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REVIEW ARTICLE

Does observance of Ramadan affect sleep in athletes and physically active individuals? A systematic review and meta-analysis

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Summary

The purpose of this systematic review and meta-analysis is to provide an accurate description of the effect of Ramadan observance on sleep duration, sleep quality, daily nap duration, and daytime sleepiness in athletes and physically active individuals. Five electronic databases (PubMed, Web of Science, Scopus, Wiley, and Taylor and Francis) were used to search for relevant studies conducted with athletes or physically active individuals during Ramadan, published in any language, and available before May 23, 2021. Studies that included assessments of sleep quantity and/or quality, and/or daytime sleepiness, and/or daily naps in athletes and physically active individuals were

Khaled Trabelsi and Achraf Ammar contributed equally to this work.

included. The methodological quality of the studies was assessed using "QualSyst". Of the 18 papers included in this study (298 participants in total), 14 were of strong quality, two were moderate, and the remaining two were rated as weak. Individuals who continued to train during Ramadan experienced a decrease in sleep duration (number of studies, $K = 17$, number of participants, $N = 289$, $g = -0.766$, 95% confidence interval [CI] −1.199 to −0.333, $p = 0.001$). Additionally, the global score of the Pittsburgh Sleep Quality Index increased from 4.053 ($K = 5$, $N = 65$, 95% CI 3.071–5.034) pre-Ramadan, to 5.346 (95% CI 4.362–6.333) during Ramadan, indicating a decrease in sleep quality. The duration of daytime naps increased during compared to pre-Ramadan ($K = 2$, $N = 31$, $g = 1.020$, 95% CI 0.595–1.445, $p = 0.000$), whereas Epworth Sleepiness Scale scores remained unchanged during versus pre-Ramadan ($K = 3$, $N = 31$, $g = 0.190$, 95% CI −0.139–0.519, $p = 0.257$). In conclusion, individuals who continued to train during Ramadan experienced a decrease in sleep duration, impairment of sleep quality, and increase in daytime nap duration, with no change in daytime sleepiness levels.

KEYWORDS
athlete, daytime sleepiness, nap, physical activity, Ramadan observance, sleep–wake patterns

1 | INTRODUCTION

Sufficient high-quality sleep contributes to a range of physiological outcomes, such as physical recovery (Venter, 2014), restoration (Brandt et al., 2016), and immune function (Mejri et al., 2014), as well as psychological functions, including mood (Souissi et al., 2020; Watson & Brickson, 2018), memory (Maquet, 2001), and cognitive performance (Souissi et al., 2020). Sleep inadequacies, common among athletes (Sargent et al., 2021; Vlahoyiannis et al., 2020), could impair physical and cognitive performances (Walsh et al., 2021). For example, insufficient sleep duration, resulting from an experimental partial sleep restriction (3–4 hr), negatively affected subsequent aerobic performance in amateur taekwondo players (Mejri et al., 2016). Similarly, 1 night of partial sleep restriction impaired sport-specific execution, such as tennis serving accuracy, in amateur tennis players (Reyner & Horne, 2013) and performance in basketball free-throw in amateur basketball players (Vitale et al., 2021). Similar deleterious effects can be seen in mood state areas, such as anxiety, fatigue, and confusion, in non-competitive physically active students (Souissi et al., 2020). Moreover, sleep quality (i.e. the subjective experience and perceived adequacy of sleep) (Gupta et al., 2017), could also influence competition outcomes (Andrade et al., 2016; Brandt et al., 2017; Juliff et al., 2018). Furthermore, the combination of an unhealthy diet and insufficient sleep (i.e. not obtaining the recommended 8–10 hr of sleep/night (National Sleep Foundation, 2016)) increases by 60% the likelihood of an adolescent athlete sustaining a new injury (Von Rosen et al., 2017).

Recently, Andrade et al. (2019) reported that athletes who compete internationally are 84% more likely to experience poor sleep quality than regional athletes. Indeed, the demands are often greater in international athletes because of greater visibility and exposure in the media (Andrade et al., 2016), pressure to achieve winning results, engendering nervousness, thoughts prior to competition (Juliff et al., 2015), and greater training volume (Roberts et al., 2019). Moreover, international athletes tend to have longer and more exhausting travel and may also suffer from the effects of jet lag, which can impair sleep quantity and quality (Roberts et al., 2019). Therefore, more attention should be paid to sleep patterns of elite athletes.

During Ramadan fasting, one of the five pillars of the Islamic religion, healthy pubescent Muslims must abstain from eating, drinking, and other specific behaviours (e.g. smoking, sexual intercourse) from dawn to sunset, during a period that lasts 29 or 30 days (lunar month). During this month, water and food consumption is exclusively nocturnal. The large quantity of food consumed during the night, coupled with increased nocturnal social activities and prayers (e.g. *Ettrawih*), could affect the sleep–wake patterns of Muslims (Chamari et al., 2012). To avoid beginning training sessions in a completely fasted state during Ramadan, training sessions for competitive soccer players (Wilson et al., 2009), amateur bodybuilders (Trabelsi et al., 2013), and recreational runners (Trabelsi et al., 2012) are often programmed at night. This has the potential to exacerbate sleep–wake disturbance, possibly engendering a decrease in sleep duration, in individuals engaged in physical activity (PA) while observing Ramadan. Therefore, assessing sleep–wake patterns to identify potential threats to sleep quality and/or quantity is important for athletes' sleep optimisation during Ramadan (Trabelsi, Stannard, et al., 2018).

In a recent systematic review and meta-analysis of studies involving sedentary and active individuals, Faris, Jahrami, Alhayki, et al. (2019); Faris, Jahrami, Obaideen et al. (2019) reported that sleep duration decreased by ~1 hr during Ramadan, more so in active individuals. The authors also found that the level of daytime sleepiness increased substantially during Ramadan (Faris, Jahrami, Alhayki, et al., 2019; Faris, Jahrami, Obaideen et al., 2019). However, the possible effect of Ramadan observance on sleep quality was not included in the meta-analysis. In another recent systematic review and meta-analysis, Trabelsi et al. (2020) reported that when athletes (aged ≥18 years) continued to train at least twice/week while observing Ramadan, sleep duration was decreased compared with their baseline levels. However, in that review, the duration of daytime naps and measures of daytime sleepiness were not included, and the analyses were limited to adult athletes; indeed, adolescent and physically active individuals were not included.

Taken together, the changes in sleep duration and quality engendered during this month of fasting in adolescent and physically active individuals, and the associated changes in daytime sleepiness and napping behaviours, remain unclear.

To expand the scope of previous reviews of the effects of Ramadan observance on sleep, the present review sought to answer the question: Does Ramadan observance influence sleep in athletes and physically active individuals?

This was achieved by (*i*) evaluating the effects of Ramadan observance on sleep duration, sleep quality, daytime sleepiness, and daily nap duration in athletes and physically active individuals, and (*ii*) investigating how moderator variables, including number and characteristics of participants (i.e. mean sample age, type of activity, level of training, number of training session/week), publication characteristics (i.e. study quality, Ramadan season, continent, fasting time length), methodology of sleep assessment (i.e. methods and duration of assessment), could influence studies' effect size. We hypothesised that Ramadan observance will decrease sleep duration, impair sleep quality, and increase daytime sleepiness and daily naps duration in physically active individuals and athletes.

2 | METHODS

2.1 | Protocol

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) were followed in this systematic review. An a priori protocol was devised and can be requested from the Corresponding Author.

2.2 | Eligibility criteria

Studies about physically active individuals or athletes who continued to train during Ramadan observance, which had been published or accepted for publication in peer-reviewed journals and written in any language, were considered. No restrictions were applied in terms of study design, setting, country, or time frame. Descriptive or review articles, conference proceedings, and articles based on either sedentary individuals or patients were excluded. Both single- and multi-group, pre–post studies and crossover design studies comparing findings before and during Ramadan observance, were considered. Only studies that included assessments of sleep quantity and/or sleep quality and/or daytime sleepiness and/or daily naps duration were included.

2.3 | Information sources and search

Five electronic databases, PubMed, Web of Science, Scopus, Wiley, and Taylor and Francis were searched, without applying any time limits or filters, using the following terms (see Table 1): "Ramadan", "athletes", "physically active", "physical activity", "sleep", "daytime nap", and "daytime sleepiness". Appropriate Boolean connectors were utilised to connect the various keywords and wild-card options (i.e. truncated words) and medical subject headings (MeSH) terms were also used where appropriate. Searches were concluded on May 23, 2021. Additionally, in order to minimise the risk of missing relevant publications, the reference lists of included manuscripts and related citations from other journals, identified via Google Scholar, were reviewed. A search of personal files was also performed and specialists in the field were contacted for information on possible upcoming studies. Further information on the search process is presented in Table 1.

