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Immediate effects of Ramadan on objective time asleep in male youth football players from the Middle East: an interrupted time-series study

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ABSTRACT

Objective: To examine the abrupt effects of Ramadan onset on actigraphy-based time asleep in male youth Muslim football players.

Methods: We adopted a quasi-experimental, interrupted time-series research design and tracked objective time asleep over a minimum of 12 consecutive nights in the two weeks prior to and immediately after Ramadan onset, respectively. Twenty-two, male academy student-athletes (chronological age range: 12.6 to 16.2 years) participated in the study (464 individual observations). Segmented generalized mixed-effects modelling estimated the effects of Ramadan onset on time asleep during the first period of night sleep only.

Results: Ramadan onset led to an immediate mean reduction of 89 min (95% confidence interval [CI], 54 to 123 min) in time asleep during the first period of night sleep compared to pre-Ramadan sleep patterns. Model-adjusted estimated marginal means for time asleep were ~ 5.7 h (95%CI, 5.1 to 6.2 h) before and ~ 4.2 h (95%CI, 3.6 to 4.7 h) after Ramadan onset. Night sleep interruptions resulting in two or more fragmented periods accounted for 8% (95%CI, 2 to 21%) to 19% (95%, 11 to 29%) of sleep observations before and after Ramadan onset, respectively.

Conclusions: The onset of Ramadan determined an abrupt reduction in time asleep of ~ 1 h 30 min in the first period of a night cycle and contributed to additional problems of heterogeneous sleep fragmentation that can impact optimal school learning and youth athlete performance development processes.

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KEYWORDS
Sleep; football; Ramadan; youth; actigraphy

Introduction

In sport, adequate sleep is pivotal for the preparation and recovery from training and competition (Fox et al. 2020). From a general standpoint, fundamental biological rhythms regulate the repetitive processes of human life cycles (Atkinson and Reilly 1996). Within this context, continuous unperturbed sleep represents a physiological necessity to preserve normal cognitive and neurobehavioral functions (Maquet 2001; Van Someren et al. 2015; Logan and McClung 2019; Walsh et al. 2020). Notwithstanding this, youth athletes are vulnerable to sleep disorders that generally involve short durations inconsistent with health recommendations due to lifestyle factors, social commitments (e.g., school), together with the demands of training and competition (Fox et al. 2020). Problems of sleep disorders and disruption are common particularly in Muslim populations throughout different seasons of the Gregorian year (BaHammam et al. 2006; Merdad et al. 2014; Farooq et al. 2015; Arora et al. 2018; Lolli et al. 2021) and periods of annual religious observances, with a particular reference to the holy month of Ramadan (Reilly and Waterhouse 2007; Bahammam and Gozal 2012; Qasrawi et al. 2017).

Ramadan is a month of the Islamic (*Hijra*) year, which follows the lunar system and has 11 fewer days than the conventional Gregorian year (Bahammam 2006). The general practice of adherents to Ramadan requires daylight abstinence from food, liquid intake, and smoking in conjunction with the observance of five prayers during daytime and until ~3 am that inevitably alter natural sleep-wakefulness cycles (Bahammam 2006). The predawn meal is taken before the *Fajir* dawn pray (*Suhoor*), whereas the break of fasting (*Iftar*) occurs after sunset (Faris et al. 2020). Sharing similarities with social jet lag (Wittmann et al. 2006), the abrupt alteration and misalignment in eating habits combined with lifestyle and environmental changes, such as delays in school timings and postponed working hours for shopping malls and broadcasting programmes, play a role in causing problems of sleep deprivation, disruption, and fragmentation, having far-reaching health-related consequences (Bonnet and Arand 2003; Van Someren et al. 2015). Regardless of the total daily sleep intake, the fragmentation of a normal sleep cycle into short and heterogeneous sleep bouts, frequently interrupted by brief awakenings, is a typical pattern for the Ramadan predawn meal during the early morning hours (Qasrawi et al. 2017) as detrimental as curtailed sleep (Van Someren et al. 2015). This is of particular concern given the prevalence of sleep interruptions in youth and adult Muslims from Middle Eastern countries (Bahammam and Gozal 2012; Bahammam et al. 2012; Herrera 2012; Farooq et al. 2015; Lolli et al. 2021).

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Despite the number of narrative and systematic reviews researching the effects of Ramadan diurnal intermittent fasting on time asleep (Waterhouse 2010; Shephard 2013; Faris et al. 2020; Trabelsi et al. 2020, 2021), studies provided conflicting findings due to methodological limitations that preclude from drawing any conclusive line of evidence and deserve attention. First, studies were inconsistent with the reporting of information relevant to what period of the year a study was conducted (Trabelsi et al. 2020). For example, Ramadan fasting may have differential psychobiological effects at different latitudes (Trabelsi et al. 2020). Likewise, research studies were inconsistent at examining night-time asleep and day-time sleep periods in conjunction (Bahammam 2006). Second, research in this field explored issues of sleep curtailments with assessments limited to the sole reliance on subjective measurement tools prone to issues of overestimation in self-perceived sleep duration (Lauderdale et al. 2008; Billings 2022) compared to, for example, the more objective actigraphy-based tracking (Scott et al. 2020). The diversity of tracking procedures contributed to the general heterogeneity of findings from evidence synthesis studies due to the incorrect amalgamation of subjective and objective sleep tracking outcomes (Faris et al. 2020; Trabelsi et al. 2020, 2021). Third, research designs generally did not consider formal between-group comparisons on the effects of Ramadan in Muslim observants against non-observants as part of a pre-defined experimental control arm (Shephard 2013; Qasrawi et al. 2017). Nevertheless, contextual elements render the recruitment of appropriately matched-control study participants prohibitive to follow relevant clinical research trial procedures (Shephard 2013). Likewise, a conventional parallel-arm clinical trial design does not permit to quantify the direct effects of Ramadan onset on sleep outcome measures (Kontopantelis et al. 2015; Lopez Bernal et al. 2018; Saeed et al. 2018; Schober and Vetter 2021). Wilson et al. (2009), as an alternative example, conducted simple pre-post descriptive analyses to compare the Ramadan period against the four weeks immediately post-Ramadan offset treated as the control period. Notwithstanding the conceptual merits of this design, drawing inferences on mean changes in sleep patterns in a study with control measurements gathered post-Ramadan is inconsistent with clinical and epidemiological evaluations of population-level public health interventions and impacts of natural or unplanned events (Lopez Bernal et al. 2018).

