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METHODS • REVIEW

Effect of diurnal fasting on sleep during Ramadan: a systematic review and meta-analysis

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Abstract

Purpose The current meta-analysis aimed to obtain a more stable estimate of the effect size of Ramadan diurnal intermittent fasting (RDF) on sleep duration and daytime sleepiness.

Methods Databases (Scopus, ScienceDirect, ProQuest Medical, PubMed/MEDLINE, Web of Science, EBSCOhost, Cochrane, CINAHL, and Google Scholar) were searched from database inception to the end of June 2019. The sleep quality measures analyzed were excessive daytime sleepiness (EDS) measured by the Epworth sleepiness scale (ESS) and total sleep time (TST). Subgroup analyses for age, sex, and levels of physical activity were conducted.

Results We identified 24 studies (involving 646 participants, median age 23.7 years, 73% men) conducted in 12 countries from 2001 to 2019. The results revealed that TST decreased from 7.2 h per night [95% confidence interval (CI) 6.7–7.8] before Ramadan to 6.4 h (95% CI 5.3–7.5) during Ramadan, while the ESS score increased slightly from 6.1 (95% CI 4.5–7.7) before Ramadan to 7.0 (95% CI 5.2–8.8) during Ramadan. Effect sizes on sleep quality measures during RDF demonstrated a moderate reduction in TST (number of studies, K = 22; number of subjects, $N = 571$, Hedges' g value of −0.43, 95% CI − 0.64 to −0.22, Q = 90, $\tau^2 = 0.15$, $I^2 = 78\%$, $P < 0.001$), while ESS score showed negligible effect on EDS (K = 9, $N = 362$, Hedges' g value of −0.06, 95% CI −0.43 to 0.28, Q = 21, $\tau^2 = 0.13$, $I^2 = 76\%$, P value = 0.001).

Conclusion During the month of Ramadan, there is approximately a 1 hour reduction in TST and nearly a 1 point increase in the ESS score.

Keywords Caloric restriction · Epworth sleepiness scale (ESS) · Excessive daytime sleepiness (EDS) · Diurnal intermittent fasting · Ramadan · Total sleep time (TST)

Introduction

Fasting is an ancient practice defined as voluntary abstinence from food and/or drinks [1], which has been recently adopted as a health and fitness trend [2]. Muslims fast from dawn to sunset for 29–30 days during Ramadan. Ramadan fasting forbids eating foods, drinking water, sexual activities, and smoking during daytime [3] and affects daily lifestyle. The predawn meal is taken before dawn (*suhoor*), and the main course is taken after sunset (*iftar*) [4]. This shift in mealtime during Ramadan might be associated with changes in caloric and nutrient intakes (heavy meals), which are variable according to the variations in dietary and social behaviors practiced during the fasting month [5, 6].

Religious practices can affect sleep [7, 8], and during Ramadan, many events occur at night [7, 9]. Ramadan can occur during any four seasons of the Gregorian year [10]. Daytime fasting is therefore longer during summer and shorter

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during winter. This practice can affect physiology and health [4, 11, 12]. While studies have examined the effects of Ramadan diurnal intermittent fasting (RDF) on human health and nutrition [13–24], few studies have examined the impact on sleep.

We conducted a systematic review and meta-analysis to answer the question: "Do practices during Ramadan affect sleep duration and daytime sleepiness?" The Epworth sleepiness scale (ESS) and reported total sleep time (TST) were used as measures for sleepiness and sleep duration, respectively. The ESS is a questionnaire developed to assess "daytime sleepiness" [25] where higher scores reflect higher likelihood to fall asleep/doze during everyday activities [26].

We hypothesized that during Ramadan, TST decreases, while daytime sleepiness increases. Inconclusive results from different studies concerning effects of RDF on sleep necessitate a systematic review.

Methods

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [27] guidelines were followed.

Database searches

Three authors (MF, FA, SJ) conducted a search of electronic databases (CINAHL, Cochrane, EBSCOhost, Google Scholar, ProQuest Medical, PubMed/MEDLINE, ScienceDirect, Scopus, Web of Science) from inception to the end of June 2019 including the keywords: "Ramadan fasting" *or* "Ramadan diurnal fasting" *or* "Ramadan intermittent fasting" *or* "Ramadan model of intermittent fasting" *or* "Ramadan fast" *or* "intermittent fasting" *and* "sleep pattern" *or* "sleep disturbances" *or* "total sleep time" *or* "excessive daytime sleepiness" *or* "sleep duration" *or* "poor sleep" *or* "sleepiness" *or* "sleep schedule." Reference lists were searched for relevant articles/reviews and to ensure inclusion of all relevant publications.

Study selection

We included studies into the effects of RDF on total sleep time (TST) and EDS using the ESS in different age groups, active, athletic, and non-active individuals.

Inclusion criteria were prospective observational studies and semi experimental/experimental/interventional studies that assessed the impact of RDF on healthy people which (1) were published between database inception and June 2019, (2) were published in English and (3) reported numerical values (e.g., mean with/without standard deviation) for either TST or ESS or both. We included studies that assessed the components: pre-fasting baseline (before Ramadan month) and post-fasting (≥ 2 weeks into Ramadan or afterward). TST measures minutes asleep after "lights off" during nighttime [28] or the difference between the time to bed and awakening, discounting time to fall asleep [29] and nap time/other brief periods of sleep [30]. Participants included in the current review were healthy, male and female subjects, aged from 10 years and above, who observed the whole month of Ramadan.

Exclusion criteria for methodological and quality issues were (1) lack of the full text after contacting authors; (2) studies that expressed changes in TST or ESS components using bar graphs and curves without reporting exact numerical values; (3) abstracts, case reports, editorials, review articles, and non-English-language articles; and (4) unpublished, non-peer-reviewed data. All of the above were excluded from the quantitative and qualitative analysis (Fig. 1).

Quality scores

Three reviewers (FA, NA, and SA) independently assessed methodological rigor using a standardized checklist consisting of six items account for sampling size/technique, measurement tool, and statistical analyses. Item scores ranged from 0 to 6. Scores of 0–2 corresponded to low quality; 3–4, medium quality; and 5–6, high quality. Disagreements between reviewers were resolved by consensus after discussion with another reviewer (HJ).

