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SYSTEMATIC REVIEW

Effects of Ramadan Fasting on Physical Performance: A Systematic Review with Meta-analysis

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Abstract

Background It is common that several athletes will fast while training or competing during Ramadan. There is currently no consensus on if or how this might affect physical performance.

Objective The aim was to conduct a systematic review combined with a meta-analysis to determine what are the effects of fasting during the month of Ramadan on physical performance.

Methods Three electronic databases were searched: PubMed, ScienceDirect, and Web of Science between from the earliest available date to May 2019. Two authors identified studies that evaluated the effects of Ramadan fasting on physical performance. Risk of bias was assessed using the Downs and Black methodological quality checklist. Pooled effects were reported as standardized mean differences (MDs) and 95% confidence intervals (CIs) using a random effects model.

Results A total of 11 studies met the inclusion criteria. Results revealed that Ramadan fasting had a deleterious effect on mean power and peak power during a Wingate and/or a repeated sprint test. In the morning, sprint performance was negatively affected by Ramadan fasting. Aerobic performance, strength, jump height, fatigue index, and total work were not affected by the intermittent fasting during the month of Ramadan.

Conclusions The majority of physical performance parameters were not influenced by Ramadan fasting when tested either in the morning or in the afternoon. Athletes appear able to participate in competition in a fasted state with little impact on physical performance. Sleep and nutrition opportunities should be optimized to minimize likelihood of accumulating fatigue.

Key Points

Ramadan fasting is not detrimental for aerobic performance.

Mean power, peak power during repeated sprint ability test and sprint performance may be negatively affected by Ramadan fasting.

1 Introduction

During the ninth month of the Islamic calendar, healthy pubertal Muslim adolescents and adults are required to fast from dawn to sunset. This fasting period involves refraining from consuming food, fluid intake, engaging in sexual activities and smoking. Elite sports training sessions and competitions are scheduled throughout the calendar year. As the Islamic year is based on the lunar calendar, the Ramadan month can occur at different periods of the year and in different seasons. The sporting calendar does not take religious observances into consideration when scheduling sports events, and Muslim athletes have to cope with this fasting period while training and competing.

During Ramadan, the consumption of food and drink is unrestricted during the hours of darkness, but meals are necessarily reduced to two rather than three or more, with no possibility of consuming daytime snacks. As a consequence, energy intake, body mass, and hydration status may be negatively affected during this month [1, 2], though it appears that blood platelet and immune function are unaffected [3].

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Reduction of total energy intake and change in diet composition, with a late evening meal and/or an early breakfast, may lead to behavior modifications including changes in sleep patterns [4], alteration of sleep amount and decrease of sleep time [5–7] as well as a decrease in fat mass [8]. Studies have shown that moderate fluid loss is detrimental to endurance exercise performance [9–11] but not to anaerobic performance [12, 13]. In addition, sleep deprivation was found not to influence anaerobic performance, while a decrease in endurance performance was observed in the same conditions [14]. In addition, a decrease in energy intake may lead to an altered availability and utilization of energetic substrate as well as hormonal and metabolic changes, which may have a negative impact on performance [15]. Taken together, and in the context of Ramadan fasting, these results suggest that endurance performance may negatively be impacted during this period.

Acknowledging that the effects of fasting on performance may be of importance especially for elite athletes, in a survey published in 2016, Farooq et al. [16] questioned 54 football players participating in the Olympic Games about fasting during the period of competition. The results showed that 61% of the players declared that they were not planning to fast at all during the tournament, and 39% declared that they intended to fast during Ramadan but not on match day. Regarding the effects of Ramadan fasting on physical performance, 81.5% of the participants agreed or strongly agreed that it can reduce endurance and 85.2% of participants disagreed or strongly disagreed that fasting can increase their physical skills [16]. Roy et al. [17] explored the measures undertaken by Muslim athletes who train and compete while fasting concomitantly. They found that athletes use a variety of coping strategies during this period, suggesting that they consider Ramadan fasting as having a negative effect on physical performance.

The decision to fast or not to fast during a competition is based on the beliefs of athletes and coaches and not on a scientific perspective. Previous narrative reviews aimed to provide recommendations and to speak about the possible effects of Ramadan fasting on performance. For instance, Chaouachi et al. [18] performed an extensive review, where they concluded that physical performance and training were not impacted if sleep, nutrition, training load, and body composition were maintained during Ramadan. Chtourou et al. [19] have previously performed a systematic review to analyze the effects of Ramadan fasting on performance of soccer players. In their review, the authors did not combine the results to conduct a meta-analysis, and only soccer players were included. Among the reviews performed, none have yet been a systematic review with meta-analysis. This type of study represents the highest level of scientific evidence [20] and can be useful for practical recommendations. In addition, experimental studies have since been performed to analyze the effects of Ramadan fasting on performance and should be considered in providing up to date recommendations based on scientific evidence.

Because of the apparent discrepant evidence in the literature about the effects of Ramadan fasting on performance, a rigorous, quantitative analysis of the literature was warranted. Indeed, the results of the studies are conflicting and the studies focused on different markers of performance making general conclusions difficult. In this context, performing a meta-analysis may help to estimate an average effect or to identify a subset of studies associated with a beneficial effect [21]. In addition, a systematic approach to synthesizing information can provide estimates of the degree of influence of a particular condition (Ramadan fasting) and whether this influence depends on specific characteristics of the studies [21]. Performing a systematic review with meta-analysis is necessary to increase the level of scientific evidence [20]. The aim of this study, therefore, was to conduct a systematic review combined with a meta-analytic approach to determine what are the effects of fasting during the month of Ramadan on physical performance. To the best of our knowledge, this is the first study to deal with this topic using this methodology. It is hypothesized that Ramadan fasting has no effect on anaerobic performance and negative impact on aerobic performance.

2 Methods

For this review, we followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines [22].

2.1 Study Selection and Eligibility Criteria

Studies were chosen if they fulfilled the following six selection criteria:

1. The study was conducted during the month of Ramadan.
2. Subjects were tested before and during the month of Ramadan
3. Subjects were athletes with a mean age $\geq$ 18 years.
4. The results were not the consequence of a training program or a competition.
5. The study was published in English.
6. The study was published in a peer-review journal.

PICOS criteria were used to define the characteristics of the studies included in this study [23]: *Population* Subjects who performed a test during the month of Ramadan; they should have not incurred injury; *Intervention* Physical tests; *Comparators* Baseline (pre), during and after Ramadan timepoints; *Outcomes* Physical markers of performance;

Study design Randomized controlled designs and cohort studies.

2.2 Search

The literature review was conducted by identifying articles using the databases PubMed, ScienceDirect and Web of Science between January and June 2019 from the earliest available date to May 2019.

The following keywords: "Ramadan" and "fasting" were used in combination with "performance", "aerobic", "anaerobic'', "repeated sprint", "VO_{2max}", "speed", "endurance", "sport", and "exercise".

2.3 Data Extraction and Assessment of Methodological Quality in Included Studies

Screening of publications identified in the search was independently conducted by two authors, MA.B. and W.D. based on the inclusion and exclusion criteria mentioned above. If disagreements regarding inclusion of ambiguous articles were observed, a third author (A-E.A.) acted as a referee. Data were extracted by MA.B. and W.D. Screening was conducted by first going through all titles and abstracts to exclude publications that were clearly irrelevant. Thereafter, full texts of the remaining publications were retrieved and screened to further assess whether the studies therein fit our selection criteria.

Two authors (MA.B. and W.D.) read and independently coded the studies. The following data were extracted:

1. author(s), title, and year of publication;
2. descriptive information, including the number of participants, sex, age, and practiced sport;
3. study characteristics such as timepoint of evaluation of physical performance;
4. test(s) for assessing changes in physical performance;
5. values for physical tests before, during and after the month of Ramadan.

Coding files were cross-checked between the authors, with discussion and agreement over any observed differences.

The risk of bias was assessed by the three authors independently using a checklist for the assessment of the methodological quality of both randomized and non-randomized studies [24]. The checklist comprises 27 items, which are distributed over five sub-scales: reporting (item 1–10), external validity (item 11–13), bias (item 14–20), confounding (items 21–26), and power (item 27). Each item had to be answered to have a global score of methodological quality for each included study. The maximal score possible was 32. Studies were classified as being of 'good quality' if they scored 20–32 points, 'moderate quality' if they scored from 11–19 points, and 'poor quality' if they scored < 11 points on the checklist [25]. Contradicting results regarding the methodological quality were discussed and A-E.A. acted as a 3rd reviewer to settle any disagreements.

