed) OR psychomotor performance) OR vigilance) OR alertness) OR reaction time) OR athletic performance) OR strength) OR anaerobic performance) OR aerobic performance) OR power) OR endurance)) OR cognitive performance))]. Searches identified papers focused on naps or napping in healthy, physically active or athletes' populations and contained keywords relating to physical and cognitive performances (e.g., physical activity, physical performance, athletic performance, strength, anaerobic performance, aerobic performance, endurance, power, agility, balance, speed, psychomotor performance, cognitive performance, vigilance, alertness, and reaction time). To identify additional studies not included in these search terms, the reference lists of the included manuscripts were checked, as well as the related citations from other articles via Google Scholar and the authors' personal files. Specialists in the field were also contacted for information about possible pending publications. In addition, target journals (i.e., Journal of Sports Sciences, British Journal of Sports Medicine, Chronobiology International, Asian Journal of Sports Medicine, Biological Rhythm Research, International Journal of Sport Physiology and Performance, European Journal of Sport Sciences, Sleep, Sleep Medicine, Sports, International Journal of Environmental Research, Journal of Sleep Research and Public Health) were hand-searched for relevant accepted studies. Definitions of key terms used in this systematic review are provided in Table 1.

Table 1 Terms used in this review

Full size table

2.3 Eligibility Criteria

To be included in the systematic review, individual studies needed to fulfil the following inclusion criteria:

(i)

primary research published in peer-reviewed journals,

(ii)

research conducted with healthy human participants (physically active or trained subjects),

(iii)

original studies that had investigated the effect of napping on physical performance,

(iv)

no severe methodological deficiencies (e.g., absence of control group and inappropriate statistical analysis procedures)

Exclusion criteria were:

(i)

data from congress or workshop publications,

(ii)

studies in which a no-nap condition was made,

(iii)

studies in which no exercise was performed after the nap,

(iv)

studies in which participants were non-physically active

No limits were set for the year of publication. Case studies, encyclopedia items, book chapters and reviews were excluded, although the bibliographies of the latter were consulted to refine article searches.

2.4 Study Selection

The process used for selecting articles is outlined in Fig. 1. Following the manual removal by the authors of duplicate studies identified by the different search engines, inclusion or exclusion of the remaining articles was performed by applying the above criteria to the title and abstract to determine eligibility in a preliminary independent screening. Selected papers were then read in full to finalize eligibility or exclusion. The reason for excluding an article during the full-text review was recorded.

Fig. 1

figure 1

Flow chart of the systematic review process (PRISMA)

Full size image

2.5 Data Collection Process

Authors collected data using a pilot-tested extraction form and resolved disagreements by consensus. Data extracted included participant characteristics (number of participants, age, sex, training program, level of practice), study characteristics (duration and timing of daytime napping, study design, time since nap's end untill exercise, and country), and key outcomes.

2.6 Quality Assessment

The methodological quality of each study was assessed using the quantitative assessment tool 'QualSyst' [34]. QualSyst contains 14 items (Table 2) that are scored depending on the degree to which specific criteria are met (yes = 2, partial = 1, no = 0). Items not applicable to a particular study design were marked as 'NA'. A summary score was calculated for each article by summing the total score obtained across relevant items and dividing it by the total possible score. Two authors (MR and MS) independently performed quality assessments, and disagreements were solved by consensus or by the intervention of a third reviewer (OH) when necessary. Studies with a score of ≥ 75% were considered as of strong quality, those rated at 55–75% as of moderate quality, and a score < 55% was judged as of weak quality. The percentage of lost points for each item was also calculated.

3 Results

A total of 18 studies met the inclusion criteria and were included in the current systematic review. These studies examined the effects of napping on physical performance. All of them used a statistical significance threshold of $p < 0.05$.

3.1 Study Selection and Characteristics

3.1.1 Study Selection

The predefined search strategies yielded a preliminary pool of 129 possible papers, 27 of which remained after duplicates had been excluded and titles and abstracts had been screened.