Given context-dependent issues of methodology in typical pre-post research on Ramadan, a quasi-experimental design, not involving conventional randomization (Kontopantelis et al. 2015), constitutes a plausible solution for examining a chronologically-ordered series of sleep observations *interrupted* at a precise time point by a pre-defined event of interest (Schober and Vetter 2021). An interrupted time-series design addresses problems of counterfactual conditionals by leveraging an analytic design that mimics a scenario where the pre-exposure observations act as the counterfactual to evaluate what would have happened *if* Ramadan *had not* occurred on acute individual-level changes in sleep duration (Saeed et al. 2018). Therefore, with the hypothesis that time asleep would remain materially unaltered over a calendar year phase other than the month of Ramadan, we adopted a quasi-experimental, interrupted time-series research design to examine the abrupt effects of Ramadan onset on actigraphy-based time asleep in male youth Muslim football players from the Middle East.

Methods

Participants

The present study sample included $n = 22$ male, full-time, male youth outfield football players enrolled as academy student-athletes (chronological age range: 12.6 to 16.1 years; standing height range: 158.8 to 192.5 cm, body mass range: 41.9 to 79.5 kg). Before Ramadan, the general schedule for this sample of academy student-athletes consisted of six school classes from 07:30 to 15:30 and double training sessions from 10:30 to 12.00 and 16:00 to 18:00 on Sunday, Monday, and Wednesday (Lolli et al. 2021). School classes from 08:00 to 15:20 and one training session in the afternoon from 15:30 to 17:30 were scheduled on Tuesday, and school classes from 07:25 to 13:30 only on Thursday (Lolli et al. 2021). During Ramadan, schedules for school classes and training sessions were modified. Student-athletes attended five school classes from 09:30 to 13:30, whereas training sessions were scheduled in the evening only 20:30 to 22:15 from Sunday to Wednesday. No activities were planned in the afternoon from 13:40 to 19:40. Sleep and training load measurements collected in student-athletes as part of the regular service provision were retrieved from the Academy records, anonymized, analyzed to address the purpose of this investigation. Signed parental consent prior to the beginning of the competitive season to use data for service provision and research purposes (Barazzetti et al. 2020). This project was part of a larger longitudinal project on youth academy athletes approved by the Anti-Doping Laboratory Institutional Review Board, Qatar (protocol number: E20140000012).

Design

We designed and planned this surveillance period (Figure 1) to gather measurements over a minimum of 12 time points in the two weeks prior to and immediately after the onset of Ramadan, respectively (Zhang et al. 2011). Time asleep, defined as '*the actual time that a person spends asleep excluding non-sleep-related activities in bed*', represented the primary outcome measure in this investigation (Reed and Sacco 2016). Secondary outcome measures were session ratings of perceived exertion (s-RPE; au) and a proxy measure of high-intensity activity determined as high-speed running distances (m) over 269 individual sessions (Borg 1990; Di Salvo et al. 2009). Time in bed and wake-after-sleep-onset represented other secondary outcome measures (Reed and Sacco 2016).

Ramadan

Sleep and training load data were collected starting from 20th March 2022 (*Shaban 1443*) until 13th April 2022 (*Ramadan 1443*), with the first official day of Ramadan occurring on 1st April 2022. Over this period, calendar prayer times ranged from 04:20 to 03:52 for the *Fajr*, 11:42 to 11:35 for the *Dhuhr*, 15:08 to 15:04 for the *Asr*, 17:45 to 17:56 for the *Maghrib*, and 19:15 to

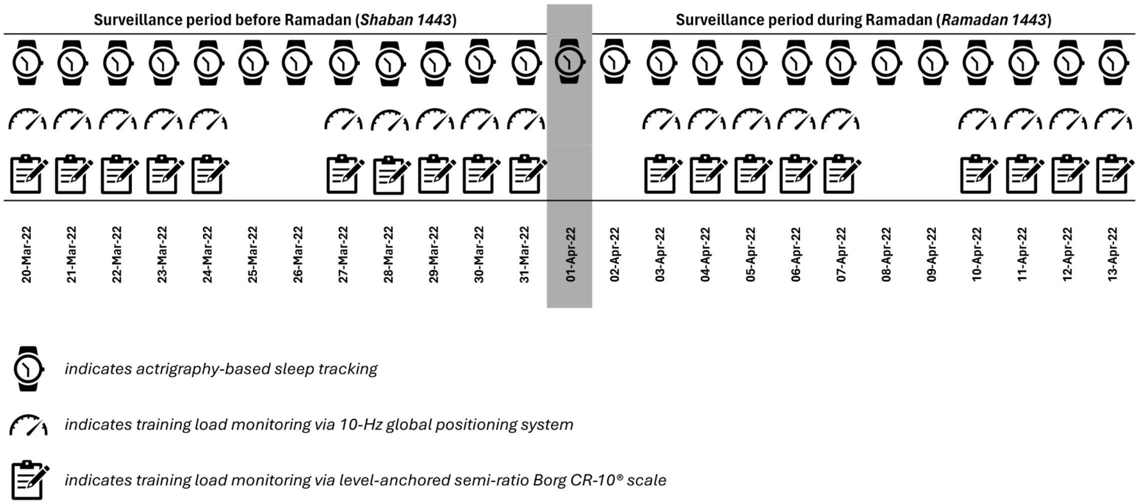

Figure 1. Visual description of the research design for the planned surveillance period starting from 20th March 2022 (*Shaban 1443*) until 13th April 2022 (*Ramadan 1443*), with the first official day of Ramadan occurring on 1st April 2022.

19:26 for the *Isha*. Sunrise timings ranged from 05:38 to 05:13, while sunset timings ranged from 17:44 to 17:55. With general knowledge from the available literature on the study of Ramadan and sleep patterns (Bahammam and Gozal 2012; Qasrawi et al. 2017; Faris et al. 2020), we defined the impact model, or the type of effect Ramadan onset is expected to have on time asleep patterns (Lopez Bernal et al. 2018), as an *abrupt level change* centred at Ramadan onset (Lopez Bernal et al. 2018; Saeed et al. 2018).