2.4 | Study selection

The process used for selecting articles is outlined in Figure 1. EndNote X8 was used to remove duplicate articles recorded in the initial search results. Titles and abstracts of all unique hits were screened by the first two authors for eligibility, and disagreements were resolved by consensus. The full texts of the selected studies were then screened for eligibility, and disagreements were, again, resolved by consensus. Reasons for excluding an article during the abstract and full-text screening were recorded.

2.5 | Data collection process

Using a pilot-tested extraction form, the two first authors independently collected data and resolved disagreements by consensus. Extracted data included participant characteristics (i.e. number of participants, age, sex, sport practiced, type of training programme, level of training), study characteristics (i.e. country, city, continent, study design, methodology of sleep assessment), and key outcomes. In cases where the outcome measure data were only presented graphically, data were extracted using WebPlot-Digitizer (Hofmann et al., 2012).

TABLE 1 A summary of the search strategy adopted in the present systematic review and meta-analysis assessing the effects of Ramadan fasting on sleep characteristics in individuals engaged in physical activity

Search strategy item	Search strategy details
String of keywords	[(Ramadan) OR (Islamic fasting) OR (dawn to sunset fasting) OR (diurnal intermittent fasting) OR (30-day consequent intermittent fasting) OR (Ramadan model of intermittent fasting) OR (intermittent prolonged fasting during Ramadan) OR (Ramadan fast)] AND [(athletes) OR (amateur) OR (recreational) OR (physically active) OR (professional) OR (player)] AND [(sleep) OR (sleep disorders) OR (sleep characteristics) OR (sleep patterns) OR (sleep architecture) OR (sleep habits) OR (sleep quality) OR (sleep quantity) OR (sleep duration) OR (total sleep time) OR (nap) OR (napping) OR (daytime nap) OR (daytime sleepiness) OR (sleepiness) OR (drowsiness) OR (Epworth sleepiness scale) OR (ESS) OR (Pittsburgh sleep quality index) OR (PSQI) OR (polysomnography) OR (PSG) OR (actigraphy) OR (sleep logs) OR (sleep diary)]
Searched databases/ bibliographic thesauri	PubMed, Web of Science, Scopus, Wiley, and Taylor and Francis
Inclusion criteria	P (population): Athletes and physically active individuals who continue to train during Ramadan I (intervention/exposure): Ramadan observance C (comparators/comparisons): pre-Ramadan O (outcomes): assessments of sleep quantity and/or quality and/or daytime sleepiness and/or daily naps S (study type): original study (any study design included)
Exclusion criteria	P: subjects not practicing PA before the beginning of Ramadan, baseline data recorded after Ramadan, sleep patterns controlled by the investigators, sedentary individuals or patients I: none C: none O: outcomes not described in sufficient detail S: commentaries, expert opinions, letters to editor, editorials, reviews, conference abstracts or proceedings
Time filter	None applied (search from inception)
Language filter	None applied (any language)
Hand-searched target journals	*Science and Medicine in Football*, *British Journal of Sports Medicine*, *Biological Rhythm Research*, *Asian Journal of Sports Medicine*, *European Journal of Applied Physiology*, *Journal of Sports Sciences*, *Journal of Sports Science and Medicine*, *PLOS One*, *Applied Physiology, Nutrition, and Metabolism*, *Biology of Sport*, *Chronobiology International*, *Physiology and Behavior*, *Sports*.

2.6 | Quality assessment

The methodological quality of each study was assessed by the two first authors, independently, using the formal quantitative assessment tool "QualSyst" (Kmet et al., 2004); any disagreements were solved by consensus or by the last author, when required. The QualSyst rating comprises 14 items (Table 2) that are scored depending on the degree to which a specific criterion is met ("yes" = 2, "partial" = 1, "no" = 0). Items not applicable to a particular study design were marked "not applicable" (NA). For each item, the percentage of lost points was calculated. For each article, a summary score was calculated by adding the total score across relevant items and dividing it by the total possible score. The studies were classified as; strong quality (a score of ≥75%), moderate quality (55–75%), or weak quality (<55%) (Kmet et al., 2004).

2.7 | Estimating fasting time length and season

For each study, the duration of the daily fast and the season (calendar month) in which Ramadan occurred were determined using a time and date website (https://www.timeanddate.com/holidays/us/ramadan-begins) as previously explained by Faris et al. (2020). Briefly, (i) the duration of the daily fast during Ramadan month was calculated using the sunrise and sunset times reported for that month for the city/country of each included study (https://www.timeanddate.com/sun/@8469718), and (ii) the reported seasons (i.e. spring, summer, autumn or winter) begin on the first day of the months that include the equinoxes and solstices. When the lunar month of Ramadan falls in two solar months, Ramadan is classified according to the solar month with a significant number of days (e.g. Ramadan in 2010 started on August 10). Thus, Ramadan was classified to run in summer not autumn.

2.8 | Meta-analysis

Initially, a random-effects model, according to the DerSimonian–Laird method (DerSimonian & Laird, 1986), was used to pool data in order to compute an estimate of the pooled sleep duration, daily nap duration, Pittsburgh Sleep Quality Index (PSQI), and Epworth Sleepiness Scale (ESS) scores before and during Ramadan. The mean sleep duration, daily nap duration, PSQI, and ESS scores and their corresponding 95% confidence interval (CI) before and during Ramadan were reported. The ESS scores were interpreted based on the reference ranges adopted for the ESS (Johns, 2019): 0–5 indicates lower normal daytime sleepiness, 6–10 indicates higher normal daytime sleepiness, 11–12 indicates mild excessive daytime sleepiness, 13–15 indicates moderate excessive daytime sleepiness, and 16–24 indicates severe excessive daytime sleepiness. The PSQI