After a careful review of the 27 full texts, 16 papers were excluded (10 studies in which no exercise was performed after the nap condition, 5 with non-physically active participants and 1 with no control group) (see Electronic Supplementary Material online for full-text articles excluded). Eleven articles were included, besides 7 additional records identified through the screening of the references and related citations from other journals via Google Scholar lists of included articles.

Therefore, 18 studies met our inclusion criteria for determining the effects of napping on physical and cognitive performances in athletes or physically active participants.

3.1.2 Study Characteristics

Data from all studies published between 2007 and 2020 are presented in Tables 3, 4, 5, 6, 7, 8, 9, 10,11, arranged by order of publication date and measured performances. Seven studies were conducted in Tunisia [23,24,25,26, 29, 31, 35], three in Japan [28, 36, 37], three in the United Kingdom [17, 27, 38], one in Germany [39], one in France [30], one in Singapore [32], one in Sweden [19] and one in Australia and New Zealand [40].

Included studies focused on the acute effects of napping on physical performance including maximal short-term performance (e.g., grip and back strength, bench and leg press, sprinting, vertical jump, 5-jump test, muscle power and fatigue index during the 30-s Wingate test (WAnT) and running repeated-sprint tests) and longer duration tests (e.g., a 3000-m run, running time to exhaustion 90% $\dot{V}O_2$ max, and karate-specific test) as well as cognitive performance (e.g., simple and choice reaction time test, mental rotation test, lower reaction test, modified flanker test, short memory test, and digit vigilance test).

3.1.3 Quality Assessment

Quality scores for the included studies ranged from 64.2% (moderate) to 89.2% (strong). Most studies (n = 14) were rated as strong quality and four were of moderate quality.

Causes of lost points included researchers blinded (88.9%), subjects blinded (83.4%) and random allocation (47.3%) (Table 2).

Table 2 Quality assessment of the studies

Full size table

Table 3 Effect of napping on muscle force performance

Full size table

3.1.4 Subject Characteristics

The studies involved in this systematic review included a total of 326 participants (273 males and 53 females). The number of participants in each trial ranged from 7 [28] to 61 [19], with a mean sample size of 18.1 (SD 6.5) and a mean age ranging from 18 [23, 35] to 35 [27] years.

These 18 studies targeted healthy, active adults of varying fitness status. Ten studies recruited physically active participants (n = 158), two investigations recruited highly trained subjects (n = 77) and six studies recruited professional athletes (n = 91) in different sport types: professional judokas at least at the black-belt 1st Dan level [23, 35], international karate athletes [25], elite netball players [40], high-level track and field athletes [32] and professional athletes in strength and weight lifting [38].

3.2 Effects of Napping on Physical Performance

3.2.1 Short-Term Physical Performance

3.2.1.1 Muscle Strength

Four studies [17, 28, 29, 38] focused on the effects of napping on muscle force following normal sleep night (NSN) and partial sleep deprivation (PSD) (Table 3) with inconclusive results. Although no significant effect of napping on grip [17, 28] and back strength [28] was observed in some studies, Brotherton et al. [38] reported a significant increase in grip strength following a 60-min nap opportunity (NAPO) in comparison with no nap after a PSD protocol at the beginning of the night (3 h of nocturnal sleep for two consecutive nights). In addition, a significant increase in performance was observed for bench press (i.e., average power, average force and peak velocity) and leg press (i.e., average power only without significant changes in average force and peak velocity). Furthermore, it has been reported that performance during a maximal voluntary isometric contraction test increased significantly following NSN after 90-min NAPO (i.e., 9%) and 40-min NAPO (i.e., 2.3%) compared to the control condition [29].

3.2.1.2 Sprint Performance

Two studies [17, 32] focused on the effects of 30-min NAPO on sprint performance (Table 4), and reported conflicting findings. Following one night of PSD, Waterhouse et al. [17] reported higher sprint performance in the NAPO group with 4% and 3% faster sprint times during the 2-m and 20-m sprint test, respectively. Nevertheless, following NSN, Suppiah et al. [32] reported that napping has no significant effects on (i) mean sprint time during 10-m and 20-m tests, and (ii) fastest sprint time during 2-m and 10-m sprint tests. Interestingly, these authors showed that fastest 20-m sprint performance decreased significantly following NAPO, indicating a slower sprint time by 0.8% [32].