Actigraphy and training load tracking

Study participants wore an ActiGraph GT9X Link (ActiGraph, Pensacola, FL, USA) activity monitor set for date of birth, stature, body mass, and non-dominant wrist. Devices tracked all activities during the surveillance period except involvement in training and official matches only. Previous research examined the validity of wearable actigraphy devices for sleep measurement (Quante et al. 2018). The ActiGraph GT9X Link monitors (35 mm × 35 mm × 100 mm, and a weight of 14 g) were configured as per the manufacturer recommendations, with the Cole-Kripke sleep scoring algorithm used to analyze the data and the Tudor-Locke algorithm (Tudor-Locke et al. 2014) set as default for automated sleep period detection (Cole et al. 1992; Quante et al. 2018). Raw data were extracted using the ActiLife software (version 6.13.4, ActiGraph, Pensacola, FL, USA), with weekdays (Sunday to Thursday) and weekends data (Friday and Saturday) examined separately. Using the actigraphy monitors, we tracked *bedtime* (hh:min) as the time at which a participant first fell asleep after going to bed; *wake-up time* (hh:min) as the time at which a participant last woke before getting up; *time in bed* (hh:min) as the time spent in bed attempting to sleep between bedtime and get-up time; *time asleep* (hh:min) as the time spent in bed asleep; and *wake-after-sleep-onset* (min) relevant to periods of wakefulness occurring after defined sleep onset (Fowler et al. 2017). All sleep scoring was conducted using 60-s epoch cycles according to manufacturer's recommendations (ActiGraph, Pensacola, FL, USA). Automated detection of a sleep period rest on satisfying the following instrumentation criteria: *i*) a minimum sleep period length of 2 h and 40 min as the minimum amount of time between bedtime and wake-time; *ii*) 5 consecutive minutes of sleep that determines the start of a sleep period; *iii*) 10 consecutive minutes of awake time that determines the end of a sleep period (ActiGraph, Pensacola, FL, USA). The minimum amount of non-zero epochs for automated sleep period detection was 15 (ActiGraph, Pensacola, FL, USA). Individual-participant actograms were inspected visually prior to validation and inclusion in the study dataset. Each session training load was quantified in terms of perceived exertion (Borg 1990) and high-speed running distance covered selected as proxy measurements according to expert knowledge and their relevance to football performance (Di Salvo et al. 2009). Student-athletes rated the global intensity (RPE) of all sessions using level-anchored semi-ratio Borg CR-10® scale (Borg 1990) and used to determine s-RPE (session-duration × score). Distances covered at high-speed running intensity (>20 km·h^{-1}) were monitored during all training sessions with 10-Hz global positioning system (GPS; StatSports Apex) (Johnston et al. 2020).

Statistical analysis

Study data were summarised as descriptive statistics presented as mean plus standard deviation (SD), median (50th percentile) plus interquartile range (IQR, 25th to 75th percentile), and frequency or percentages where applicable. Uncertainty for frequency and percentages outcome statistics was calculated using the Agresti-Coull method (Agresti and Coull 1998). Density probability plots summarised the distribution of bedtimes, wake-up times, time in bed, wake-after-sleep-onset, s-RPE, and high-speed running distance data along their respective measurement spectrums over the surveillance periods before and immediately after Ramadan onset, respectively (Parzen 1962; Stigler 1978; Cox 2005, 2007). With the present study impact model pre-defined as an *abrupt level change* (Lopez Bernal et al. 2018), using the *xtmixed* command (Saeed et al. 2018), a segmented generalized mixed-effects modelling approach estimated pre-post effects of Ramadan onset on time asleep examined during the first period of night sleep only (Supplementary File 1). Clinical evidence informed the consideration and definition of the first period of night sleep as the first period of continuous sleep when starting a given night cycle according to the observed bedtimes and wake-up times (Wilckens et al. 2014; Van Someren et al. 2015). The model included the primary outcome measure as the dependent variable, time, day type (0, *weekday*; 1, *weekend*), and a time-by-day type interaction term specified as fixed effects, plus individual student-athlete specified as random effect with the covariance matrix structure set to *identity*. Regression coefficients were reported as point estimates with 95% confidence intervals (CI). Model random effects were summarised as variance components estimates reported as point SD with the respective 95%CI on the original measurement scale for sources of between-subject and within-subject variability (Stram and Lee 1994; Solomon 2005; Senn 2016). Statistical analyses were carried out using Stata (StataMP v14.0; StataCorp LP, College Station, TX) and R (version 3.6.3, R Foundation for Statistical Computing).

Results

Actigraphy-based sleep tracking observations ranged from 8 to 25 measurements per student-athlete over the entire surveillance period (464 individual observations). Figure 2 illustrates the distribution of bedtimes and wake-up times measurements in the two weeks preceding and immediately after Ramadan onset by weekday (Figure 2(a,b)) and weekend (Figure 2(c,d)) periods. Bedtimes and wake-up times for periods immediately after Ramadan onset showed bimodal and irregular distributions that highlighted heterogeneous sleep patterns and suggested problems of sleep fragmentation compared to the generally unimodal yet skewed density curves for these variables in the two weeks preceding Ramadan onset (Figure 2). Night sleep interruptions resulting in two or more sleep periods accounted for 9% (95%CI, 6 to 14%), 11% (95%CI, 8 to 17%), 8% (95%CI, 2 to 21%), 19% (95%CI, 11 to 29%) of observations before and after Ramadan onset during weekdays and weekends, respectively.

Table 1 summarises parameter estimates from the segmented generalized mixed-effects model for time asleep. Model-based estimates indicated Ramadan onset resulted in an immediate mean reduction of 89 min (95% CI, 54 to 123 min) in time asleep per first night cycle period (Figure 3). Figure 4 illustrates the time asleep distribution in the second and subsequent periods of night sleep over the two weeks preceding and immediately after Ramadan onset by weekday and weekend day types. Day-time sleep periods (e.g., nap) accounted for 1% and 6% of the individual measurements before and after Ramadan onset. Prior to Ramadan onset, the typical day-time asleep was ~2.5 h during weekends. The median day-time asleep was 2.7 h (IQR, 2.3 to 2.8 h) and 6.5 h (IQR 5.1 to 8 h) during weekday and weekend periods immediately after Ramadan onset, respectively. Regression diagnostics indicated the best model residuals were well-behaved and suggested adequate fit (Supplementary File 2). Figure 5 illustrates the distribution of time in bed and wake-after-sleep onset measurements over the first night cycle period by study surveillance phase and day type.