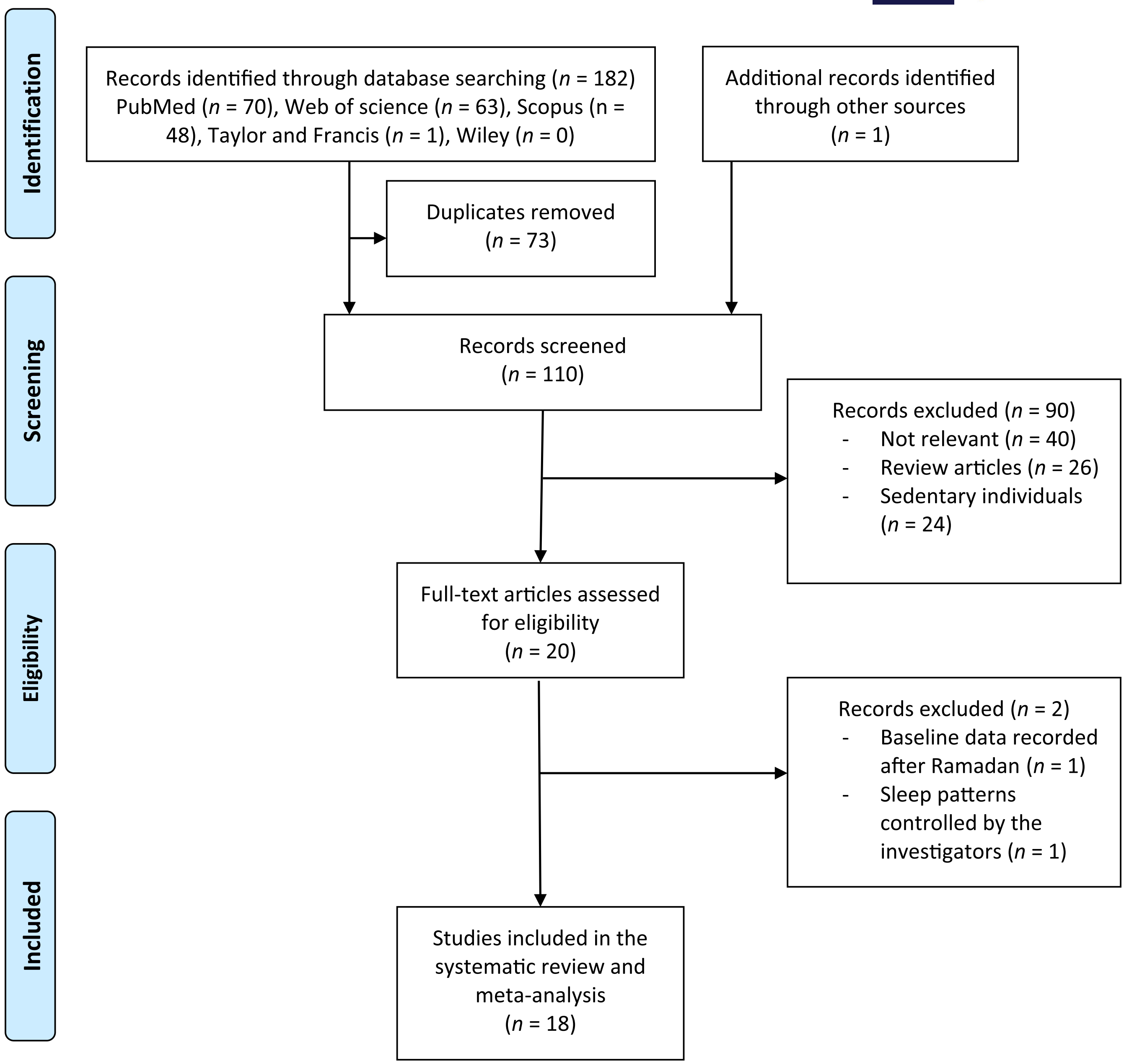

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

scores were interpreted based on the reference ranges adopted for PSQI questionnaire: <5 indicates a good sleep quality and ≥5 indicates a poor sleep quality (Buysse et al., 1989).

Additionally, a series of one-group meta-analyses (pre–post) were performed using before-Ramadan and during-Ramadan means and standard deviations (*SDs*), sample size, and pre–post correlation values. For studies that did not report pre–post correlations, available pre–post correlation values were imputed from previous studies examining similar outcomes. Specifically, for studies examining sleep duration, the average correlation value of 0.512 from five studies (Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019, Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020) was used. An average value of 0.512 from four studies was used for PSQI scores (Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020). Given that pre–post correlations were not available in all articles examining the effects of Ramadan fasting on ESS scores and daily nap duration, we followed the recommendations of Higgins and Green (2011), assuming a conservative estimation of $r = 0.5$ for these two variables.

Hedges' *g* value was used to measure effect size (ES): 0.8 reflects a large effect, 0.5 reflects a medium effect, and ≤0.2 was considered

TABLE 2 Quality assessment of the 18 included studies

	Question described	Appropriate study design	Appropriate subject selection	Characteristics described	Random allocation	Researchers blinded	Subjects blinded	Outcome measures well defined and robust to bias
Karli et al. (2007)	1	1	1	1	NA	NA	NA	1
Zerguini et al. (2007)	2	1	2	1	NA	NA	NA	1
Leiper et al. (2008)	2	2	2	2	NA	NA	NA	1
Meckel et al. (2008)	2	1	2	2	NA	NA	NA	2
Chennaoui et al. (2009)	2	1	1	1	NA	NA	NA	1
Aziz et al. (2010)	2	2	1	1	NA	NA	NA	1
Tian et al. (2011)	1	1	1	1	NA	NA	NA	1
Aziz et al. (2012)	2	2	1	1	NA	NA	NA	2
Herrera (2012)	2	2	1	1	NA	NA	NA	2
Bouhlel et el. (2014)	2	0	1	1	NA	NA	NA	0
Chamari et al. (2016)	2	1	2	2	NA	NA	NA	2
Aziz et al. (2017)	2	1	2	2	NA	NA	NA	1
Aziz et al. (2018)	2	1	2	2	NA	NA	NA	1
Boukhris, Hsouna, et al. (2019)	2	1	2	2	NA	NA	NA	1
Boukhris, Trabelsi, et al. (2019)	2	1	2	2	NA	NA	NA	1
Hsouna et al. (2019)	2	1	2	2	NA	NA	NA	1
Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al. (2020)	2	1	2	2	NA	NA	NA	1
Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn, et al. (2020)	2	1	2	2	NA	NA	NA	1
% of lost points	5.6	41.7	19.4	22.2	–	–	–	41.7

NA, not applicable.

a small effect (Hedges, 1981). In addition, Forest plots were utilised to illustrate point estimates of the effect size and 95% CIs. A negative ES value indicates that Ramadan fasting decreased outcomes, while a positive ES indicates that Ramadan fasting increased outcomes.

Two statistics, Q (Morris, 2008) and I^2 (Higgins et al., 2003), were utilised to assess statistical heterogeneity. Substantial heterogeneity was considered for I^2 values of >50% and indicated that a random-effect model was preferred to a fixed-effect model (Higgins et al., 2003). To identify potential sources of variance and of heterogeneity, moderator analysis was performed using subgroup analysis for categorical variables (i.e. level of training, continent). Additionally, meta-regression for integer or decimal variables (i.e. year of experimental protocol, fasting time length, age mean sample age, sample size, number of training session/week, duration of sleep assessment, study quality score) and for categorical variables (i.e. activity, method of sleep duration assessment) was also performed.

Funnel plots' potential asymmetries, the Begg and Mazumdar's rank correlation test (Kendall's S statistic P–Q) (Begg & Mazumdar, 1994), the Egger's linear regression test (Egger et al., 1997), and the Duval and Tweedie's trim-and-fill test (Duval & Tweedie, 2000) were used to examine publication bias.

The stability of the pooled ES of each study was assessed by sensitivity analyses and involved removing individual studies from the analysis and computing the impact of the excluded study. Also, a cumulative meta-analysis was conducted to further ensure the stability and reliability of the results.

A significance level of $p < 0.05$ was adopted, a priori, for all analyses. Meta-analysis was conducted with commercial Comprehensive Meta-Analysis software (CMA version 3.0, Biostat).

3 | RESULTS

3.1 | Selection of studies for systematic review and meta-analysis

The predefined search strategies yielded a preliminary pool of 183 possible papers. A total of 73 duplicates were removed. Then, 110

Sample size appropriate	Analytical methods well described	Estimate of variance reported	Controlled for confounding	Results reported in detail	Conclusion supported by results	Rating, %	Study quality
1	1	2	1	2	2	45.5	Weak
2	2	2	1	2	2	81.8	Strong
2	2	2	1	2	2	90.9	Strong
2	2	2	1	2	2	90.9	Strong
1	1	2	1	2	2	68.2	Moderate
1	2	2	1	2	2	77.3	Strong
1	0	2	1	2	2	54.5	Weak
1	2	2	1	2	2	81.8	Strong
2	2	2	2	2	2	95.5	Strong
1	1	2	1	2	2	59.09	Moderate
1	2	2	1	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
1	2	2	2	2	2	86.4	Strong
38.9	1.4	0.0	27.8	0.0	0.0		

published papers were screened by titles and abstracts for eligibility, of which 20 published studies met the inclusion criteria. After a careful review of the 20 full texts, 18 articles were included (Figure 1).

3.2 | Study characteristics

A total of 18 studies, comprising 298 active participants, from seven countries and three continents, were included in this meta-analysis. The studies were published between the years 2007 and 2020. The characteristics of the included studies are summarised in Table 3. The highest number of Ramadan observants was 54, in the report of Leiper et al. (2008); whilst numbers ranged between eight and 48 in the remaining studies. All participants were men, with mean ages ranging from 15 to 27 years. The study population included non-athlete physically active individuals who were moderately trained (i.e. recreational, amateur) in 10 studies (Aziz et al., 2010; Aziz et al., 2017; Aziz et al., 2018; Bouhlel et al., 2014; Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020; Meckel et al., 2008), and highly trained participants in eight studies (Aziz et al., 2012; Chamari et al., 2016; Chennaoui et al., 2009; Herrera, 2012; Karli et al., 2007; Leiper et al., 2008; Tian et al., 2011; Zerguini et al., 2007). Three studies included adolescent athletes (Bouhlel et al., 2014; Leiper et al., 2008; Meckel et al., 2008). All studies included healthy Muslim men who were engaged in PA and fasted during Ramadan.

3.3 | Quality assessment of studies selected for systematic review and meta-analysis

Of the 18 selected articles, 14 were of strong quality, two were moderate, and the remaining two were rated as weak (Table 2). The highest percentage of lost points from study quality prospective, was (i) inappropriate study design (41.7%), (ii) outcome measures not well defined and robust to bias (41.7%), and (iii) an inadequate sample size (38.9%) (Table 2).

TABLE 3 A summary of the 18 studies assessing sleep characteristics during Ramadan in men engaged in physical activity.