Table 4 Effects of napping on sprint performance

Full size table

3.2.1.3 Jumping Performance

Studies investigating the effect of NAPO on jumping performance following NSN and PSD showed inconclusive results [25, 26, 40] (Table 5). In a test–retest protocol, Daaloul et al. [25] found that 30-min NAPO increased countermovement jump (CMJ) and squat jump (SJ) performance in the retest sessions that took place after an exhausting task, i.e., the karate-specific test. This indicates that the nap mitigated the karate-specific test-induced fatigue.

Table 5 Effect of napping on jump performance

Full size table

Furthermore, Hsouna et al. [26] showed a significant increase of 5-jump test performance by 3.5% and 3.7% after 35-min and 45-min NAPO, respectively. However, no significant effect was observed with 25-min nap duration [26].

Moreover, an observational study over 26 sport games reported no significant improvement of CMJ performance (i.e., mean jump velocity and height jump), while peak jump velocity increased significantly for participants who had short naps (≈ 15 min) [40]. It is important to mention that, in this study, athletes individually decided in their free time, which lasted 2 h, whether to nap or not prior to performance measurement. If a nap was taken, they were asked to note the estimated duration.

3.2.1.4 Running Repeated Sprint Test

Pelka et al. [39], Hammouda et al. [35], Boukhris et al. [24], Abdessalem et al. [31], Romdhani et al. [23] and Boukhris et al. [29] focused on the acute effects of various durations of napping on performance and fatigue during repeated short-term efforts (Table 6).

Table 6 Effects of napping on repeated-sprint exercise performance

Full size table

For 6 × 4 s sprint, Pelka et al. [39] showed a significant increase of the average maximum speed after a 25-min NAPO following NSN.

Romdhani et al. [23] and Hammouda et al. [35] are part of a large study that investigated the effect of two NAPO (90 min; N90 and 20 min; N20) following a night of PSD (4:30 h of nocturnal sleep) during the running-based anaerobic sprint test, (RAST, 6 × 35-m sprint, with 10 s in between for the turn-around). The results of the study showed that both nap durations enhanced maximum power

(Pmax). However, minimum power (Pmin) and mean power (Pmean) increased only after the long nap (i.e., N90) compared to control condition. In addition, a significant decrease was observed for fatigue index (FI) after N90.

Moreover, significant improvements in 5-m shuttle run test performance (i.e., 6 × 30 s sprints) have been reported following NSN [24, 29, 31]. Boukhris et al. [24] found an increase of total distance (TD) following all NAPO (i.e., 25 (N25), 35 (N35) and 45 (N45) min) and best distance (BD) following N25 and N45 in comparison with no-nap condition. They concluded that the highest repeated-sprint performances were realized after the longest nap opportunity (i.e., N45). However, FI remained unchanged. In a more recent study, these authors showed that TD and BD increased significantly following 90 (N90) and 40 min (N40) NAPO with greater improvement after N90 [29]. TD increased significantly from 704 ± 37 m in control condition to 759 ± 71 m and 793 ± 64 m, for N40 and N90, respectively. Similarly, BD values were 129 ± 6 m for control condition, reaching 139 ± 11 m and 142 ± 13 m for N40 and N90, respectively. This greater improvement following the N90 was accompanied by a significant decrease in the FI from 15 ± 4% in control condition to 10 ± 3% in N90. No significant improvement of FI was recorded following N40 [29].

In another study, Abdessalem et al. [31] reported that N25 at 14:00 and 15:00 h increased performance during the 5-m shuttle run test following NSN, whereas N25 at 13:00 h did not.

3.2.1.5 30-s Wingate Test

Two studies focused on the effects of napping on the WAnT performance following NSN [28, 30] (Table 7). No significant effects of different NAPO (i.e., 30, 60 and 90 min) were observed for the different measured variables (i.e., peak power (Ppeak), Pmean and FI).