Figure 6 illustrates density curves for the distribution of individual s-RPE and high-speed running distances during

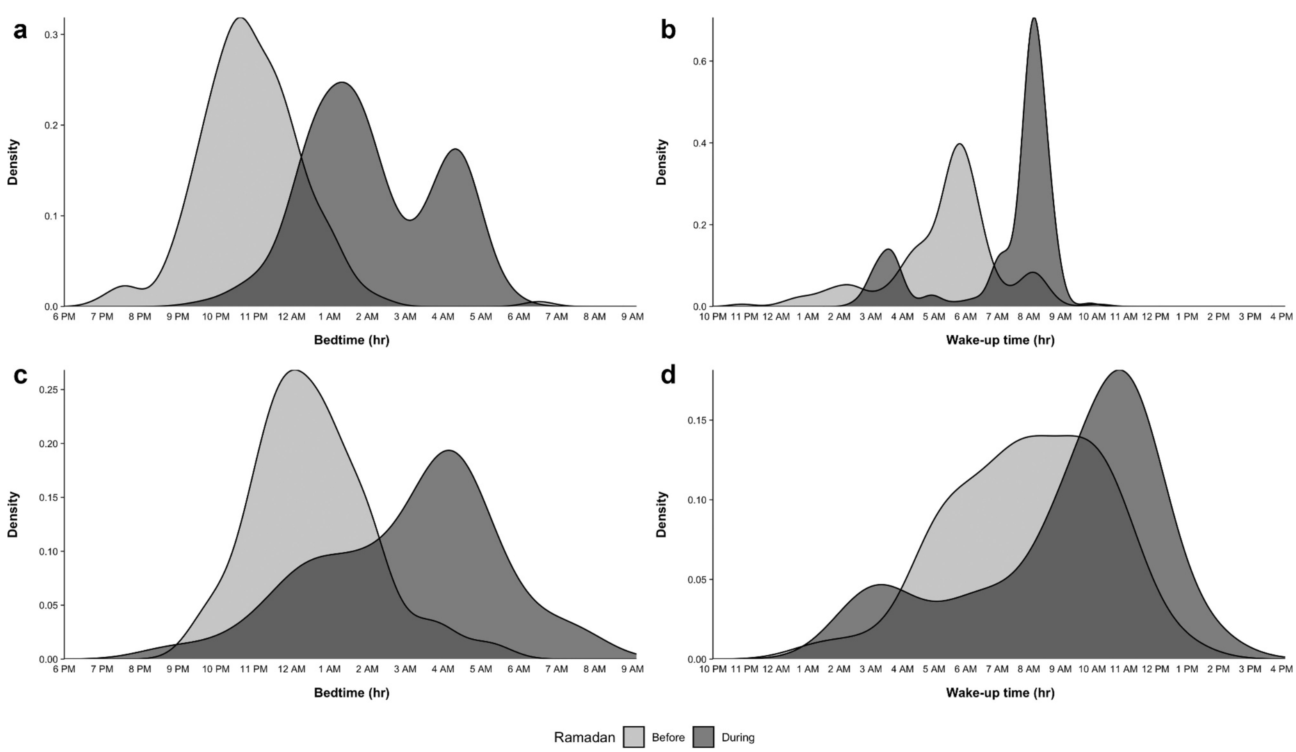

Figure 2. Kernel density curves for individual-participant bedtime and wake-up time observations before (light grey) and immediately after (black) Ramadan onset during weekday (a, b) and weekend (c, d) periods, respectively.

Table 1. Parameter estimates from the segmented generalized mixed-effects model for time asleep in minutes (measurement range: 15 to 22 individual-participant observations per time point).

Description	Estimate	95%CI	
Fixed effect			
Baseline time asleep	327	293	361
Pre-Ramadan trend	1	−3	4
Immediate or abrupt level change	−89	−123	−54
Impact of Ramadan on time asleep trend	3	−1	8
Influence of weekend	38	19	56
Random effect			
Between-subject variability	±46	32	65
Within-subject variability	±91	85	97

CI, confidence interval. *Random effects* are summarised as standard deviation on the original measurements scale.

morning and afternoon sessions in periods preceding and immediately after Ramadan onset, respectively. The median s-RPE and high-speed running distance covered were 140 au (IQR, 120 to 210 au) and 14 m (IQR, 3 to 34 m) during morning training sessions in the two weeks preceding Ramadan onset (Figure 6(a,c)). Descriptive information for afternoon training sessions revealed median s-RPE and high-speed running distance values of 300 au (IQR, 200 to 420 au), 320 (IQR, 240 to 350 au), 115 m (IQR, 44 to 224 m), and 132 (IQR, 58 to 218 m) for training sessions in the two weeks preceding and immediately after Ramadan onset, respectively (Figure 6(b,d)).

Discussion

For the first time, we adopted a quasi-experimental, interrupted time-series research design to examine the abrupt effects of Ramadan onset on actigraphy-based measurements of sleep. In addition to the problems of insufficient sleep during time periods preceding Ramadan, the main findings of our study indicated Ramadan onset led to systematic disruptions and heterogeneous fragmentation of a night cycle that resulted in additional time curtailments of ~ 1 to 2 h in the first period of night sleep irrespective of school and training schedule adjustments nor any daytime sleep compensation.

In Islamic countries, the timing of morning commitments is generally delayed and adjusted to accommodate Ramadan observance (Roky et al. 2004; Qasrawi et al. 2017). However, researchers raised concerns regarding how such policies may lead to a concurrent delay in bedtime that can influence time asleep itself (Roky et al. 2004; Qasrawi et al. 2017; Bahammam and Pirzada 2021). For example, Farooq et al. (2015) highlighted that children and adolescents may face meaningful challenges in following a healthy sleep routine consistent with age-specific recommendations (Hirshkowitz et al. 2015) when Ramadan falls during the school year (DeLang et al. 2022). Contextually, any school commitment still requires an early morning wake-up time for a 6-h school day, regardless of any minor adjustment to the school schedule during the month of Ramadan (Farooq et al. 2015). Practical modifications to school and training also took place in our study, with the first morning school class moved to 09:30 from 08:00 alongside inherent adjustments in session training time and volume (Figure 4). Notwithstanding this, the frequency of bedtimes from our study participants was systematically shifted to later hours with Ramadan onset yet fundamentally heterogeneous irrespective of day type (Figure 2(a,c)). Formal comparison of our findings with timing insights from the existing literature remain prohibitive given research exploring the effects of Ramadan diurnal fasting on objective sleep outcomes only ($n = 8$ studies) involved mainly general populations of adult participants from the Kingdom of Saudi Arabia also examined in different seasons (Faris et al. 2020; Trabelsi et al. 2020, 2021). Existing studies involving populations of youth and adolescents from the State of Qatar assessed the effects