Study	Average fasting time duration, hr/day	Season/year of experimental protocol	City Country Continent	Number of subjects	Study design	Age, years	Activity	Level of practice
Karli et al. (2007)	12.8	Autumn/2006	Ankara Turkey Asia	10	Observational	22 ± 1	Power athletes (2 wrestlers, 7 sprinters and 1 thrower)	Elite
Zerguini et al. (2007)	12.1	Autumn/2004	Algiers Algeria Africa	48	Observational	25	Soccer	Professional
Leiper et al. (2008)	13	Autumn/2006	Tunis Tunisia Africa	54 observant, 33 non-observant	Observational	18 ± 1	Soccer	Elite
Meckel et al. (2008)	NM	NM	Netanya Israel Asia	19	Observational	15.1 ± 0.9	Soccer	Amateur: First division team in the Israeli youth league
Chennaoui et al. (2009)	11.2	Autumn/2004	Lille France Europe	8	Observational	25 ± 1	Middle-distance running	Professional
Aziz et al. (2010)	13.5	NM	NM Singapore Asia	10	Observational	27 ± 7	Running	Moderately trained
Tian et al. (2011)	13.4	Autumn/2009	Changi Singapore Asia	18	Observational	21 ± 3	Martial art (Penacksilat)	Elite
Aziz et al. (2012)	13.7	NM	NM Singapore Asia	9	Observational	19 ± 1	Martial art (Penack silat)	Elite
Herrera (2012)	14.1	Autumn/2010	Doha Qatar Asia	9	Observational	26 ± 4	Soccer	Professional
Bouhlel et al. (2014)	15	NM	Sousse Tunisia Africa	10	Observational	18.5 ± 0.5	Karate	Amateur

Training programme	Sleep parameters	Method of sleep measurement	Measurement period	Effect description
>2 hr a day; 6 days/week.	Sleep duration	NM	NM	No change
NM	Sleep duration	NM	2 weeks Bef-R, in the last week of Ramadan and PR	No change
	Sleep quality			Three-quarters of the players reported that the quality of their sleep was poorer than Bef-R
NM	Sleep duration	Questionnaire	Daily records	Loss of 60 min sleep/day throughout Ramadan in the fasting group (observant) and loss of 105 min/day during the first week of Ramadan in the non-fasting group (non-observant). No difference between observant and non-observant players
	Sleep quality			No change in the fasters and non-fasters. Only one player of the non-observant group reported better than usual overnight sleep quality during compared to Bef-R.
	Periods of sleep interruption			Increased twofold
6.4 ± 0.2 hr/week (bef-R) versus 4.5 ± 0.1 hr/week (Ramadan)	Sleep duration	NM	Each day during the week before fasting, and during the last week of the Ramadan fast	No change
6–10 times/week for ≥3 years	Sleep duration	Sleep logs	Day −5 (24 hr): Bef-R; Day 0, Day 21 and Day 31 (24 hr): during Ramadan	Decreased by 86 min at 21 days after the beginning of Ramadan and did not change at the end of Ramadan
2–4 times/week, between 15 and 25 km/week, during the last 3 months before the start of the study	Sleep duration	NM	24 hr before the testing during the control and Ramadan periods	Decreased 180 min
	Daytime sleepiness	KSS	On the testing day during the control and Ramadan periods	No change
8.9 ± 2.8 hr/week	Sleep duration	NM	NM	Decreased 102 min
	Daily naps	NM	NM	Increased 162 min
3–4 times/week, for 60–90 min/session	Daytime sleepiness	ESS	2 weeks Bef-R and during the last 2 weeks of Ramadan	No change
NM	Sleep duration	PSQI	1-week Bef-R and during the last week of Ramadan	78 min/day less sleep in RA4 compared with before Ramadan
	Sleep efficiency	PSQI		No change
	Sleep latency	PSQI		No change
	Insomnia symptoms	ISI		No change
	Daytime sleepiness	ESS		No change
5 times/week, for 2 hr	TST	NM	During a control period and during the fourth week of Ramadan	No change

(Continues)

TABLE 3 (Continued)

Study	Average fasting time duration, hr/day	Season/year of experimental protocol	City Country Continent	Number of subjects	Study design	Age, years	Activity	Level of practice
Chamari et al. (2016)	14.7	Summer/2013	Doha Qatar Asia	11	Observational	21.6 ± 4.8	Cycling	Professional:7 seniors and 4 juniors
Aziz et al. (2017)	15.4	NM	NM Singapore Asia	14	Observational	21.8 ± 2.4	Soccer	Amateur
Aziz et al. (2018)	13.5	Summer/2014	NM Singapore Asia	13	Observational	20.1 ± 0.9	Soccer	Local league (amateur)
Boukhris, Hsouna, et al. (2019)	15.8	Summer/2016	Sfax Tunisia Africa	13	Observational	21.2 ± 2.9	Running	Moderately trained
Boukhris, Trabelsi, et al. (2019)	15.8	Summer/2016	Sfax Tunisia Africa	14	Observational	21.6 ± 3.3	Running	Moderately trained
Hsouna et al. (2019)	15.8	Summer/2016	Sfax Tunisia Africa	12	Observational	21.9 ± 2.4	Running	Moderately trained
Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al. (2020)	15.8	Summer/2016	Sfax Tunisia Africa	12	Observational	21.1 ± 3.2	Running	Moderately trained
Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn, et al. (2020)	15.8	Summer/2016	Sfax Tunisia Africa	14	Observational	22 ± 3	Running	Moderately trained

Bef-R, before Ramadan; BR, last week before Ramadan; EEG, electroencephalography; ESS, Epworth Sleepiness Scale; ISI, Insomnia Severity Index; KSS, Karolinska Sleepiness Scale; NM, not mentioned; PR, the end of the second week post-Ramadan; PSQI, Pittsburgh Sleep Quality Index; RA1, the end of the first week of Ramadan; RA4, the end of the fourth week of Ramadan; REM, Rapid eye movement.

Training programme	Sleep parameters	Method of sleep measurement	Measurement period	Effect description
NM	Sleep duration	Ambulatory EEG	BR, RA1, RA4 and PR	No change
	Sleep macro-architecture			Light sleep duration significantly increased at RA1 and RA4 and then turned back to baseline values at post-Ramadan, while deep and REM sleep stages duration progressively decreased during the study to reach significantly lower values than baseline at PR
	Periods of sleep interruption			Increased twofold
3–5 times a week, between 60 and 90 min/session, and played a competitive match at the end of the week	Sleep duration	Actigraphy	24 hr	No change
Before the first match of the control session, the team trained four-times/week and played one league match at the end of the week. During Ramadan, training was reduced to between 2 and 3 times/week and no-competitive match was played.	Sleep duration	Actigraphy	In the Ramadan-fasted and non-fasted state	No change
	Daily nap	Actigraphy		Increased during Ramadan
	Daytime sleepiness	ESS		No change
Aerobic training (e.g. jogging) for ≥3 hr/week	Sleep latency	PSQI	15 days Bef-R, the first 10 days of Ramadan, the last 10 days of Ramadan, 10 days after Ramadan and 20 days after Ramadan	No change
	Sleep efficiency			No change
	Sleep duration			Decreased after Ramadan in comparison with during Ramadan
	Total score of PSQI			Increased 10 days after Ramadan in comparison with during Ramadan
Aerobic training (e.g. jogging) for ≥3 hr/week	Sleep latency	PSQI	Bef-R, during the end of Ramadan and after Ramadan	No change
	Sleep efficiency			Decreased during and after Ramadan in comparison with Bef-R
	Sleep duration			Decreased during and after Ramadan in comparison with Bef-R
	Total score of PSQI			Increased during and after Ramadan in comparison with Bef-R
Aerobic training (e.g. jogging) for ≥3 hr/week	Sleep latency	PSQI	15 days Bef-R, the first 10 days of Ramadan, the last 10 days of Ramadan, 10 days after Ramadan and 20 days after Ramadan	No change
	Sleep efficiency			No change
	Sleep duration			
	Total score of PSQI			No change
Aerobic training (e.g. jogging) for ≥3 hr/week	Sleep latency	PSQI	Bef-R, during the end of Ramadan and after Ramadan	No change
	Sleep efficiency			No change
	Sleep duration			Decreased during Ramadan in comparison with Bef-R
	Total score of PSQI			Increased during Ramadan in comparison with before and after Ramadan
Aerobic training (e.g. jogging) for ≥3 hr/week	Sleep latency	PSQI	Before Ramadan, during the end of Ramadan and after Ramadan	No change
	Sleep efficiency			No change
	Sleep duration			Decreased during Ramadan in comparison with Bef-R
	Total score of PSQI			Increased during Ramadan in comparison with before and after Ramadan

3.4 | Description of studies selected for review and meta-analysis

A description of the subjects and the methods in the 18 studies that are summarised in this paper is presented in Table 3.