Table 7 Effect of napping on the 30-s Wingate test performance

Full size table

3.2.2 Endurance Performance

Only three studies investigated the acute effect of napping on endurance exercise following NSN and PSD [19, 25, 27] (Table 8). A study conducted by Blanchfield et al. [26] tested the effect of 40-min NAPO on evening endurance exercise performance in trained male runners who had also participated in morning exercise. The authors reported that napping improved time to exhaustion (TE) at 90% $\dot{V}O_2max$ of five runners who slept less than 7 h the previous night [27]. Moreover, Keramidas et al. [19] investigated the effect of 30-min NAPO after military sustained operations following PSD in a total of 61 participants (i.e., participants were allowed to take 5 h of sleep during 51 h). The results showed that 3000-m run performance was significantly impaired by 2.3% in the control group but not in the 30-min NAPO group. In lunge trials, the number of repetitions increased significantly by 7.1% only in the nap group [19].

Table 8 Effects of napping on performance during long-duration exercise

Full size table

Furthermore, a recent study examined the effect of napping on TE during a karate-specific test following two nocturnal regimens (i.e., PSD and NSN) [25]. It was reported that 30-min NAPO improved karate-specific test performance following one PSD night (4 h of nocturnal sleep), while no significant improvement was observed after NSN [25].

3.3 Effect of Napping on Specific-Sport Skills

In two independent studies, Morita et al. [36, 37] reported an enhancing effect of napping on juggling performance (Table 9). In the first study, participants were assigned to either 120-min NAPO or rest and their juggling performance was evaluated at 10:30 and 17:30 h [36]. Mean number of juggled catches in the nap group increased significantly in the retest, while the control group did not increase its performance. Further, performance was 20% higher for the nap group in comparison with the control group [36].

Table 9 Effects of napping on juggling

Full size table

In the second study, two retests (i.e., retest-1 at 17:30 h the same day, and retest-2 at 10:30 h the following morning) and 70-min NAPO at 14:00 h were implemented [37]. The results showed that performance for the nap group was 41 and 49% higher than for the control group for retest-1 and retest-2, respectively [37].

3.4 Effect of Napping on Cognitive Performance

Seven out of the 18 studies included in this systematic review investigated the acute effect of napping on cognitive performance [17, 23, 25, 26, 28, 29, 31] following NSN and PSD (Table 10 and 11). NAPO generally improved performance on reaction time tests (i.e., simple reaction test [25, 28], choice reaction test [23, 28], mental rotation test [25], lower reaction test [25] and modified flanker task [28]), indicating a shorter reaction time. In one study, Waterhouse et al. [17] investigated the effect of 30-min NAPO on short-term memory performance following PSD, and the results showed a significant positive effect of napping on digit-forward and digit-backward memory tests. Furthermore, performance during the digit-cancellation test was evaluated following various NAPO (i.e., 25, 35, 40, 45 and 90 min) [26, 29, 31]. While no significant effect was observed for 25- and 35-min NAPO [26, 31], attention scores were significantly higher following 40 (i.e., 7.1%), 45 (i.e., 7.5%) and 90 (i.e., 9.2%) -min NAPO compared to control condition [26, 29]. It is important to mention that attention performance was significantly higher (i.e., 2.3%) after 90-min NAPO compared to 40-min NAPO [29].

Table 10 Effects of napping on reaction time

Full size table

Table 11 Effects of napping on memory and attention

Full size table

4 Discussion

Most studies (n = 15) confirmed the beneficial effect of napping after both NSN and PSD protocols and showed that diurnal napping improved short-term physical performance (n = 10), endurance performance (n = 3) and specific skills performance (n = 2). Two studies showed no significant napping effect and only one study showed a reduced sprint performance following diurnal napping. Moreover, napping improved reaction time (n = 3), attention (n = 2) and short-term memory (n = 1) performances. The discrepancies between these findings could be due to factors related to the exercise protocol (e.g., type, duration), the napping protocol (i.e., duration, timing and type), sleep protocol (i.e., total sleep deprivation, PSD, NSN) and duration of sleep deprivation protocol (e.g., one, two nights of PSD).