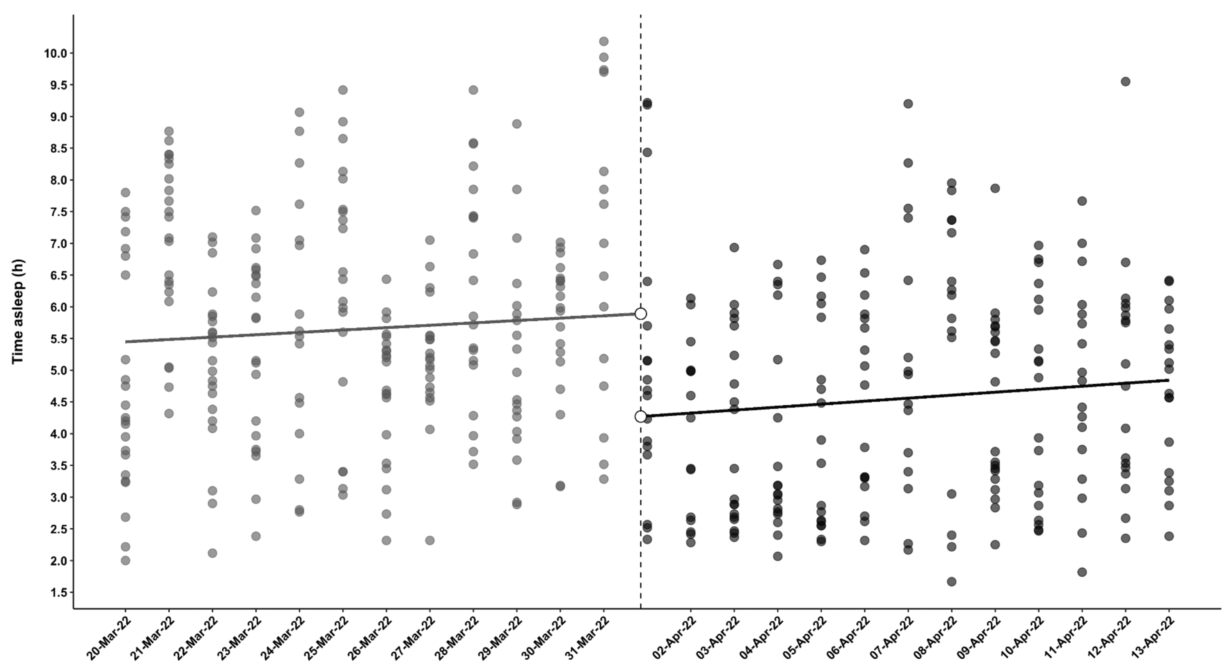

Figure 3. Interrupted time series with level change impact model for pre-post effects of Ramadan onset on time asleep. Light grey and black scatter dots denote individual-participant observations before and immediately after Ramadan onset, respectively. Solid line denotes the fitted model, the vertical dashed line indicates Ramadan onset.

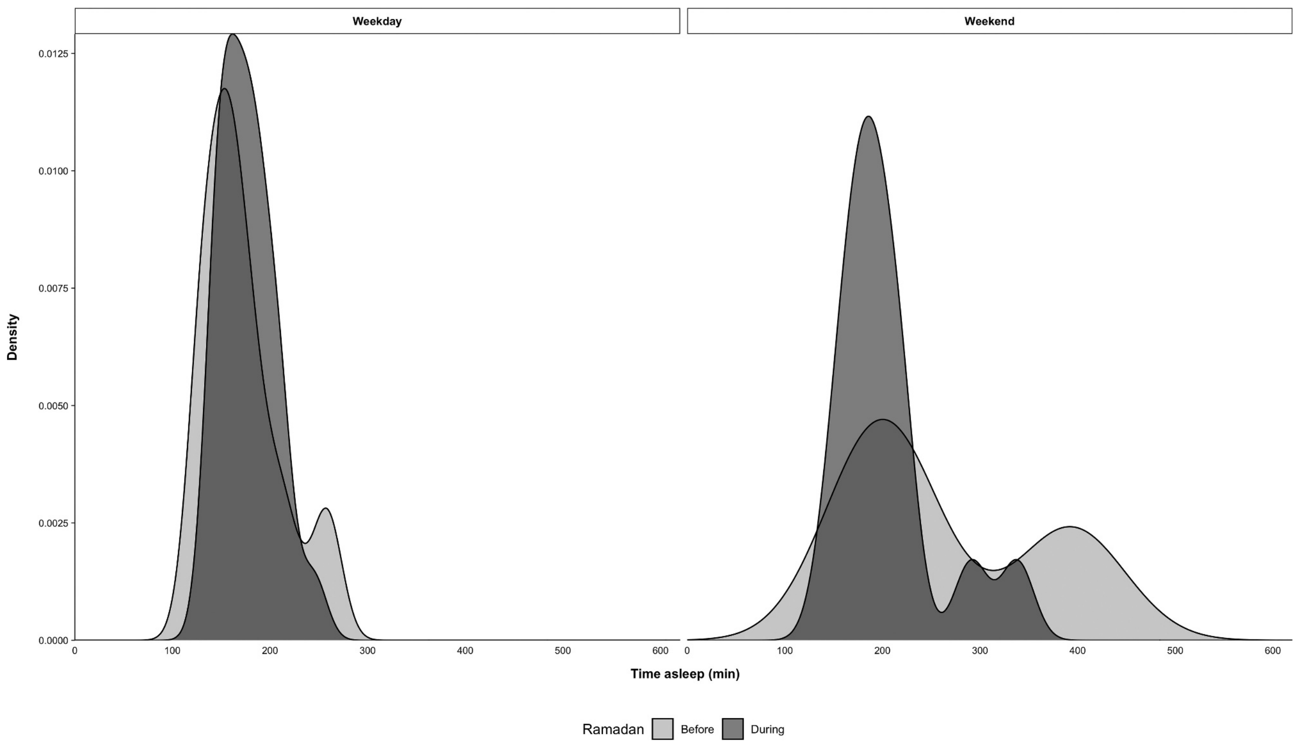

Figure 4. Kernel density curves for individual-participant time asleep observations in the second and subsequent periods of night sleep over the two weeks before (light grey) and immediately after (black) Ramadan onset during weekday and weekend day types.