2.4 Dependent Variables

The dependent variables extracted from the selected studies were all markers of performance obtained during the tests:

1. peak power during a Wingate or a repeated sprint ability (RSA) test on an ergocycle;
2. mean power during a Wingate or an RSA test on an ergocycle;
3. total work performed during a Wingate or a RSA test on an ergocycle;
4. fatigue index during a RSA test on an ergocycle or running;
5. level of strength;
6. jump height;
7. aerobic performance;
8. running sprint time.

In the included studies, subjects were tested at different timepoints during the month of Ramadan. All included studies tested the dependent variables before Ramadan (pre) and during the 3rd or 4th week of Ramadan. In our analysis, the 3rd and the 4th weeks (3rd/4th) were considered as the same timepoint. When possible, we analyzed pre values data with 1st week data (1st) and with 2nd week data (2nd) considering these 2 weeks as different timepoints. We also differentiated between morning performance and afternoon performance. In addition, in only one study [26], the subjects were tested in the evening, which did not allow any statistical analysis to be performed for this time of the day.

2.5 Meta-analysis

Effect sizes (ES) were calculated by dividing the mean difference by the pooled between-subject standard deviation at the different timepoints [27].

To perform the meta-analysis, ES were combined using an Excel workbook (ESCI for meta-analysis, https://thenewstatistics.com/itns/esci/). An overall effect size was obtained and interpreted according to the following criteria: 0–0.2 = trivial, 0.21–0.6 = small, 0.61–1.2 = moderate, 1.21–2 = large, 2.1–4 = very large, and 4 = nearly perfect [28]. From this interpretation, conclusions were made regarding the effects of Ramadan fasting on the variables.

Mean change at different timepoints extracted from all studies was expressed as percentages of change. Data were presented as ES ± 95% confidence intervals (95%CI)

with statistical significance set at $P < 0.05$. The presence of statistical heterogeneity was determined by the I^2 statistic and Q statistic [27]. I^2 values of 25%, 50%, and 75% represented low, medium, and high heterogeneity, respectively [29]. Pooled data on outcomes were analyzed using random effects, as we assumed heterogeneity in the selected protocols and conditions.

3 Results

3.1 Literature Search

Figure 1 presents the flow chart of the search and selection process. The searches identified 262 relevant articles out of which 20 were initially selected, checking their full texts for the relevance criteria. A total of 9 studies for which the full text was reviewed were excluded from qualitative synthesis, as follows: the results were the consequence of a training program or competition ($n = 4$) [30–33], the mean age of the subjects was < 18 years ($n = 4$) [34–37], and the study was written in French ($n = 1$) [38]. A total of 11 studies were included in the review. Characteristics of the included studies are presented in Table 1.

3.2 Methodological Quality

Using the methodological quality checklist led to a mean score (± standard deviation) of 18.8 ± 1.3 (range 17–20). According to Davies et al. [25], this score represents a moderate quality of the articles when taken as a mean (Table 2).

3.3 Effects of Fasting on Performance

3.3.1 Aerobic Performance

A total of 5 studies analyzed the effects of Ramadan fasting on aerobic performance when the test was performed in the afternoon [42–44, 46, 48]. Two studies evaluated the effects of fasting on aerobic performance when the test was performed in the morning [46, 47]. Regarding the timepoints of performance assessment, aerobic performance was tested at Pre, 2nd, 3rd/4th and after Ramadan.

The variables included were: speed/power at maximal oxygen uptake (VO_{2max}) [42, 43, 47], 5000 m time [42], total distance during a Yo–Yo Intermittent Running Test level 1 (YYIRT-1) or a multistage shuttle test [44, 46], the maximal velocity reached during the YYIRT-1 [44], and the total distance performance during a 12 minutes run [48].

Trivial-to-small effect sizes were observed for aerobic performance, indicating that there was little influence of fasting during the month of Ramadan on performance when aerobic exercise was performed either in the morning or in the afternoon (Table 3, Figs. 2, 3).