4.1 Nap Opportunities Following Sleep Deprivation

Concerning maximal short-term exercise, the effect of napping seems to be more pronounced following PSD for sprint [17], strength [38] and jump [25] compared to NSN in which no improvement was observed [28] or performance was even impaired [32]. Moreover, the results showed that NAPO of various durations (i.e., 30, 60 and 90 min) has no significant effect on Wingate test performances [28, 30] following NSN. Similarly, studies investigating napping effects on endurance performance reported improvement with 30- [19, 25] and 40-min [27] NAPO following PSD; however, no significant difference has been noticed following NSN [25, 27]. These results could be explained by the task and its duration. Interestingly, regarding running repeated-sprint exercises, performance improved whether following PSD [23] or NSN [24, 29, 31, 39] with NAPO ranging from 25 [31, 39] to 90 min [23, 29]. These findings suggest that “replacement naps” which occur following PSD resulted in better physical performance regardless of the type of the exercise, while “prophylactic naps” might only enhance running repeated-sprint performance.

A recent study examined the efficacy of daytime napping to supplement night-time sleep in athletes [41]. Three conditions were compared: 9 h in bed overnight with no daytime nap, 8 h in bed overnight with a 1 h NAPO and 7 h in bed overnight with a 2 h NAPO. Polysomnographic records showed no significant differences between the different conditions in total sleep time; as a result, daytime napping may be an effective strategy to supplement athletes’ night-time sleep [41]. This could explain the effectiveness of napping following PSD.

In this context, the evidence suggests that sleep disturbance is common among athletes, which implies poorer sleep duration and lower sleep quality [9, 42,43,44]. In fact, sleep troubles occur more frequently on training days [12, 13, 45], night(s) before [3, 11] and following [46, 47] competitions, which may provide a more convincing justification for introducing napping into daily athletic schedules to counteract the lack of sleep experienced by athletes.

Further, chronic sleep restriction was associated with an increased sports injury in 112 adolescent athletes over a 21-month period [48]. The authors reported that less than 8 h of sleep per night was the strongest predictor of injury. Indeed, over the supervised 21 months, 65% of athletes who reported sleeping less than 8 h per night experienced at least one injury. Moreover, it has been reported that the match environment resulted in very high levels of cortisol and reduced sleep quantity and quality when compared to control condition in elite athletes [47].

In this context, a recent investigation found that 90-min NAPO enhanced antioxidant defence after exercise by reducing sleep loss-induced muscle and oxidative damage [23]. In addition, it has been reported that napping normalizes sleep loss-induced biochemical disruption [49]. Thus, a long NAPO could be preventive against injuries. However, to the authors' knowledge, no study has examined the effect of napping on injuries among athletes. Therefore, further investigation, preferably in long-term studies, is required to identify the direct link between napping and injuries.

Given that participants in the two studies [28, 30] investigating the effect of napping on Wingate test exercises following NSN are non-professional, are not part of a professional team or are not following a specific training program, we suppose that they did not have sleep debt. Therefore, the lack of significant differences can only confirm the above-mentioned speculations that some exercises (i.e., Wingate test, sprint, strength, and jumping) might not be sufficiently affected by "prophylactic naps". Nevertheless, the effect of "replacement naps" on various variables during Wingate tests could be the topic of future studies.

Moreover, it is accepted that 80% of the energy turnover during the Wingate test is derived from lactic and alactic anaerobic metabolism [50]. Further, aerobic metabolism has been estimated to provide 9–40% of the energy utilized during the Wingate test depending on the age and training status of the subjects [51]. Obviously, evidence suggests that Wingate test is an exhaustive and highly anaerobic test. However, the running repeated-sprint tests used in the studies selected for the present systematic review [23, 24, 29, 31, 39] seem to be more exhausting compared to the Wingate test. Indeed, such exercises (i.e., the running repeated-sprint tests) requires the repetition of maximal (all-out) effort six times (i.e., 6 × 4 s [52], 6 × 30 s [24, 31], 6 × 35 m [23]) which implies more muscle groups in comparison with efforts on cycle ergometer during the Wingate test. In addition, the repetition of maximal effort in repeated-sprint exercises, such as 6 × 30 s or 6 × 35 s, leads to high accumulation of lactate [53], and consequently to greater fatigue compared to maximal short-term exercises (i.e., sprint, jump, strength) and the Wingate test. Therefore, the repetitive and tiring aspect of running repeated-sprint exercises could be a possible explanation for the improvement in performance even following NSN.