Main outcomes and measures

The principal outcome was to report the impact of RDF on effect size changes in TST and EDS using the ESS. Two authors (FA and MF) independently screened titles and abstracts of identified studies and assessed them for eligibility. Screening consisted of a survey of all titles and abstracts to exclude irrelevant publications. One author (FA) performed the initial data extraction, which was validated by other authors (FA, NA, SA, AA, and IA). Any eligibility-related disagreements were resolved through dialog with a fifth author (HJ). To standardize data extraction, the review team collected data for study characteristics (e.g., title, year, sample size, country, and participant characteristics such as age/sex) and values of TST and ESS score before and at the end of Ramadan fasting.

Data were extracted manually and were coded into Microsoft Excel Sheet 2019 in preparation for analysis.

Data synthesis and statistical analyses

Combined means were computed when the study included subgroups (e.g., males and females) and expressed different means and standard deviations for each subgroup. *P* values for these combined subgroup means were calculated. All other

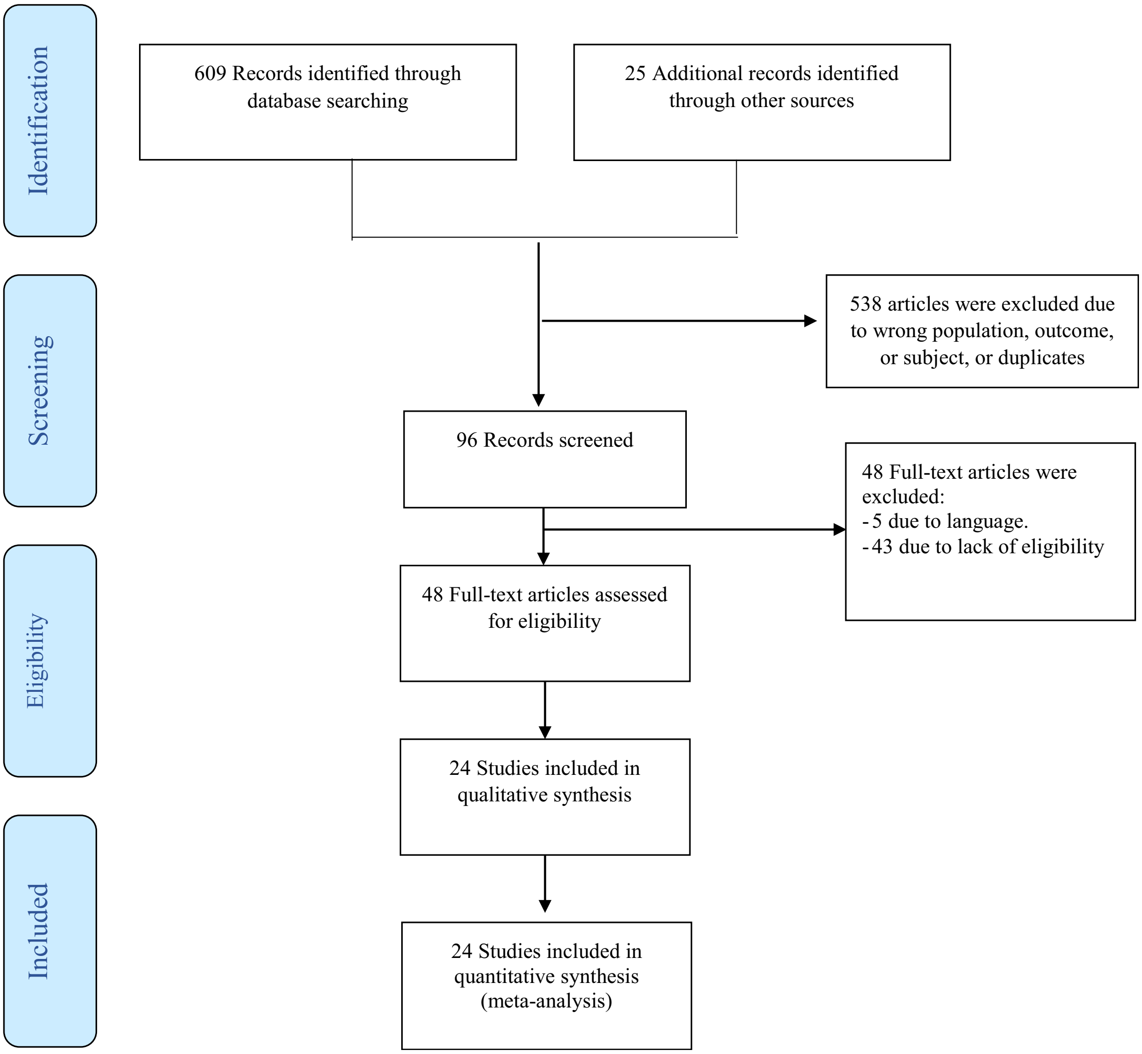

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart for the selection of publications included in the systematic review and meta-analysis. Other resources included the manual screening of references used by the obtained articles

descriptive and inferential tests were performed using STATA software (Stata, M.P., 15.0. College Station, TX: StataCorp, 2017).

Initially, data were pooled to estimate the pooled TST and ESS scores at two time points: baseline (before Ramadan) and at the end of Ramadan. The data were pooled in this meta-analysis using a random-effects model according to the DerSimonian–Laird method, reporting the mean TST and corresponding 95% confidence interval (CI) for the two time points. ESS scores were evaluated and interpreted based on the reference ranges adopted for ESS: 0–5 for lower normal daytime sleepiness, 6–10 for higher normal daytime sleepiness, 11–12 for mild EDS, 13–15 for moderate EDS, and 16–24 for severe EDS [31].

Additionally, we performed a series of one group meta-analysis (pre-post) using a pre- and post-means model, sample size, and *P* values (paired groups). Hedges' g value was used to measure effect size: 0.8 reflects a large effect, 0.5 reflects a medium effect, and ≤ 0.2 was considered a small effect. In addition to Hedges' g values, forest plots were used to present results graphically and illustrate point estimates of the effect size and 95% confidence intervals. Random-effects modeling was used for all analyses. I^2 and τ^2 statistics were used to assess the heterogeneity of the solicited studies between and within studies, respectively. Comprehensive Meta-Analysis version 2 was used for all analyses [32]. Leave-one-out sensitivity analyses were conducted by iteratively eliminating one study at a time to confirm that our meta-analysis findings were not driven by any single study. Moderator analysis was performed using subgroup analysis for categorical variables (population type) and meta-regression for integer or decimal variables (age, percentage of male subjects).

