Is daytime napping an effective strategy to improve sport-related cognitive and physical performance and reduce fatigue? A systematic review and meta-analysis of randomised controlled trials

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ABSTRACT

Objective To estimate the association between daytime napping and cognitive and physical sport performance and fatigue after normal sleep and partial sleep deprivation (less sleep duration than necessary).

Design Systematic review and meta-analysis.

Data sources The PubMed, Scopus, Web of Science, Cochrane Central, SportDiscus and PsycINFO databases.

Eligibility criteria for selecting studies Randomised controlled trials on the effect of daytime napping on sport performance and fatigue available from inception to 2 December 2022. Standardised mean differences (SMD) and their 95% compatibility intervals (CI) were estimated with the DerSimonian-Laird method through random effect models.

Results In the 22 included trials, 291 male participants (164 trained athletes and 127 physically active adults) aged between 18 and 35 years were studied. When performed after a normal night of sleep, napping from 12:30 hours to 16:50 hours (with 14:00 hours being the most frequent time) improved cognitive (SMD=0.69, 95% CI: 0.37 to 1.00; I^2=71.5%) and physical performance (SMD=0.99, 95% CI: 0.67 to 1.31; I^2=89.1%) and reduced the perception of fatigue (SMD=−0.76, 95% CI: −1.24 to −0.28; I^2=89.5%). The positive effects of napping were also confirmed after partial sleep deprivation. Overall, the benefits were higher with a nap duration between 30 and <60 min and when the time from nap awakening to test was greater than 1 hour.

Conclusions After a night of normal sleep or partial sleep deprivation, a daytime nap between 30 and <60 min has a moderate-to-high effect on the improvement of cognitive performance and physical performance and on the reduction of perceived fatigue.

PROSPERO registration number CRD42020212272.

WHAT IS ALREADY KNOWN?

⇒ Recent systematic reviews have supported the favourable effects of daytime napping on sports performance and subjective ratings of fatigue in both normal sleep and partial sleep deprivation conditions, but no meta-analysis has yet been conducted to estimate the magnitude of these benefits.

WHAT ARE THE NEW FINDINGS?

⇒ Postlunch (approximately at 14:00 hours) napping from 30 to <60 min has a high supplemental beneficial effect on physical performance and promotes a moderate improvement in cognitive performance and a reduction in perceived fatigue after sports activity.

⇒ A minimum time of 60 min after awakening from the nap is required to avoid the benefits of the nap on sports performance being attenuated by sleep inertia.

⇒ Although evidence from studies conducted under partial sleep deprivation suggests benefits similar to those observed after normal sleep, no solid recommendation can yet be stated about whether daytime napping compensates for the loss in sports performance resulting from partial sleep deprivation.

INTRODUCTION

It is well established that nocturnal sleep must be of sufficient duration and good quality for optimal performance in sports activities.[1] Recent evidence reported that napping during the day, in addition to compensating for the debit caused by partial sleep deprivation in the previous night, may have further beneficial effects even after a good night's sleep.[2–4] Naps can be used to alleviate the effects of partial sleep deprivation due to, for example, stress and anxiety about the next day's competition, jetlag because of transmeridional travel, training and matches at unusual times, or as a regular practice to enhance rest by distributing total sleep between night and day periods.[5–8] In fact, it has been suggested that napping can be an effective non-invasive strategy in the above-mentioned situations, although the benefits may vary according to the extent of previous partial sleep deprivation and the specific needs of recovery for each sport modality; other relevant factors are nap duration and timing (eg, midmorning, postlunch), time from nap awakening to sport activity, the individual profile of the sport practitioner and the method (ie, objective or subjective) used to assess napping.[1 3 9]

Additionally, the effects of napping may be different depending on the parameter used to measure sport performance. Several criteria related to performance on a sport activity are available, such as cognitive performance (eg, reaction time, short-term memory, attention and alertness),[10–13] physical performance (eg, speed, strength and endurance)[13–18] and perception of fatigue or exhaustion.[10 18–20] As the relative weight of each of these performance-related parameters varies according to the sport modality, it is relevant to estimate the effects of napping on each specific group of parameters.

Three recent systematic reviews[3 9 21] and two narrative reviews[2 7] reported positive effects of napping on sport performance, such as improving physical (eg, jump, strength, running repeated-sprint) and cognitive performance (eg, attention and reaction time), lowering perceived fatigue, enhancing the recovery process and counteracting the negative effect of partial sleep deprivation on physical and cognitive performance. However, to the best of our knowledge, no meta-analysis of clinical trials has yet estimated the magnitude of these effects, which is crucial to support the development of recommendations that are sufficiently applicable in practice.

Therefore, the objective of this systematic review and meta-analysis was to synthesise the evidence from randomised controlled trials and estimate the standardised mean difference (SMD) of daytime napping on cognitive performance, physical performance and the perception of fatigue in physically active adults and athletes. In addition, the quantitative implications of nap duration and wash-out time (from nap awakening to the start of the sport activity) on these effects were explored.

METHODS

This systematic review and meta-analysis was performed according to the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[22] and the PERSiST guidance.[23] The PRISMA checklist is available in online supplemental material 2. The protocol was registered in PROSPERO (CRD42020212272).

Information sources and search strategy

The PubMed, Scopus, Web of Science, Cochrane Central, SportDiscus and PsycINFO databases were searched for randomised controlled trials on the association between daytime napping and sport performance and fatigue published from inception to 2 December 2022. No language restriction was applied.

Eligibility criteria

The search criteria according to the PICO(S) strategy were as follows: (1) Participants: adults (18 years and older) stated as athletes of any sport modality or physically active (ie, non-athletes regularly practising exercises) individuals; (2) Intervention: napping or daytime sleep of any duration, after normal sleep or partial sleep deprivation (ie, less sleep duration than necessary, which, for young adults and adults, ranges from 7 to 9 hours)[24]; (3) Comparison: non-napping in the same sleep condition (ie, normal sleep or partial sleep deprivation); (4) Outcome: cognitive or physical performance, or perception of fatigue (considered a complex and multidimensional outcome from the lassitude/exhaustion of physical or mental capacity)[25 26] and (5) Study design: randomised controlled trial.

The exclusion criteria were as follows: study participants younger than 18 years; participants not clearly described as athletes or physically active individuals; studies conducted exclusively during or after Ramadan (because the observance of Ramadan may affect sleep-wake patterns in athletes and physically active individuals)[27]; reviews, observational studies, case series, qualitative studies and non-eligible publication types, such as editorials, letters to the editor, erratum, study protocols and preprint papers. No filter or exclusion criteria regarding gender were applied in the literature search.

Selection process and data collection

The search strategy included the terms "napping", "daytime sleep", "sport performance" and "fatigue" and their variations, which were combined with Boolean operators and adapted to the appropriate syntax for each database. The detailed syntax can be found in online supplemental material table S2.

The articles identified in each source were combined in a single database, and duplicates were eliminated with EndNote V.X9 software (Clarivate, The EndNote Team, Pennsylvania, USA). The article selection process was carried out independently by two reviewers (AEM and SNdA-A), and any discrepancies were resolved by consulting a third reviewer (AIT-C). Initially, the titles and abstracts were all screened, and studies that clearly did not meet the inclusion criteria were discarded. The remaining studies were then retrieved from the full text, and finally, those meeting the inclusion criteria were included. The reference lists of the literature reviews found were analysed for any original studies that had not been identified in the original search.

From the included studies, the following data were extracted by one reviewer (AEM) and confirmed by a second reviewer (SNdA-A), and any discrepancies were resolved by consulting a third reviewer (AIT-C): authors, year, country, study design, sample size, participant characteristics (gender, age, athletes or physically active individuals), intervention characteristics (nap duration and sleep assessment method), outcome (sport performance test applied, test schedule and time from nap awakening to test) and main results. In some studies,[10 12 14 15 28–35] data were extracted from graphs using PlotDigitizer online software (www.plotdigitizer.com). It was not necessary to contact the authors to ask for additional data. An included study that was written in Japanese[35] was translated into English by a native Japanese speaker.

Risk of bias assessment

Two researchers (SNdA-A and AIT-C) independently conducted a quality assessment, following the Cochrane Collaboration's tool for assessing the risk of bias (RoB 2.0 tool).[36] Any disagreement was resolved through discussion, and if a consensus could not be reached, a third reviewer (VM-V) was consulted. The RoB 2.0 tool covers bias in five domains: randomisation process, deviations from intended interventions, missing outcome data, measurement of the outcome and selection of the reported result. Overall, a trial was considered at 'low risk of bias' if all domains were judged as 'low risk', 'some concerns' if there was at least one domain rated as having 'some concerns' and 'high risk of bias' if there was at least one domain judged as 'high risk'.

Synthesis methods

Considering that partial sleep deprivation has implications for both sleep requirements and sport performance, analyses were performed separately for studies reporting that the previous night was considered normal sleep and for those reporting that the sleep duration time was restricted, generating partial sleep deprivation as described above.

Because of the diversity and specificity of sport performance parameters, it would not be feasible to analyse each parameter as an outcome. Therefore, we combined the parameters into three major groups. The first group was (1) cognitive performance, comprising indicators of cognitive function such as attention, alertness and reaction time. Another group was defined as (2) physical performance and included all tests that measured strength, endurance, speed, distance and power. The last group was (3) fatigue, including different instruments assessing the perception of fatigue or exhaustion after the sport activity.

In nine studies with data from different nap durations,[10 13 16 28 32 33 37–39] each duration was analysed separately and contrasted with the non-nap reference group. In a study that analysed daytime napping with the same duration but performed at different times in the afternoon (13 hours, 14 hours and 15 hours),[14] it was decided to include in the analysis only data from the nap taken at 14 hours, as this was the most frequent napping time among the studies included. One of the studies[28] had data of interest for time periods before, during and after Ramadan, but only data from before Ramadan were taken into account for this study. When data were available for more than one parameter corresponding to the same dimension of sport performance (eg, total distance and higher distance from the 5 m shuttle run test to evaluate physical performance), pooled estimates were calculated with random effect models.[40]

For each study, we calculated the mean change score[41] by subtracting the baseline value from the value recorded as close as possible to the end of the intervention or control period. Next, we checked whether normality could be assumed for these variables, and thus, meta-analysis was allowed. First, we observed that practically in all studies, the authors tested the normality of their outcome variables through specific tests, such as the Shapiro-Wilks test. Second, we calculated the mean/SD ratio of the change score for each intervention group (ie, nap and no-nap) in the normal sleep condition (online supplemental material table S5). Three of the studies had a mean/SD ratio <2, indicating skewness.[34 37 39] In two of them,[34 37] it was assumed that, as reported by the authors, normality had been verified with statistical tests. Regarding the other study, because this information was missing and because there were no data to calculate the mean/SD ratio, that study[39] was retained in the main analyses, and we were attentive to its influence on the results by excluding it in the sensitivity analyses. For sleep deprivation, meta-regression was not performed because this method is not recommended when fewer than 10 studies are available.[42]

Random effect models were used to estimate the SMD and the 95% compatibility intervals (95% CIs)[43] of the sport performance or fatigue group according to the mean change score ±SD in each nap and non-nap condition.[40] The SMD was used to estimate the effect size because the included studies provided outcome values using different scales to measure sports performance and fatigue.[42] In one study, the SD was estimated based on the SE and sample size.[31] In three studies,[32 38 39] the SMD (95% CI) was calculated based on the *p* value and Cohen's d statistics using the corresponding *z* score.

Study heterogeneity was assessed using the I^2 statistic[44] and classified as not important (0%–40%), moderate (30%–60%), substantial (50%–90%) and considerable (75%–100%). The corresponding p values were considered, particularly when heterogeneity was found in the overlapping zones of these intervals.[42]

Heterogeneity was explored through subgroup analyses by nap duration (<30 min, 30 to <60 min and 60 min or more)[45]; time from nap awakening to sport activity or test (≤60 min, >60 min), due to the potential effect of sleep inertia[2]; study population (athletes, as stated by the authors or with more than 7 hours/week, and physically active or exercising less than 7 hours/week) and the method used to assess napping (objective, as measured with polysomnography, actigraphy or electroencephalogram, or subjective, as self-reported by the study participant). Moreover, for studies in a normal sleep condition, random effects (Sidik-Jonkman method) meta-regression models were used to examine whether trial-level covariates (mean age of participants—ranging from 18.3 to 35.0 years, nap duration—ranging from 10 to 120 min and time from nap awakening to test—ranging from 15 to 270 min) influenced heterogeneity. Meta-regression was not performed with studies in a partial sleep deprivation condition because this method is not recommended when fewer than 10 studies are available.[42] More information on meta-regression in normal sleep can be found in online supplemental material (meta-regression).

To assess the robustness of summary estimates and to detect whether any single study accounted for a large proportion of heterogeneity, sensitivity analyses were performed using the leave-one-out method, and new SMD (95% CI) were generated by removing the included studies one-by-one from the analyses. Finally, we evaluated publication bias through visual inspection of funnel plots and Egger's regression asymmetry test to assess small study effects.[46] Publication bias was not assessed for studies in partial sleep deprivation because this method is not recommended when fewer than 10 studies are available.[42]

The criterion proposed by Cohen[47] to classify the effect size estimator (ie, SMD) as small (SMD=0.2), medium (SMD=0.5) or large (SMD=0.8) was considered. STATA SE V.15 software (StataCorp) was used for the statistical procedures. In accordance with recent recommendations,[43] we used the expression 'high compatibility' instead of 'statistically significant', which was assumed when the p value was <0.10.