Napping seems to be an effective strategy to improve various physical performances by counteracting the negative effects of sleep deprivation. However, the effectiveness of the nap is limited to running repeated-sprint performance following NSN. Further, it can be concluded that the more exhaustive and repetitious the exercise is, the more the need for a nap will be important.

4.2 Longer Nap Opportunities Lead to Greater Improvement

In addition, the currently included studies revealed that longer NAPO resulted in greater improvement in physical and cognitive performance. The results showed no significant difference in attention scores with short NAPO (i.e., 25 and 35 min) [26, 31]; however, performance improved significantly following longer NAPO (i.e., 40, 45 and 90 min) compared to control conditions [26, 29] following NSN. Importantly, improvement was greater with the increase of NAPO duration (i.e., 7.1%, 7.5% and 9.2% for 40, 45 and 90 min, respectively). In addition, attention performance was significantly higher (i.e., 2.3%) after 90-min NAPO compared to 40-min NAPO [27].

Similarly for physical performance, strength [29], jump [26] and running repeated-sprint [23, 24, 29] performances were higher following longer NAPO. It is postulated that a set of running repeated-sprints is highly demanding and induces fatigue on multiple parameters [54]. Induced fatigue is operationalized through a reduction in speed performance [54], impairment of the autonomic nervous system (i.e., parasympathetic reactivation) [55] and greater inflammatory response after NSN [56] and especially after PSD [15]. Aerobic capacity is recognized as an important factor influencing the ability to resist fatigue during running repeated-sprint exercises. Previous research established significant correlations between (i) $\dot{V}O_2max$ and FI [57], (ii) mean sprint time and the velocity at onset of blood lactate accumulation and (iii) sprint decrement and the peak blood lactate concentration [53]. Surprisingly, the improvement of running repeated-sprint performances following 25–45-min NAPO were not accompanied by a significant change in the FI [24]. These results are consistent with those of Romdhani et al. [23] and Boukhris et al. [29] who showed no significant improvement for FI with 20 [23] and 40 min [29] NAPO; however, they reported a significant diminution (21.7–33.3%) of FI after 90-min NAPO following PSD [23] and NSN [29]. This could be related to a greater duration of slow wave sleep (SWS) in N90 compared to N40 and N20, which has a restorative effect. Therefore, it is obvious that a longer nap is needed to simultaneously improve performance and fatigue resistance.

4.3 Optimal Nap Duration for Athletes Undergoing Chronic Lack of Sleep

Only two studies [36, 37] examined the effect of NAPO on sports-specific skills. Three-ball cascade juggling was the task selected in these two studies because it requires the training and engagement of complex motor skill activities similar to real sports. It has been reported that 120-min NAPO enhanced juggling performance through motor learning facilitation [36]. Importantly, Morita el al. [37] reported a further improvement in juggling performance the following morning for the nap group compared to the no-nap group. Therefore, the advantageous effect of naps—in facilitating the consolidation of motor memory—was considerably strengthened by nocturnal sleep which led to higher performance the following day. Further, polysomnographic records showed a significant increase in SWS duration after the learning task (≈ 40 min out of 111 min of TST) compared to the baseline (≈ 26 min out of 109 min of TST) [36]. This suggests that SWS facilitated learning during the juggling task. Consequently, long naps, i.e., naps containing SWS, may improve motor learning during sport-specific tasks and lead to faster acquisition of skills.