The estimating algorithm for a random-effects meta-regression model was obtained using methods of moments [33]. The beta-co-effects and *P* values resulting from modeling were reported. Graphical plots are presented to aid visual interpretation of the results. Funnel-plot-based analysis was used to detect publication bias. Furthermore, the nonparametric trim and fill method was used to confirm findings [34]. Subgroup analysis for physical activity (PA) was performed to investigate differences in sleep quality between PA levels.

Results

Study characteristics

A total of 24 studies (K = 24, $N = 646$) from 12 countries were included in this meta-analysis. The studies were published between the years 2001 and 2019, with 90% of the studies published after the year 2005. Table 1 shows characteristics of the studies included in the meta-analysis.

The median number of participants was 14 (range: 7–127 participants). The median age of participants was 23.7 years of age. A total of 172 participants were female (approximately 27%), from four studies. The study population included healthy adults (general population) in 15 studies, athletes in 8 studies, and teens in 2 studies. All studies included healthy Muslim participants who actively fast during Ramadan.

The studies, which reported either TST or ESS score or both as their parameters, were chosen for the subsequent analyses. The TST and ESS values measured before Ramadan (baseline values) and at the end of Ramadan were analyzed. Nine of the studies reported EDS using ESS, 22 studies reported TST, and 5 studies reported both parameters.

The overall quality assessment of the included studies produced a mean score of 4.2, which is representative of medium quality.

Sleep duration

Twenty-two (K = 22, $N = 571$) studies reported TST before and at the end of Ramadan. Table 2 presents a summary of studies that reported TST and the ESS score both before and during Ramadan. TST is assessed by sleep diaries, actigraphy, and polysomnography (PSG) (Table 2).

The meta-analytic pooling of the TST before Ramadan (baseline) revealed that the participants got 7.2 h per night (95% CI 6.692–7.782) with statistically significant evidence in terms of between-study heterogeneity (Q = 6167, $\tau^2 = 1.59$, $I^2 = 99.0\%$, $P < 0.001$). Detailed results are presented in the forest plot in Fig. 2. Subgroup analysis revealed that

Table 1 Characteristics of studies included in the meta-analysis

First author	City, country	Year	Sample size	Male (%)	Population	Activity level	Age*
Roky [35]	Casablanca, Morocco	2001	8	100.0	Adult	Inactive	25.00
BaHammam [36]	Riyadh, KSA	2003	56	55.4	Adult	Inactive	22.6 ± 1.3
BaHammam [37]	Riyadh, KSA	2004	8	100.0	Adult	Inactive	31.8 ± 2
Margolis [38]	Al-Ain, UAE	2004	137	28	Adults	Inactive	19–23
BaHammam [39]	Riyadh, KSA	2005	71	62.0	Adult	Inactive	31.2 ± 2.25
Zerguini [40]	Algiers, Algeria	2007	48	100.0	Adult	Active, athletic	25.00
Karli [41]	Ankara, Turkey	2007	10	100.0	Adult	Active, athletic	22.3 ± 1.25
Meckel [42]	Netanya, Israel	2008	19	100.0	Teen	Active, athletic	15.1 ± 0.9
Leiper [43]	Tunis, Tunisia	2008	54	100.0	Adolescent	Active	18 ± 1
Chennaoui [44]	Lille, France	2009	8	100.0	Adult	Active, athletic	25 ± 1.3
Wilson [45]	Doha, Qatar	2009	20	100.0	Adult	Active, athletic	25 ± 3.4
BaHammam [46]	Riyadh, KSA	2010	7	100.0	Adult	Inactive	20.5 ± 2.9
Tian [47]	Changi, Singapore	2011	18	100.0	Adult	Active, athletic	20.9 ± 3.3
Herrera [48]	Doha, Qatar	2012	9	100.0	Adult	Active, athletic	26 ± 4
Haouari-Oukerro [49]	Tunis, Tunisia	2013	38	100.0	Adult	Inactive	20.8 ± 1
BaHammam [30]	Riyadh, KSA	2013	8	100.0	Adult	Inactive	25.3 ± 2.9
BaHammam [50]	Riyadh, KSA	2013	8	100.0	Adult	Inactive	36.25 ± 4.5
Saiyad [51]	Ahmedabad, India	2014	50	46.0	Adult	Inactive	25.00
Farooq [52]	Doha, Qatar	2015	18	100.0	Preteen/teen boys	Active	12.6 ± 1.5
Almeneessier [53]	Riyadh, KSA	2017	8	100.0	Adult	Inactive	26.6 ± 4.9
Nugraha [54]	Hanover, Germany	2017	25	100.0	Adult	Inactive	26.1 ± 0.98
Almeneessier [55]	Riyadh, KSA	2017	8	100.0	Adult	Inactive	25.4 ± 3.5
Hsouna [56]	Sfax, Tunisia	2019	12	100.0	Adult	Active	21.9 ± 2.4
Boukhris [57]	Sfax, Tunisia	2019	14	100.0	Adult	Active	21.6 ± 3.3

Table 2 Summary of studies reporting total sleep time (TST) and Epworth sleepiness scale (ESS) both before and during Ramadan fasting month