RESULTS

Study selection

As depicted in figure 1, from the 3421 studies initially identified, 90 were selected for the full-text evaluation, of which 68 did not meet the inclusion criteria and were excluded. The complete list of the articles excluded and the reasons for each is presented in online supplemental material table S3. Thus, 22 studies were finally included.[10–20 28–35 37–39]

Characteristics of the included studies

The characteristics of the included studies and their main results are summarised in table 1. Almost two-thirds (n=14 studies)[10 12 14 16 20 28–32 34 37–39] of the included studies were carried out in Tunisia, two in France,[11 18] two in the UK,[17 19] two in Japan,[13 35] one in Thailand[15] and one in Australia.[33] The sample size varied from 7 to 20 participants in each trial, totalling 291 male participants (164 trained athletes and 127 physically active adults) aged between 18 and 35 years. Some studies reported the usual duration of night-time sleep between 7 and 9 hours,[11 12 16 18–20 28 33 35 37] and some reported applying the Pittsburgh Sleep Quality Index to ensure that the participants usually had good sleep quality.[14 28 30 31] Nap duration was self-reported in 12 studies[10 16 17 20 28–32 37–39]; 5 studies used polysomnography[11 13 18 33 35]; 3 studies assessed sleep parameters with actigraphy or accelerometers[12 19 34] and 1 used electroencephalograms.[15] All studies were randomised crossover trials with a time between nap and non-nap conditions varying from 2 to 7 days. All studies evaluated post lunch nap time, ranging from 12:30 to 16:50 hours, with 14:00 hours being the most frequent time. Regarding nap duration, nine studies[10 13 16 28 32 33 37–39] tested two

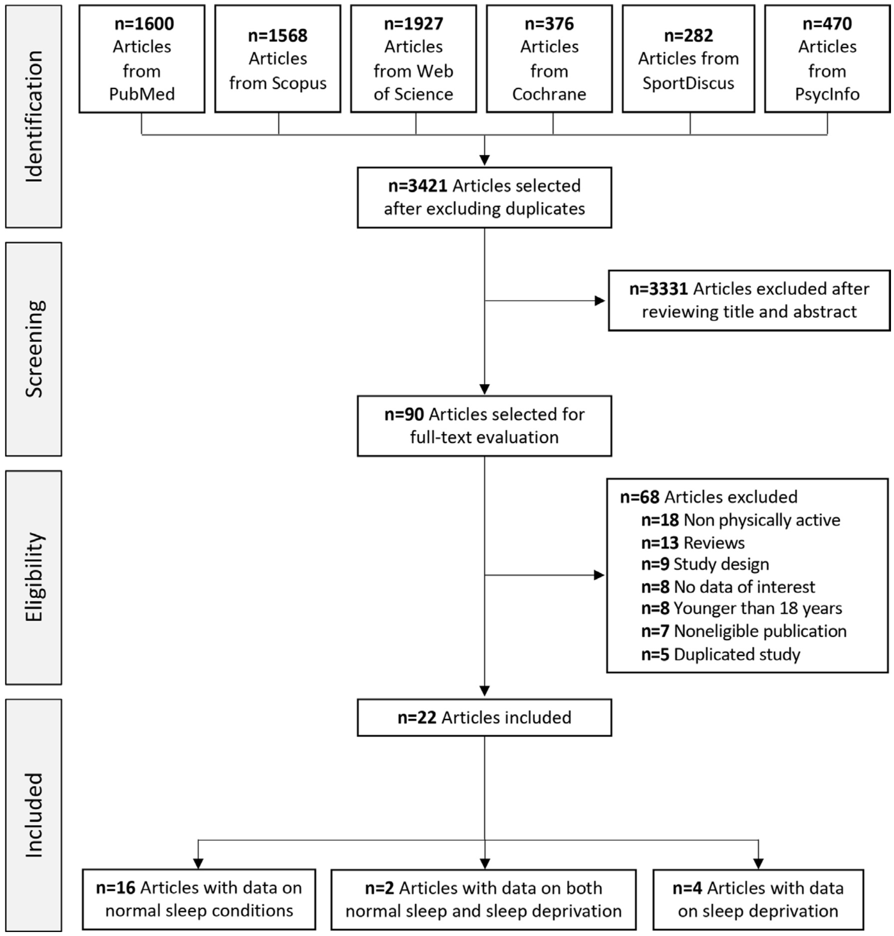

Figure 1 Flow diagram of the study selection.

or more different nap durations ranging from 20 to 120 min, and the other studies considered only a single duration varying from 10 to 60 min.

Cognitive performance was mostly measured with digital cancellation or reaction time tests (12 out of 14 studies). The 5 m run test was the most frequently used test (8 of 21 studies) to evaluate physical performance. Among the studies considering fatigue, the rate of perceived exertion test was mostly applied (12 of 18 studies). The specific tests used in each study and considered for the present analyses are presented in online supplemental material table S4.

Main results from the meta-analyses

The main analyses showed that after a normal night of sleep, napping improved cognitive (SMD=0.69, 95% CI: 0.37 to 1.00; I^2=71.5%) (figure 2A) and physical performance (SMD=0.99, 95% CI: 0.67 to 1.31; I^2=89.1%) (figure 2B) and reduced the perception of fatigue (SMD=−0.76, 95% CI: −1.24 to –0.28; I^2=89.5%) (figure 2C). In the subgroup analyses, the benefits of napping were overall clearer for nap durations between 30 and <60 min, when the time from nap awakening to test was more than 60 min, in physically active non-athlete individuals and when naps were self-reported (figure 2D–F items).

Likewise, daytime napping after partial sleep deprivation also showed a positive effect, with a high compatibility of an improvement in cognitive (SMD=1.61, 95% CI: 0.05 to 3.16; I^2=83.1%) (figure 3A) and physical performance (SMD=0.91, 95% CI: 0.51 to 1.31; I^2=88.2%) (figure 3B) and perceived fatigue reduction (SMD=−0.96, 95% CI: −1.80 to –0.13; I^2=86.4%) (figure 3C). The results of subgroup analyses in the partial sleep-deprived condition, although much less precise due to the scarcity of studies, were similar to those observed in normal sleep (figure 3D–F items). As an exception, the SMD of napping on physical performance after partially deprived sleep was higher when napping was objectively measured than when it was self-reported (figure 3E).

Meta-regression models after normal sleep (figure 4A–I items) showed that cognitive performance (p=0.044) (figure 4C) and physical performance (p=0.004) (figure 4F) improved, while fatigue decreased (p=0.050) (figure 4I) as the time from nap awakening to test increased.

Risk of bias

The overall risk of bias assessment showed that 72.7% of studies presented some concerns, and 27.3% were scored as high risk. The complete report of the risk of bias assessment is available in online supplemental material figure S1.

Publication bias

Publication bias was observed for the nap effects after normal sleep on cognitive (p=0.022) and physical (p=0.001) performance and fatigue (p=0.020) (online supplemental material figure S2).

Sensitivity analyses

Finally, sensitivity analyses indicate that, in general, after normal sleep, there is no change in the direction or level

Table 1 Characteristics of the randomised controlled trials

Authors, year	Country	Study population*	Sample size	Mean age (year) ±SD	Napping start time	Nap duration groups (min)	Time from nap awakening to test (min) (nap duration)	Wash-out intervention-control	Sleep assessment	Night-time sleep condition (criteria)	Outcome analysed† and main results§: Cognitive performance	Physical performance	Fatigue
Abdessalem *et al*[14] 2019	Tunisia	Physically active (≥3 hours/week)	18	20.5±3.0	14 hours‡	0, 25	COGN: 150 (25), PHYS, FATG: 165 (25)	NR	SR	Normal (sleep-satiated, PSQI ≥5)	(–)	(+)	(–)
Ajjimaporn *et al*[15] 2020	Thailand	Trained soccer players (>9 hours/week)	11	20.0±1.0	14 hours	0, 20	All: 100 (20)	2 days	EEG	Partially deprived (5.5 hours less)	(–)	(?)	(–)
Blanchfield *et al*[19] 2018	UK	Trained runners	11	35.0±12.0	14:00-16:50	0, 20	All: 50 (20)	5–9 days	ACT/SR	Normal (≈7.5 hours, sleep efficiency >92%)	NR	(+)	(–)
Boukhris *et al*[37] 2019	Tunisia	Physically active (≥3 h/week)	17	21.3±3.4	14 hours	0, 25, 35, 45	All: 155 (25), 145 (35), 135 (45)	3 days	SR	Normal (≈7 hours)	NR	(+)	(–)
Boukhris *et al*[16] 2020	Tunisia	Amateur team sport players (≥8 hours/week)	14	20.3±3.0	14 hours	0, 40, 90	All: 140 (40), 90 (90)	3 days	SR	Normal (7–9 hours)	(+)	(+)	(?)
Boukhris *et al*[28] 2022	Tunisia	Physically active (≥4 hours/week)	15	21.0±3.0	14 hours	0, 25, 45	All: 155 (25), 135 (45)	NR	SR	Normal (only Before Ramadan)	NR	(+)	(?)
Brotherton *et al*[17] 2019	UK	Resistance-trained athletes	15	22.7±2.5	13 hours	0, 60	COGN: 180 (60), PHYS, FATG: 210(60)	7 days	SR	Two nights partially deprived (4.5 hours less)	(+)	(?)	(?)
Daaloul *et al*[20] 2019	Tunisia	Karate athletes	13	23.0±2.0	13 hours	0, 30	All: 30 (30)	7 days	SR	Normal (>7 hours)/ Partially deprived (3 hours less)	(+)	(?)	(–)
Hammouda *et al*[38] 2018	Tunisia	Professional judokas	9	18.5±0.9	13 hours (90), 14:10 (20)	0, 20, 90	All: 30 (20, 90)	7 days	SR	Partially deprived (4.5 hours less)	NR	(+)	NR
Hsouna *et al*[10] 2019	Tunisia	Physically active (≥3 hours/week)	20	21.1±3.6	14 hours	0, 25, 35, 45	All: 155 (25), 145 (35), 135 (45)	3 days	SR	Normal (NR)	(?)	(?)	(+)
Hsouna *et al*[31] 2020*	Tunisia	Physically active (≥3 hours/week)	12	21.1±3.2	14 hours	0, 25	All: 155 (25)	3 days	SR	Normal (NR)	(–)	(+)	(–)
Hsouna *et al*[30] 2020†	Tunisia	Physically active (≥3 hours/week)	14	22.0±3.0	14 hours	0, 35	All: 145 (35)	3 days	SR	Normal (NR)	(–)	(+)	(–)
Hsouna *et al*[29] 2022	Tunisia	Amateur soccer players (≥10 hours/week)	12	23.0±3.0	14 hours	0, 40	All: 140 (40)	3 days	SR	Normal (late evening soccer match on the previous night)	NR	(+)	(?)
Petit *et al*[18] 2014	France	Highly trained athletes	16	22.2±1.7	13 hours	0, 20	All: 130 (20)	NR (two nights/wk)	PSG	Normal (≈ 8 hour)	NR	(–)	(–)
Petit *et al*[11] 2018	France	Highly trained athletes	16	22.2±1.7	13 hours	0, 20	All: 130 (20)	NR	PSG	Normal (≈ 8 hours)	(?)	NR	NR
Romdhani *et al*[32] 2020	Tunisia	Highly trained judokas	9	18.8±1.1	13 hours (90), 14:10 (20)	0, 20, 90	All: 30 (20), 30 (90)	7 days	SR	Partially deprived (4 hours less)	(?)	(+)	(–)
Romdhani *et al*[39] 2021	Tunisia	Highly trained judokas	14	20.4±1.2	13 hours (90), 14:10 (20)	0, 20, 90	All: 30 (20), 30 (90)	7 days	SR	Normal (≈ 8.5 hours)	(?)	(?)	NR
Romyn *et al*[33] 2022	Australia	Semiprofessional soccer players	12	18.3±1.0	14 hours (120), 15 hours (60)	0, 60, 120	All: 15 (60, 120)	1 day	PSG	Normal (7–9 hours)	(–)	(–)	(–)
Souabni *et al*[34] 2022	Tunisia	Elite basketball players	12	26.3±5.2	13 hours	0, 40	All: 80 (40)	3 days	ACT/SR	Normal (NR)	NR	(+)	(–)
Souissi *et al*[12] 2020	Tunisia	Physically active students	14	20.5±1.5	13 hours	0, 30	All: 270 (30)	4 days	ACT/SR	Normal (8 hour)/partially deprived (3 hours less)	(+)	(+)	(+)
Tanabe *et al*[13] 2020	Japan	Physically active (≥1 h/week)	7	21.1±0.4	12:30 (90), 13 hours (60), 13:30 (30)	0, 30, 60, 90	All: 60 (30, 60, 90)	3 days	PSG	Normal (NR)	(?)	(–)	NR
Yamamoto and Hayashi[35] 2006	Japan	Physically active (≥10 hours/week)	10	20.3±1.1	14 hours	0, 10	All: 50	2 days	PSG	Normal (≈ 7 hours)	NR	(+)	(+)

*All study participants were men.
†The list of the specific tests used in each study for each dimension of sport performance can be found in online supplemental material table S4.
‡Data available for daytime napping taken at 13 hours and 15 hours were not used in the present analyses.
§The signals in the outcomes analysed and main results columns indicate: (+) The evidence of an association is highly compatible; (–) The evidence of an association is weakly compatible; (?) The results are mixed according to the performance or fatigue indicator, nap duration or normal sleep or partial sleep deprivation condition.
ACT, accelerometer; COGN, cognitive performance; EEG, electroencephalogram; FATG, fatigue; NR, not reported; PHYS, physical performance; PSG, polysomnography; PSQI, Pittsburgh Sleep Quality Index; RCT, randomised controlled trial; SR, self-reported.