3.5 | Effect of Ramadan on sleep duration

A total of 17 studies measured sleep duration in physically active men before and during Ramadan. These studies are summarised in Table 3.

The meta-analytic pooling of sleep duration before Ramadan showed that the participants accrued 7.901 hr per night (95% CI 7.452–8.349) with significant heterogeneity (Q = 459.394, df = 16, p = 0.000; I^2 = 96.517%). Detailed results are presented in the Forest plot in Figure S1.

Subgroup analysis revealed that highly trained participants had a similar overall pooled estimate of sleep duration compared to moderately trained counterparts. Sleep durations for highly trained and moderately trained participants were 7.966 hr (95% CI 7.341–8.591) and 7.840 hr (95% CI 7.217–8.342), respectively.

Sleep duration decreased during Ramadan to 7.082 hr (95% CI 6.5582–7.607), with significant heterogeneity (Q = 486.431, df = 16, p = 0.000; I^2 = 96.711%). Detailed results are presented in the Forest plot in Figure S2. Sleep duration for highly trained participants was 7.132 hr (95% CI 6.171–7.044) and sleep duration for moderately trained men was 7.021 hr (95% CI 6.175–7.871).

Meta-analysis was carried out using data from 17 studies, and the pooled results demonstrated a significant medium-to-large negative effect (ES = −0.766, SE = 0.221, 95% CI −1.199 to −0.333, Z-value = −3.466, p = 0.001; Figure 2) of Ramadan observance on sleep duration. A significant heterogeneity (Q = 168.292, df = 16, p = 0.000; I^2 = 90.493%) was detected; therefore, a subgroup analysis and meta-regression analysis were performed.

Nine studies included moderately trained individuals (Aziz et al., 2010; Aziz et al., 2017; Aziz et al., 2018; Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020; Meckel et al., 2008) and eight studies highly trained participants (Aziz et al., 2010, 2017, 2018; Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020; Meckel et al., 2008). The subgroup analysis for the categorical variable "level of training" revealed that Ramadan fasting had a more significant impact on sleep duration in more highly trained participants than in moderately trained participants, with a Hedges' g of −0.950 (SE = 0.341, 95% CI −1.618 to −0.283, Z-value = −2.789, p = 0.005) and −0.617 (SE = 0.318, 95% CI −1.241 to 0.006, Z-value = −1.942, p = 0.052), respectively (Figure S3).

A subgroup analysis for the categorical variable "continent" revealed that Ramadan observance had a more significant impact on sleep duration in individuals living in Africa (g = −0.952, SE = 0.331, 95% CI −1.600 to −0.304, Z-value = −2.878, p = 0.004) compared to those living in Asia (g = −0.426, SE = 0.331, 95% CI −1.111 to −0.187, Z-value = −1.395, p = 0.163) (Figure S4).

A subgroup analysis for the categorical variable "season" revealed that Ramadan observance had a more significant impact on sleep

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Zerguini, 2007	-0.014	0.140	0.020	-0.289	0.261	-0.099	0.921
Karli, 2007	0.762	0.332	0.110	0.112	1.412	2.299	0.022
Leiper, 2008	-4.165	0.418	0.174	-4.983	-3.347	-9.975	0.000
Meckel, 2008	0.000	0.217	0.047	-0.425	0.425	0.000	1.000
Chennaoui, 2009	-2.087	0.602	0.362	-3.266	-0.908	-3.468	0.001
Aziz, 2010	-1.829	0.495	0.245	-2.798	-0.859	-3.696	0.000
Tian, 2011	-0.927	0.270	0.073	-1.455	-0.398	-3.436	0.001
Bouhlel, 2014	-0.335	0.295	0.087	-0.913	0.244	-1.134	0.257
Herrera, 2012	-0.808	0.352	0.124	-1.498	-0.118	-2.296	0.022
Chamari, 2016	-0.608	0.303	0.092	-1.203	-0.014	-2.006	0.045
Aziz, 2017	-0.116	0.249	0.062	-0.605	0.373	-0.465	0.642
Aziz, 2018	-0.390	0.267	0.072	-0.914	0.134	-1.458	0.145
Boukhris, 2019b	0.227	0.309	0.096	-0.380	0.834	0.733	0.463
Boukhris, 2019c	-1.092	0.432	0.186	-1.938	-0.246	-2.530	0.011
Hsouna, 2019	0.211	0.207	0.043	-0.195	0.617	1.020	0.308
Hsouna, 2020a	-0.596	0.217	0.047	-1.020	-0.171	-2.751	0.006
Hsouna, 2020b	-2.442	0.414	0.171	-3.253	-1.631	-5.901	0.000
	-0.766	0.221	0.049	-1.199	-0.333	-3.466	0.001

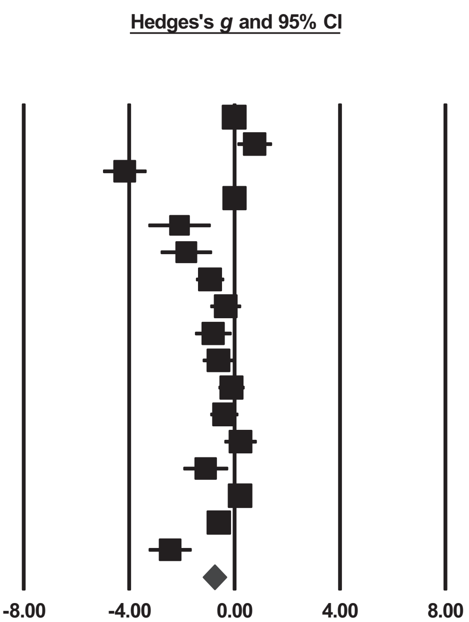

FIGURE 2 Forest plot for Hedges' g value on sleep duration in physically active individuals and athletes

duration during the autumn (g = −1.137, SE = 0.541, 95% CI −2.022 to −0.253, Z-value = −2.521, p = 0.012) compared to summer season (g = −0.643, SE = 0.411, 95% CI −1.450 to 0.163, Z-value = −1.563, p = 0.118) (Figure S5).

Meta-regression analyses revealed no impact of study quality score (coefficient −0.017, SE = 0.018, 95% CI −0.052 to 0.018, z = −0.96, p = 0.335), mean sample age (coefficient −0.017, SE = 0.082, 95% CI −0.177 to 0.143, z = −0.21, p = 0.834), type of activity (Q = 2.79, df = 4, p = 0.593), fasting time length (coefficient 0.173, SE = 0.180, 95% CI −0.181 to 0.526, z = −0.96, p = 0.338), method of sleep duration assessment (Q = 0.93, df = 3, p = 0.817), number of training session/week (coefficient −0.001, SE = 0.204, 95% CI −0.401 to 0.400, z = −0.00, p = 0.998), or duration of sleep assessment (coefficient −0.012, SE = 0.021, 95% CI −0.052 to 0.031, z = −0.49, p = 0.621), sample size of study (coefficient −0.034, SE = 0.019, 95% CI −0.071 to 0.003, z = −1.82, p = 0.069), and year of the experimental protocol (coefficient 0.05, SE = 0.066, 95% CI −0.079 to 0.18, z = −0.76, p = 0.447). Graph of subgroup analysis for these integers can be found as supplementary Figures (Figures S6–S14, respectively).

Visual inspection of the Funnel plot (Figure 3) and results of the Begg and Mazumdar's test (Kendall's S statistic $P–Q$ = −66.00; tau without continuity correction = −0.485, z = 2.719, p = 0.003; tau with continuity correction = −0.478, z = 2.677, p = 0.004) and of the Egger's linear regression test (intercept = −5.694, SE = 1.838, 95% CI −9.612 to −1.776, t = 3.098, df = 15, p = 0.003) provided evidence of publication bias. With the Duval and Tweedie trim-and-fill analysis, two studies (Hsouna et al., 2019; Karli et al., 2007) were trimmed, resulting in a "true ES" of −0.948 (95% CI −1.411 to −0.4851, Q = 238.119).

3.6 | Effect of Ramadan on sleep quality–Global score PSQI

Six studies (Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Herrera, 2012; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020) used the PSQI questionnaire to evaluate sleep quality in physically active men.

The meta-analytic pooling of the PSQI scores before Ramadan revealed that participants had a score of 4.053 (95% CI 3.071–5.034), with significant heterogeneity (Q = 129.958, df = 5, p = 0.000; I^2 = 96.153%). Detailed Forest plot results are presented in Figure S15.