It is a well-known fact that, in sport situations, executive function (e.g., reaction time, fast judgment) and physical fitness should be exerted at an optimal level to achieve maximal performance [58, 59]. Further, it has been reported that elite athletes require a higher level of cognitive engagement in their sports [2]. According to Lastella et al. [60], the ability to make fast and accurate decisions in team sports is just as important as executing skills efficiently during competitions. In this context, rapid eye movement (REM) sleep has a vital role with restorative benefits for cognition [61, 62] and is also associated with memory consolidation and learning of motor skills [63, 64]. In this way, Tanabe et al. [28] investigated the effect of various NAPO (i.e., 30, 60 and 90 min) on executive functions during a simple reaction test, choice reaction test and modified flanker task. The results showed that only the longest NAPO (i.e., 90 min) was followed by an improvement in reaction time for all executive function tasks and is associated with an increase in cerebral blood flow [28]. These results confirm previous assumptions that 90 min is the optimal NAPO duration [29]. Effectively, during a digit cancellation test, attention scores after a 90-min NAPO were significantly higher compared to the control and the 40-min NAPO conditions by 9.2 and 2.3%, respectively [29]. Similarly to previous papers [36, 37], results of all these investigations suggest that naps containing SWS may result in higher performances. In this vein, it was suggested that non-rapid eye movement (NREM) sleep is the time in which the body actively repairs and restores itself [63, 64]. In addition, SWS—also known as deep NREM sleep—is thought to play an important role in cerebral restoration and recovery [65, 66] through a notable release of growth hormone [47]. The effectiveness of the 90-min NAPO compared to lower nap durations (e.g., 30, 40 and 60 min) is most likely due to the occurrence of NREM sleep between the 10th and the 70th min in addition to REM sleep between 70 and 90th min [67].

It is also well known that performance is temporarily impaired by a transient state between sleep to fully awake called "sleep inertia", which disappears approximately one hour after waking [68]. This could be a possible explanation for the performance impairment observed in Suppiah et al.s [32] study during sprint exercise, which took place 45 min after waking. Therefore, it would be safe to recommend a duration of at least 1 h between the end of the nap and the start of exercise to allow one to be fully awake and avoid sleep inertia. Moreover, it is noteworthy that—although no significant difference was observed in SWS duration between 60- and 90-min NAPO—sleepiness scores were significantly higher after 60-min NAPO compared to scores before the nap [28], probably due to sleep inertia. In this context, Stampi [68] investigated the effects of three nap durations (20, 50 and 80 min) on sleep inertia. The study showed that 50-min naps generated more severe sleep inertia. Similarly, it has been shown that 60-min naps induce severe sleep inertia [69]. Importantly, Davies et al. [67] considered that a 90-min nap duration is optimal as it allows a complete sleep cycle (NREM + REM) to occur and thereby could reduce the severity of sleep inertia, since REM sleep is a lighter sleep state and waking up from this sleep stage is easier [70]. These findings provide supplementary evidence for the hypothesis that the optimal diurnal nap duration for athletes might be 90 min to avoid the impairment of performance due to sleep inertia [71].

4.4 Methodological Considerations

Less than half of the studies (n = 8) in the present systematic review used objective measurements of sleep or NAPO (i.e., actigraphy and/or polysomnography). Such equipment provides details about sleep patterns (i.e., TST, SE, sleep-onset latency, wakefulness after sleep onset and sleep stages) [72]. The conclusions of this paper highlight the importance of quality and duration of the nap and the previous night's sleep. However, evidence suggests that NAPO could be underestimated when self-reported [73]. Therefore, an objective recording of sleep pattern is recommended for future research for a better understanding of the underlying mechanisms and a better exploitation of the benefits of napping. Sleep assessment methods have been discussed lately in a critical review [74]. It has been concluded that polysomnography is the gold standard of sleep measurement, providing the most accurate results both in terms of quality and quantity. However, it is a complex and expansive technique.