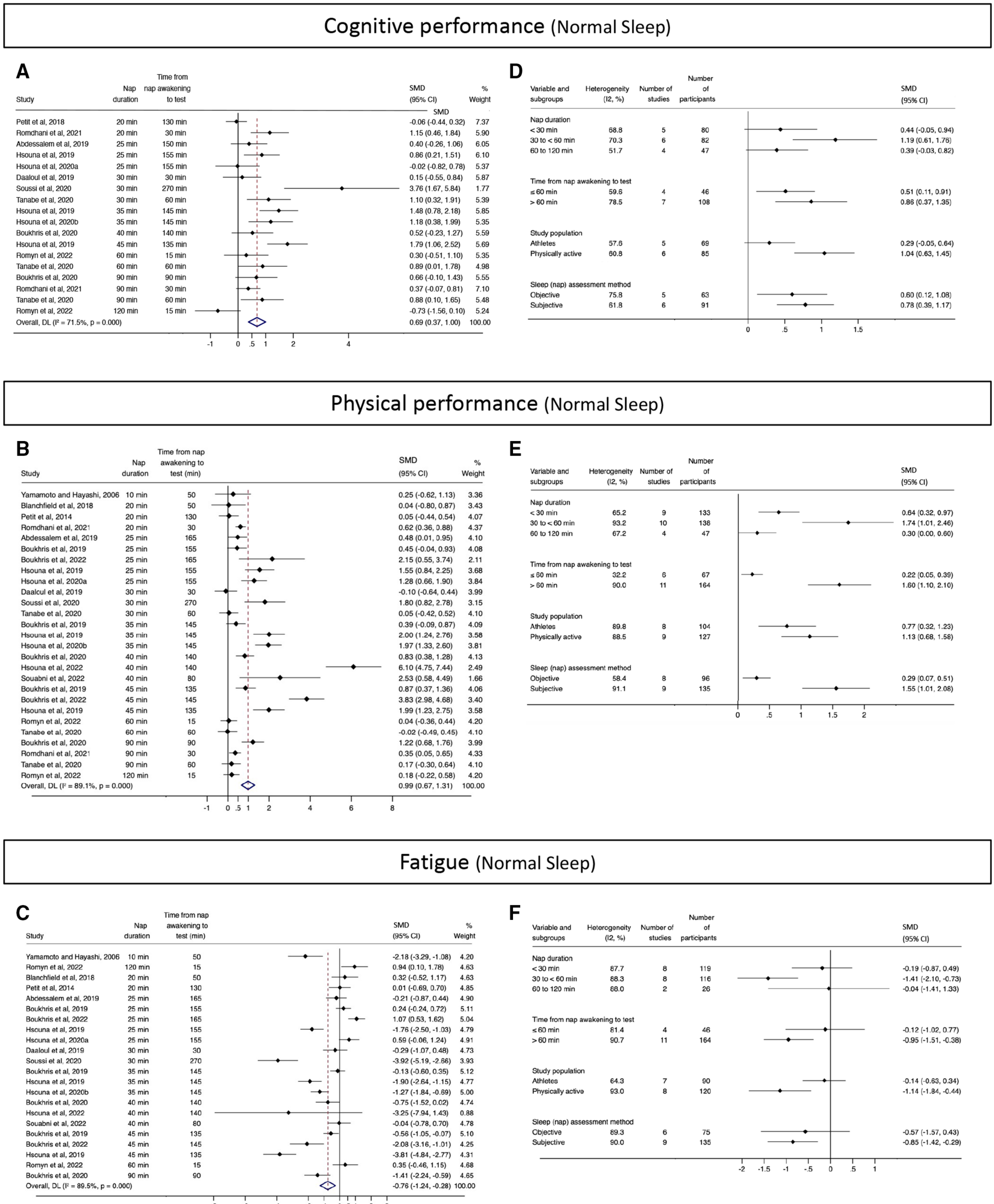

Figure 2 Forest plot of the effects of daytime napping after normal sleep on cognitive and physical performance and fatigue in total and by subgroups.

of compatibility of the overall effect of napping on the outcomes analysed when any of the included studies are omitted (online supplemental material figure S3). Conversely, the global effect of napping after sleep deprivation was less compatible with changes in cognitive performance when any of the included studies except Ajjimaporn *et al*[15] were individually removed. Furthermore, in the partial sleep deprivation condition, the effect of napping on fatigue showed

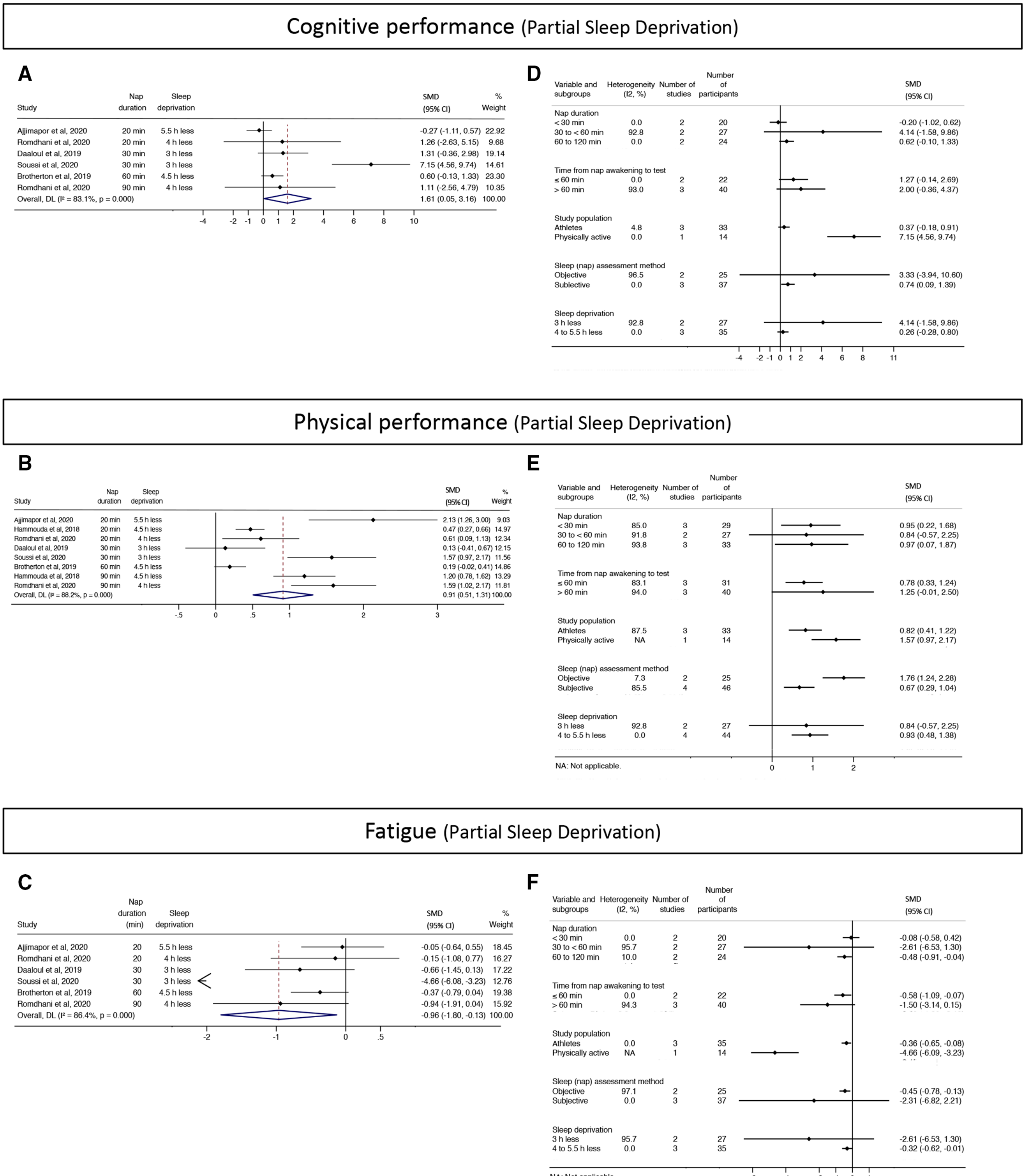

Figure 3 Forest plot of the effects of daytime napping after partial sleep deprivation on cognitive and physical performance and fatigue in total and by subgroups.

low compatibility of changes by omitting the study by Brotherton *et al*.[17]

DISCUSSION

Main findings

This meta-analysis supports that daytime napping exerts a highly beneficial effect on the improvement of physical performance among athletes and physically active young men. In addition, a moderate improvement after daytime napping was observed in cognitive performance and in the reduction of perceived fatigue after a sport activity. These results were clearer for a nap duration between 30 and <60 min and when the time after nap awakening to test was equal to or greater than 60 min. Moreover, greater benefits were observed in physically

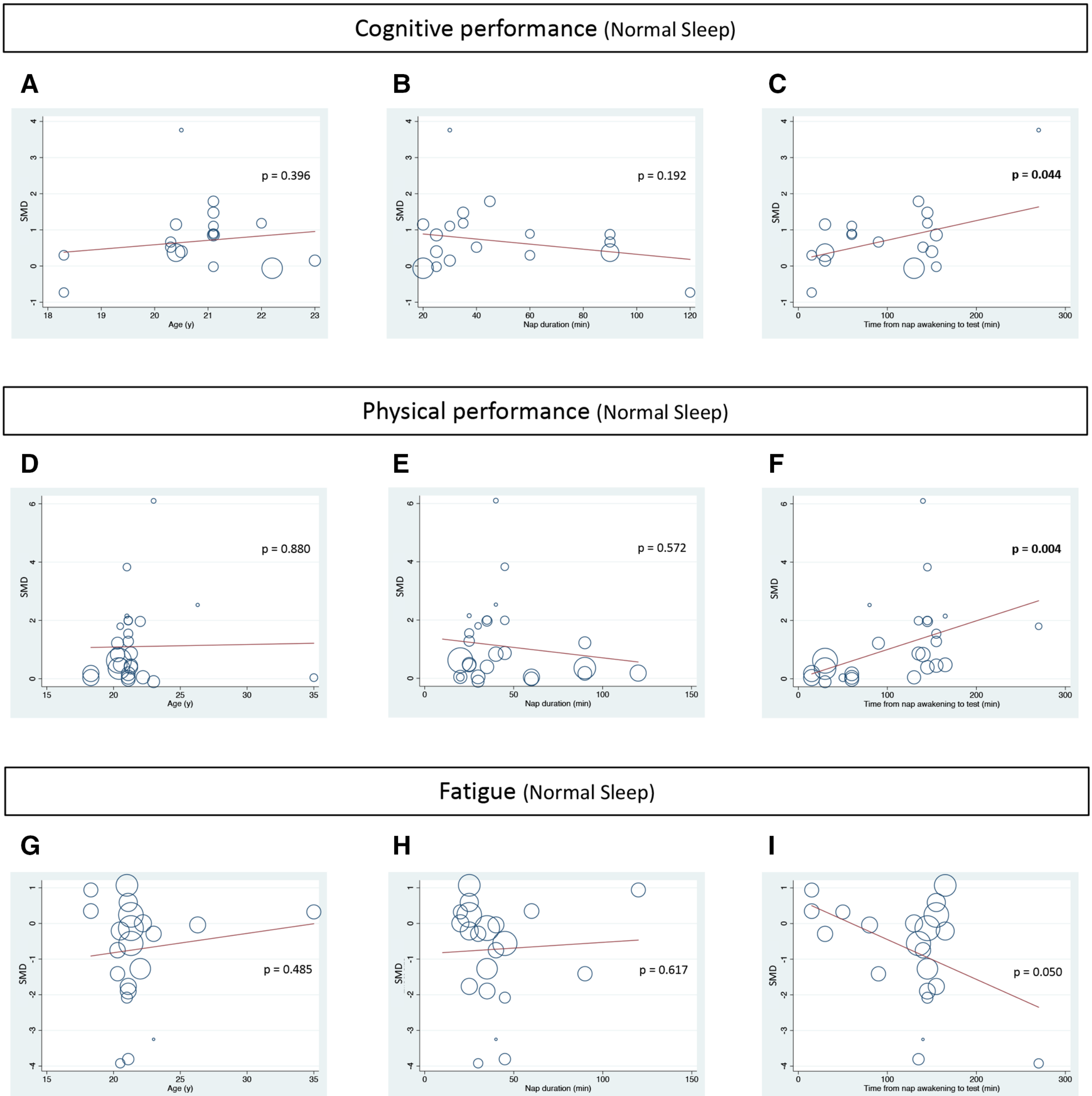

Figure 4 Meta-regression of age, nap duration and time from nap awakening to test on the effect of daytime napping on cognitive and physical performance and fatigue in a normal sleep condition.

active individuals than in athletes, as well as when naps were self-reported than when they were objectively measured. Importantly, evidence is more robust for daytime napping taken after a normal sleep night, meaning that napping could provide a supplemental benefit on sport performance even under optimal sleep conditions. The evidence from studies under partial sleep deprivation goes in the same favourable direction to napping, although their results are less robust and based on fewer studies. Therefore, although the available studies point in that direction, it cannot yet be affirmed that daytime napping is sufficient to compensate for the lower sport performance resulting from partial sleep deprivation.

Nap duration and time from nap awakening to the start of the sport activity

Our results are partially in agreement with previous systematic reviews on the same subject. Souabni *et al*[9] concluded that daytime napping (particularly a 90 min nap) seemed to be an advantageous strategy to improve the recovery process and counteract the negative effect of partial sleep deprivation on physical and cognitive performance. Similarly, in a narrative review, Botonis *et al*[2] stated that compared with short-term naps (20–30 min), long-term naps (>35–90 min) appear to provide superior benefits to athletes. Lastella *et al*[3] recommended that athletes consider napping between 20 and 90 min and should allow 30 min to reduce sleep inertia prior to training or competition to obtain better performance outcomes, but they did not specify whether these parameters should change in normal sleep or partial sleep deprivation. In our study, the most appropriate nap duration after normal sleep was between 30 and less than 60 min. Moreover, our data support that from nap awakening to sport practice, a minimal 60 min interval is needed, possibly to avoid the undesirable effect of sleep inertia.[33] In addition to updating the findings from previous reviews, the present meta-analysis provides estimates (SMD) of the magnitude of the benefits of napping specific for each group of sport performance indicators (ie, physical, mental and fatigue reduction) and explores the quantitative implications of nap duration and the time from nap awakening to the start of the sport activity on these effects.