First author	TST assessment method	TST before Ramadan (hours/night)	TST during Ramadan (hours/night)	*P* value	TST Hedges	ESS before Ramadan (scale)	ESS during Ramadan (scale)	*P* value	ESS Hedges
Roky [35]	PSG	7.03 ± 0.15	6.38 ± 0.278	0.0001	− 2.478	–	–	–	–
BaHammam [36]	Sleep diary	6 ± 1.5	5.96 ± 2.2	0.9107	− 0.015	8.3 ± 3.7	10.4 ± 4.5	0.05	0.264
BaHammam [37]	PSG	6.8 ± 1.1	4.8 ± 1.8	0.05	− 0.743	3 ± 3	3.6 ± 1.2	0.6076	0.169
Margolis [38]	Sleep diary	6.22 ± 1.45	5.22 ± 1.85	<0.0001	− 0.354	10.04 ± 3.47	10.46 ± 3.57	0.3427	0.022
BaHammam [39]	Sleep diary	6.59 ± 0.76	6.81 ± 0.85	0.111	0.189	4.81 ± 0.67	4.75 ± 0.82	0.65	− 0.054
Zerguini [40]	Sleep diary	8.24 ± 0.92	8.38 ± 1.63	0.71	0.053	–	–	–	–
Karli [41]	Sleep diary	8.32 ± 0.82	9.17 ± 1.14	0.0716	0.590	–	–	–	–
Meckel [42]	Sleep diary	8.6 ± 0.7	8.6 ± 0.5	1	–	–	–	–	–
Leiper [43]	Sleep diary	9.13 ± 0.1	8.32 ± 0.22	0.0001	− 0.564	–	–	–	–
Chennaoui [44]	Sleep diary	7.27 ± 0.67	5.84 ± 0.45	0.0002	− 2.220	–	–	–	–
BaHammam [50]	Actigraphy	5.91 ± 1.36	4.78 ± 1.36	<0.001	− 1.700	2.88 ± 1.46	2.38 ± 1.19	0.59	− 0.177
Wilson [45]	Actigraphy	9.49 ± 1.25	8.1 ± 0.42	0.0005	− 1.156	–	–	–	–
BaHammam [46]	Actigraphy (armband)	6.42 ± 1.27	6.34 ± 0.75	0.888	− 0.048	–	–	–	–
Tian [47]	Sleep diary	7 ± 1.7	5.3 ± 1.8	0.005	− 0.726	–	–	–	–
Herrera [48]	Sleep diary	6.6 ± 2	5.3 ± 1	0.04	− 0.737	6.1 ± 5	7.9 ± 5	0.26	0.365
Haouari-Oukerro [49]	Sleep diary	7.4 ± 0.15	3.72 ± 0.18	<0.01	− 0.432	–	–	–	–
BaHammam [30]	Actigraphy	6.3 ± 1.2	6.2 ± 1.3	0.875	− 0.051	7.1 ± 2.7	–	–	–
Saiyad [51]	Sleep diary	–	–	–	–	4.5 ± 3.09	10.26 ± 3.58	< 0.0001	0.590
Farooq [52]	Sleep diary	9.3 ± 0.5	7.5 ± 0.7	< 0.0001	− 1.136	–	–	–	–
Almeenessier [53]	Actigraphy	5.3 ± 1.2	5.1 ± 1.3	0.753	− 0.102	–	–	–	–
Nugraha [54]	–	–	–	–	–	7.96 ± 0.76	6.68 ± 0.88	<0.0001	− 0.901
Almeneessier [55]	Actigraphy	5.4 ± 1.2	5.2 ± 1.3	0.753	− 0.533	–	–	–	–
Hsouna [56]	Sleep diary	7.33 ± 1.3	7.5 ± 1.73	0.785	0.075	–	–	–	–
Boukhris [57]	Sleep diary	7.9 ± 1.6	6.9 ± 1.4	0.0902	− 0.460	–	–	–	–

participants with higher PA levels (i.e., athletes) had a higher overall pooled estimate of TST compared to those with lower levels of PA (i.e., the general population). The TST for participants with high PA and low PA were 8.18 (95% CI 7.6–8.73) and 6.55 (95% CI 6.23–6.88), respectively.

TST reduced during Ramadan fasting month to 6.435 (95% CI 5.332–7.538) with statistically significant evidence in terms of between-study heterogeneity ($Q = 13{,}083$, $\tau^2 = 6.86$, $I^2 = 99.0\%$, $P < 0.001$). Detailed results are presented in the forest plot in Fig. 3. TST for adults with low PA was 5.76 (95% CI 4.76–6.76), and TST for adults with higher PA was 7.4 (6.74–8.01).

Analysis of difference in effect size between baseline (before) and during Ramadan revealed that Ramadan fasting moderately impacts TST, with a Hedges' g value of − 0.430 (95% CI − 0.638 to − 0.222, $Q = 90$, $\tau^2 = 0.15$, $I^2 = 77.8\%$, $P < 0.001$) (Fig. 4). Moderator analysis using meta-regression revealed that age and proportion of female sex were a strong significant predictor for change in TST for both time points ($P = 0.0001$). A subgroup analysis for the categorical variable PA revealed that cases with higher PA appeared to have a higher impact on TST during Ramadan fasting compared to cases with lower PA, with a Hedges' g of 0.56 (95% CI 0.1–1.0) and 0.30 (0.08–0.53), respectively.

Visual inspection of the funnel plot indicated that there was no publication bias in the included studies for the effect of Ramadan on TST (Fig. 5). This was confirmed with nonparametric trim and fill method which showed Kendall's S statistics (P–Q) with continuity correction of $\tau^2 = - 0.40$ and $P = 0.01$.

Excessive daytime sleepiness (EDS)

Nine studies ($K = 9$, $N = 362$) studies reported EDS scores as measured using ESS. The meta-analytic pooling of the ESS scores before Ramadan (baseline) revealed that the participants had 6.125 (95% CI 4.503–7.747) with statistically significant evidence in terms of between-study heterogeneity ($Q = 617$, $\tau^2 = 5.63$, $I^2 = 98.0\%$, $P < 0.001$). Detailed results are presented in the forest plot in Fig. 6. Subgroup analysis revealed that participants with high PA (i.e., athletes) had a similar overall pooled ESS score estimate compared to those of lower level of PA (i.e., the general population). ESS score

Study name	Mean	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Roky 2001	7.030	0.053	0.003	6.926	7.134	132.559	0.000
BaHammam 2003	6.000	0.200	0.040	5.607	6.393	29.933	0.000
BaHammam 2004	6.800	0.389	0.151	6.038	7.562	17.485	0.000
BaHammam 2005	6.589	0.090	0.008	6.413	6.765	73.245	0.000
Karli 2007	8.320	0.259	0.067	7.812	8.828	32.086	0.000
Meckel 2007	8.600	0.161	0.026	8.285	8.915	53.552	0.000
Zerguini 2007	8.240	0.133	0.018	7.980	8.500	62.188	0.000
Leiper 2008	9.130	0.014	0.000	9.103	9.157	670.915	0.000
Chennaoui 2009	7.267	0.237	0.056	6.803	7.731	30.678	0.000
Wilson 2009	9.490	0.334	0.112	8.835	10.145	28.407	0.000
BaHammam 2010	6.420	0.480	0.230	5.479	7.361	13.375	0.000
Margolis 2010	6.220	0.129	0.017	5.968	6.472	48.342	0.000
Tian 2011	7.000	0.401	0.161	6.215	7.785	17.470	0.000
Herrera 2012	6.600	0.667	0.444	5.293	7.907	9.900	0.000
BaHammam 2013a	6.300	0.424	0.180	5.468	7.132	14.849	0.000
BaHammam 2013b	5.910	0.481	0.231	4.968	6.852	12.291	0.000
Haouari-Oukerro 2013	7.400	0.024	0.001	7.352	7.448	304.111	0.000
Farooq 2015	9.300	0.118	0.014	9.069	9.531	78.913	0.000
AlMenessier 2017	5.300	0.424	0.180	4.468	6.132	12.492	0.000
AlMenessier 2018	5.400	0.424	0.180	4.568	6.232	12.728	0.000
Hsouna 2019	7.330	0.375	0.141	6.594	8.066	19.532	0.000
Boukhris 2019	7.900	0.428	0.183	7.062	8.738	18.474	0.000
	7.237	0.278	0.077	6.692	7.782	26.032	0.000