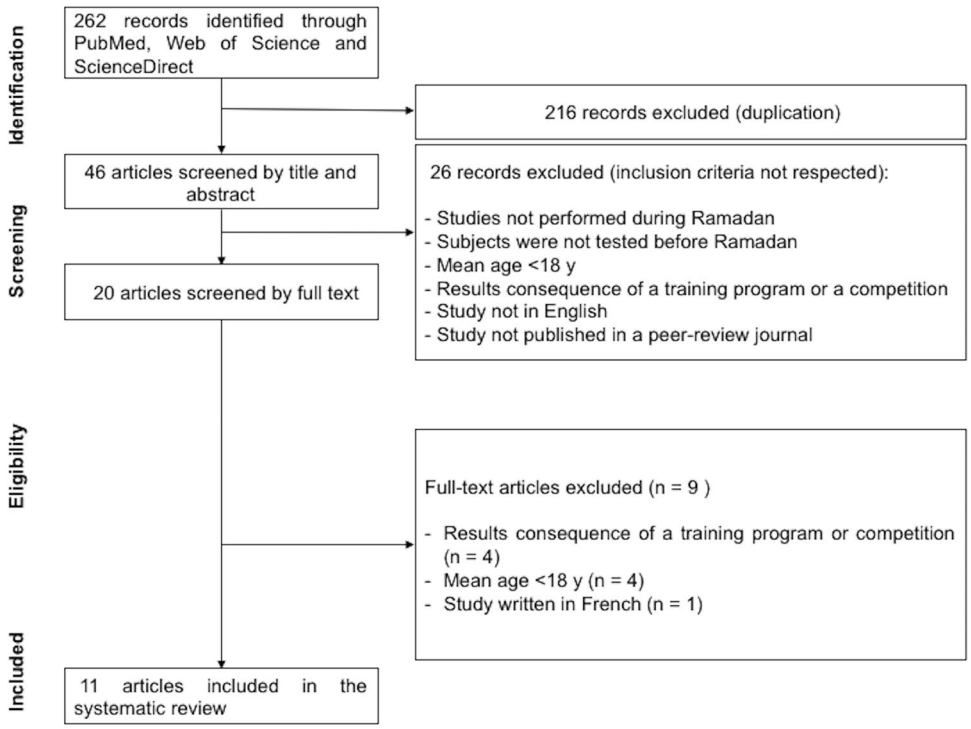

Fig. 1 Flow chart showing the study selection process

Table 1 Description of the studies included in the systematic review

Study	Methodological score	Subjects	Part of the day and timepoint	Physical tests	Main results
Abedelmalek et al., 2015 [33]	18 (69.2%)	11 healthy male soccer players	Afternoon (Pre, 1st, 4th)	Wingate test: PP, MP, FI	PP: − 8.5% (1st); − 19.1% (4th) MP: − 3.4% (1st); − 12.6% (4th) FI: − 0.2% (1st); − 0.7% (4th)
Aloui et al., 2013 [34]	20 (76.9%)	12 healthy amateur soccer players	Morning (Pre, 1st, 2nd 4th, after)	RSA: PP, TW MVC	PP: − 1.3% (2nd); − 0.6% (4th); − 0.3 (after) TW: 0.6% (2nd); 0.4% (4th); 0.2% (after) MVC: − 0.3% (2nd); − 0.1% (after)
			Afternoon (Pre, 1st, 2nd 4th, after)		PP: − 4.9% (2nd); − 4.2% (4th): 0.3% (after) TW: 0.5% (4th) MVC: − 8.2% (4th)
Aziz et al., 2012 [20]	20 (76.9%)	9 healthy male Muslim athletes	Morning (Pre, 3rd or 4th)	Wingate test: TW, Texh	TW: − 6.9% (3rd or 4th) Texh: − 31.7% (3rd, 4th)
			Afternoon (Pre, 3rd or 4th)		TW: − 5.5% (3rd, 4th) Texh: − 45.9% (3rd, 4th)
			Evening (Pre, 3rd or 4th)		TW: − 2.5% (3rd, 4th) Texh: − 0.9% (3rd, 4th)
Bouhlel et al., 2013 [35]	17 (65.3%)	10 male physical education students	Afternoon (Pre, 1st, 4th)	Sprint: PP (arms, legs) VJH HF (right, left)	PP: arms: − 28.2% (1st); − 12.1% (4th) Legs: − 13.6% (1st); − 6.6% (4th) HF: right: 6.2% (1st); − 3.2% (4th) Left: − 4.4% (4th) VJH: − 8.8% (1st); − 5.3% (4th)
Brisswalter et al., 2011 [36]	20 (76.9%)	18 well-trained Muslims runners	Unspecified (Pre, 4th)	VO_{2max} Speed@VO_{2max} 5000 m RTT MVIC K ex	Speed@VO_{2max}: − 11.9% (4th) 5000 m RTT: 6% (4th) MVIC K ex: − 3.8% (4th)
Chaouachi et al., 2009 [37]	19 (73%)	15 healthy male elite judo athletes	Afternoon (Pre, 2nd, 3rd or 4th, after)	SJH SJF CMJ H 30"JAP Sprint 5 m, 10 m, 30 m Speed@VO_{2max}	SJH: − 1.2% (2nd); − 0.5% (3rd or 4th); − 0.5% (after) SJF: − 0.9% (2nd); − 4.3% (3rd or 4th); − 2.2% (after) CMJ H: − 2% (2nd); − 1.1% (3rd or 4th); − 1.5% (after) 30"JAP: − 4.3% (3rd or 4th) 5 m: 0.8% (2nd); 3.4% (3rd or 4th); 1.7% (after) 10 m: 1.5% (2nd); 2.5% (3rd or 4th); 1.5% (after) 30 m: 0.6% (2nd); 1.3% (3rd or 4th); 0.9% (after) Speed@VO_{2max}: 1.5% (2nd); 1.5% (after)
Chtourou et al., 2011 [38]	20 (76.9%)	20 male soccer players	Afternoon (Pre, 2nd, 4th, after)	TD YOYO MAV YOYO RSA: PP, TW Wingate test: PP, MP, FI	TD YOYO: − 8.7% (2nd); − 11.9% (4th) MAV YOYO: − 2.5% (2nd); − 3.7% (4th) RSA TW: 0.3% (2nd); − 3.8% (4th) PP: − 1.6% (2nd); − 1.8% (4th) MP: − 4.3% (4th) FI: 6.8% (2nd); 11.4% (4th)
Karli et al., 2007 [39]	18 (69.2%)	10 male elite power athletes	Afternoon (Pre, 4th, after)	Wingate test: PP, MP, FI	PP: 5.6% (4th); 9.3% (after) MP: − 0.4% (4th) FI: 11.1% (4th)

Table 1 (continued)

Study	Methodological score	Subjects	Part of the day and timepoint	Physical tests	Main results
Kirkendall et al., 2008 [40]	18 (69.2%)	53 male soccer players	Morning (Pre, 2nd, 3rd or 4th, after)	Sprint: 10 m, 30 m FI: 10 m, 30 m MSTTD VJH AT	10 m: − 4.3% (2nd); − 1.1% (3rd or 4th); − 2.7% (after) 30 m: − 3.4% (2nd); − 2.3% (3rd or 4th); − 3.6% (after) FI 10 m: 20.7% (2nd); 6.5% (3rd or 4th); − 10.9% (after) FI 30 m: 37.1%(2nd); 13.8% (3rd or 4th); − 27.6% (after) MSTTD: − 8.9% (2nd); 4.7% (3rd or 4th); 12.5% (after) VJH: − 0.4% (2nd); − 1.1% (3rd or 4th); − 2.4% (after) AT: 0.6% (2nd); − 1.3% (3rd or 4th); − 2.6% (after)
			Afternoon (Pre, 2nd, 3rd or 4th, after)		10 m: 0.6% (2nd), (3rd or 4th), (after) 30 m: − 0.5% (2nd), − 0.2% (after) FI 10 m: 6.5% (3rd or 4th) 30 m: 5.4% (3rd or 4th) MSTTD: 3.5% (2nd); 23.3% (after) VJH: 3.9% (2nd); 6.3% (3rd or 4th); 4.5% (after) AT: − 1.3% (3rd or 4th); (after)
Mirzaei et al., 2012 [41]	17 (65.3%)	14 male collegiate wrestlers	Morning (Pre, 3rd or 4th)	VO_{2max}: PP RAST: MP, FI SF BPF DLF	PP: − 3.8% (3rd or 4th) MP: − 6.1% (3rd or 4th) FI: − 0.7% (3rd or 4th) SF: 3.6% (3rd or 4th) BPF: 1.5% (3rd or 4th) DLF: 2.6% (3rd or 4th)
Zerguini et al., 2007 [42]	20 (76.9%)	48 professional soccer players	Unspecified (Pre, 3rd or 4th, after)	AT VJH Sprint: 5 m, 10 m, 20 m 12 min RD	AT: − 5.3% (3rd or 4th); − 4% (after) VJH: 0.4% (3rd or 4th); − 3.6% (after) 5 m: 7.4% (3rd or 4th); 13.3% (after) 10 m: − 5.4% (3rd or 4th); 3.5% (after) 20 m: − 1% (3rd or 4th); 1.3% (after) 12 min RD: − 15.9% (3rd or 4th); − 7.3% (after)

PP peak power, *MP* mean power, *FI* fatigue index, *TW* total work, *MVC* maximal voluntary contraction, *Texh* time-to-exhaustion, *VJH* vertical jump height, *HF* handgrip force, *MVIC K EX* maximal voluntary isometric contraction Knee extensors, *5000 m RTT* 5000 m running time trial, *SJH* Squat jump height, *SJF* Squat jump force, *CMJH* counter movement height, *30" JAP* 30" jump average power, *m* meters, *TD YOYO* total distance during yoyo test, *MAV YOYO* maximal aerobic velocity during yoyo test, *MP* mean power, *FI* fatigue index, *MSTTD* multistage shuttle test total distance, *AT* agility time, *12 min RD* 12 min run distance, *RAST* running anaerobic sprint test, *SF* squat force, *BPF* Bench press force, *DLF* deadlift force. 3rd or 4th: the measures were taken during the last 2 weeks of Ramadan, the exact time-point is not specified

3.3.2 Peak Power

The effects of Ramadan fasting on peak power were assessed by 4 studies in the afternoon [39–41, 44, 45] and by 1 study in the morning [40]. Peak power was tested during a Wingate test in 3 studies [39, 44, 45] and an RSA test in 2 studies [40, 44]. In one study [41], maximal power output was tested during short all-out sprints (7 s) of the arms and the legs.

Peak power was tested at Pre, 1st, 2nd, 3rd/4th, and after Ramadan.

In the afternoon, the results showed a moderate effect size when comparing Pre with 1st (− 1.13; 95% CI − 1.92 to − 0.33) (Table 3, Fig. 4). The mean decrease of performance in the afternoon was 16.8% at 1st (Table 1). At the other timepoints, trivial-to-small effect sizes were observed for this parameter.

3.3.3 Total Work

The effects of Ramadan fasting on total work were mostly evaluated in the afternoon with 3 studies [26, 40, 44], while 2 studies analyzed these effects in the morning [26, 40]. One study assessed the effects of Ramadan fasting on total work in the evening [26]. Total work was tested during a Wingate test in 1 study [26] and a RSA test in 2 studies [40, 44].

Total work was tested at Pre, 2nd, and 3rd/4th weeks of Ramadan.

Trivial-to-small effect sizes were observed for total work indicating that there was little influence of fasting during the month of Ramadan on performance when the subjects were tested either in the morning or in the afternoon (Table 3, Figs. 3, 5).

3.3.4 Strength

Overall, 6 studies analyzed the effects of Ramadan fasting on strength during the month of Ramadan. Two studies tested this parameter in the morning [40, 47] and 4 studies in the afternoon [40–43]. Tests used to assess the level of strength were isometric maximal voluntary contraction of knee extensors at 90° [40, 42], handgrip force of right and left arms [41], the repetition maximum (RM) during squat, bench press, and dead lift [47].

Strength was tested at Pre, 1st, 2nd, and 3rd/4th weeks of Ramadan.

The statistical analysis indicated a minor effect of Ramadan fasting on strength. Trivial and small effect sizes were observed for this variable (Table 3, Figs. 3, 6).

3.3.5 Fatigue Index

Fatigue index was calculated before, during and after Ramadan in the afternoon by 4 studies [39, 44–46] and in the morning by 2 studies [46, 47]. The tests used to calculate the fatigue index were: the Wingate test [39, 44, 45] and the RSA running test with 10 m [46], 30 m [46], and 35 m [47].