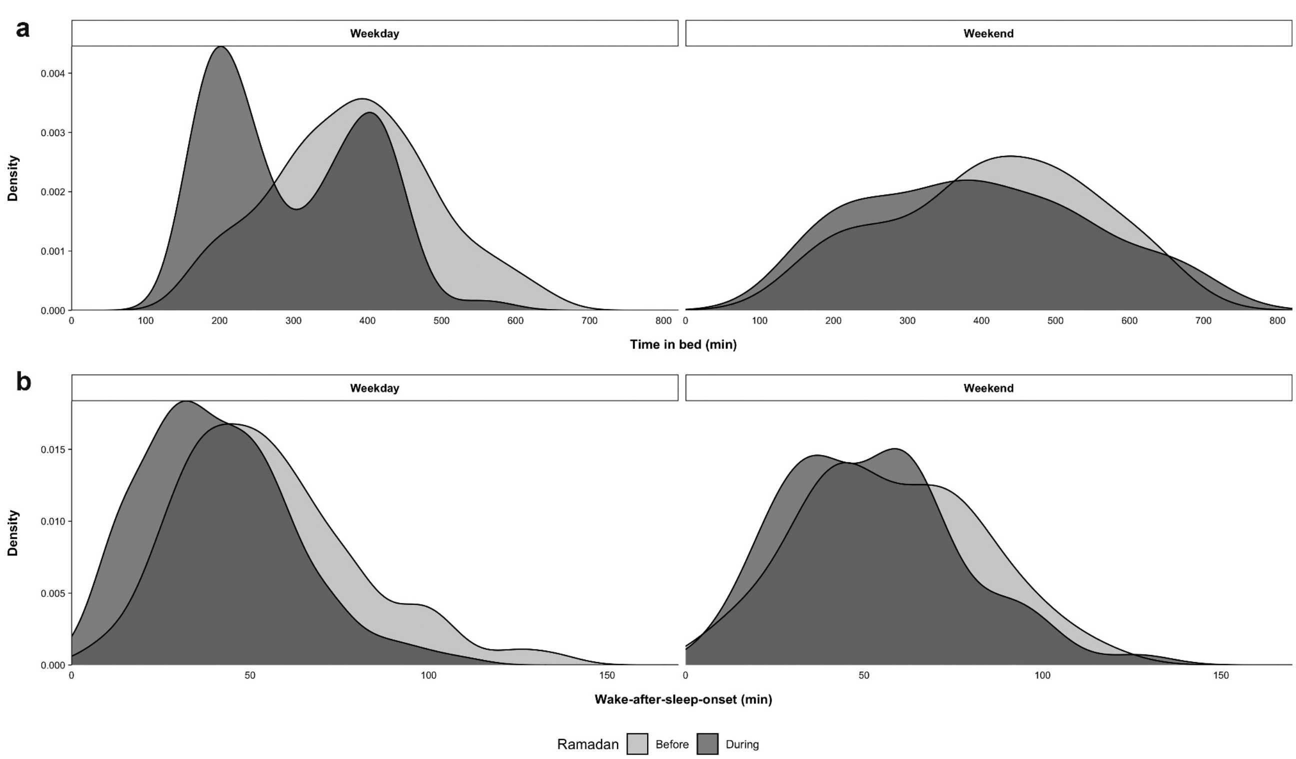

Figure 5. Kernel density curves for individual-participant time in bed (a) and wake-after-sleep-onset (b) observations before (light grey) and immediately after (black) Ramadan onset during weekday and weekend day types.

of Ramadan onset using subjective measurement tools (Wilson et al. 2009; Herrera 2012; Farooq et al. 2015) that are prone to bias and with the potential to provide spurious clinical insights (Lauderdale et al. 2008; Billings 2022). Actigraphy-based sleep tracking in first-team professional football players competing in the Qatar Stars League revealed their time asleep *during* Ramadan increased by ~99 min when compared to the weeks after *the end of* Ramadan observance (Wilson et al. 2009). The delay in bedtimes

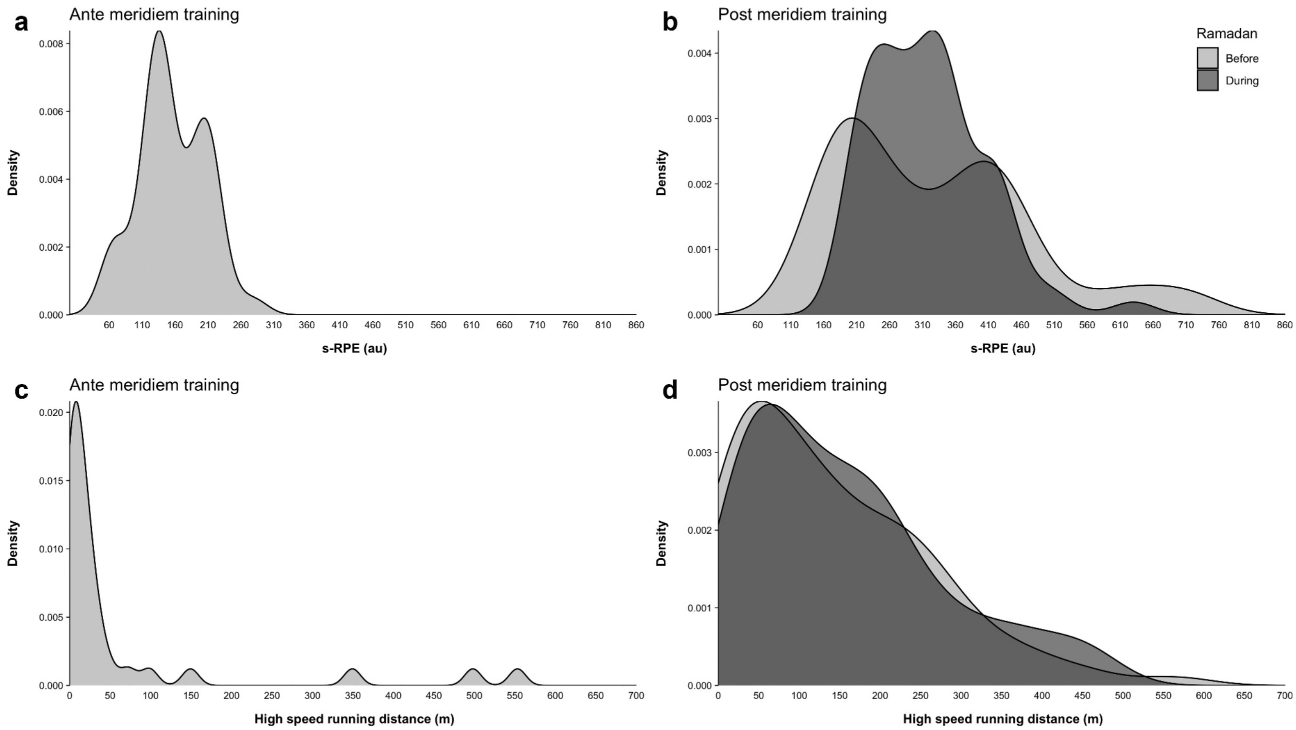

Figure 6. Kernel density curves for individual-participant s-RPE (au) and high-speed running distance covered (m) observations before (light grey) and immediately after (black) Ramadan onset, respectively.

and, importantly, wake-up times would explain how first-team professional football players in that study attempted to cope with the demands of Ramadan onset, although information relevant to fulfilling any potential work obligation in the morning was not reported (Wilson et al. 2009). The heterogeneity and operational inconsistencies of definitions provided for describing *time asleep* in these and other studies (Gringras et al. 2012; Reed and Sacco 2016; Faris et al. 2020) also pose additional challenges that render any practical between-study comparison implausible. Collectively, the sample characteristics, research designs, and methodologies of investigations conducted in populations from the State of Qatar preclude drawing any direct empirically plausible generalisation relevant to our study settings.