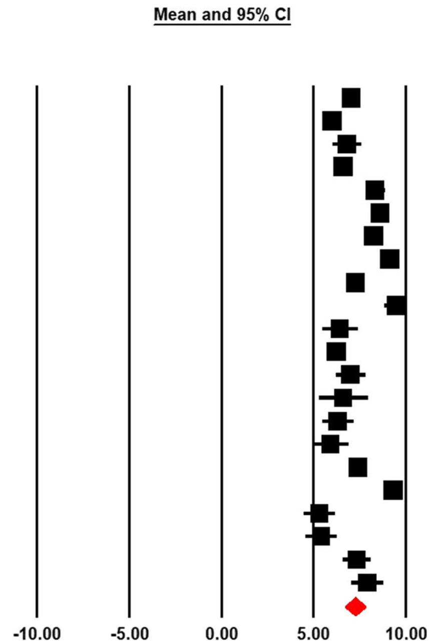

Fig. 2 Forest plot for total sleep time (TST) for healthy subjects before Ramadan fasting month, with mean of 7.237 h/day (95% CI 6.692–7.782)

increased slightly during Ramadan to 7.01 (95% CI 5.2–8.78, Q = 580, $\tau^2 = 6.26$, $I^2 = 99.0\%$, P < 0.001) (Fig. 7).

Analysis of difference in effect size between baseline (before) and during Ramadan revealed that fasting had a negligible impact on ESS score with a Hedges' g value of − 0.06 (Fig. 8). Moderator analysis using meta-regression revealed that age was not a predictor for changes in ESS score due to Ramadan fasting. However, the proportion of females was a significant predictor for change in ESS score ($P = 0.03$).

Visual inspection of the funnel plot indicated that there was no publication bias in the included studies for the effect of Ramadan on ESS scores (Fig. 9). However, more studies will be needed to confirm this.

Discussion

The main finding of this systematic review and meta-analysis is that Ramadan and associated practices impact sleep duration and daytime sleepiness. Baseline TST across the total studied population was 7.2 h, which decreased by ~1 h during Ramadan. Ramadan fasting was found to impact daytime

Study name	Mean	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Roky 2001	6.380	0.098	0.010	6.187	6.573	64.911	0.000
BaHammam 2003	5.960	0.294	0.086	5.384	6.536	20.273	0.000
BaHammam 2004	4.800	0.636	0.405	3.553	6.047	7.542	0.000
BaHammam 2005	6.807	0.101	0.010	6.608	7.006	67.163	0.000
Karli 2007	9.170	0.360	0.130	8.463	9.877	25.437	0.000
Meckel 2007	8.600	0.115	0.013	8.375	8.825	74.973	0.000
Zerguini 2007	8.380	0.235	0.055	7.920	8.840	35.684	0.000
Leiper 2008	8.320	0.030	0.001	8.261	8.379	277.906	0.000
Chennaoui 2009	5.840	0.159	0.025	5.528	6.152	36.707	0.000
Wilson 2009	8.100	0.112	0.013	7.880	8.320	72.161	0.000
BaHammam 2010	6.340	0.283	0.080	5.784	6.896	22.365	0.000
Margolis 2010	5.220	0.164	0.027	4.898	5.542	31.798	0.000
Tian 2011	5.300	0.424	0.180	4.468	6.132	12.492	0.000
Herrera 2012	5.300	0.333	0.111	4.647	5.953	15.900	0.000
BaHammam 2013a	6.200	0.460	0.211	5.299	7.101	13.489	0.000
BaHammam 2013b	4.780	0.481	0.231	3.838	5.722	9.941	0.000
Haouari-Oukerro 2013	3.716	0.030	0.001	3.658	3.774	125.175	0.000
Farooq 2015	7.500	0.165	0.027	7.177	7.823	45.457	0.000
AlMenessier 2017	5.100	0.460	0.211	4.199	6.001	11.096	0.000
AlMenessier 2018	5.200	0.460	0.211	4.299	6.101	11.314	0.000
Hsouna 2019	7.500	0.499	0.249	6.521	8.479	15.018	0.000
Boukhris 2019	6.900	0.374	0.140	6.167	7.633	18.441	0.000
	6.435	0.563	0.317	5.332	7.538	11.434	0.000

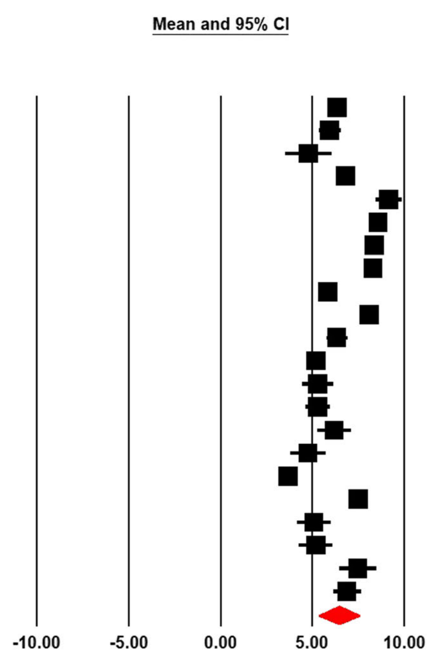

Fig. 3 Forest plot for total sleep time (TST) for healthy subjects during Ramadan fasting month, with mean of 6.435 h/day (95% CI 5.332–7.538)