Fatigue index was calculated at Pre, 2nd, 3rd/4th, and after Ramadan.

Trivial-to-small effect sizes were observed for this parameter, indicating that Ramadan fasting had little influence on fatigue index when the subjects were tested either in the afternoon or in the morning (Table 3, Figs. 2, 7).

3.3.6 Jump Height

Subjects were tested in the afternoon for jump height in 4 studies [41, 43, 46, 48]. Only one study evaluated the effects of Ramadan fasting on jump height in the morning [46]. The insufficient data did not allow us to include these results in the meta-analysis for this time of the day. Different tests were used to analyze jump height: countermovement jump [41, 43, 46, 48] and squat jump [43].

Jump height was tested at Pre, 2nd, 3rd/4th, and after Ramadan.

Trivial effect sizes indicated that fasting during Ramadan had little influence on jump height when the test was performed in the afternoon (Table 3, Fig. 6).

3.3.7 Mean Power

Mean power was only tested in the afternoon by 4 studies [39, 43–45]. Mean power was tested during the Wingate test [39, 44, 45] and 30 s repeated jump test [43].

Mean power was tested at Pre, 2nd, 3rd/4th, and after Ramadan.

Small and trivial effect sizes were observed at 2nd and after Ramadan, indicating little effect at these timepoints. However, a moderate effect size (− 0.66; 95% CI – 1.31 to 0) was observed at 3rd/4th week during Ramadan (Table 3, Fig. 4). These results indicate a decrease of performance for this variable in comparison with Pre. On average, the decrease of performance was 5.1% at the end of Ramadan (Table 1).

3.3.8 Sprint Time

Subjects were tested on sprint time in the afternoon in 3 studies [43, 46, 48]. Only one study evaluated the effects of fasting on sprint time in the morning [46]. As this study tested two different sprint distances, the data were used to perform an analysis for this time of the day. Sprint time was tested on different distances: 5 m [43, 48], 10 m [43, 46, 48], 20 m [48], and 30 m [43, 46].

Sprint time was tested at Pre, 2nd, 3rd/4th, and after Ramadan.

Trivial-to-small effect sizes were observed for this parameter in the afternoon indicating that there was little influence of fasting during the month of Ramadan on sprint performance (Table 3, Fig. 5). However, in the morning, the results showed a moderate effect size when comparing Pre with 2nd (− 1.03; 95% CI − 1.26 to − 0.79) and when comparing Pre with after Ramadan (− 0.86; 95% CI − 1.09 to − 0.64) (Table 3, Fig. 3). The mean decrease of performance in the morning was 3.9% at 2nd and 3.2% after Ramadan (Table 1).

Table 2 Methodological quality of the included studies

Study	Total score (/32)	Reporting (/11)	External validity (/3)	Internal validity—bias (/7)	Internal validity—confounding (/6)	Power (/5)	Conflict of interest
Abedelmalek et al., 2015 [33]	18 (56.3%)	8	0	3	2	5	Unspecified
Aloui et al., 2013 [34]	20 (62.5%)	9	1	3	2	5	Unspecified
Aziz et al, 2012 [20]	20 (62.5%)	9	1	3	2	5	No
Bouhlel et al., 2013 [35]	17 (53.1%)	7	1	2	2	5	No
Brisswalter et al., 2011 [36]	20 (62.5%)	8	2	3	2	5	No
Chaouachi et al, 2009 [37]	19 (59.4%)	9	1	2	2	5	Unspecified
Chtourou et al., 2011 [38]	20 (62.5%)	9	1	3	2	5	No
Karli et al., 2007 [39]	18 (56.3%)	9	1	2	1	5	Unspecified
Kirkendall et al., 2008 [40]	18 (56.3%)	8	1	2	2	5	Unspecified
Mirzaei et al., 2012 [41]	17 (53.1%)	6	1	3	2	5	Unspecified
Zerguini et al., 2007 [42]	20 (62.5%)	6	3	3	3	5	No

Table 3 Mean standardized differences for variables assessed pre-, during and post-Ramadan

Variables	Pre-1st week		Pre-2nd week		Pre-3rd/4th week		Pre–Post	
	ES (95% CI)	Range	ES (95% CI)	Range	ES (95% CI)	Range	ES (95% CI)	Range
Tests conducted in the afternoon								
Mean power	N/A	N/A	− 0.246 (− 0.58 to 0.09)	− 0.37; − 0.09	− 0.655 (− 1.31 to 0)	− 2.46; − 0.03	0.06 (− 0.39; 0.50)	− 0.13; 0.33
Peak power	− 1.132 (− 1.92 to − 0.33)	− 2.11; − 0.69	− 0.279 (− 0.63 to 0.07)	− 0.40; − 0.18	− 0.417 (− 0.82 to − 0.01)	− 1.20 to 0.39	0.38 (− 0.36 to 1.13)	0.03; 0.8
Fatigue index	N/A	N/A	0.274 (0.09 to 0.45)	0.24; 0.41	0.114 (− 0.24 to 0.46)	− 0.24 to 0.69	0.309 (0.12 to 0.49)	0.25; 0.6
Total work	N/A	N/A	0.013 (− 0.33 to 0.35)	− 0.05; 0.05	− 0.313 (− 0.66 to 0.03)	− 0.53; 0.04	− 0.282 (− 0.86; 0.30)	− 0.57; 0.03
Force	0.181 (− 0.29 to 0.65)	− 0.05;0.43	− 0.429 (− 1.13 to 0.27)	− 0.82; − 0.1	− 0.507 (− 0.78 to − 0.23)	− 0.83; − 0.24	− 0.131 (− 0.51 to 0.24)	− 0.23; − 0.01
Jump height	N/A	N/A	0.031 (− 0.36 to 0.42)	− 0.23; 0.33	0.028 (− 0.29 to 0.34)	− 0.54; 0.49	− 0.026 (− 0.41; 0.35)	− 0.32; 0.39
Sprint	N/A	N/A	0.068 (− 0.09 to 0.22)	− 0.13; 0.28	0.151 (− 0.07 to 0.37)	− 0.37; 0.67	0.215 (0.06 to 0.36)	− 0.05; 0.58
Aerobic	N/A	N/A	− 0.029 (− 0.32 to 0.26)	− 0.31; 0.36	− 0.425 (− 0.93 to 0.08)	− 2.08; 0.4	0.200 (− 0.67 to 1.07)	− 0.51; 0.79
Tests conducted in the morning								
Fatigue index	N/A	N/A	− 0.456 (− 0.88 to − 0.02)	− 0.68; − 0.24	− 0.235 (− 0.41 to − 0.05)	− 0.29; − 0.02	0.475 (0.16 to 0.78)	0.32; 0.64
Force	N/A	N/A	N/A	N/A	0.121 (− 0.14 to 0.38)	0.09; 0.2	N/A	N/A
Sprint	N/A	N/A	− 1.025 (− 1.26 to − 0.78)	− 1.05; − 1	− 0.461 (− 0.86 to − 0.05)	− 0.67; − 0.26	− 0.864 (− 1.08 to − 0.64)	− 0.9; − 0.83
Aerobic	N/A	N/A	N/A	N/A	0.108 (− 0.18 to 0.40)	− 0.14; 0.2	N/A	N/A