Daytime napping and cognitive performance

In the compilation of all studies of daytime napping and cognitive performance in normal sleep conditions, a medium SMD with substantial heterogeneity was observed. Among the studies analysing this relationship in partial sleep deprivation, the global estimate was highly in favour of napping, although in the sensitivity analysis, this result was not sustained when omitting any study. Notably, the study by Souissi *et al*[12] found a considerably larger effect of a 30 min nap (after sleeping 5 hours at night instead of 8 hours) on the increase in vigilance (the number cancellation test) and on the reduction in reaction time compared with the other studies analysing similar outcomes under partial sleep deprivation conditions. This is possibly due to the characteristics of the participants because while Souissi *et al*[12] studied healthy young trained males, in the other studies, all participants were professional athletes. Compared with non-athletes, athletes have a higher basal performance level due to a more controlled routine of training and rest schedules.[48] Thus, the magnitude of the effect of napping on sport performance is possibly clearer in non-athletes than in athletes because in the latter, only small improvements could be achieved.

Furthermore, subgroup analyses revealed that in a normal sleep condition, cognitive performance improved only after 30 to <60 min of nap duration. It is possible that naps longer than 30 min may be more compatible to generate improvements in cognitive function by favouring longer durations in non-rapid eye movement (NREM) sleep stages (ie, N2 and N3) or even allowing a full sleep cycle (NREM-REM).[49] In this regard, it has been observed that the restorative effect of sleep correlated with time spent in NREM sleep and with electroencephalographic slow wave energy, which is thought to reflect renormalisation of synaptic strength.[50] Among studies on the effect of napping on cognitive performance after partial sleep deprivation, only the results from the study of Souissi *et al*[12] were compatible with such an effect. Therefore, it is not yet appropriate to speculate whether and to what extent daytime napping is able to compensate for the deterioration in brain functions resulting from partial sleep deprivation during the previous night. It is known that sleep deprivation promotes neurocognitive deficits, dysregulation of physiological functions regulated by the circadian rhythm (eg, temperature, blood pressure), and incomplete muscle recovery, which may accumulate over time in chronic partial sleep loss (restriction or deprivation).[51–53]

Daytime napping and physical performance

A similar pattern of benefits of napping was observed in our results for different parameters of physical performance, such as strength, endurance and speed, both after normal sleep and partial sleep deprivation. Although considerable heterogeneity was detected between the studies included in the normal sleep and partial sleep deprivation analyses, the SMD was high in both cases. Such concordant heterogeneity is possibly because SMD was smaller in some studies with athletes than in others studying physically active individuals (ie, non-athletes regularly practising exercises). As discussed before, it is necessary to consider that the margin for improvement in physical performance is smaller in trained athletes than in non-athletes. It is also necessary to highlight that professional athletes report poorer sleep quality and hygiene than an age-matched cohort of non-athletes.[54] Thus, the presence of chronic sleep-related problems may represent a barrier to the potential beneficial effects of napping on physical performance.

With respect to the duration of the nap, benefits in physical parameters were observed in all nap durations studied after a normal sleep night, although these benefits were higher for 30 to <60 min. However, we observed that when the time from nap awakening increased, the benefits of naps on physical performance also increased. On the one hand, daytime napping promotes muscle relaxation and structural and functional recovery.[55] On the other hand, an approximate minimum time of 60 min after nap awakening might be recommended to overcome the inertia of sleep and, therefore, reach optimal physical performance.[3]

Daytime napping and perceived fatigue

The effects of napping on perceived fatigue were mostly compatible in studies whose participants were non-athletes. In addition, the studies by Souissi *et al*[12] and Hsouna *et al*[10] reported a benefit associated with daytime napping that was considerably greater than the others with respect to reducing fatigue at the end of sports activity. It is remarkable that the study by Souissi *et al*[12] applied the longest time between the end of the nap and the sport activity (270 min) compared with the other studies (from 15 to 165 min), and an association with this time interval was observed for perceived fatigue for normal sleep but not for partial sleep deprivation. It can be suggested that the participants of that study[12] were less likely to feel the effects of fatigue because they were less affected by the perception of drowsiness compared with those who woke up from the nap and had to exercise after a short wash-out time (ie, <1 hour).

In the subgroup analysis by nap duration after normal sleep, a significantly high SMD on perceived fatigue was observed only for naps between 30 and <60 min. Similar to what was said about cognitive performance, while a short nap allows sleep to reach the superficial levels of sleep, which would be sufficient for partial relaxation, a nap of longer duration that includes more time in deeper sleep stages may be required to mitigate the perception of fatigue and physical and mental exhaustion resulting from the sport activity.

Limitations

As potential limitations of the present findings, considerable unexplained heterogeneity was detected. This could be partially justified because our results are based on the pooling estimates of different performance parameters, and SMD had to be used.[42] Therefore, the interpretation of standardised measures requires caution because the SD may vary over study populations. It is also important to note that the study samples were generally small, which could lead to small sample bias.[56] In addition, different methods were used to certify that the participants slept during the nap period (self-report, actigraphy, polysomnography and electroencephalography). More than half of the studies included in this review are based solely on the participants' report that they had slept within the allotted time. Therefore, we do not rule out possible reporting bias because self-reported sleep data do not closely correspond with objective measures of sleep as assessed using actigraphy[57 58] and polysomnography.[59] In this sense, it is possible that reporting bias (added to the reduced number of studies in each subgroup) may have had some influence on the differences found in the effect of napping on sports performance, in the same way as has been observed in physical performance when comparing results in normal sleep (in which the effect is greater in studies with subjectively measured sleep) with partial sleep deprivation (in which the effect is greater in studies with objectively measured sleep). In addition, athletes underestimate sleep quantity during daytime nap opportunities,[60] and in comparison with non-athlete controls, elite athletes showed significantly shorter sleep latencies.[61] Furthermore, the present results are restricted to young males and cannot be extrapolated to males of other ages and to females. Finally, we detected significant publication bias in studies of normal sleep conditions for all outcomes and in studies on partial sleep deprivation for physical performance. Therefore, the corresponding findings should be confirmed as more studies become available with varying sample sizes and favourable, neutral or unfavourable results on the association studied.

Considering the above limitations, some recommendations aimed at improving the quality and broadening the generalisability of future research on the effects of napping and sports performance are presented in online supplemental material table S6. In summary, these are suggestions based on the available evidence focused on methodological aspects such as population, exposure (napping), the results (sports performance) and study design.

CONCLUSIONS

In addition to updating the results from previous systematic reviews, we extend knowledge by quantifying the effect of the benefits of napping on different dimensions of sport performance, both under normal sleep and partial sleep deprivation conditions. We concluded that post lunch napping from 30 to <60 min after optimal sleep conditions has a moderate-to-high supplemental beneficial effect on improving cognitive and physical performance and fatigue reduction. Importantly, our findings suggest that a minimum time of 60 min after awakening from napping is required to avoid nap benefits being attenuated by sleep inertia. In addition, because there are fewer studies with sleep-deprived individuals, no firm recommendation can be drawn as to whether daytime napping compensates for the loss in sport performance resulting from partial sleep deprivation. These results apply only for young males aged 18–35 years and physically active individuals or athletes, and extrapolation from other populations requires further evidence.

Contributors AEM, VM-V, AIT-C and SNdA-A conceived and designed the study. AEM, AIT-C and SNdA-A performed the screening, study selection, data extraction, and analysed and interpreted the data. AEM drafted the manuscript with input from VM-V, SNdA-A, MG-M, RFR, BB-P and AIT-C. All authors have read and approved the final version.

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SUPPLEMENTAL MATERIAL

Is daytime napping an effective strategy to improve sport-related cognitive and physical performance and reduce perceived fatigue? A systematic review and meta-analysis of randomized controlled trials

Table S2. Search strategy (December 2, 2022) detailed for each database.

PubMed:
(napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND (exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion)
Scopus:
TITLE-ABS-KEY (napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND TITLE-ABS-KEY (exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion)
Web of Science:
TS=(napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND TS=(exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion)
Cochrane CENTRAL:
(napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND (exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion) *in Title Abstract Keyword - (Word variations have been searched)*
SportDiscus:
AB (napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND AB (exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion)
PsycInfo:
AB (napping OR siesta OR nap OR "nap sleep" OR "nap time" OR "day sleep" OR "daytime sleep" OR "daytime nap" OR "daytime napping" OR "day time sleep" OR "day time nap" OR "day time napping" OR "day-time sleep" OR "day-time nap" OR "day-time napping") AND AB (exercise OR "physical activity" OR fitness OR "physical performance" OR "sport performance" OR training OR "physical exercise" OR "athletic performance" OR fatigue OR exertion OR exhaustion)

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Table S3. Excluded studies by reason for exclusion (n = 68).

Non stated physically active individuals (n = 18)
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Reviews (n = 13)
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2. Driss, T., et al., Diurnal nap could enhance recovery process and counteract the negative effect of partial sleep deprivation on physical and cognitive performances. Acta Physiologica, 2021. 233.

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Table S4. Specific tests used in each study for each outcome analyzed.

Authors, Year	Cognitive Performance	Physical Performance	Fatigue
Abdessalem et al., 2019	Digit cancellation test	5 m shuttle run test [to determine best distance (BD), total distance (TD)]	Rating of perceived exertion (RPE)
Ajjimaporn et al., 2020	Auditory reaction time	Running-based Anaerobic Sprint Test (RAST), Isometric leg strength test	RPE
Blanchfield et al., 2018	None	Endurance performance: Time to exhaustion (TTE) at 90% $\dot{V}O_2$max	Brunel Mood Scale (BRUMS), item fatigue
Boukhris et al., 2019	None	5 m shuttle run test [to determine best distance (BD), total distance (TD)]	RPE and Fatigue index
Boukhris et al., 2020	Digit cancellation test	5-m shuttle run test (BD and TD), and the maximal voluntary isometric contraction (MVIC) test	RPE and Fatigue index
Boukhris et al., 2022	None	5 m shuttle run test [to determine great distance (GD), total distance (TD)]	RPE and Fatigue index
Brotherton et al., 2018	Alertness	Submaximal weightlifting performance (one-repetition maximum (1RM) for bench press and inclined leg press)	RPE, tiredness
Daaloul et al., 2018	Alertness, simple reaction time, mental rotation test and lower reaction test	Squat jump (SJ), counter movement jump (CMJ), KST	Fatigue (0-100 VAS)
Hammouda et al., 2018	None	Running-based anaerobic sprint test	Fatigue index (results unavailable)
Hsouna et al., 2019	Digit cancellation test	5-jump test	The Hooper questionnaire
Hsouna et al., 2020a	Digit cancellation test	5 m shuttle run test	RPE
Hsouna et al., 2020b	Digit cancellation test	5 m shuttle run test	RPE
Hsouna et al., 2022	None	5 m shuttle run test	RPE
Petit et al., 2014	None	Wingate test	Fatigue index
Petit et al., 2018	P300, an Auditory Event-related potentials (ERP), subjective alertness (VAS) and an Attentional Performance (TAP-M): alertness, divided attention, sustained attention, visual scanning, flexibility and distractibility)	None	None
Romdhani et al., 2020	Simple reaction time, Multi-choice reaction time	Running-Based Anaerobic Sprint Test (RAST)	RPE and Fatigue index
Romdhani et al., 2021	Multi-choice reaction time (s)	Running-Based Anaerobic Sprint Test (RAST)	None
Romyn et al., 2022	Response time	3-m split, 5-m split, 10-m print, agility	Perceived exertion

Souabni et al., 2022	None	Defensive (DA) and offensive (OA) agility, upper body power (UBP), Shooting skills test (SST)	RPE and Fatigue index
Souissi et al., 2020	Simple reaction time	5-m shuttle run test	Fatigue index
Tanabe et al. 2018	Simple reaction time, Multi-choice reaction time, Modified flanker task	Grip strength (right and left hands), Back strength, Wingate test (mean and peak power)	None
Yamamoto and Hayashi, 2006	None	Exercise duration	RPE

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Table S5. Analysis of the distribution of outcomes according to mean (x), standard deviation (sd) and x/sd ratio in the intervention (Nap) and control (No-nap) groups.