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight	Relative weight
Roky 2001	-2.478	0.695	0.483	-3.839	-1.116	-3.567	0.000	1.77	
BaHammam 2003	-0.015	0.132	0.017	-0.273	0.243	-0.113	0.910	6.61	
BaHammam 2004	-0.743	0.365	0.133	-1.459	-0.028	-2.036	0.042	3.93	
BaHammam 2005	0.189	0.118	0.014	-0.043	0.422	1.599	0.110	6.74	
Karli 2007	0.590	0.318	0.101	-0.033	1.213	1.857	0.063	4.43	
Zerguini 2007	0.053	0.142	0.020	-0.225	0.332	0.374	0.709	6.50	
Leiper 2008	-0.564	0.145	0.021	-0.848	-0.281	-3.900	0.000	6.47	
Chennaoui 2009	-2.220	0.638	0.407	-3.470	-0.970	-3.481	0.001	2.01	
Wilson 2009	-1.156	0.333	0.111	-1.810	-0.503	-3.471	0.001	4.27	
BaHammam 2010	-0.048	0.329	0.108	-0.693	0.597	-0.146	0.884	4.31	
Margolis 2010	-0.354	0.091	0.008	-0.533	-0.176	-3.897	0.000	6.98	
Tian 2011	-0.726	0.256	0.065	-1.226	-0.225	-2.839	0.005	5.16	
Herrera 2012	-0.737	0.348	0.121	-1.419	-0.056	-2.121	0.034	4.11	
BaHammam 2013a	-0.051	0.315	0.099	-0.668	0.565	-0.163	0.871	4.47	
BaHammam 2013b	-1.700	0.528	0.279	-2.735	-0.664	-3.216	0.001	2.61	
Haouari-Oukerro 2013	-0.432	0.166	0.028	-0.758	-0.105	-2.593	0.010	6.23	
Farooq 2015	-1.136	0.294	0.087	-1.712	-0.559	-3.861	0.000	4.70	
AlMenessier 2017	-0.533	0.341	0.116	-1.201	0.136	-1.560	0.119	4.18	
AlMenessier 2018	-0.102	0.315	0.099	-0.720	0.516	-0.325	0.745	4.46	
Hsouna 2019	0.075	0.269	0.072	-0.452	0.602	0.279	0.780	5.00	
Boukhris 2019	-0.460	0.266	0.071	-0.982	0.061	-1.730	0.084	5.03	
	-0.430	0.106	0.011	-0.638	-0.222	-4.051	0.000		

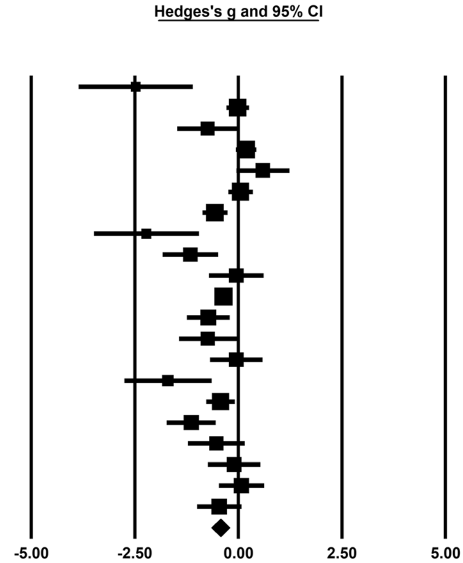

Fig. 4 Forest plot for Hedges' g value for effect size on total sleep time (TST) in healthy subjects, indicating significant medium effect for Ramadan fasting (− 0.430, 95% CI − 0.638 to − 0.222)

sleepiness, reflected by lower ESS scores during Ramadan. A systematic review and meta-analysis published while this study was in preparation examined the impact of RDF on sleep–wake patterns of athletes across 13 studies [57] and concluded that TST only decreased during Ramadan when training continued at least twice/week. This is consistent with our results that TST is reduced in normal healthy people (including athletes) during Ramadan.

Different factors can cause TST to decrease in fasting individuals. Firstly, eating habits change during Ramadan. Interruptions in early morning rapid eye movement (REM) sleep are decreased in those who wake up early to consume the predawn meal *suhoor* compared to those who may remain awake all night [25]. Disruption of mealtimes also affects circadian rhythm [58]. Late-night-dinner eating (LNDE) negatively affects circadian rhythm and hormone secretion, regardless of fasting [59]. Sleeping with a full stomach causes gastroesophageal reflux and reduced diet-induced thermogenesis, affecting quality of sleep [60]. Core body temperature decreases upon sleep onset, while increases promote wakefulness [36], and LNDE may cause an increase, prolonging sleep latency [59]. Eating 30 min before bedtime [35], but not 3–

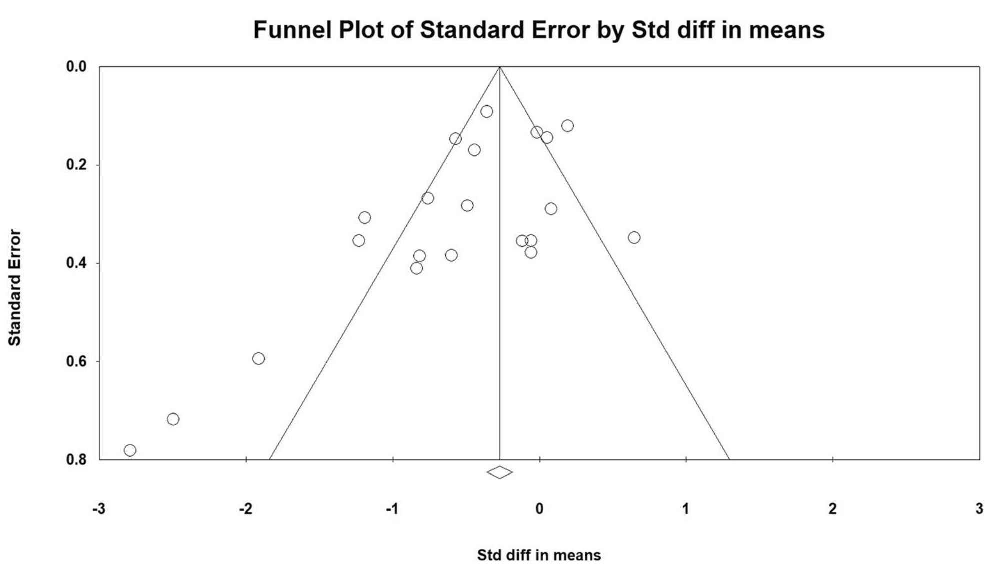

Fig. 5 Funnel plot for studies included in the meta-analysis for total sleep time (TST) indicating the lack of publication bias