ES effect size, *CI* confidence intervals, *N/A* non-applicable

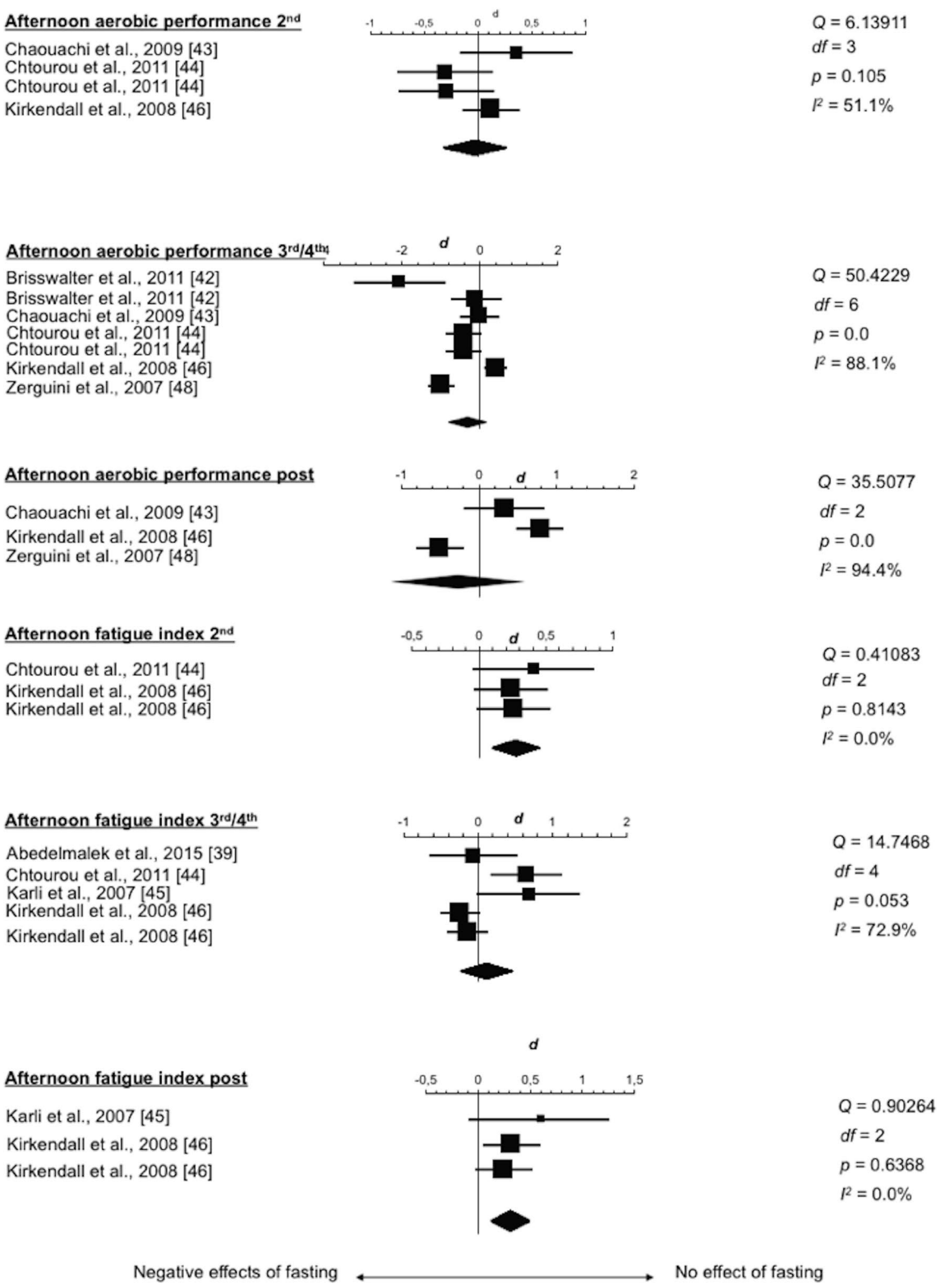

Fig. 2 Effect of Ramadan fasting on aerobic performance and fatigue index when performed in the afternoon. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

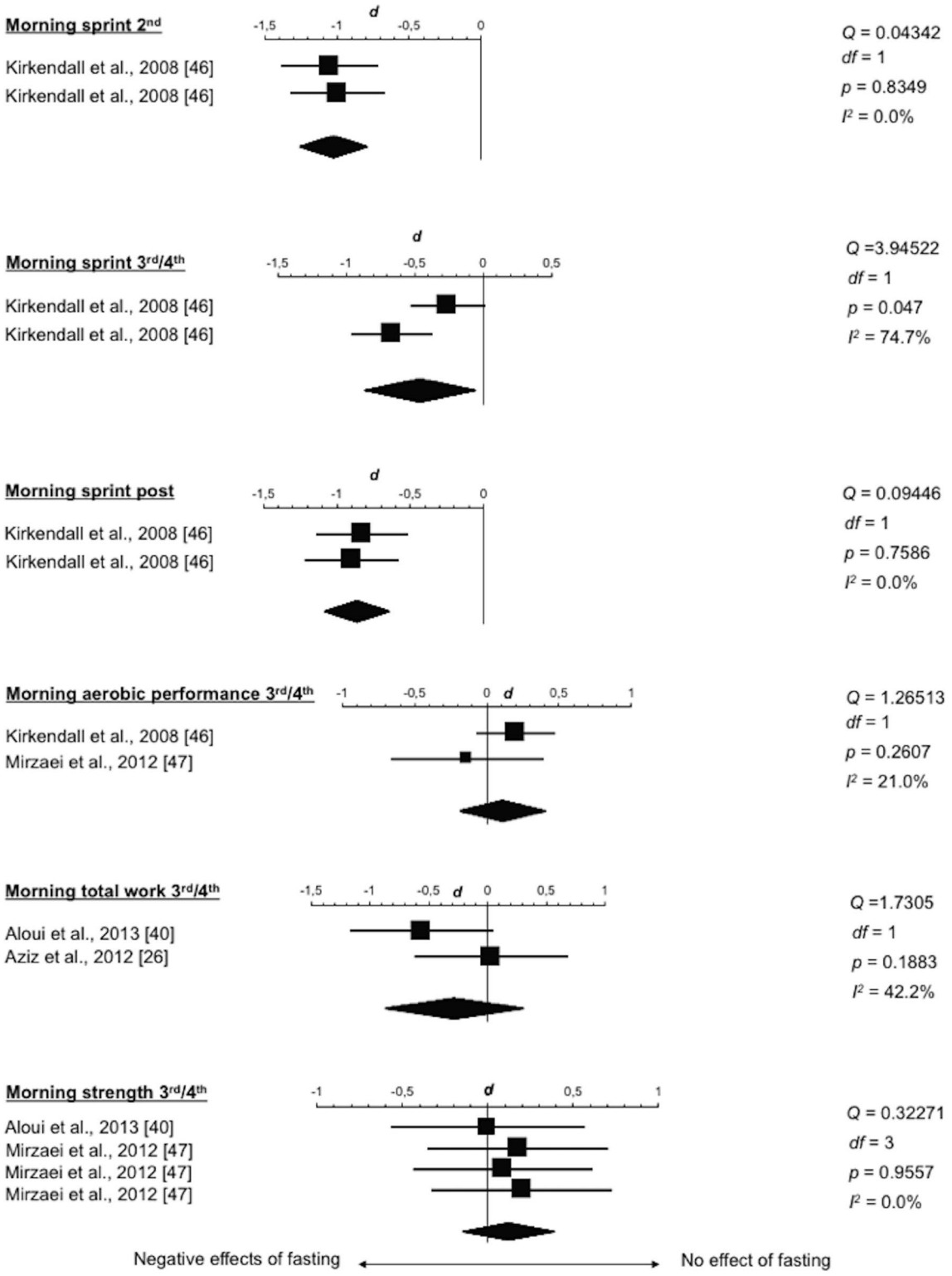

Fig. 3 Effect of Ramadan fasting on sprint, aerobic performance, total work and strength when performed in the morning. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

4 Discussion

To the best of our knowledge, the present review with meta-analysis is the first to report the effects of fasting during the month of Ramadan on physical performance. The results showed that Ramadan fasting negatively impacted mean power and peak power performed during a Wingate or RSA test when performed in the afternoon. In addition, fasting was detrimental to running sprint performance when the exercise was performed in the morning. However, the other parameters measured were not influenced by Ramadan fasting.

4.1 Methodological Quality of the Included Studies

Taken as a mean, the level of methodological quality of the articles included in this systematic review was moderate with a low variability of methodological scores between studies (coefficient of variation inter-studies = 6.9%). Specifically, based on the methodological quality developed by Downs and Black [24], the included studies showed a low level of "external validity", "internal validity–bias", and "internal validity–confounding". "External validity" refers to "the extent to which the findings from the study could be generalised to the population from which the study subjects were derived". The maximal score that can be obtained for this sub-scale was 3. In the present systematic review, the mean score obtained by the included studies was 1.2, and only one study reached 3 points [48]. Caution should be exercised when generalizing the results of these studies. Regarding "internal validity–bias", this is defined by Downs and Black [24] as the "biases in the measurement of the intervention and the outcome". This sub-scale involves the reliability and validity of the tools used in the study, the relevance of the statistical tests, the presence or absence of a double blinding process and the follow-up of the subjects. As for the 'external validity' sub-scale, the global mean score was low (2.6 out of a possible 7 points) indicating a high level of biases. The highest score obtained was 3. Such a low score may have consequences for the interpretation and confidence of the findings from these studies. The sub-scale "internal validity–confounding" has a maximum of 6 points, which was not achieved by any of the studies included in this systematic review. The mean score of the included studies was 2. This low score can be an issue also for generalising the results, as this sub-scale represents the bias that can occur in the recruitment of the subjects. It can be noted that all the included studies were considered ecologically valid, as they were performed in a "real-world" context. Therefore, the conditions of practice are near to what can be found in sports settings with Muslim athletes.