Reference	Sample size	Nap duration	Outcome	Test	x-Nap	sd-Nap	x-sd-Nap ratio	x-No-nap	sd-No-nap	x-sd-No-nap ratio
Romdhani et al, 2021	14	20 min	COGN	MCRT			***			***
Abdessalem et al, 2019	18	25 min	COGN	NCORR	69.00	11.00	6.27	65.00	9.00	7.22
Hsouna et al, 2019	20	25 min	COGN	NCR	67.80	3.30	20.55	65.00	3.20	20.31
Hsouna et al, 2020a	12	25 min	COGN	DCT	65.60	11.40	5.75	65.80	10.00	6.58
Daaloul et al, 2019	13	30 min	COGN	ALERT	7.10	1.30	5.46	5.60	2.20	2.55
Daaloul et al, 2019	13	30 min	COGN	SRT	278.70	24.90	11.19	21.00	8.00	2.63
Daaloul et al, 2019	13	30 min	COGN	MRT	21.00	8.00	2.63	20.80	8.40	2.48
Soussi et al, 2020	14	30 min	COGN	VIGIL	71.50	1.10	65.00	68.60	1.00	68.60
Soussi et al, 2020	14	30 min	COGN	REACT	0.31	0.01	61.00	0.28	0.01	46.33
Tanabe et al, 2020	7	30 min	COGN	SRT	307.40	21.90	14.04	283.00	14.90	18.99
Tanabe et al, 2020	7	30 min	COGN	MRT	381.10	43.20	8.82	348.00	24.60	14.15
Hsouna et al, 2019	20	35 min	COGN	NCR	69.80	3.30	21.15	65.00	3.20	20.31
Hsouna et al, 2020b	14	35 min	COGN	ATTS	67.64	2.78	24.33	64.50	2.52	25.60
Boukhris et al, 2020	14	40 min	COGN	ATTS	85.00	12.00	7.08	79.00	11.00	7.18
Boukhris et al, 2020	14	40 min	COGN	MVIC	812.00	100.00	8.12	769.00	94.00	8.18
Hsouna et al, 2019	20	45 min	COGN	NCR	71.00	3.50	20.29	65.00	3.20	20.31
Romyn et al, 2022	12	60 min	COGN	RESPT	224.00	28.28	7.92	217.00	17.67	12.28
Tanabe et al, 2020	7	60 min	COGN	SRT	307.40	21.90	14.04	284.80	7.60	37.47
Tanabe et al, 2020	7	60 min	COGN	MRT	381.10	43.20	8.82	365.90	14.30	25.59
Boukhris et al, 2020	14	90 min	COGN	ATTS	87.00	13.00	6.69	79.00	11.00	7.18
Boukhris et al, 2020	14	90 min	COGN	MVIC	843.00	102.00	8.26	769.00	94.00	8.18
Romdhani et al, 2021	14	90 min	COGN	MCRT			***			***
Tanabe et al, 2020	7	90 min	COGN	SRT	307.40	21.90	14.04	289.70	14.30	20.26
Tanabe et al, 2020	7	90 min	COGN	MRT	381.10	43.20	8.82	353.10	24.70	14.30
Romyn et al, 2022	12	120 min	COGN	RESPT	202.00	22.98	8.79	217.00	17.67	12.28
Yamamoto and Hayashi, 2006	10	10 min	PHYS	EXDUR	1013.00	108.00	9.38	986.00	104.00	9.48
Blanchfield et al, 2018	11	20 min	PHYS	RTTE	596.00	148.00	4.03	589.00	216.00	2.73
Petit et al, 2014	16	20 min	PHYS	PP	1023.34	210.90	4.85	1014.44	161.30	6.29
Petit et al, 2014	16	20 min	PHYS	MP	713.36	110.10	6.48	708.86	93.20	7.61
Romdhani et al, 2021	14	20 min	PHYS	PMAX			***			***
Romdhani et al, 2021	14	20 min	PHYS	PMEAN			***			***
Abdessalem et al, 2019	18	25 min	PHYS	TD	724.00	62.00	11.68	697.00	74.00	9.42
Abdessalem et al, 2019	18	25 min	PHYS	HD	134.00	14.00	9.57	126.00	14.00	9.00
Boukhris et al, 2019	17	25 min	PHYS	BD	134.10	13.40	10.01	126.40	13.60	9.29

Boukhris et al, 2019	17	25 min	PHYS	TD	719.90	65.50	10.99	697.10	74.10	9.41
Boukhris et al, 2022	15	25 min	PHYS	GD	135.00	3.00	45.00	126.00	3.00	42.00
Boukhris et al, 2022	15	25 min	PHYS	TD	720.00	18.00	40.00	694.00	20.00	34.70
Hsouna et al, 2019	20	25 min	PHYS	AS5JT	2.74	0.04	68.50	2.67	0.05	53.40
Hsouna et al, 2020a	12	25 min	PHYS	TD	736.00	16.00	46.00	718.00	15.00	47.87
Hsouna et al, 2020a	12	25 min	PHYS	BD	135.00	4.00	33.75	130.00	3.00	43.33
Daaloul et al, 2019	13	30 min	PHYS	SJ	39.00	5.20	7.50	39.60	4.40	9.00
Daaloul et al, 2019	13	30 min	PHYS	CMJ	42.30	5.20	8.13	42.70	4.20	10.17
Soussi et al, 2020	14	30 min	PHYS	TD	747.00	3.00	249.00	743.00	3.00	247.67
Soussi et al, 2020	14	30 min	PHYS	PD	142.60	1.50	95.07	139.10	1.50	92.73
Tanabe et al, 2020	7	30 min	PHYS	GSRH	47.10	7.30	6.45	47.10	5.80	8.12
Tanabe et al, 2020	7	30 min	PHYS	GSLH	43.70	5.50	7.95	44.60	7.00	6.37
Tanabe et al, 2020	7	30 min	PHYS	BS	143.50	28.30	5.07	141.40	26.90	5.26
Tanabe et al, 2020	7	30 min	PHYS	WTMP	634.90	96.60	6.57	625.00	76.70	8.15
Tanabe et al, 2020	7	30 min	PHYS	WTPP	841.90	139.60	6.03	816.60	91.10	8.96
Boukhris et al, 2019	17	35 min	PHYS	BD	131.10	7.80	16.81	126.40	13.60	9.29
Boukhris et al, 2019	17	35 min	PHYS	TD	720.50	52.20	13.80	697.10	74.10	9.41
Hsouna et al, 2019	20	35 min	PHYS	AS5JT	2.77	0.05	55.40	2.67	0.05	53.40
Hsouna et al, 2020b	14	35 min	PHYS	TD	718.00	14.00	51.29	684.00	20.00	34.20
Hsouna et al, 2020b	14	35 min	PHYS	BD	129.00	2.00	64.50	124.00	3.00	41.33
Boukhris et al, 2020	14	40 min	PHYS	HD	139.00	11.00	12.64	129.00	6.00	21.50
Boukhris et al, 2020	14	40 min	PHYS	TD	759.00	71.00	10.69	704.00	37.00	19.03
Hsouna et al, 2022	12	40 min	PHYS	TD	702.00	11.00	63.82	640.00	10.00	64.00
Hsouna et al, 2022	12	40 min	PHYS	BD	126.00	1.00	126.00	116.00	2.00	58.00
Souabni et al, 2022	12	40 min	PHYS	DA	5.62	0.06	93.67	6.00	0.04	150.00
Souabni et al, 2022	12	40 min	PHYS	OA	8.48	0.08	106.00	8.72	0.14	62.29
Souabni et al, 2022	12	40 min	PHYS	UBP	6.91	0.25	27.64	6.52	0.23	28.35
Souabni et al, 2022	12	40 min	PHYS	SST	87.00	9.00	9.67	86.00	10.00	8.60
Boukhris et al, 2019	17	45 min	PHYS	BD	139.60	15.90	8.78	126.40	13.60	9.29
Boukhris et al, 2019	17	45 min	PHYS	TD	755.10	63.30	11.93	697.10	74.10	9.41
Boukhris et al, 2022	15	45 min	PHYS	GD	140.00	4.00	35.00	126.00	3.00	42.00
Boukhris et al, 2022	15	45 min	PHYS	TD	758.00	14.00	54.14	694.00	20.00	34.70
Hsouna et al, 2019	20	45 min	PHYS	AS5JT	2.78	0.06	46.33	2.67	0.05	53.40
Romyn et al, 2022	12	60 min	PHYS	3MSPL	0.83	0.09	9.22	0.81	0.08	10.13
Romyn et al, 2022	12	60 min	PHYS	5MSPL	1.18	0.09	13.11	1.18	0.07	16.86
Romyn et al, 2022	12	60 min	PHYS	10MSPL	1.98	0.08	24.75	1.97	0.09	21.89
Romyn et al, 2022	12	60 min	PHYS	AGYL	2.45	0.11	22.27	2.47	0.11	22.45
Tanabe et al, 2020	7	60 min	PHYS	GSRH	47.40	7.60	6.24	47.10	5.80	8.12

Tanabe et al, 2020	7	60 min	PHYS	GSLH	43.20	5.80	7.45	44.60	7.00	6.37
Tanabe et al, 2020	7	60 min	PHYS	BS	142.90	24.70	5.79	141.40	26.90	5.26
Tanabe et al, 2020	7	60 min	PHYS	WTMP	625.90	65.90	9.50	625.00	76.70	8.15
Tanabe et al, 2020	7	60 min	PHYS	WTPP	817.30	97.10	8.42	816.60	91.10	8.96
Boukhris et al, 2020	14	90 min	PHYS	HD	142.00	13.00	10.92	129.00	6.00	21.50
Boukhris et al, 2020	14	90 min	PHYS	TD	793.00	64.00	12.39	704.00	37.00	19.03
Romdhani et al, 2021	14	90 min	PHYS	PMAX			***			***
Romdhani et al, 2021	14	90 min	PHYS	PMEAN			***			***
Tanabe et al, 2020	7	90 min	PHYS	GSRH	48.40	6.30	7.68	47.10	5.80	8.12
Tanabe et al, 2020	7	90 min	PHYS	GSLH	45.40	5.10	8.90	44.60	7.00	6.37
Tanabe et al, 2020	7	90 min	PHYS	BS	150.00	27.70	5.42	141.40	26.90	5.26
Tanabe et al, 2020	7	90 min	PHYS	WTMP	628.10	69.00	9.10	625.00	76.70	8.15
Tanabe et al, 2020	7	90 min	PHYS	WTPP	831.90	105.80	7.86	816.60	91.10	8.96
Romyn et al, 2022	12	120 min	PHYS	3MSPL	0.82	0.07	11.71	0.81	0.08	10.13
Romyn et al, 2022	12	120 min	PHYS	5MSPL	1.20	0.08	15.00	1.18	0.07	16.86
Romyn et al, 2022	12	120 min	PHYS	10MSPL	1.99	0.08	24.88	1.97	0.09	21.89
Romyn et al, 2022	12	120 min	PHYS	AGYL	2.48	0.11	22.55	2.47	0.11	22.45
Yamamoto and Hayashi, 2006	10	10 min	FATG	RPE	15.40	1.00	15.40	17.20	0.60	28.67
Blanchfield et al, 2018	11	20 min	FATG	FATGB	2.80	1.80	1.56	2.20	1.90	1.16
Petit et al, 2014	16	20 min	FATG	FI	53.96	8.70	6.20	53.92	7.40	7.29
Abdessalem et al, 2019	18	25 min	FATG	RPE	4.40	1.60	2.75	4.70	1.20	3.92
Boukhris et al, 2019	17	25 min	FATG	FI	13.30	6.00	2.22	11.70	3.20	3.66
Boukhris et al, 2019	17	25 min	FATG	RPE	4.80	1.50	3.20	4.60	1.10	4.18
Boukhris et al, 2022	15	25 min	FATG	FI	13.40	1.60	8.38	11.90	0.90	13.22
Boukhris et al, 2022	15	25 min	FATG	RPE	5.00	0.30	16.67	4.70	0.30	15.67
Hsouna et al, 2019	20	25 min	FATG	FATG	4.05	0.20	20.25	4.50	0.30	15.00
Hsouna et al, 2020a	12	25 min	FATG	FI	12.30	1.40	8.79	11.20	0.90	12.44
Hsouna et al, 2020a	12	25 min	FATG	RPE	4.83	1.31	3.69	4.54	0.73	6.22
Daaloul et al, 2019	13	30 min	FATG	FATG	4.10	1.20	3.42	4.40	0.80	5.50
Soussi et al, 2020	14	30 min	FATG	FI	11.00	0.90	12.22	14.00	0.60	23.33
Boukhris et al, 2019	17	35 min	FATG	FATG	10.50	5.80	1.81*	11.70	3.20	3.66
Boukhris et al, 2019	17	35 min	FATG	RPE	4.60	1.20	3.83	4.60	1.10	4.18
Hsouna et al, 2019	20	35 min	FATG	FATG	3.95	0.28	14.11	4.50	0.30	15.00
Hsouna et al, 2020b	14	35 min	FATG	FI	10.40	1.60	6.50	11.70	0.90	13.00
Hsouna et al, 2020b	14	35 min	FATG	RPE	4.22	0.18	23.44	4.59	0.28	16.39
Boukhris et al, 2020	14	40 min	FATG	FI	12.00	4.00	3.00	15.00	4.00	3.75
Hsouna et al, 2022	12	40 min	FATG	FI	13.60	1.60	8.50	15.00	1.40	10.71
Hsouna et al, 2022	12	40 min	FATG	RPE	4.62	0.17	27.18	5.65	0.19	29.74

Souabni et al, 2022	12	40 min	FATG	FATG	1.00	1.54	0.65**	0.50	1.34	0.37**
Souabni et al, 2022	12	40 min	FATG	RPE	10.30	1.30	7.92	11.00	2.00	5.50
Boukhris et al, 2019	17	45 min	FATG	FI	10.80	2.40	4.50	11.70	3.20	3.66
Boukhris et al, 2019	17	45 min	FATG	RPE	3.70	1.10	3.36	4.60	1.10	4.18
Boukhris et al, 2022	15	45 min	FATG	FI	10.70	0.60	17.83	11.90	0.90	13.22
Boukhris et al, 2022	15	45 min	FATG	RPE	3.90	0.30	13.00	4.70	0.30	15.67
Hsouna et al, 2019	20	45 min	FATG	FATG	3.30	0.33	10.00	4.50	0.30	15.00
Romyn et al, 2022	12	60 min	FATG	PEREX	12.00	2.30	5.22	11.20	2.30	4.87
Boukhris et al, 2020	14	90 min	FATG	FI	10.00	3.00	3.33	15.00	4.00	3.75
Romyn et al, 2022	12	120 min	FATG	PEREX	13.20	1.94	6.80	11.20	2.30	4.87

*Boukhris et al, 2019: FI: The Shapiro–Wilk test revealed that sleep quality, RPE, FI, and BD data were normally distributed.