Importantly, a recent systematic review focused on the effect of sleep extension in athletes [75]. Several factors have been identified including athletes' chronotype, sleep patterns and habitual amount of sleep. According to Silva et al. [75], the most important factor is to identify the athlete's normal sleep pattern and whether he/she is getting adequate sleep, which has been neglected in the studies included in the present systematic review. Indeed, out of the 8 studies in which sleep was measured objectively, five studies [25, 27,28,29, 32] assessed the total sleep time for only one night before the experimental trial. However, for a reliable measure of total sleep time, the minimum recommended period is 7 days [76]. Exclusively, Petit et al. [30] and Morita et al. [36, 37] assessed TST for more than 7 days and could report the exact habitual amount of sleep. Moreover, discrepancies in the strength of the results could be explained by the difference between the protocols used. Tanabe et al. [28] and Boukhris et al. [29] used an NSN protocol, Waterhouse et al. [17] used a one night PSD protocol (i.e., 4 h of sleep) and Brodherton et al. [38] used a PSD for two consecutive nights (i.e., 3 h of sleep per night). Furthermore, in Brodherton et al. [38], study participants were familiarized with performance measurement and sessions were not randomized. All these factors could affect the results and explain discrepancies between studies.

Therefore, researchers should take into consideration all those factors to draw firm conclusions. In addition, nap conditions (i.e., participants' need to rest in a familiar, quiet, darkened room until they fall asleep) should be respected in all studies. Furthermore, future investigations may involve repeated naps with habitual/non-habitual nappers during a micro-cycle to explore the chronic effect of napping on physical and cognitive performance.

5 Strengths and Weaknesses

This is the first systematic review of the effects of napping on athletic and cognitive performance. The strengths of the present analysis include a comprehensive coverage of the available literature and a careful appraisal of its quality. Moreover, the databases PubMed, Web of Science, Scopus and Google Scholar were searched without time limit and studies published in all languages were included. One major limitation is the paucity of studies that objectively evaluated nap and nocturnal sleep durations. Therefore, it should be acknowledged that further research including objective sleep measures—preferably polysomnography—are required. Meta-analyses were not conducted owing to the low number of studies of each type of physical effort.

6 Conclusion

The findings of the current review are meaningful for understanding the benefits of napping for elite athletes to alleviate the negative effects of partial sleep deprivation. It is likely that "replacement naps" persistently improved the physical/cognitive performance of several aspects of exercises. Therefore, a diurnal nap is an appropriate solution to enhance recovery processes and counteract the negative effect of PSD before and following competition or training. In addition, the advantageous effects of a nap can be further enhanced following nocturnal sleep and are apparent in performance the following day. A possible suggestion to coaches in technical-based sports is to use the morning trainings scheduled time for technical practice of various individual skills and to introduce NAPO in the mid-afternoon. Naps containing SWS might improve motor memory during sport-specific learning and lead to faster acquisition of skills, and therefore, consolidate the learning process and lead to better mastery of sport skills. Nonetheless, a greater understanding of the effect of naps on sport-specific skills learning is central to future research in real sport training especially for young athletes playing various sports (e.g., football, basketball, tennis, and swimming).

Finally, this systematic review revealed that longer nap opportunities resulted in greater improvement in physical performance and lower induced fatigue. In addition, both NREM and REM sleep are thought to play a role in memory consolidation, cerebral restoration, recovery and learning of motor skills. Since a 90-min nap was found to reduce sleep inertia—compared to shorter naps—and allows a complete sleep cycle (NREM + REM) to occur, it might be suggested as the optimal diurnal nap duration especially for elite athletes who experience chronic sleep loss.

That being said, coaches, sports scientists and medical staff should be careful to use napping interventions as a measure to improve sports performance due to the quality of the evidence, risk of bias and the limited data.

6.1 Research Agenda

Based on the limitations found in the included studies in the current review, future studies on the potential effect of napping on physical performances should:

Gain more insight into the individual differences—based on sport type, chronotype, habitual amount of sleep, athletes' normal sleep patterns, if they were familiarized with performance, sleep deprivation protocol and napping conditions—that may influence the beneficial effect of naps.

Evaluate the time course of the beneficial effect of napping, especially following the recommended nap duration, i.e., 90 min.

Use multiple devices (i.e., polysomnography, actigraphy, heart rate variability) for a better understanding of sleep architecture.

Obtain more specific information on the contribution of sleep stages to the enhancement of sport skills performance.

Data availability

Data sharing is not applicable to this article. All data extracted are presented in Tables 3 through 11.

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Ethics declarations

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