The PSQI scores increased during Ramadan to 5.346 (95% CI 4.362–6.331, Q = 108.906, df = 5, p = 0.000; I^2 = 95.409%) (Figure S16).

The summarised effects of six ESs demonstrated a non-significant large positive effect (ES = 1.038, SE = 0.663, 95% CI −0.262 to 2.337, Z-value = 1.565, p = 0.118; Figure 4) of Ramadan observance on PSQI scores. A significant heterogeneity (Q = 94.047, df = 5, p = 0.000; I^2 = 83.994%) was computed.

A Funnel plot (Figure S17) showed evidence of publication bias, a conclusion confirmed by the Egger's linear regression test (intercept = 6.856, SE = 2.876, 95% CI −1.130 to 14.842, t = 2.384, df = 4, p = 0.038). However, the Begg and Mazumdar's rank correlation test (Kendall's S statistic $P–Q$ = 7; tau without continuity correction = 0.467, z = 1.315, p = 0.094; tau with continuity correction = 0.400, z = 1.127, p = 0.130) did not provide evidence of publication bias. The Duval and Tweedie's trim-and-fill test identified one missing study (Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020), resulting in a "true ES" of 0.508 (95% CI −0.777 to 1.793, Q = 94.371).

3.7 | Effect of Ramadan fasting on daily naps

The duration of daily naps duration before and during Ramadan was reported in two studies (Aziz et al., 2018; Tian et al., 2011).

The meta-analytic pooling of the duration of daily naps before Ramadan showed that participants napped 12.9 min/day (95% CI 6.54–19.2), without a significant heterogeneity (Q = 1.216, df = 1,

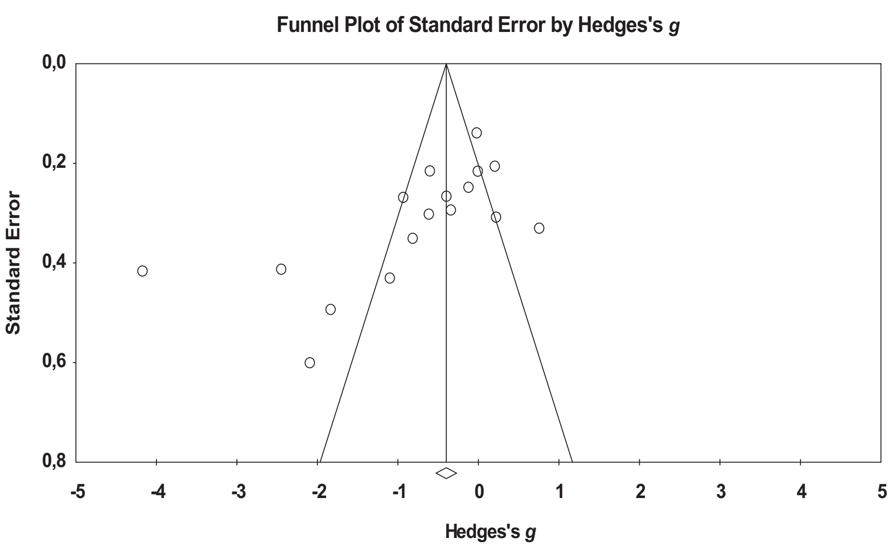

FIGURE 3 Funnel plot of sleep duration for physically active individuals and athletes during Ramadan observance, showing evidence of publication bias

Study name	Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Herrera, 2012	0.151	0.294	0.086	-0.426	0.727	0.512	0.609
Boukhris, 2019b	-0.744	0.277	0.076	-1.286	-0.202	-2.690	0.007
Boukhris, 2019c	1.299	0.346	0.120	0.620	1.977	3.752	0.000
Hsouna, 2019	-1.502	0.297	0.088	-2.085	-0.920	-5.053	0.000
Hsouna, 2020a	5.470	1.356	1.838	2.813	8.127	4.034	0.000
Hsouna, 2020b	4.243	0.917	0.841	2.446	6.040	4.628	0.000
	1.038	0.663	0.440	-0.262	2.337	1.565	0.118

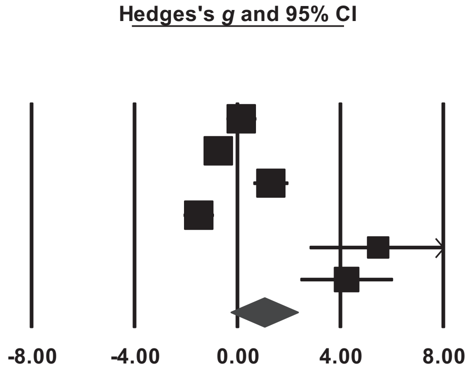

FIGURE 4 Forest plot for Hedges' *g* value on Pittsburgh Sleep Quality Index (PSQI) scores in physically active individuals and athletes. ">" denotes a value >8

Study name	Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Tian, 2011	1.335	0.317	0.100	0.715	1.956	4.218	0.000
Aziz, 2018	0.742	0.298	0.089	0.159	1.325	2.493	0.013
	1.029	0.297	0.088	0.448	1.610	3.469	0.001

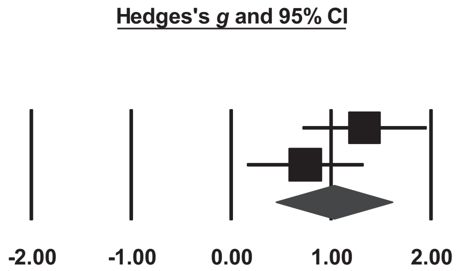

FIGURE 5 Forest plot for Hedges' *g* value on daily naps duration in athletes

$p = 0.270$; $I^2 = 17.745\%$). Detailed Forest plot results are presented in Figure S18.

Daily nap duration increased during Ramadan to 141.6 min (95% CI 63.66–219.6), with significant heterogeneity ($Q = 3.184$, $df = 1$, $p = 0.074$; $I^2 = 68.598\%$). Detailed results are presented in the Forest plot in Figure S19.

The summarised effects of two ESs demonstrated a significant large positive effect (ES = 1.020, $SE = 0.217$, 95% CI 0.595–1.445, Z-value = 4.705, $p = 0.000$; Figure 5) of Ramadan observance on daily nap duration. A non-significant heterogeneity ($Q = 1.738$, $df = 1$, $p = 0.187$; $I^2 = 42.475\%$) was computed.

3.8 | Effect of Ramadan on daytime sleepiness

Three studies used the ESS questionnaire to evaluate the effect of Ramadan observance on the level of daytime sleepiness in individuals engaged in PA during Ramadan.

The meta-analytic pooling of the ESS scores before Ramadan revealed an average of 7.447 (95% CI 5.338–9.555), with significant heterogeneity ($Q = 4.995$, $df = 2$, $p = 0.082$; $I^2 = 59.963\%$). Detailed results are presented in the Forest plot in Figure S20.

The ESS scores increased during Ramadan to 8.468 (95% CI 5.452–11.484, $Q = 11.830$, $df = 2$, $p = 0.003$; $I^2 = 83.064\%$) (Figure S21).

The summarised effects of three ESs demonstrated a small but non-significant positive effect (ES = 0.190, $SE = 0.168$, 95% CI −0.139 to 0.519, Z-value = 1.133, $p = 0.257$; Figure 6) of Ramadan observance on ESS scores in individuals engaged in PA, without a significant heterogeneity ($Q = 0.919$, $df = 2$, $p = 0.257$; $I^2 = 0.000\%$).

A visual inspection of the Funnel plot (Figure S22) showed no evidence of publication bias, a conclusion confirmed by Begg and Mazumdar's rank correlation test (Kendall's S statistic $P–Q = 3.00$; tau without continuity correction = 1.00, $z = 1.567$, $p = 0.059$; tau with continuity correction = 0.667, $z = 1.044$, $p = 0.148$) and by Egger's linear regression test (intercept = 6.382, $SE = 0.019$, 95% CI 6.181–6.584, $t = 402.182$, $df = 1$, $p = 0.001$). The Duval and Tweedie's trim-and-fill test did not identify any missing study.

3.8.1 | Sensitivity and cumulative meta-analysis

In conclusion, both sensitivity analysis and cumulative meta-analysis confirmed the reliability and stability of the present findings (Figures S23–S26).