**Souabni et al, 2022: FATG: The Shapiro–Wilk W-test revealed that ESS, RPE, HR mean, HR peak, SST, Hooper's fatigue and total score were normally distributed.

***Romdhani et al, 2021: The Shapiro–Wilks revealed that data were normally distributed. The authors directly reported the MD (95% CI) between the N20 or N90 and No-Nap groups.

Table S6. Recommendations for future studies on the effect of daytime napping on sport performance and fatigue.

Study Characteristic	Recommendations
Population	Considering gender differences in sleep,[1] in addition to the age-related physiological changes for both sleep and sports practice,[2, 3] it is essential to conduct studies in both genders and at older ages. Furthermore, although sample size calculations were presented in most of the studies, the sample sizes were generally small (between 7 and 20 participants), which has led to an increase in the measures of dispersion (i.e., compatibility interval, standard deviation) and small sample bias.[4] Therefore, it is recommended to use more conservative parameters for sample size calculation, such as those found in the results of this review, ensuring an increase in the statistical power to detect differences. This is particularly important in studies with professional athletes, in whose margin of improvement in sports performance is minimal.
Exposure (napping)	Future studies on this topic should use PSG to assess napping, the gold-standard method for sleep assessment. This would be useful not only to confirm that the participant has slept but also to assess the architecture of the sleep period.[5] In addition, both the timing of the nap (or of the activities in the control group) and its duration are parameters to be noted. The optimal time to assess napping seems to be after lunch and the sports activities in the afternoon or evening. Although the usual time of the available studies was at 2 p.m., it is not reasonable to fix this time as a recommendation because lunch time can vary according to cultural, labor and geographical aspects. Regarding nap duration, it is recommended to evaluate at least two different durations so that it can be assessed whether there is a dose—response effect, in addition to a ceiling effect (i.e., a limit from which to increase the duration of the nap does not lead to additional benefits).
Outcomes (sport performance)	In addition to considering the most appropriate tests for this purpose in each sport modality, it would be useful for future meta-analyses to also measure performance according to frequently used tests, such as the 5-m shuttle run test for physical performance, the digital cancellation test to measure cognitive performance, and the fatigue index to measure perceived fatigue. Specifically, this would allow calculation of the nonstandardized effect of napping on each of these indicators of sports performance, so that more easily interpretable and practically applicable measures would be available.
Study design	The crossover controlled clinical trial with randomization of intervention (nap, no nap) has been the most commonly used design thus far, with a washout time ranging from 1 to 7 days. Considering that circadian rhythm dynamics, sleep needs and sports training rhythm may vary according to the day of the week, a 7-day washout time is recommended in order to minimize the impact of these variations on the results. On the other hand, considering what was observed in the meta-regression on the effect of the time between the awakening from the nap and the sports activity on the results, it seems that 60 minutes is the minimum time necessary to overcome the feeling of sleep inertia before the test.
Other recommendations	Despite the increase in costs and methodological complexity, repeating the two phases of the experiment once or twice with the same participants would make it possible to control the effect of intraindividual variability, enhancing the robustness of the findings. Finally, considering the predominance of studies coming from the same country, Tunisia, it is also advisable to carry out studies on this subject in other countries with different geographical positions, habits and customs to broaden and reinforce the generalization of the findings.

References cited in this table: (1) Krishnan V, Collop NA. Gender differences in sleep disorders. Curr Opin Pulm Med 2006;12(6):383-9. (2).Cameron AFM, Perera N, Fulcher M. Professional Athletes Have Poorer Sleep Quality and Sleep Hygiene Compared With an Age-Matched Cohort. Clin J Sport Med 2021;31(6):488-493. (3) Mander BA, Winer JR, Walker MP. Sleep and Human Aging. Neuron 2017;94(1):19-36. (4) Lin L. Bias caused by sampling error in meta-analysis with small sample sizes. PLoS One 2018;13(9):e0204056. (5) Rundo JV, Downey R, 3rd. Polysomnography. Handb Clin Neurol 2019;160:381-392.

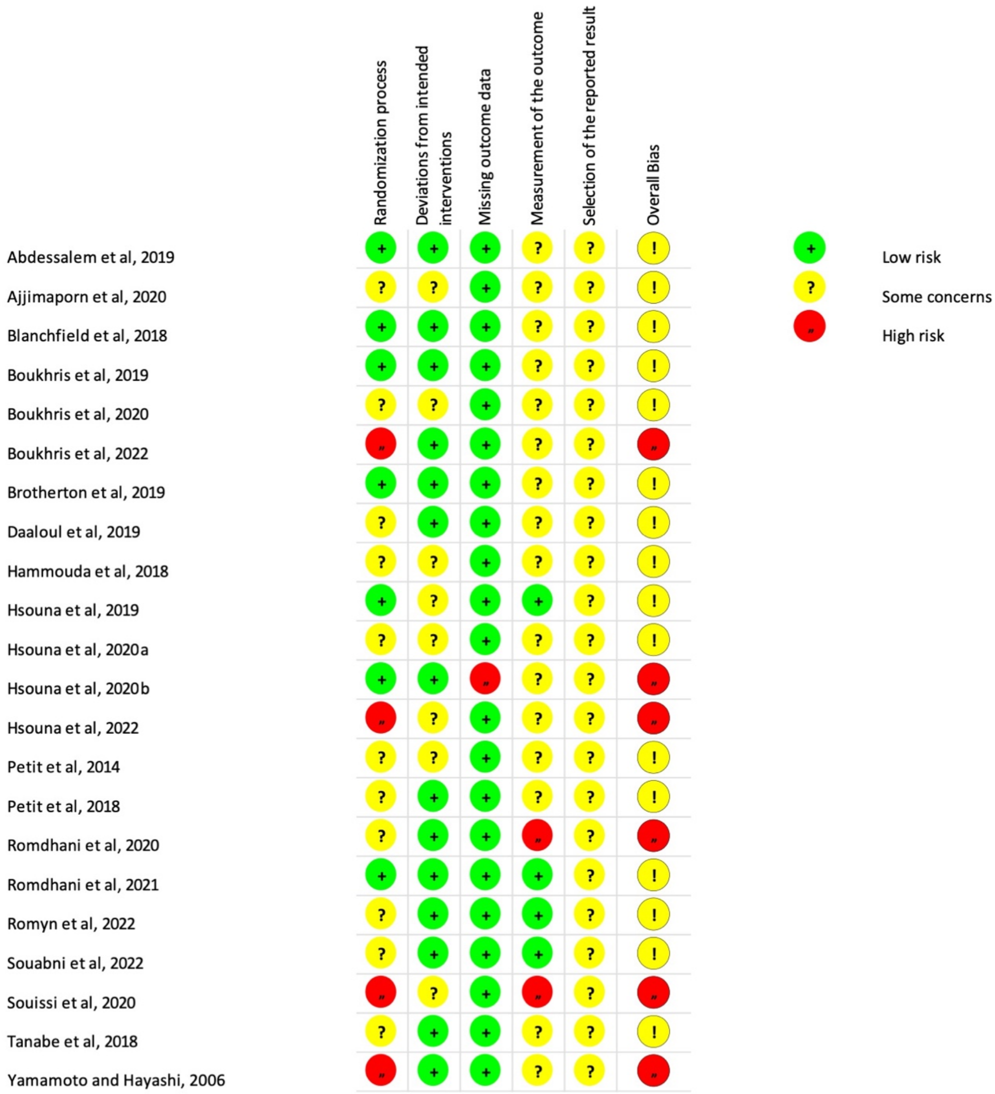
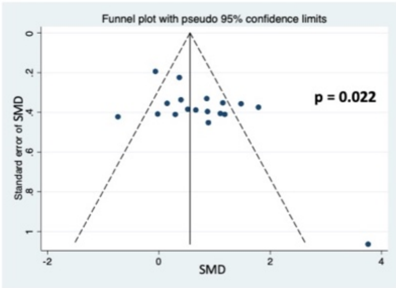


Figure S1. Risk of bias assessment.

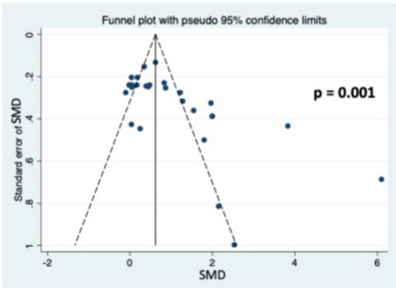
Cognitive performance

Normal Sleep



Physical performance

Normal Sleep



Fatigue

Normal Sleep

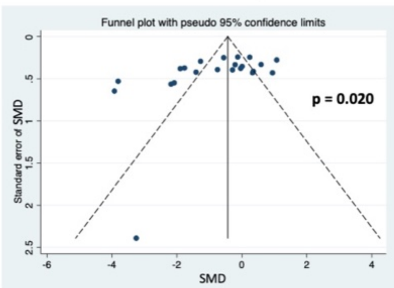


Figure S2. Publication bias in normal sleep.

Cognitive performance

Normal Sleep

Study omitted	Estimate	[95% Conf.	Interval]
Petit et al, 2018	.74375463	.43189207	1.0556172
Romdhani et al, 2021	.65924382	.33477163	.9837159
Abdessalem et al, 2019	.70954275	.37671140	1.0423741
Hsouna et al, 2019	.67925209	.34775278	1.0107514
Hsouna et al, 2020a	.72851104	.40435207	1.0526700
Daaloul et al, 2019	.72314674	.39456719	1.0517263
Soussi et al, 2020	.62997383	.33532870	.9246189
Tanabe et al, 2020	.66482997	.33993813	.9897217
Hsouna et al, 2019	.63504827	.32216755	.9479289
Hsouna et al, 2020b	.66002733	.33676821	.9832864
Boukhris et al, 2020	.70042694	.36952978	1.0313241
Hsouna et al, 2019	.61296946	.31379557	.9121433
Romyn et al, 2022	.71205842	.38344508	1.0406718
Tanabe et al, 2020	.67885143	.35208920	1.0056137
Boukhris et al, 2020	.69182670	.36128178	1.0223715
Romdhani et al, 2021	.71725148	.37500557	1.0594975
Tanabe et al, 2020	.67896575	.35034215	1.0075893
Romyn et al, 2022	.75798857	.45611396	1.0598632
Combined	.68762623	.37451298	1.0007395

Partial Sleep Deprivation

Study omitted	Estimate	[95% Conf.	Interval]
Daaloul et al, 2019	1.7354630	-.14201489	3.6129410
Soussi et al, 2020	.3693747	-.17604518	.9147946
Romdhani et al, 2020	1.6651227	-.01844214	3.3486876
Brotherton et al, 2019	2.0491927	-.48078853	4.5791740
Ajjimapor et al, 2020	2.2384744	.04248931	4.4344597
Romdhani et al, 2020	1.6874781	-.00635041	3.3813064
Combined	1.6090756	.05431541	3.1638359

Physical performance

Normal Sleep

Study omitted	Estimate	[95% Conf.	Interval]
Petit et al, 2014	1.0320410	.70488846	1.3591934
Blanchfield et al, 2018	1.0247973	.70049113	1.3491036
Romdhani et al, 2021	1.0217937	.67538100	1.3682064
Hsouna et al, 2020a	.9794117	.65431225	1.3045112
Boukhris et al, 2022	.9641198	.64464748	1.2835922
Abdessalem et al, 2019	1.0167698	.68566346	1.3478761
Boukhris et al, 2019	1.0175594	.68699753	1.3481213
Hsouna et al, 2019	.9679903	.64554816	1.2904325
Daaloul et al, 2019	1.0358577	.71103311	1.3606822
Tanabe et al, 2020	1.0325074	.70509303	1.3599217
Soussi et al, 2020	.9624084	.64158291	1.2832341
Boukhris et al, 2019	1.0199052	.68944550	1.3503649
Hsouna et al, 2020b	.9456805	.62953216	1.2618290
Hsouna et al, 2019	.9484421	.63066304	1.2662213
Hsouna et al, 2022	.8373625	.55931026	1.1154149
Souabni et al, 2022	.9629048	.64443702	1.2813727
Boukhris et al, 2020	1.0021118	.67066705	1.3335567
Hsouna et al, 2019	.9489352	.63102049	1.2668500
Boukhris et al, 2022	.8634183	.57635587	1.1504809
Boukhris et al, 2019	.9994243	.66951174	1.3293370
Romyn et al, 2022	1.0344927	.70618445	1.3628010
Tanabe et al, 2020	1.0347646	.70838070	1.3611486
Romdhani et al, 2021	1.0288820	.68993306	1.3678309
Tanabe et al, 2020	1.0284348	.69953680	1.3573327
Boukhris et al, 2020	.9821641	.65587354	1.3084548
Romyn et al, 2022	1.0300840	.69930989	1.3608581
Yamamoto and Hayashi, 2006	1.0170815	.69231588	1.3418471
Combined	.9897622	.67263974	1.3068847

Partial Sleep Deprivation

Study omitted	Estimate	[95% Conf.	Interval]
Daaloul et al, 2019	1.0224391	.58049077	1.4643874
Soussi et al, 2020	.8159581	.41166955	1.2202467
Hammouda et al, 2018	1.0128356	.46149281	1.5641783
Romdhani et al, 2020	.9600330	.50722873	1.4128373
Brotherton et al, 2019	1.0433085	.57561189	1.5110050
Ajjimapor et al, 2020	.7827507	.39615786	1.1693436
Hammouda et al, 2018	.8639219	.43599799	1.2918459
Romdhani et al, 2020	.8091117	.40931210	1.2089113
Combined	.9106002	.50631926	1.3148812