Research in this field informed clinical and methodological considerations for devoting a particular attention to the first period of a night cycle in our study (Wilckens et al. 2014; Van Someren et al. 2015). Importantly, clinical evidence in this and other domains substantiated the importance of a one-off, unperturbed continuous period of sleep as a *conditio sine qua non* to ensure optimal cognitive and physiological processes (Akerstedt et al. 1994; Wilckens et al. 2014; Van Someren et al. 2015). Any disruption of a night cycle that typically occurs during Ramadan can result in any form of sleep loss that ultimately impairs exposure to natural daylight-darkness alternation and, physiologically, determines alterations in the circulating levels of leptin and ghrelin that are pivotal in appetite regulation (Knutson et al. 2007; Reilly and Waterhouse 2007; Shephard 2013). From a medical perspective, sleep loss denotes not only any curtailment in duration but also reflects the influence of clinical and contextual factors that diversify sleep loss itself into different aetiological patterns (Luboshitzky et al. 2001; Reynolds and Banks 2010; Craven et al. 2022). Partial sleep deprivation, or restricted sleep, refers to when individuals complete sleep cycles shorter than their normal age-specific requirements in periods of delayed sleep onset (*early restriction*) or earlier sleep offset (*late restriction*) (Craven et al. 2022). Sleep fragmentation combines features of both early and late sleep restriction patterns yet resulting in a general sleep cycle that is disrupted by one or more nocturnal awakenings (Luboshitzky et al. 2001; Reynolds and Banks 2010; Craven et al. 2022). Sleep fragmentation *per se* represents a clinical problem that can have negative cardiometabolic health-related consequences for youth and adult populations as detrimental as curtailed sleep (Van Someren et al. 2015). Likewise, timing regularity between-night cycles is central to preserve circadian synchronisation between the body clock and exogenous factors that are harmonised by the natural environmental daylight-darkness alternation (Reilly and Waterhouse 2007). Night sleep interruptions that resulted in two or more sleep periods accounted for 8% (95%CI, 2 to 21%) to 19% (95%, 11 to 29%) only of the present study observations, thereby highlighting further the clear heterogeneity of sleep loss patterns. However, the bimodal yet heterogeneous distribution of bedtime and wake-up time with Ramadan onset (Figure 2), particularly during weekdays, precluded identifying a distinct clinical pattern of sleep loss despite evident sleep curtailment issues compared to the general habits before Ramadan (Figure 3). The nature of the bedtime data distribution during weekdays (Figure 2(a)) provided insights regarding the impact of Ramadan, whose extent seems fundamentally multifactorial. Logically, such data patterns highlighted additional problems of sleep regularity that become further compromised during the first phases of Ramadan observance. The bimodal distribution of bedtimes would thus indicate idiosyncratic yet irregular coping strategies by student-athletes from our study to adapt to Ramadan onset (Figure 1).

Nevertheless, these patterns may also reflect the influence of lifestyle and environmental changes determining a shift in weekday bedtimes due to the transition to Ramadan reconcilable with the general effects of social jet lag (Logan and McClung 2019). We maintain these considerations remain speculative and limited to the logical reasoning of our study findings. Contextualising further our results in practice, insights from our study mandate adopting an integrated approach that involves different strategies to reduce the burden of inconsistent sleep habits and fragmentation for the youth Muslim observant. First, including regular sleep hygiene education programmes as part of a school curriculum (Ming et al. 2011) seems paramount to increase awareness and promote healthy habits during Ramadan observance and throughout other phases over a Gregorian calendar. Second, reconsidering any existing modification of typical weekly school schedules to address further Ramadan onset may also constitute a strategy. While it might appear a logical solution, the general practice of delaying school times during Ramadan remains a matter of debate among researchers in this field. Farooq et al. (2015) emphasised how school commitments pose a burden to the observant Muslim and the need for adequate revisions during Ramadan. Conversely, Bahammam and Pirzada (2021) raised concerns regarding the general practice of delaying school and work time during Ramadan and how a fixed time for starting work and school is best aligned with human circadian biology regardless of the seasonal time of Ramadan observance itself. Despite anticipated problems of circadian desynchronisation due to the inevitable interference of Ramadan onset with fundamental human rhythms, ensuring the Muslim observant has adequate time, principally, for night sleep alongside the provision of relevant education on sleep hygiene remains the most viable solution to promote adequate and continuous time asleep consistent with age-specific requirements. Therefore, our investigation was also important to highlight the need to address contextual factors and educational problems that pose an additional burden to Ramadan observance in young Muslims from Middle Eastern countries.