4.2 Effects of Ramadan Fasting on Performance

4.2.1 Detrimental Effects

In this meta-analysis, 4 included studies analyzed the effects of Ramadan fasting on mean power during a Wingate test or a RSA test. The results showed a decrease of performance at the end of the month (3rd/4th week) when the test was performed in the afternoon. Among the studies testing this parameter, the study of Abedelmalek et al. [39] showed a large difference in results compared to the 3 other included studies [43–45]. In their study, the authors found a large detrimental effect of Ramadan fasting on mean power, while the effect was small in the other studies. This inconsistency is confirmed by a high level of heterogeneity ($I^2 = 76.6\%$) which is an indicator linked to the total variation across studies [29]. The fact that most of the variability across studies is due to heterogeneity is demonstrated by a high value of I^2.

Differences in the methodology used in the included studies may also explain these results. In the study of Abedelmalek et al. [39], the subjects were amateur football players participating in 3 training sessions per week. These characteristics were different from the study of Chaouachi et al. [43] and that of Karli et al. [45] in which the subjects were elite judokas participating in 9 training sessions and power athletes participating in 6 training sessions per week, respectively. The fact that the decrease in performance is observed at the end of Ramadan in one study but not in the others may be explained by a lower level of fasting-induced fatigue in well-trained athletes. Ramadan fasting may induce a physical fatigue due to sleep disturbances and dehydration. It has been shown that sleep quality and quantity are negatively impacted during the month of Ramadan [5–7] and that the level of hydration decreases during the daytime [2]. At the end of the month, the accumulation of worse sleep and dehydration may have more of a negative impact on amateur athletes such as the subjects in the study of Abedelmalek et al. [39] than on the subjects of the other studies evaluating mean power. It is well-known that elite athletes are more resistant to fatigue in comparison to amateur athletes [49]. Thus, it can be hypothesized that this higher level of resistance to fatigue can also be observed during a period of intermittent fasting and lead to a higher level of performance in well-trained athletes. As a consequence, and taking into account all these parameters, it would be too speculative to conclude that Ramadan fasting is detrimental to mean power performance. Other studies are needed, especially to compare the response to fasting between well-trained athletes and amateur athletes.

Peak power is the second parameter negatively affected by Ramadan fasting. Our results show that, during the first week of the month, peak power performance is moderately

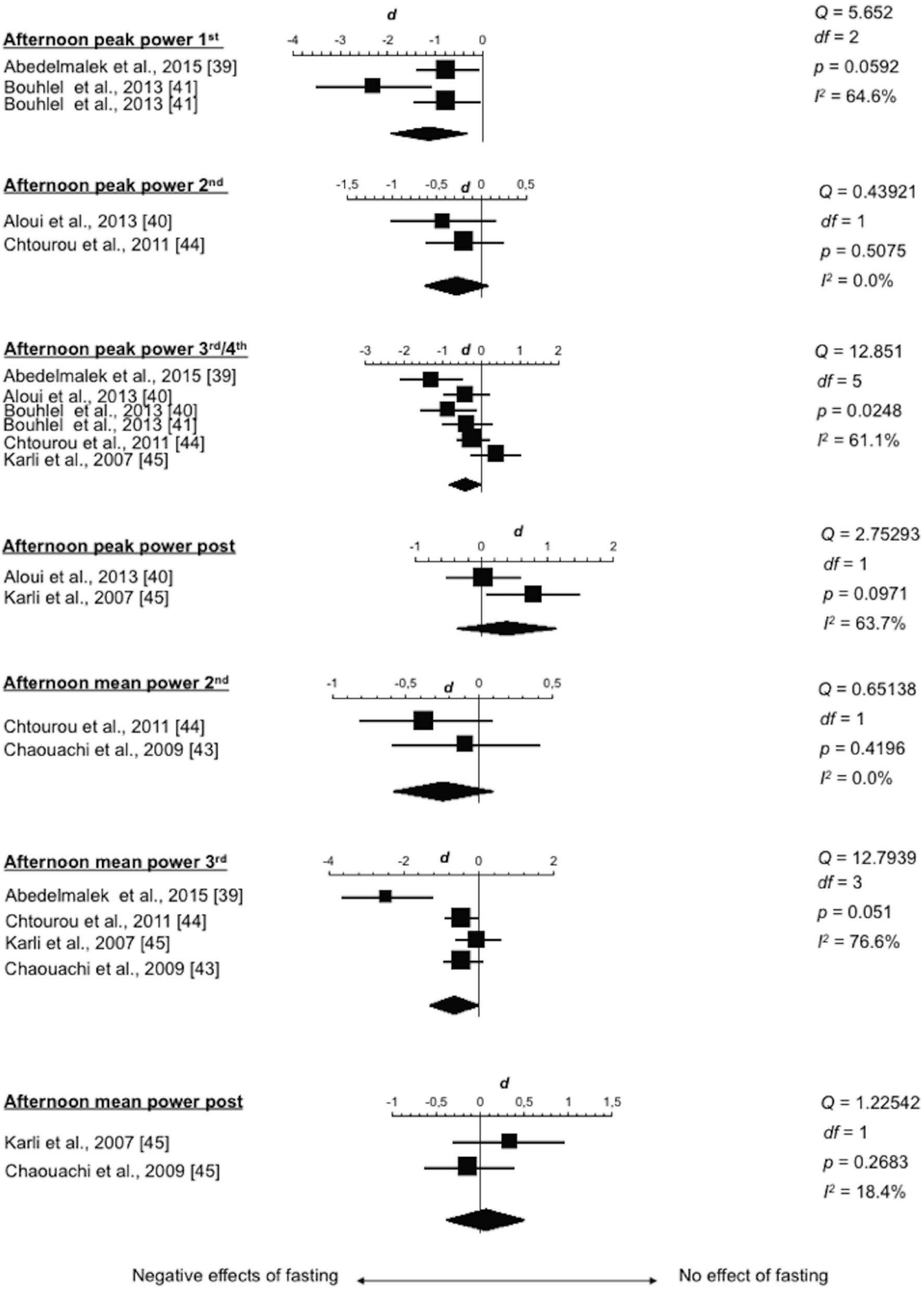

Fig. 4 Effect of Ramadan fasting on peak power and mean power when performed in the afternoon. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