Study name	Mean	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
BaHammam 2003	8.300	0.494	0.244	7.331	9.269	16.787	0.000
BaHammam 2004	3.000	1.061	1.125	0.921	5.079	2.828	0.005
BaHammam 2005	4.810	0.080	0.006	4.653	4.967	60.223	0.000
Margolis 2010	10.040	0.308	0.095	9.437	10.643	32.607	0.000
Herrera 2012	6.100	1.667	2.778	2.833	9.367	3.660	0.000
BaHammam 2013a	7.100	0.955	0.911	5.229	8.971	7.438	0.000
BaHammam 2013b	2.880	0.516	0.266	1.868	3.892	5.579	0.000
Shaista Saiyad 2014	4.500	0.437	0.191	3.644	5.356	10.298	0.000
Nugraha 2017	7.960	0.152	0.023	7.662	8.258	52.368	0.000
	6.125	0.828	0.685	4.503	7.747	7.400	0.000

(Statistics for each study)

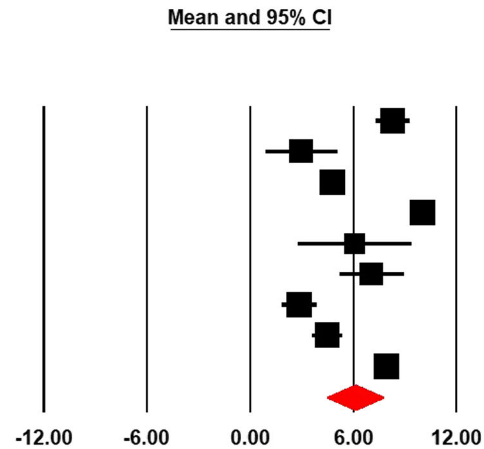

Fig. 6 Forest plot for excessive daytime sleepiness (EDS) measured by Epworth sleepiness scale (ESS) for healthy subjects before Ramadan fasting month, with mean score of 6.125 (95% CI 4.503–7.747)

3.5 h [25, 61, 62], reduces nocturnal sleep time. Secondly, melatonin, which has a smaller and delayed night peak and flatter slope in serum concentrations [37, 63] and lower nocturnal melatonin levels during Ramadan, also affects circadian rhythm. However, intermittent fasting has no significant influence on the circadian pattern of melatonin [53].

A subgroup analysis of age and PA revealed differences in TST. Teenagers, who tend to sleep longer regardless (baseline: 8–9 h), showed the most significant decrease in TST. This may be attributable to lifestyle changes (late-night activities including social gatherings, television exclusives, nightly prayers/recitation). Further, provided that young adults represent a considerable part of the reviewed subjects, there is a possible impact for the social media and screen time on sleep, which are known to be significantly associated with disturbed sleep [64]. A significant reduction in TST apparently does not negatively affect quality of sleep [30]. TST also significantly decreases by ~1 h during Ramadan in athletes [48].

TST also decreased in adults during Ramadan, possibly because of a delay of bedtime due to a delay in the start of work during Ramadan in some Muslim countries. Despite a delay in rise time during Ramadan, the delay in bedtime is more prominent, explaining the decreased TST [50]. Previously discussed lifestyle changes also contribute to changes in TST in adults during Ramadan.

Only 9/24 studies included in this analysis presented ESS data before and during Ramadan. These studies showed an increase in the pooled average ESS score from baseline 6.1 to 7.0 during Ramadan. The Hedges' g result was −0.060, indicating that fasting during Ramadan has a minimal, even insignificant effect on the ESS score compared to baseline.

These is some evidence indicating that high caloric intake and meal components may influence sleep quality and duration and hence daytime sleepiness [65]. Unfortunately, most of the previous studies did not control for this confounder. However, studies that objectively assessed daytime sleepiness while controlling for caloric intake and meal composition (in addition to other confounders like sleep duration at night, sleep–wake schedule, light exposure, and energy expenditure) have reported no increase in somnolence during fasting [30, 55, 62, 66].

In the literature, there is great variability in ESS results before and during Ramadan. Some studies show no significant change in the baseline ESS scores compared to Ramadan ESS scores (Table 2). However, other studies [36, 51]

Study name	Mean	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
BaHammam 2003	10.400	0.601	0.362	9.221	11.579	17.295	0.000
BaHammam 2004	3.600	0.424	0.180	2.768	4.432	8.485	0.000
BaHammam 2005	4.750	0.097	0.009	4.559	4.941	48.751	0.000
Margolis 2010	10.460	0.317	0.100	9.839	11.081	33.019	0.000
Herrera 2012	7.900	1.667	2.778	4.633	11.167	4.740	0.000
BaHammam 2013b	2.380	0.421	0.177	1.555	3.205	5.657	0.000
Shaista Saiyad 2014	10.260	0.506	0.256	9.268	11.252	20.265	0.000
Nugraha 2017	6.680	0.176	0.031	6.335	7.025	37.955	0.000
	7.002	0.913	0.833	5.213	8.790	7.672	0.000

(Statistics for each study)

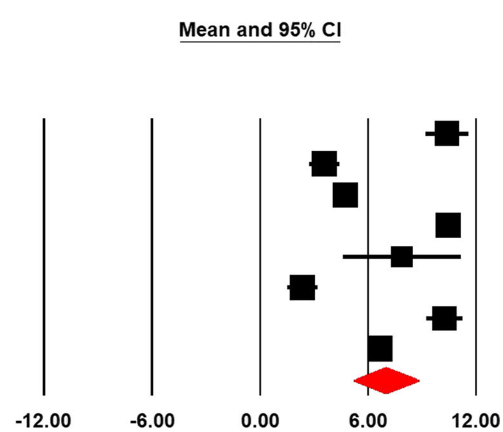

Fig. 7 Forest plot for excessive daytime sleepiness (EDS) measured by Epworth sleepiness scale (ESS) for healthy subjects during Ramadan fasting month, with mean score of 7.002 (95% CI 5.213–8.790)

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
BaHammam 2003	0.264	0.134	0.018	0.001	0.527	1.969	0.049	21.02
BaHammam 2004	0.169	0.317	0.101	-0.453	0.790	0.533	0.594	13.43
BaHammam 2005	-0.054	0.117	0.014	-0.284	0.177	-0.455	0.649	21.65
Herrera 2012	0.365	0.313	0.098	-0.249	0.979	1.166	0.244	13.58
BaHammam 2013b	-0.177	0.317	0.101	-0.799	0.445	-0.559	0.576	13.42
Nugraha 2017	-0.901	0.232	0.054	-1.356	-0.447	-3.888	0.000	16.89
	-0.060	0.175	0.031	-0.403	0.284	-0.341	0.733	

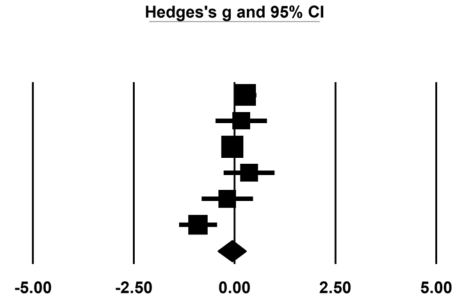

Fig. 8 Forest plot for Hedges' g values for effect size on excessive daytime sleepiness (EDS) measured by Epworth sleepiness scale (ESS) for healthy subjects, indicating a negligible effect for Ramadan fasting (− 0.060, 95% CI − 0.4.3 to 0.284)

demonstrated an increase in daytime somnolence and ESS scores during Ramadan, which was explained by the decreased nighttime sleep duration. BaHammam [36] reported an increase in daytime napping to counteract daytime sleepiness in a study conducted in Saudi Arabia.