Limitations

This first adoption of a quasi-experimental, interrupted time-series research design provided insights that advance current knowledge on changes in sleep patterns with Ramadan onset, yet requiring different considerations. The design of an interrupted time-series research study rests on meeting relevant assumptions and methodological standards (Kontopantelis et al. 2015; Bernal et al. 2017; Lopez Bernal et al. 2018). First, a fundamental assumption is that without the Ramadan onset, the effect we aimed to quantify, the pre-Ramadan sleep patterns would have remained unchanged into the Ramadan onset weeks and independent of any external factor that could have influenced the trends we observed (Kontopantelis et al. 2015). Second, a plausible justification of counterfactual definition (i.e., *the sleep patterns trend had Ramadan not occurred*) and an a priori context-informed definition of the impact model (i.e., *the type of effect that Ramadan onset is expected to have on objective sleep outcome measures*) requires careful attention for handling potential threats to validity for interrupted time-series regression analyses and to avoid spurious results (Bernal et al. 2017; Lopez Bernal et al. 2018). Impact models may take different forms whose pre-specification is contingent on prior and substantive contextual knowledge (Bernal et al. 2017; Lopez Bernal et al. 2018). The sudden occurrence of Ramadan typically leads to a cascade of changes in daily habits in Islamic countries, with a particular reference to a delayed start of work and school, shorter working hours, and social activities taking place until late at night that informed the specification of the impact model as *an abrupt level change model* centred at Ramadan onset. Third, interrupted time-series regression models are prone to bias and sampling imprecision when studying an effect with fewer than 12 data points before and after the time point of interest (Lopez Bernal et al. 2018). Accordingly, the limited size of our study sample and the participants' compliance with actigraphy-tracking not homogenous at all time points (Figure 2) constitute potential limitations that require careful attention. This probably resulted in potential actigraphy-based measurement imbalance across the planned surveillance time points, yet minimal given the degree of uncertainty in our model effects (Table 1). Notwithstanding this, and more specifically, our results indicated our sample was suitable enough for reasonably precise estimation of the abrupt level change and relevant sources of variability in time asleep given the width of the uncertainty surrounding the estimates for the fixed and random effects (Table 1). These outcomes highlighted further the importance of tracking study participants over a sufficiently adequate number of measurement occasions as a main research design justification criterion (Zhang et al. 2011) that may be explored further in settings similar to our study. Given these important aspects, we designed our study to plan a 25-day data collection period that could be realistically feasible to guarantee sufficient adherence in a Muslim population of youth athletes and address minimum data points requirements for interrupted time-series studies (Zhang et al. 2011; Lopez Bernal et al. 2018).

It is also important to highlight that interrupted time-series regression models are generally designed using country-wide, aggregate epidemiological data, whereas our study investigated the natural effects of Ramadan onset via an interrupted time-series regression model applied to individual-participant outcome measures. Ensuring linearity of trends, the characteristics of the population remained unchanged throughout the study, and no comparator was considered in the model to adjust results for changes whose extent rest solely on the natural experiment or the intervention itself represent other key assumptions for the validity of interrupted time-series regression studies (Kontopantelis et al. 2015) which our investigation satisfied. Likewise, the absence of information from sleep diaries complementary to our primary data collection, the lack of chronotype assessment, the criteria adopted for automated sleep detection, and the methodological challenges of comparing results with studies conducted in a different season of a Gregorian calendar also deserve particular attention. Sleep diaries constitute a feasible and inexpensive mean for collecting sleep data, although the fact that self-reported sleep outcomes are prone to response bias limit their utility (Lauderdale et al. 2008; Billings 2022). We also highlight the fact the quasi-experimental, interrupted time-series research design of the present investigation considered time asleep as the only primary outcome measure. The fundamental raison d'être of sleep tracking intends to provide an objective quantification of a person's sleep (Reed and Sacco 2016). Specifically, the *time in bed*, *time asleep*, and *wake-after-sleep-onset* variables all represent, essentially, alternative calculations of distinct measures yet part of the same physiological measurement defining different aspects relevant to a persons' sleep construct, with *time in bed* capturing them all (Reed and Sacco 2016). However, the fundamental meaning of sleep is mainly a question of '*sleep continuity*' whose physiological underpinnings rest on formal quantification of '*time asleep*' (Akerstedt et al. 1994). Accordingly, this highlights further the primary importance of time asleep per se also given its consideration as the numerator variable of the sleep efficiency index. Specifically, this index is calculated as the simple ratio of time asleep divided by total time spent in bed and multiplied by 100 to yield a percentage statistic (Reed and Sacco 2016). Such calculations, let alone general considerations in sleep research (Reed and Sacco 2016), substantiate the fundamental importance of *time asleep* despite conceptual and methodological pitfalls inherent to the sleep efficiency index due to mathematical coupling issues between the numerator variable (Y), *time asleep*, being included as part of the denominator variable (X), *time in bed* (Altman 1991; Walsh and Lee 1998). While automated sleep period detection followed manufacturer settings, it may have contributed to the limited number of nap periods in our set of observations based on 2 h and 40 min as a criterion denoting the minimum amount of time between bedtime and wake-up time. Adherence to manufacturer recommendations, coupled with the absence of a formal sleep diary implementation in our study, also requires attention to what bedtime per se constitutes from conceptual and operational standpoints. Actigraphy-based tracking facilitates automated sleep period detection, whose calculation generally starts at bedtime and that is referred to as *the actual time at which an individual first fell asleep after going to bed*. However, the absence of sleep diary data collection likely resulted in underestimating *non-sleep-related activities in bed* that are part of bedtime itself, given its general definition that can refer to when a person physically enters in bed. Fundamentally, such practical aspects indicate the need for scientific consensus on established operational taxonomies relevant to calculations of proxy sleep measures across different commercial manufacturers for methodological and practical consistency. Also, investigations exploring the effects of Ramadan in populations from the State of Qatar took place in September (Wilson et al. 2009; Herrera 2012; Farooq et al. 2015) and thus suggest caution when comparing and generalising our study findings. Narrative and systematic reviews on the effects of Ramadan also explored its influence on athletes' physical performance, with inconsistent findings (Waterhouse 2010; Abaïdia et al. 2020). Nonetheless, any potential short-term performance decrement appears unlikely to be meaningful in professional athletes.

Conclusions

This is the first quasi-experimental, interrupted time-series study to explore the abrupt effects of Ramadan on objective time asleep outcomes in young Muslim football players. The onset of Ramadan resulted in an abrupt reduction in time asleep of ~1 h 30 min during the first period of a night cycle and contributed to additional problems of heterogeneous sleep fragmentation. Training loads were consistent with pre-Ramadan observance values aside from differences in morning training volumes. Curtailment and fragmentation of a sleep cycle require careful monitoring and can impact optimal school learning and youth athlete performance development processes.

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Author contributions

Lorenzo Lolli: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Project administration. **Warren Gregson**: Conceptualization, Methodology, Investigation, Writing – original draft. **Adam Pulford**: Supervision, Writing – review & editing. **Tane Kanope**: Supervision, Writing – review & editing. **Emmanuel Lopez**: Supervision, Writing – review & editing. **Valter Di Salvo**: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Code availability statement

Supplementary File 1 includes Stata base commands.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval statement and informed consent

Signed parental consent prior to the beginning of the competitive season to use data for service provision and research purposes. This project was part of a larger longitudinal project on youth academy athletes approved by the Anti-Doping Laboratory Institutional Review Board, Qatar (protocol number: E20140000012).

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