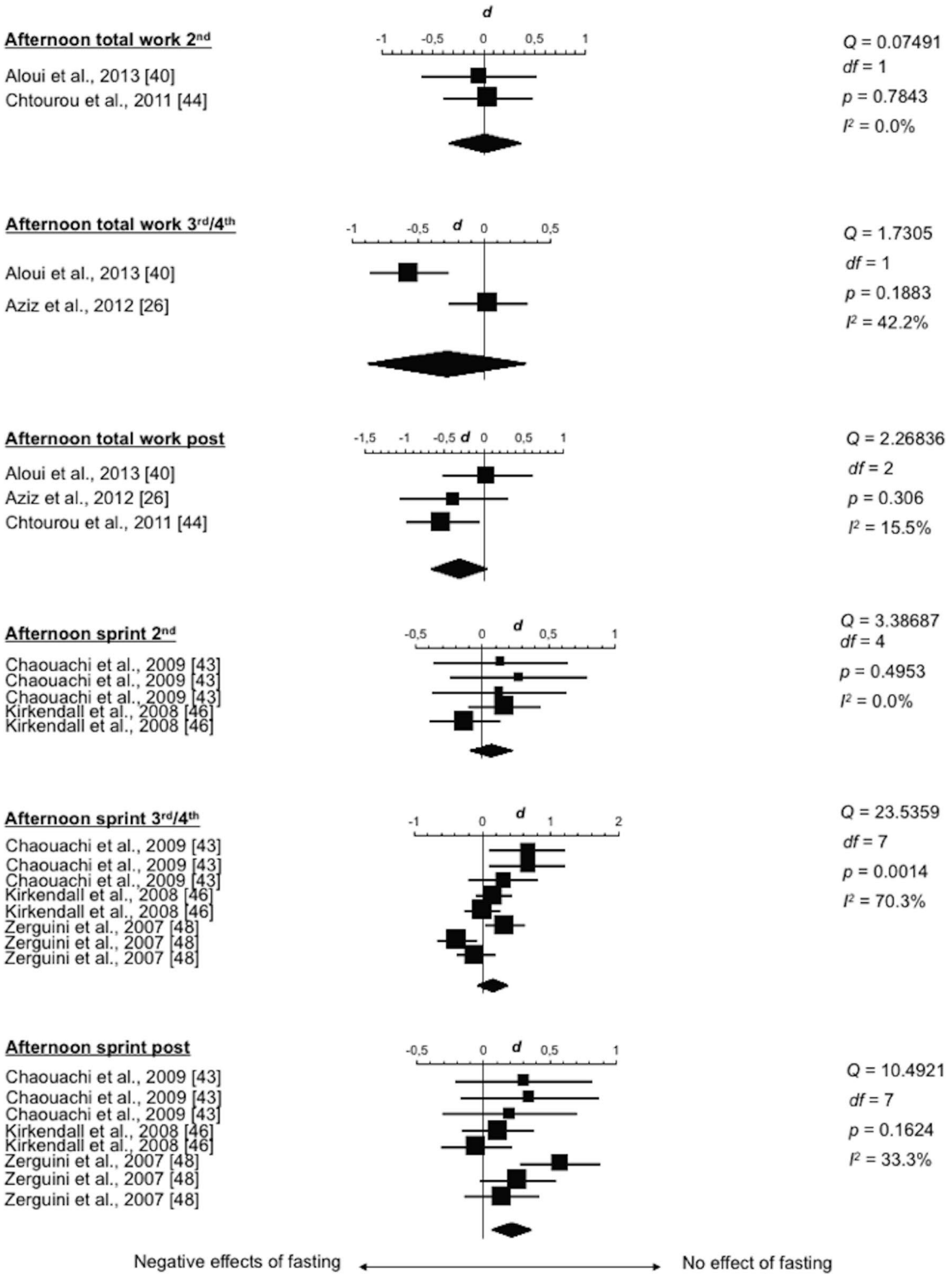

Fig. 5 Effect of Ramadan fasting on total work and sprint performance when performed in the afternoon. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

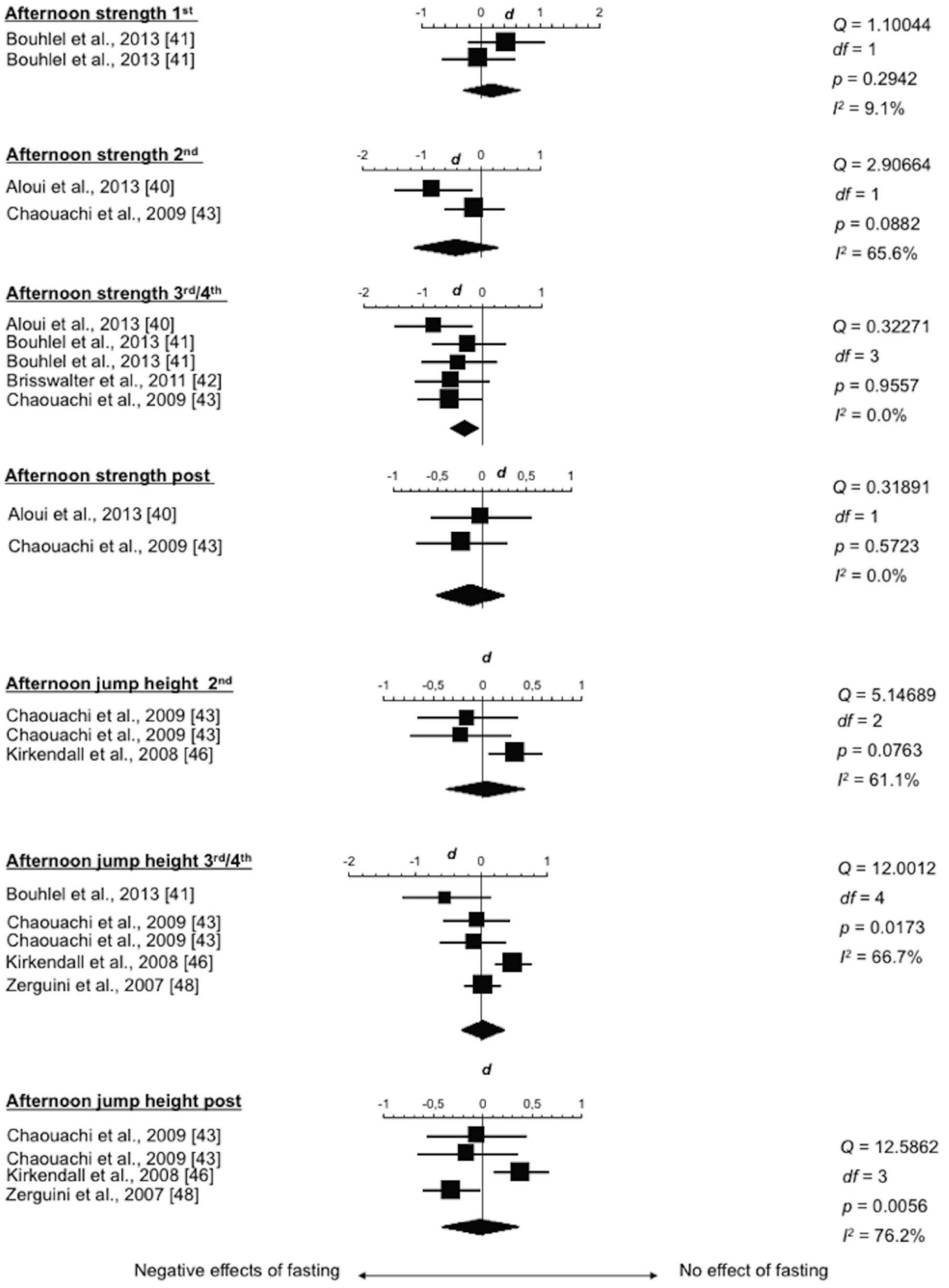

Fig. 6 Effect of Ramadan fasting on strength and jump height when performed in the afternoon. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