Increased daytime somnolence during Ramadan may result from reduced TST and changes in lifestyle during Ramadan [59]. Sleep during Ramadan is usually interrupted by the *suhoor*, which takes place late at night in most Middle Eastern countries.

Ramadan is considered a special occasion in Gulf Cooperation Council and other Arab countries because of altered sleep habits. In many Arab countries, work start time is delayed, and working hours are adjusted for fasting individuals. Studies conducted in the UAE, KSA, and Morocco [10, 36–39, 67] report significantly delayed rise times and bedtime during Ramadan [39], which is due partially to the delay in the start of work, as well as delayed work hours for shopping malls, stores, and restaurants, and the late-night broadcasting of interesting TV programs [10, 25]. Further, excessive eating reported during Ramadan nights [68] can induce a shift which delays the circadian rhythm, resulting in delayed sleep [10, 69]. A study which objectively assessed sleep–wake schedule in the KSA using the SenseWear Pro Armband™ in eight Muslim and eight non-Muslim volunteers during a baseline period (1 week before Ramadan) and the first 2 weeks of Ramadan reported a delay in bedtime and wake times and a significant reduction in TST in Muslim compared to non-Muslims [30]. However, these changes cannot be generalized to other Arab countries as sleep disturbances are related to lifestyle changes associated with Ramadan rather than specifically with intermittent diurnal fasting [10, 30, 46, 53, 55, 59, 62]. Therefore, many of the reported changes also reflect region-dependent cultural and lifestyle changes [10]. It is important to consider both nighttime sleep duration and daytime naps [25, 70].

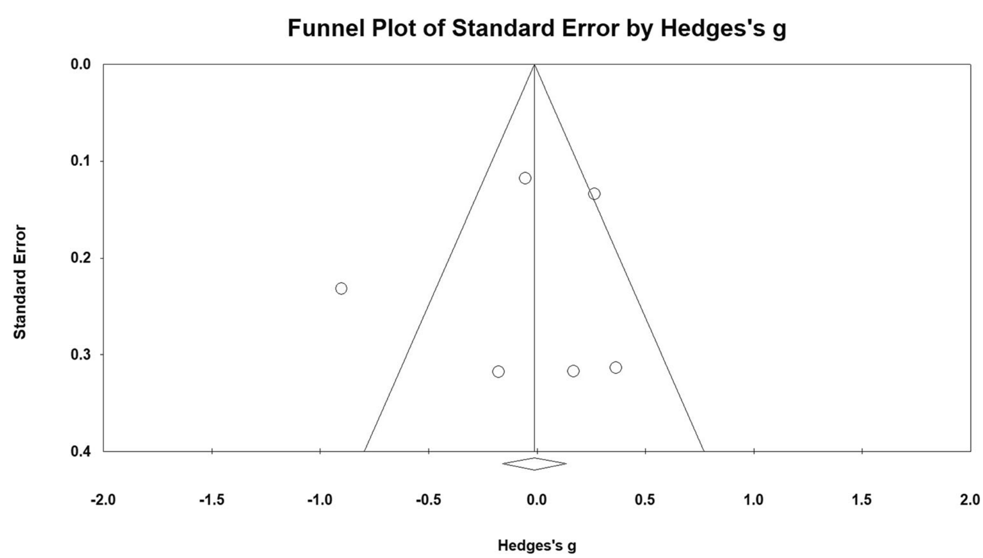

Fig. 9 Funnel plot for studies included in the meta-analysis for excessive daytime sleepiness (EDS) measured using the Epworth sleepiness scale (ESS), indicating the lack of publication bias

It is complicated to study the effects of RDF on sleep and EDS during Ramadan due to the lifestyle changes that affect TST and daytime sleepiness [59]. Most previous studies were conducted in free-living, unconstrained environments and did not control for these lifestyle changes. This meta-analysis, therefore, reflects the impact of all changes during Ramadan, including fasting and lifestyle changes. Current findings do not imply that fasting alone results in decreased TST and increased daytime sleepiness [59]. Recent experimental studies that controlled for environmental conditions and sleep–wake patterns during Ramadan revealed no significant changes in sleep architecture or daytime sleepiness [59]. Dietary and lifestyle changes during Ramadan significantly impact the cardiometabolic system and circadian rhythm. These changes include a sudden shift in mealtimes and sleep times, patterns, and duration as well as reduced diurnal exercise, delays in work start time, increased nocturnal light exposure, and increased nocturnal activities [71].

This is the first systematic meta-analysis to examine the cumulative effects of Ramadan on sleep duration and daytime sleepiness among healthy subjects. However, there are limitations. Firstly, there have only been a relatively small number of studies which covered both TST and ESS scores during Ramadan. Also, some studies were excluded since they were not published in English. Most included studies had a small sample of young recruits, possibly not representative of the large-scale effects of fasting. Criterion for recruitment was variable between studies depending on age, PA, nonsmokers, absence of chronic illness, etc., yielding variable-calculated values between groups. ESS is limited as a determinant for sleepiness due to its subjective nature. Finally, Ramadan is accompanied by different lifestyle changes in Islamic countries that influence the measured variables. Changes in TST and daytime sleepiness therefore reflect all behavioral changes occurring during Ramadan, not fasting specifically.

Further, provided that young population represents a considerable part of the reviewed subjects, there is a possible impact of the social media and screen time on sleep, which are known to be significantly associated with disturbed sleep. Moreover, the current results may not apply to older subjects who are expected to be less affected by changes in sleep habits, including bedtime and rise time, and EDS, during Ramadan month as they tend to be less engaged in social activities and keener to conserve their sleep habits due to work and family commitments.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights and informed consent This article does not contain any studies with human participants performed by any of the authors.

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