Fatigue

Normal Sleep

Study omitted	Estimate	[95% Conf.	Interval]
Blanchfield et al, 2018	-.81146365	-1.3101766	-.3127507
Petit et al, 2014	-.79953253	-1.3044534	-.2946116
Abdessalem et al, 2019	-.78974807	-1.2975810	-.2819151
Boukhris et al, 2019	-.81524789	-1.3240739	-.3064218
Boukhris et al, 2022	-.84747899	-1.3201568	-.3748010
Hsouna et al, 2019	-.70488858	-1.1938279	-.2159492
Hsouna et al, 2020a	-.82733893	-1.3232582	-.3314198
Daaloul et al, 2019	-.78379631	-1.2879726	-.2796200
Soussi et al, 2020	-.61992872	-1.0789969	-.1608605
Boukhris et al, 2019	-.79809701	-1.3160161	-.2801779
Hsouna et al, 2019	-.69758785	-1.1834369	-.2117388
Hsouna et al, 2020b	-.73257267	-1.2339967	-.2311487
Boukhris et al, 2020	-.76081687	-1.2645259	-.2571078
Hsouna et al, 2022	-.73503566	-1.2190797	-.2509915
Souabni et al, 2022	-.79648465	-1.3004365	-.2925328
Boukhris et al, 2019	-.77520263	-1.2935959	-.2568092
Boukhris et al, 2022	-.69704443	-1.1844063	-.2096826
Hsouna et al, 2019	-.60600066	-1.0517306	-.1602707
Romyn et al, 2022	-.81327611	-1.3121651	-.3143871
Boukhris et al, 2020	-.72630799	-1.2224993	-.2301167
Romyn et al, 2022	-.83827037	-1.3277739	-.3487668
Yamamoto and Hayashi, 2006	-.69311404	-1.1793623	-.20686577
Combined	-.75734408	-1.2394554	-.2752327

Partial Sleep Deprivation

Study omitted	Estimate	[95% Conf.	Interval]
Daaloul et al, 2019	-1.0607325	-2.0797985	-.04166658
Soussi et al, 2020	-.3623781	-.6456733	-.07908299
Brotherton et al, 2019	-1.1693966	-2.3467412	.00794795
Romdhani et al, 2020	-1.1461543	-2.1260092	-.16629930
Romdhani et al, 2020	-.9890058	-1.9593190	-.01869280
Ajjimapor et al, 2020	-1.2085466	-2.2654343	-.15165907
Combined	-.96317668	-1.7961013	-.13025202

Figure S3. Sensitivity analyses in normal sleep and partial sleep-deprived conditions.

Meta-Regression

For studies in a normal sleep condition, random effects (Sidik-Jonkman method) meta-regression models were used to examine whether trial-level covariates (mean age of participants – ranging from 18.3 to 35.0 years—, nap duration – ranging from 10 to 120 –, and time from nap awakening to test – ranging from 15 to 270 min) influenced heterogeneity.

Meta-regression was not performed with studies in a partial sleep deprivation condition because this method is not recommended when fewer than 10 studies are available.

Because of the small number of studies, multivariate meta-regression models were not recommended. Thus, univariate meta-regression models were estimated, as with any linear regression model, to estimate the proportion of between-trial heterogeneity explained by the model, as well as the change in the effect size estimate for each 1-unit change in the characteristic included as a predictor in the model.

The variability explained by each model was tested using the Wald test, and residual heterogeneity estimates (τ, τ^2, I^2, H^2) were also calculated for each model. The normality assumption for meta-regression was checked using bubble plots and residual value Q-Q, as presented in the following pages.

Outcome: **Cognitive performance**
Covariate: age (years)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	0.722	1	0.396
Test of Residual Heterogeneity	59.727	16	< .001

Note. *p* -values are approximate.
Note. The model was estimated using Restricted ML method.

Coefficients

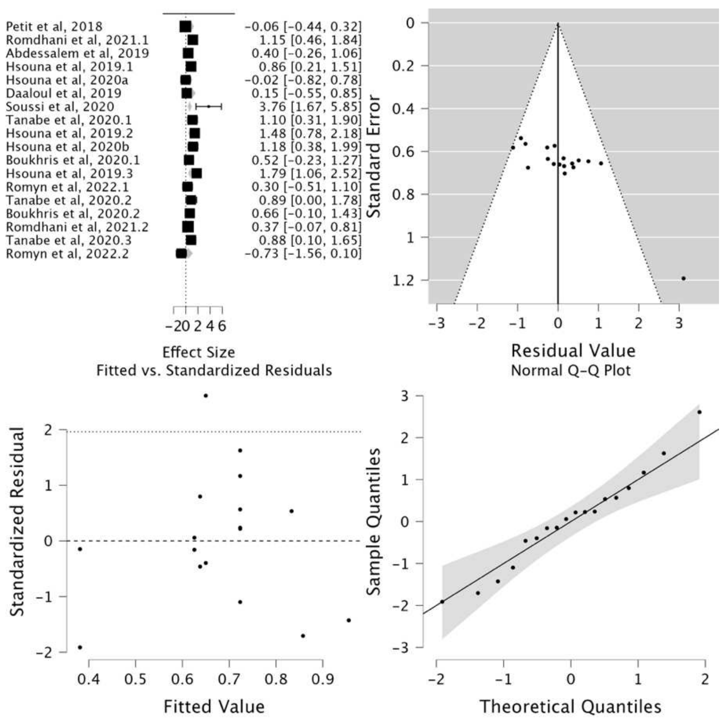
	Estimate	Standard Error	z	p
intercept	-1.855	2.999	-0.619	0.536
edadcont	0.122	0.144	0.850	0.396

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	0.318
τ	0.564
I^2 (%)	71.599
H^2	3.521

Diagnostic Plots



Covariate: nap duration (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	1.705	1	0.192
Test of Residual Heterogeneity	58.534	16	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

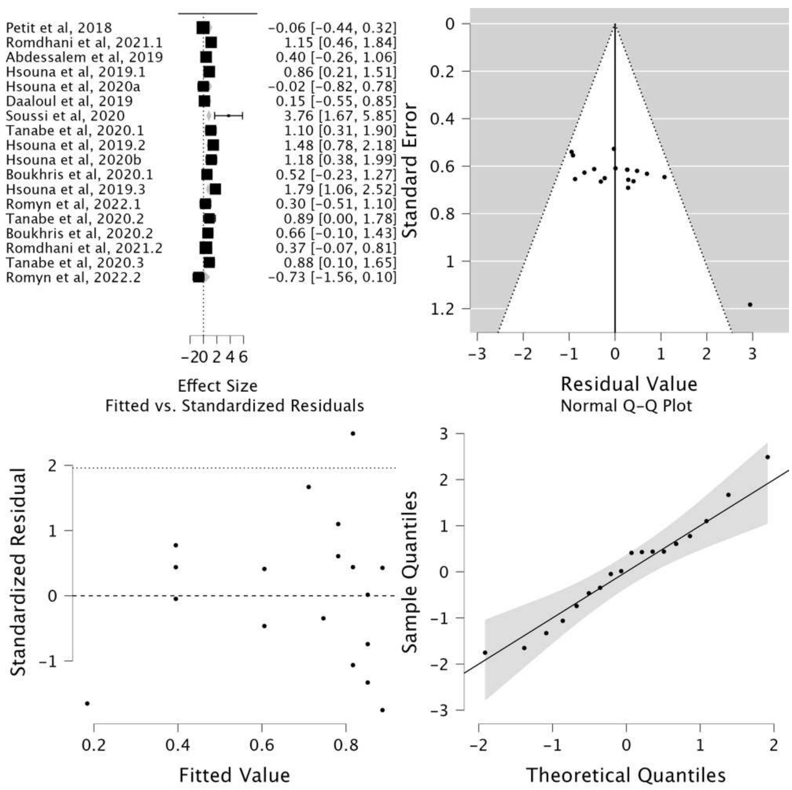
	Estimate	Standard Error	z	p
intercept	1.027	0.305	3.366	< .001
napdur	-0.007	0.005	-1.306	0.192

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	0.302
τ	0.550
I^2 (%)	70.333
H^2	3.371

Diagnostic Plots



Covariate: time from nap awakening to test (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	4.063	1	0.044
Test of Residual Heterogeneity	56.042	16	< .001

Note. *p* -values are approximate.
Note. The model was estimated using Restricted ML method.

Coefficients

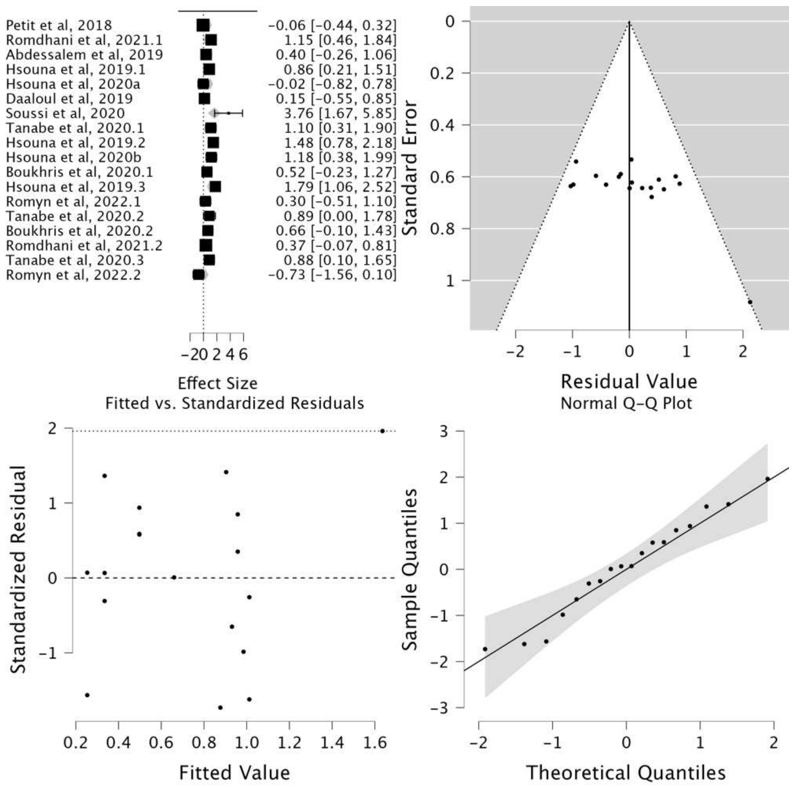
	Estimate	Standard Error	z	p
intercept	0.172	0.299	0.576	0.564
washout	0.005	0.003	2.016	0.044

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	0.289
τ	0.537
I^2 (%)	69.760
H^2	3.307

Diagnostic Plots



Mesas AE, *et al. Br J Sports Med* 2023;0:1–11. doi: 10.1136/bjsports-2022-106355

Outcome: **Physical performance**
Covariate: age (years)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	0.023	1	0.880
Test of Residual Heterogeneity	238.659	25	< .001

Note. *p* -values are approximate.
Note. The model was estimated using Restricted ML method.

Coefficients

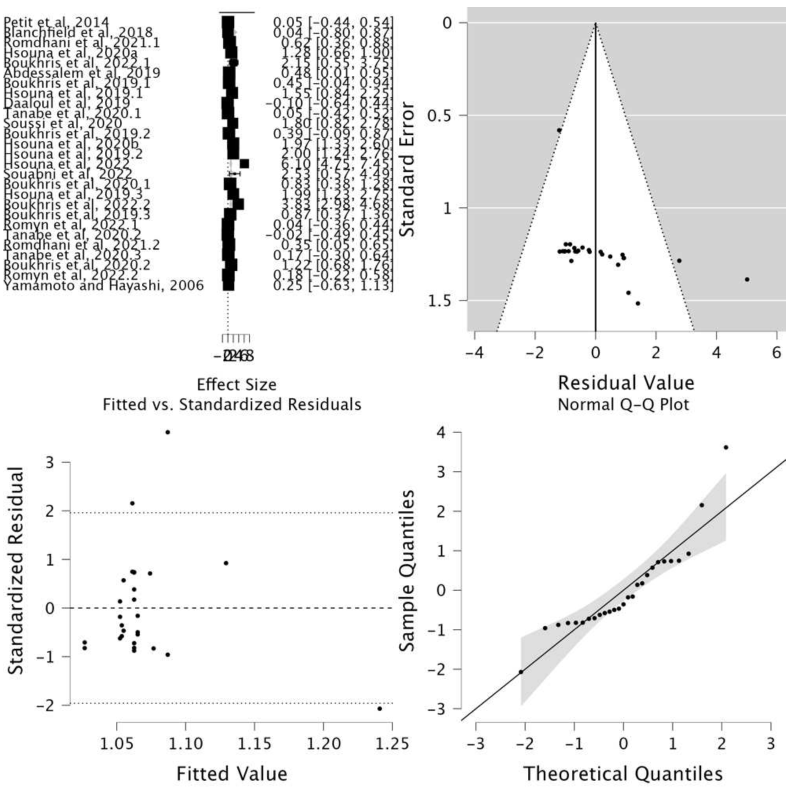
	Estimate	Standard Error	z	p
intercept	0.792	1.850	0.428	0.668
edadcont	0.013	0.085	0.151	0.880

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.528
τ	1.236
I^2 (%)	95.620
H^2	22.832

Diagnostic Plots



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Covariate: nap duration (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	0.320	1	0.572
Test of Residual Heterogeneity	232.809	25	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