Study name	Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aziz, 2012	0.327	0.311	0.097	-0.282	0.936	1.052	0.293
Herrera, 2012	0.325	0.311	0.097	-0.284	0.934	1.047	0.295
Aziz, 2018	0.000	0.260	0.067	-0.509	0.509	0.000	1.000
	0.190	0.168	0.028	-0.139	0.519	1.133	0.257

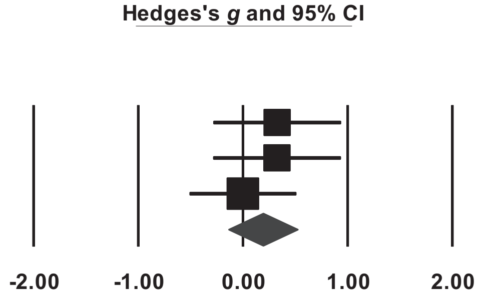

FIGURE 6 Forest plot for Hedges' *g* value on Epworth Sleepiness Scale (ESS) scores in athletes

4 | DISCUSSION

The purpose of the present study was to conduct a systematic review and meta-analysis of studies evaluating the effects of Ramadan observance on sleep duration, sleep quality, daytime sleepiness, and daily nap duration in athletes and physically active individuals, and to examine possible moderating variables of this relationship.

The results of the 17 studies that were reviewed support the conclusion that training during Ramadan is associated with a decreased sleep duration in athletes and physically active men. Sleep quality, which was measured by the global score of PSQI and reported in six studies, was impaired during Ramadan. Daytime sleepiness, which was measured using the ESS in three studies, remained unchanged from before to during Ramadan. Self-estimated daily nap duration was evaluated in only two studies and appeared to be increased in athletes observing Ramadan.

4.1 | Effect of Ramadan observance on sleep duration

In accordance with previous meta-analyses conducted on studies of athletes (Trabelsi et al., 2020) and a sample composed of sedentary individuals and athletes (Faris, Jahrami, Alhayki, et al., 2019; Faris, Jahrami, Obaideen et al., 2019), the results of the present meta-analysis suggest that athletes and physically active men, who continue to train at least twice/week during Ramadan, experience a reduction in sleep quantity. The meta-analytic pooling of sleep duration data showed that sleep duration decreased <1 hr, from 7.901 hr before Ramadan, to 7.082 hr during Ramadan. The pooled sleep duration during Ramadan was less than the recommended 8 hr/day (Halson, 2014), suggesting that the amount of sleep was not optimal to maintain cognitive and physical performances during the month of Ramadan. Several factors may explain the reduced sleep duration during Ramadan observance. The large amount of food consumed at night could have negatively affected circadian rhythms and hormone secretion (Almeneessier & BaHammam, 2018). Additionally, eating close to bedtime is known to reduce sleep duration (Roky et al., 2001). Furthermore, sleeping with a full stomach during Ramadan could have increased core body temperature and consequently promoted night wakefulness (BaHammam, 2003). Indeed, results of previous studies showed that late-dinners who consumed 30–60 min before bedtime (Roky et al., 2001), but not dinners who consumed 3 hr before bedtime (BaHammam, 2004), decrease sleep duration during Ramadan.

The reduced sleep duration may also be explained by the increase of the night-time social activities (Faris, Jahrami, Alhayki, et al., 2019; Faris, Jahrami, Obaideen et al., 2019), such as watching Ramadan television programmes, shopping, meetings in the coffee shops, and religious activities (e.g. *Quran* reading group, *Quran* recitation, prayer such as *Ettarawih*). Increased nocturnal light exposure has also been suggested as factor leading to the decrease of sleep duration during Ramadan (Almeneessier et al., 2018; Faris, Jahrami, Alhayki, et al., 2019; Faris, Jahrami, Obaideen et al., 2019).

A subgroup analysis of level of training revealed differences in sleep duration and showed that Ramadan observance appeared to have a greater impact on sleep duration in highly trained participants ($g = -0.950$), than in moderately trained participants ($g = -0.617$). A possible explanation of this finding is the difference in training loads of highly trained participants, as the results of a recent systematic review and meta-analysis indicated that a high training load decreases sleep duration in athletes (Roberts et al., 2019). Additionally, highly trained participants continue to compete during the month of Ramadan, and anxiety or thoughts about the competition have been shown to decrease sleep duration the night before competition (Erlacher et al., 2011; Juliff et al., 2015). Nevertheless, this is only concerning the nights preceding competition and would have had a minimal effect on the observed results across the whole month of Ramadan. A recent narrative review and expert consensus recommendations on "sleep and the athlete" topic confirm these possible explanations and identified training loads, the night before competition, evening competition (start times after 6:30 p.m.), short-haul and long-haul travel, and early morning training (start times before 8:00 a.m.) as the sport-specific risk factors for sleep inadequacy including the reduction of sleep duration in highly trained participants (Walsh et al., 2021).

In the studies that were included in the evaluation of the effects of Ramadan observance on sleep duration in individuals engaged in PA, there was a high heterogeneity between the results ($I^2 = 90.493\%$).

As the lunar calendar is shorter than the solar year, Ramadan migrates throughout the seasons, coming 10–12 days earlier each year (Chtourou et al., 2018). A recent meta-analysis in healthy, non-athlete Muslims, revealed that the season of the fasting month and the fasting length of time may play a fundamental role in shaping the beneficial effect of Ramadan fasting on variable metabolic syndrome (MetS) components (i.e. waist circumference, systolic blood pressure, fasting plasma/serum glucose, triglycerides, and high-density lipoprotein cholesterol) (Faris et al., 2020). Given that several reports have highlighted the existence of a dose–response relationship between MetS and short sleep duration (Hua et al., 2021; Iftikhar et al., 2015), it is worth investigating whether Ramadan's season and fasting duration can also moderate sleep duration. Indeed, a subgroup analysis of Ramadan's season revealed differences in sleep durations and showed that Ramadan observance induce shorter sleep duration during the autumn ($g = -1.14$) compared to the summer one ($g = -0.64$). These results could be explained by the trainability level of the recruited participants, as ~87% (78/89) of the participants during the summer season were moderately trained participants, while those recruited during the autumn season (147 athletes) were highly trained participants suggested to have more sport-specific risk factors for sleep inadequacy (Walsh et al., 2021). Therefore, these results should be interpreted with caution and further studies should specifically investigate the moderating effect of Ramadan's season on sleep duration in homogeneous populations from a trainability level prospective.

The results of the subgroup analysis according to "continent" revealed that sleep duration was more impacted by Ramadan fasting in individuals engaged in PA from Africa than those from Asia. This finding could be probably explained by the fact that African individuals engaged in PA during Ramadan are mostly from Tunisia and physically active (non-competitive). Indeed, it appears that they have focussed less on sleep hygiene practices during Ramadan compared to athletes from Asia.

However, the meta-regression showed that there was no significant moderation effect of the fasting length time. This result was expected given that the fasting length time did not differ substantially between the analysed studies (i.e. 14.2 ± 1.5 hr).

4.2 | Effect of Ramadan observance on sleep quality

Our meta-analysis showed global PSQI scores did not change significantly from before to during Ramadan in individuals who continue to train during Ramadan. However, during the month of Ramadan, PSQI scores reached a value of >5 (PSQI score = 5.346), indicating poor sleep quality (Buysse et al., 1989). Based on a research conducted outside of Ramadan month (Shechter et al., 2012), Faris, Jahrami, Alhayki, et al. (2019); Faris, Jahrami, Obaideen et al. (2019) speculated that diet, particularly fat and carbohydrate intake, negatively impacts sleep quality during Ramadan. However, when looking further at the results of individual studies included in this meta-analysis (Boukhris, Hsouna, et al., 2019; Boukhris, Trabelsi, et al., 2019; Hsouna et al., 2019; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Irandoust, et al., 2020; Hsouna, Boukhris, Trabelsi, Abdessalem, Ammar, Glenn et al., 2020), no significant relationship ($p > 0.05$) was found between fat intake or carbohydrate intake and sleep quality, and no significant relationship ($p > 0.05$) was found between fat intake or carbohydrate intake and sleep quality during Ramadan.

Ramadan fasting is generally associated with changes in training plans, sleep schedules (Chtourou et al., 2018; Trabelsi, Moalla, et al., 2018), and dietary habits such as changes in food quantity and quality, nocturnal food consumption, and meal frequency (Sadeghirad et al., 2014). Although, Ramadan fasting has many beneficial effects on various anthropometric, metabolic, and inflammatory factors that interfere with the sleep quality and duration (Faris, Jahrami, Alhayki, et al., 2019; Faris, Jahrami, Obaideen et al., 2019; Jahrami et al., 2020), the associated dietary changes could induce gastrointestinal disorders (Chtourou et al., 2018), which has been previously suggested to impair athletes' sleep quality via sleep interruption (Drew et al., 2018). For instance, the only study that used the "gold standard" of polysomnography for sleep assessment before and during Ramadan is that of Chamari et al. (2016). The authors demonstrated that the duration of the light sleep stage increased significantly during, compared to before, Ramadan (Chamari et al., 2016). This change has been attributed to an increased number of awakenings and was suggested to reflect increased night-time metabolism, due to the late *Suhoor* meal (last meal before starting the day fast) and/or increased food-seeking behaviours (Chamari et al., 2016). These suggestions are consistent with the findings of Nakajima (2018) who reported that sleeping with a full stomach provokes gastroesophageal reflux and reduced diet-induced thermogenesis, and therefore affects sleep quality.