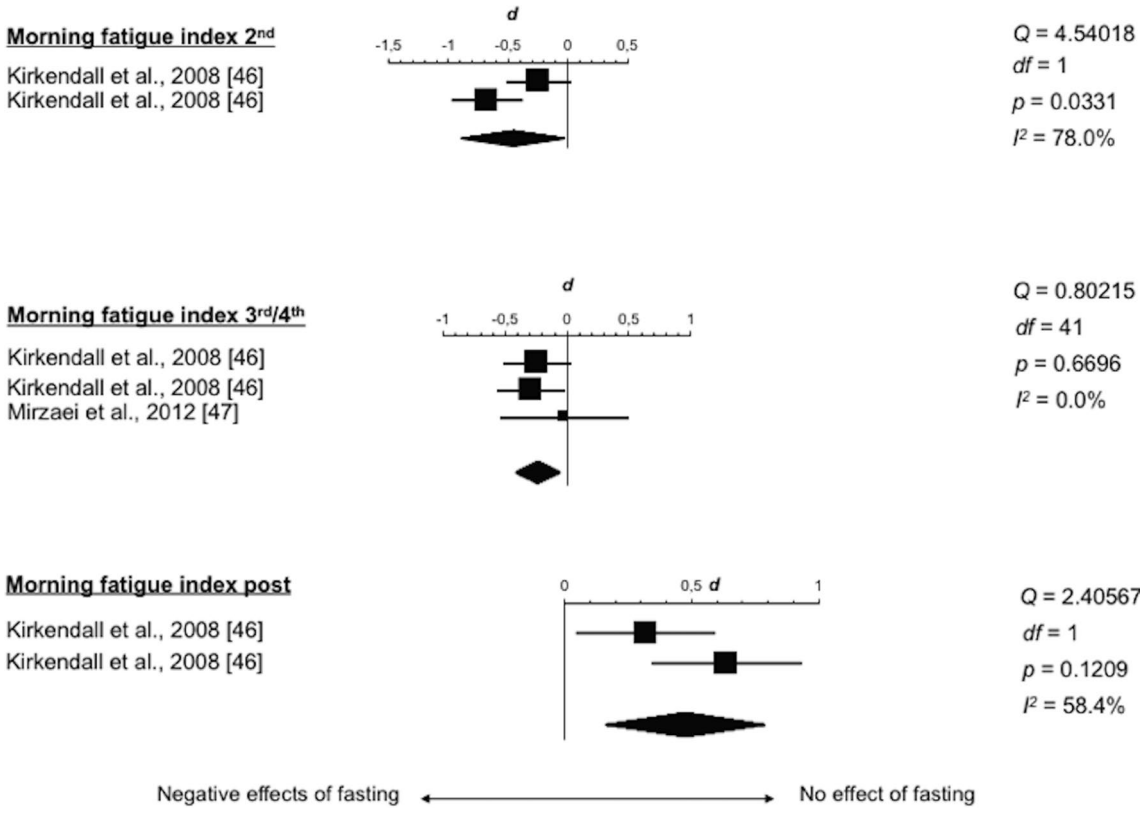

Fig. 7 Effect of Ramadan fasting on fatigue index when performed in the morning. 1st, 2nd, 3rd/4th, post: mean standardized difference between 1st week, 2nd week, 3rd or 4th week, post with pre-Ramadan values, respectively

affected with a decrease ranging from − 8.5 to − 28.5%. Comparing the results of the different studies evaluating peak power showed consistency in the results with a moderate-to-large negative effect of intermittent fasting on this outcome during the first week of Ramadan. However, the low number of studies may represent a limitation for the interpretation of results. It has been hypothesized that adaptation to dietary and/or sleep constraints linked to Ramadan fasting may explain a decrease in performance during the first week of Ramadan [41]. Intermittent fasting during Ramadan induces several physiological changes, social changes and a daily reorganisation of numbers and time of meals [5, 50, 51]. The possibility to eat only between sunset and dawn limits the number of meals to two per 24 h. In addition, participation in night prayers may delay the time to go to bed and perturb the circadian rhythm of sleep synchronisers [5, 50, 51]. This is especially true when the day is long, for example in summer. Consequently, this global reorganisation may induce acute physiological changes affecting body weight [2], blood pressure and red blood cell production [52], blood glucose concentration [53], lipid profile [54], nocturnal peak of melatonin, cortisol, and testosterone secretion [55]. We can hypothetically consider that these changes were deleterious for peak power performance during the first week of Ramadan.

Sprint performance during the second week of Ramadan and after Ramadan was the only parameter impacted in the morning. However, these results were obtained in only one study and with two different distances [46]. The very low level of heterogeneity ($I^2 = 0\%$) indicates consistent results which can be explained by the fact that the subjects were the same for both distances. It is established that sprint performances over short distances are related to each other (e.g., 10 m with 20 m) [56]. Thus, in the context of fatigue, performance over all short distances may be reduced to the same extent. Contrary to these results, Aloui et al. [40] found a higher performance in the morning than in the afternoon during repeated sprint test and maximal voluntary contraction test. These differences may be explained by the type of test performed in the studies.

4.2.2 Neutral Effects

Contrary to our hypothesis, aerobic performance was not negatively impacted by intermittent fasting during the month of Ramadan. Depending on the timepoint of measurement,

the heterogeneity between studies was moderate to large (Fig. 2) indicating inconsistency between the results of included studies. During the second week of Ramadan, none of the included studies showed a negative effect of Ramadan fasting on aerobic performance (trivial-to-small effect sizes). However, at the end of Ramadan, Zerguini et al. [48] and Brisswalter et al. [42] found moderate-to-large detrimental effects of fasting on aerobic performance, respectively. These results were different from the studies of Chaouachi et al. [43], Chtourou et al. [44], and Kirkendall et al. [46] who found trivial-to-small effects of Ramadan fasting on aerobic performance. Differences in outcomes measured and subjects involved in the studies may explain these different results. In addition, in the studies included in this meta-analysis, the impact of some confounders such as nutrition and sleep were not taken into account in the analysis, which represents a limitation of the included studies. Psychological aspects related to mood and motivation may also explain these results. Roky et al. [57] showed that mood and alertness were significantly reduced at the end of Ramadan. Zerguini et al. [48] suggested that the players who believe that fasting has a deleterious effect on performance may be less motivated to perform a maximal effort. Png et al. [58] compared the responses of eating two meals composed of a different glycemic index (36 vs 57) at *suhur* on a 30-min time-trial run on a treadmill. The results showed that the distance covered during the 30-min time trial run was significantly lower when eating the meal with a lower glycemic index. Studies have also shown an increased endurance performance following the use of mouth-rinsing strategies [59, 60]. It has been shown that, during the month of Ramadan, rinsing the mouth with a water-based solution added with or without 2 g of carbohydrates may improve running or cycling performance [59, 60]. These results highlight the importance of nutrition on performance during the month of Ramadan, and the need to put into perspective the results of the studies according to nutritional strategies used by the participants. Previous studies have shown a deleterious effect of reduced sleep quality and quantity on endurance performance [14]. During the month of Ramadan, sleep is negatively impacted and may have influenced the results of the studies [7]. As for nutrition, this factor needs to be assessed and documented as a confounder that may influence performance and recovery during Ramadan.

Consistent with our hypothesis, as expected for the parameters discussed before, anaerobic performance was not impacted by intermittent fasting during the month of Ramadan. This may be explained by the duration of the effort, which is not influenced by nutritional aspects, dehydration, or sleep [12–14].

4.3 Limitations

This meta-analysis presents some limitations. First, some studies did not evaluate performance at the same timepoint which may have limited the number of studies for some parameters. Second, the effects of intermittent fasting were mostly evaluated during the afternoon and no data are available regarding the effects of fasting in the evening. Third, there was heterogeneity regarding the level of the participants and the activity performed. Due to the included criteria, some participants were amateur athletes, while others were elite athletes, which may have influenced the response to Ramadan fasting. In addition some participants were team sports athletes and others were individual sports athletes. Fourth, the tests were performed at a given timepoint without taking into account the repeatability of performances in real-world setting. Due to the lack of data in the scientific literature, the effects of Ramadan on the activity performed during team sports competitions were not evaluated. In the included studies, the authors used repeated measures by comparing the values before Ramadan with the values during and/or after Ramadan. Only three studies used a mixed approach, i.e., comparing with a control group (nonfasting) and with pre-Ramadan values [41, 42, 46]. As the studies were performed in Muslim countries, it can be problematic to ask people not to fast during Ramadan. To perform the meta-analysis, due to the absence of a control group in the majority of the included studies, a pre–post approach was used to analyze the effects of Ramadan fasting on performance. The fact that Ramadan occurs at different times of the year may influence performance. Changes in climate, duration of the daylight and nights, and social context may have an impact and need to be taken into account when studying Ramadan fasting effects.

5 Conclusion and Practical Applications

This systematic review with meta-analysis provides updated insights regarding the effects of intermittent fasting during the month of Ramadan on physical performance. The main results showed that mean power and peak power during a Wingate and/or a repeated sprint test are decreased during Ramadan when performed in the afternoon. Sprint performance is also decreased when the test is performed in the morning. However, no effect of Ramadan fasting was observed for aerobic performance and other anaerobic outcomes.

To date, athletes and coaches have adapted their attitudes toward Ramadan fasting according to their beliefs and not on an evidence-based approach [16]. The results of this review show that Ramadan fasting has no deleterious effects on the majority of the outcomes measured. As a

practical application, an approach consisting of eating on the days of competitions to avoid negative effects of intermittent fasting on physical performance is not supported by the present results. Thus, it appears that athletes may be able to compete in a fasted state without decreasing their physical performance. Priority should be given to sleep and nutrition optimization, which is a determinant factor of performance during this period, at the time of *iftar* and *suhur*. However, in the case of several competitions in a short period, the results of this meta-analysis may not be applicable and other studies in this field are needed.

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Data Availability Statement Data analyzed during this study are included in this published article (and Electronic Supplementary Material Appendix S1).

Compliance with Ethical Standards

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Conflicts of Interest Abd-Elbasset Abaïdia, Wael Daab, and Mohamed Amine Bouzid declare that they have no conflicts of interest with the content of this article.

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