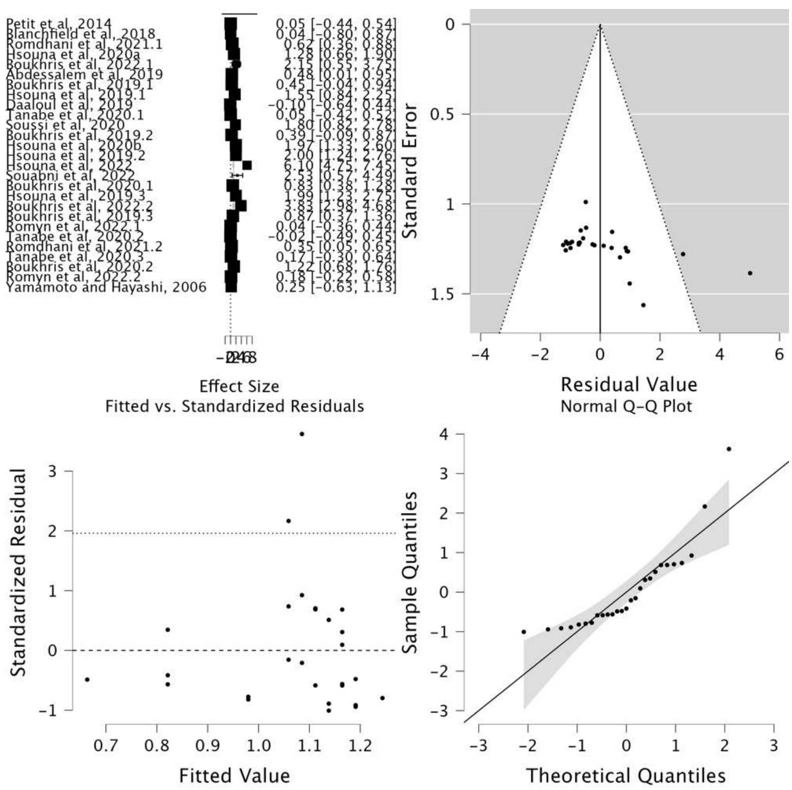
	Estimate	Standard Error	z	p
intercept	1.296	0.474	2.733	0.006
napdur	-0.005	0.009	-0.565	0.572

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.510
τ	1.229
I^2 (%)	95.345
H^2	21.480

Diagnostic Plots



Mesas AE, *et al. Br J Sports Med* 2023;0:1–11. doi: 10.1136/bjsports-2022-106355

Covariate: time from nap awakening to test (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	8.241	1	0.004
Test of Residual Heterogeneity	183.417	25	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

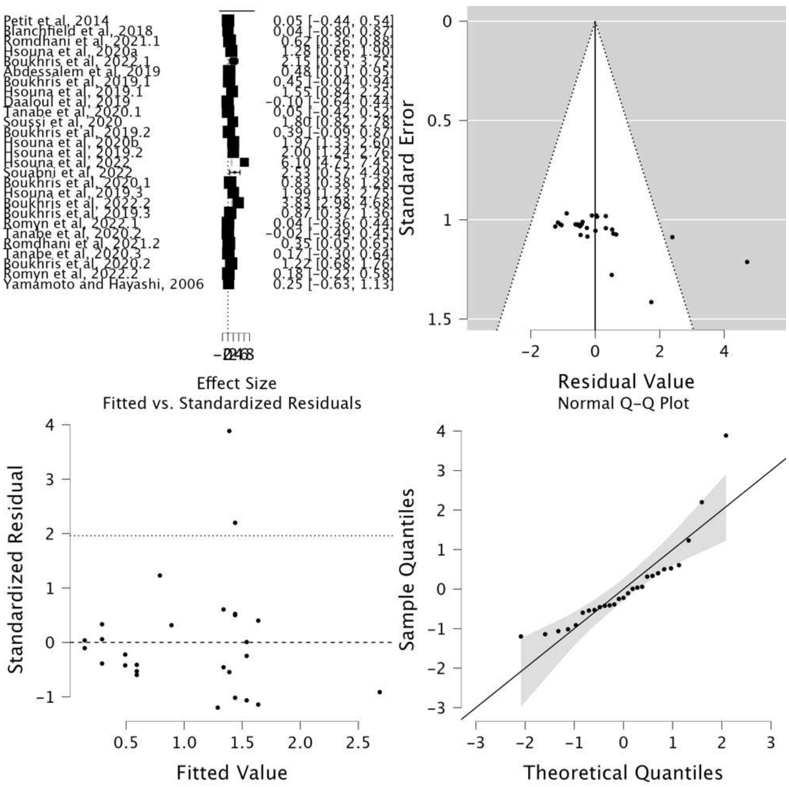
	Estimate	Standard Error	z	p
intercept	-0.006	0.422	-0.015	0.988
washout	0.010	0.003	2.871	0.004

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.058
τ	1.029
I^2 (%)	93.601
H^2	15.628

Diagnostic Plots



Outcome: **Fatigue**

Covariate: age (years)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	0.487	1	0.485
Test of Residual Heterogeneity	197.668	20	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

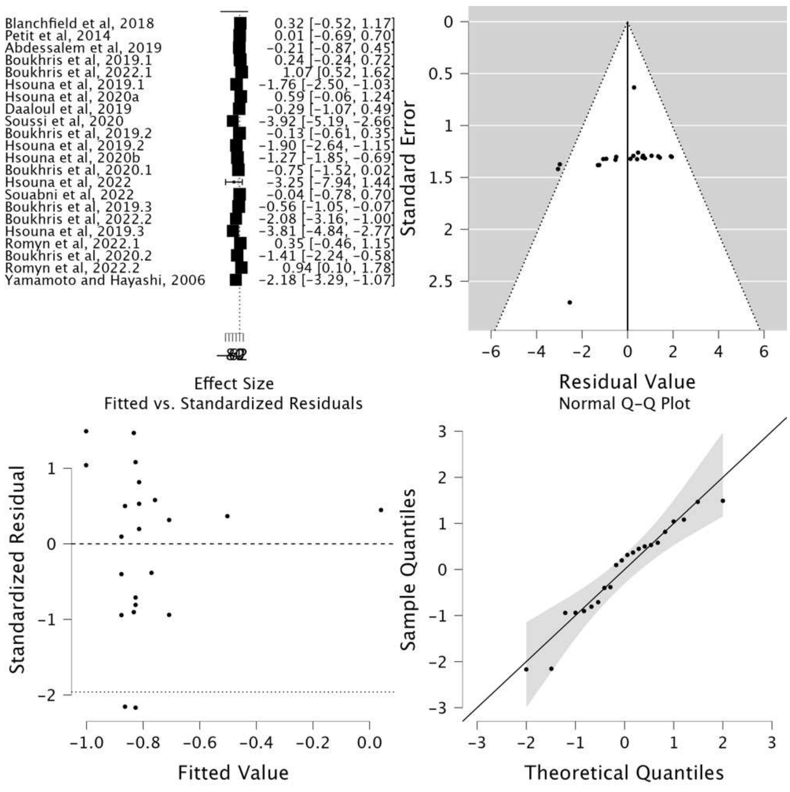
	Estimate	Standard Error	z	p
intercept	-2.143	1.970	-1.088	0.277
edadcont	0.062	0.089	0.698	0.485

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.697
τ	1.303
I^2 (%)	92.856
H^2	13.997

Diagnostic Plots



Covariate: nap duration (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	0.250	1	0.617
Test of Residual Heterogeneity	199.523	20	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

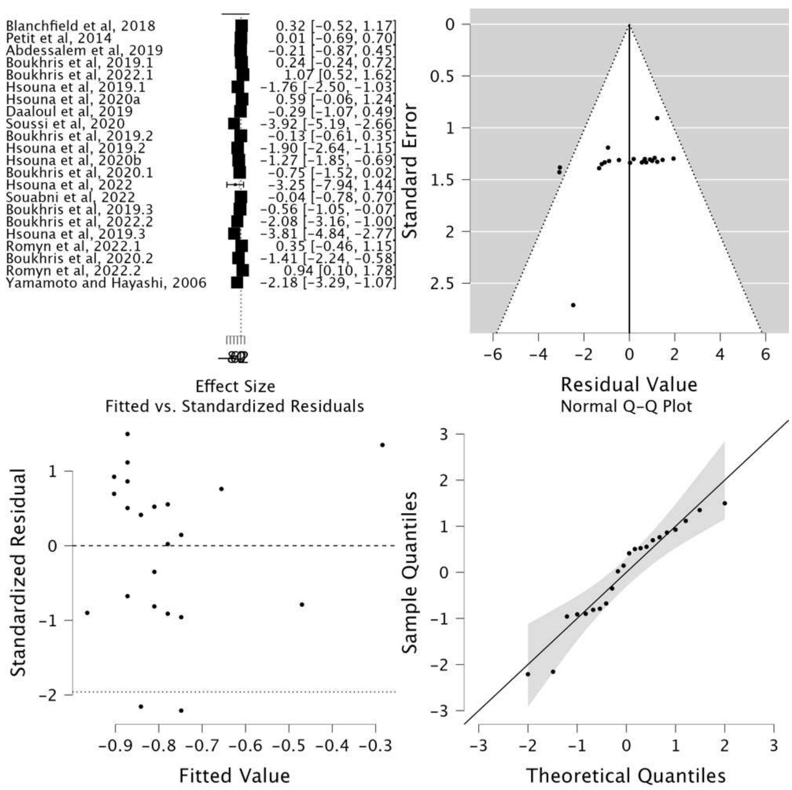
	Estimate	Standard Error	z	p
intercept	-1.027	0.569	-1.803	0.071
napdur	0.006	0.012	0.500	0.617

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.725
τ	1.313
I^2 (%)	92.938
H^2	14.160

Diagnostic Plots



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Covariate: time from nap awakening to test (min)

Fixed and Random Effects

	Q	df	p
Omnibus test of Model Coefficients	3.854	1	0.050
Test of Residual Heterogeneity	191.116	20	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Coefficients

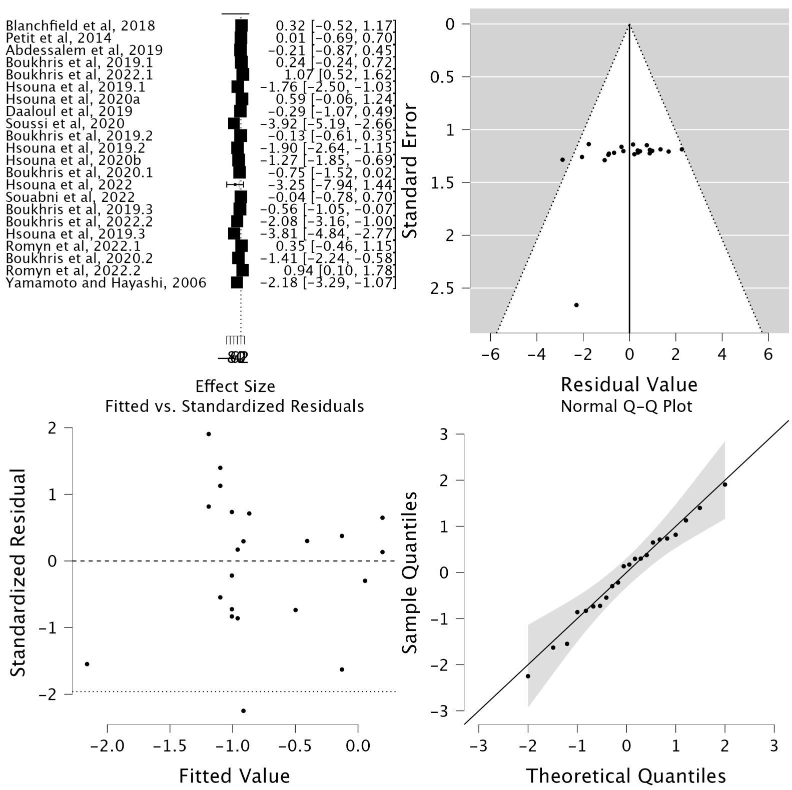
	Estimate	Standard Error	z	p
intercept	0.334	0.628	0.532	0.595
washout	-0.009	0.005	-1.963	0.050

Note. Wald test.

Residual Heterogeneity Estimates

	Estimate
τ^2	1.452
τ	1.205
I^2 (%)	91.718
H^2	12.074

Diagnostic Plots



SUPPLEMENTAL MATERIAL

Is daytime napping an effective strategy to improve sport-related cognitive and physical performance and reduce perceived fatigue? A systematic review and meta-analysis of randomized controlled trials

Table S1. PRISMA checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title page (p.1)
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	p. 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	p. 4-5
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	p. 5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	p. 5-6
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	p. 5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Table S2 (Supplementary material)
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	p. 6-7
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	p. 6-7
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	p. 7-8
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	p. 7-8
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	p. 7
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	p. 8-9

Section and Topic	Item #	Checklist item	Location where item is reported
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	p. 8-9
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	p. 8-9
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	p. 8-9
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	p. 8-9
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	p. 8-9
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	p. 10
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	p. 10
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	p. 8-10
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	p. 10-11 and Figure 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Table S3 (Supplementary material)
Study characteristics	17	Cite each included study and present its characteristics.	p. 11, Table 1 and Table S4 (Supplementary material)
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Figure S1 (Supplementary material)
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Figures 2 and 3, and Table S5 (Supplementary material)
Results of syntheses	20a	For each synthesis, briefly summarize the characteristics and risk of bias among contributing studies.	p. 12
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	p. 11, Tables 2 and 3
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	p. 11, Figures 2, 3 and 4
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	p. 12 and Figure S3 (Supplementary material)

Section and Topic	Item #	Checklist item	Location where item is reported
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	p. 12-13
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	p. 11, Figures 2 and 3

DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	p. 13-14
	23b	Discuss any limitations of the evidence included in the review.	p. 17-18
	23c	Discuss any limitations of the review processes used.	p. 17-18
	23d	Discuss implications of the results for practice, policy, and future research.	p. 13-19 and Table S6 (Supplementary material)
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	p. 5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	p. 5
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Not applicable
Competing interests	26	Declare any competing interests of review authors.	p. 19
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Supplementary material: data extracted from included studies; and data used for all analyses.