Taken together, we can speculate that gastrointestinal tract symptoms may have contributed to impaired sleep quality of individuals engaged in PA during Ramadan. However, future studies examining the link between sleep quality and gastrointestinal disorders during Ramadan are needed.

In addition, at the end of the nocturnal training sessions that occurred during Ramadan, some athletes and/or physically active individuals may increase their water intake to replace fluid lost, perhaps because of the instructions of the coach or medical staff. However, the absence of strict monitoring of hydration status during Ramadan observance could provoke a state of hypohydration or overhydration in individuals engaged in PA. To maintain body fluids homeostasis, it was recommended to consume 1.5-times the amount of water lost during training session via sweating (Coyle, 2004). Nevertheless, increasing water intake up to the values cited previously is unlikely to be effective as prompt diuresis will ensue, and the excess water will soon be expelled in the urine (Maughan & Shirreffs, 2012). In this case, void frequency will likely increase during night-time and subjects will sometimes have to wake-up at night to urinate, which may lead to greater sleep disturbance and impairment in sleep quality.

It is worth noting that, although practicing PA during Ramadan affects sleep quality, it is not possible to know if the time spent in the different sleeping phases was impacted during Ramadan. The use of objective sleep assessments (i.e. polysomnography), instead of subjective assessments, in future Ramadan-based studies is warranted.

4.3 | Effect of Ramadan observance on daytime naps

It is well documented that the negative effects of sleep disruption on cognitive and physical performances are attenuated by napping (Blanchfield et al., 2018; Boukhris, Abdessalem, et al., 2019; Chtourou et al., 2019; Hammouda et al., 2018; O'Donnell et al., 2018; Romdhani et al., 2020; Souabni et al., 2021; Waterhouse et al., 2007). Napping can benefit performance, even if the prior night's sleep has been adequate (Abdessalem et al., 2019; Ammar et al., 2021; Boukhris et al., 2020 and Hsouna et al., 2021).

The present meta-analysis showed that athletes who continue to train during Ramadan observance experienced an increase ($g = 1.083$) in daytime nap duration; it appears that these individuals used daytime napping as a strategy to supplement their night-time sleep during Ramadan. Duration of daily naps increased from 12.9 min/day before Ramadan to 141.6 min/day during Ramadan. After any sleep or nap there is a temporary period of decreased mental ability. In order to avoid this "sleep inertia", a 30-min nap was suggested by Davenne (2009), while Simpson et al. (2017) recommended that naps should be of ≤30 min in duration. However, naps substantially <1 hr provide insufficient time for the onset of slow-wave sleep stages, which possess the greatest recuperative value (Waterhouse, 2010). In the two studies (Aziz et al., 2018; Tian et al., 2011) included in our meta-analysis, the pooled nap opportunity duration recorded during Ramadan was >2 hr, thereby providing sufficient time for the slow-wave stages of sleep to be achieved, and good recovery attained.

However, results of the effects of Ramadan observance on the self-reported duration of daily naps should be interpreted with caution. First, Lastella et al. (2018) showed that, when soccer players self-reported nap duration, they underestimated the actual nap duration (recorded using polysomnography) by ~10 min/hr of nap. Moreover, only two studies on athletes were included in this meta-analysis; indicating that more rigorous studies are needed to confirm the veracity of our findings. Indeed, it is still unknown if the napping during Ramadan achieves an effect counteracting the potential negative effects of decreased sleep duration in athletes.

4.4 | Effect of Ramadan observance on daytime sleepiness

Aziz et al. (2010, 2012) speculated that, during Ramadan, a loss of 1–2 hr of sleep per day accumulates, resulting in chronic excessive daytime sleepiness towards the end of the month. This potentially elicits a negative impact upon the individual's daytime fatigue, behaviour, lethargy, and mood.

Our meta-analysis showed that individuals who continue to train during Ramadan did not experience any increase in daytime sleepiness; the pooled average of the ESS score increased by ~1 point from 7.447 before Ramadan, to 8.468 during Ramadan, although remaining in the range of higher levels of normal daytime sleepiness in both conditions. Similar levels of daytime sleepiness before and during Ramadan observance were also reported in the meta-analysis of Faris, Jahrami, Alhayki, et al. (2019); Faris, Jahrami, Obaideen et al. (2019).

Despite shorter hours of sleep during Ramadan, symptoms of excessive daytime sleepiness were not reported. It is possible that daily naps and/or other adaptive responses to daytime sleepiness may have contributed to the lack of significant changes in the ESS score during Ramadan. Indeed, napping can be regarded as a countermeasure to decrease the levels of the homeostatic process, i.e. the pressure to sleep depending on the duration of wakefulness, that could be increased by the reduced sleep duration here observed, thus potentially improving alertness and performance (Garbarino et al., 2004).

4.5 | Strengths and weaknesses

The strengths of the present systematic review and meta-analysis are (*i*) the inclusion of moderately and highly trained participants, as well as physically active adolescents, (*ii*) the absence of language restriction, and (*iii*) the comprehensive coverage of the literature followed by careful appraisal of the included studies' quality. Sensitivity analyses and cumulative meta-analyses confirmed the reliability and stability of the current findings.

We assert that any weaknesses in the present study are related to the availability of data, or lack thereof, and not our methodology. Specifically, the interpretation of the results of the meta-analysis involving sleep duration is challenged by the significant amount of heterogeneity and the evidence of publication bias in the selected papers. Indeed, all results must be interpreted with caution, due to methodological issues in most studies (*e.g.*, lack of control group, small sample size, different training loads, subjective measurement tools) (Trabelsi et al., 2020). In addition, as in the studies included in the systematic review and meta-analysis of Trabelsi et al. (2020), the timing of training sessions during Ramadan was not reported in most selected articles in the present work (Aziz et al., 2010, 2018; Bouhlel et al., 2014; Boukhris, Hsouna, et al., 2019; Chamari et al., 2016; Chennaoui et al., 2009; Herrera, 2012; Karli et al., 2007; Meckel et al., 2008; Tian et al., 2011), which makes determination of causal effect of the timing of training during Ramadan on sleep duration impossible. This issue should be avoided in future Ramadan-based studies.

A significant amount of heterogeneity was also reported in the results of the meta-analysis involving sleep quality. However, given the small number of studies, it was not possible to perform a subgroup analysis and/or meta-regression to detect sources of heterogeneity.

Another weakness of this study is that there were only two studies evaluating daily nap duration and only three studies evaluating daytime sleepiness; accordingly, more research on these topics is needed. The lack of a control group is another weakness associated with Ramadan studies. It is, indeed, very much challenging to find a non-fasted group in Muslim majority countries, while finding a fasting group in non-Muslim majority countries comes with equivalent challenges. Finally, it is a weakness in the literature that studies have been limited to only male participants. Future studies should include women, although we note a major difficulty in assessing the effects of Ramadan fasting in women given that they are forbidden to fast during their menstrual period; so, the 29- or 30-day period of fasting is interrupted during this time.

5 | CONCLUSIONS

Athletes and physically active men, who continued their exercise routines while observing Ramadan, experienced a decrease in sleep duration and a reduction in sleep quality. Daytime sleepiness scores remained unchanged from before to during Ramadan. Two studies reported that day nap durations increased during Ramadan in male athletes. The implementation of sleep hygiene practices during Ramadan may improve the overall quantity and quality of sleep for individuals engaged in PA. However, future studies would benefit from a more rigorous study design, including sample sizes with adequate power and a control group.

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CONFLICT OF INTEREST

All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

AUTHOR CONTRIBUTIONS

KT and AA conceptualised and planned the study. KT, AA, and HC undertook the study selection and quality assessment. KT, AA, OB, and HC performed data extraction. AA, KT, and OB performed the data analysis and synthesis. All authors contributed to data interpretation. KT drafted the manuscript, which was critically reviewed by AA, JMG, OB, AK, BB, PZ, PL, SG, CCTC, KC, NLB, DWH, and HC. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this meta-analysis are available on request from the corresponding author.

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