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Impact of Ramadan intermittent fasting on cognitive function in trained cyclists: a pilot study

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ABSTRACT: This study assessed selected measures of cognitive function in trained cyclists who observed daylight fasting during Ramadan. Eleven cyclists volunteered to participate (age: 21.6±4.8 years, VO_2max: 57.7±5.6 ml·kg^{-1}·min^{-1}) and were followed for 2 months. Cognitive function (Cambridge Neuropsychological Test Automated Battery (CANTAB), Reaction Time index (RTI) and Rapid Visual Information Processing (RVP) tests) and sleep architecture (ambulatory EEG) were assessed: before Ramadan (BR), in the 1st week (RA1) and 4th week of Ramadan (RA4), and 2 weeks post-Ramadan (PR). Both cognitive tests were performed twice per day: before and after Ramadan at 8-10 a.m. and 4-6 p.m., and during Ramadan at 4-6 p.m. and 0-2 a.m., respectively. Training load (TL) by the rating of perceived exertion (RPE) method and wellness (Hooper index) were measured daily. If the TL increased over the study period, this variable was stable during Ramadan. The perceived fatigue and delayed onset muscle soreness (DOMS) increased at RA4. Sleep patterns and architecture showed clear disturbances, with significant increases in the number of awakenings and light sleep durations during Ramadan (RA1 and RA4), together with decreased durations of deep and REM sleep stages at PR. RTI (simple and multiple reaction index) reaction and movement times did not vary over the study period. The RVP test showed reduced false alarms during Ramadan, suggesting reduced impulsivity. Overall accuracy significantly increased at RA1, RA4 and PR compared to baseline. At RA4, the accuracy was higher at 0-2 a.m. compared to 4-6 p.m. Despite the observed disturbances in sleep architecture, Ramadan fasting did not negatively impact the cognitive performance of trained cyclists from the Middle East.

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INTRODUCTION

Muslim athletes experience specific challenges during the month of Ramadan. During this 29-30-day period, they are required to train or even compete while they do not eat or drink from dawn to sunset. Given the constraints that Ramadan intermittent fasting (RIF) can induce on Muslim athletes, researchers have mainly investigated the link between RIF and physical performance in athletes [1, 2]. Interestingly, researchers found that when athletes' sleep schedule was controlled, the effects of RIF on physical performance were negligible [1, 3]. This suggests that cognitive function could moderate the relationship between RIF and physical performance.

The literature indicates that limited attention has been given to the impact of RIF on cognitive performance in athletes [4]. Recently, Tian et al. [4] examined the effect RIF on cognitive function according to time of day in healthy Muslim athletes. They found that (a) in the morning (09:00 h), detection and identification performances were better during fasting than after Ramadan, while (b) in the afternoon (16:00 h), verbal learning and short-term memory performances were better after Ramadan than during fasting. These findings indicate that the effects of RIF on cognitive function were heterogeneous and domain-specific with respect to the time of day.

Ramadan adaptations depend on geographical location and/or culture [5, 6]. While some Muslims keep relatively active during the day, others simply invert day/night patterns, keeping active at night by shifting their main sleep to the daylight time. In the Middle East, for instance, hot climate likely contributed to the more common night-to-day shift, with most athletes sleeping during the day, and living/training at night. Therefore, testing cognitive function in such a population has to be done taking into account the individuals' lifestyle. It would make no sense to wake up an athlete at 9 a.m. during Ramadan to test his cognitive function, knowing that he went to bed and fell asleep only a few hours before. Therefore, for such a population cognitive function testing should be performed as follows: in the morning and afternoon before and after Ramadan [4], and shifted to afternoon and evening during Ramadan, in order to respect the fasters' circadian rhythm.

Moreover, as sleep schedule and quality could impact on cognitive function [5], a sleep-related measure could help interpret the results of cognitive function measures during Ramadan. Sleep can be monitored through objective measures, such as ambulatory polysomnography via light belt devices. It can also be assessed every day through the Hooper index [7, 8], with quality of sleep reported by the study participants. The latter index, reporting the athletes' wellness, can also serve, along with the training load monitoring assessment [9], to check if there is any possibility of training impacting the athletes' general wellness/fatigue status, and thus cognitive function.

The present study tested how RIF influences cognitive function according to time of day in trained athletes from the Middle East fasting during Ramadan. Cognitive function was examined through simple and complex reaction movement time (RTI) and rapid visual information processing (RVP) because these measures have been related to sports requirements [4, 10-14]. Measures of training load, wellness and sleep were also assessed to neutralize any confounding factors.

MATERIALS AND METHODS

Participants. Eleven healthy male trained cyclists (7 seniors and 4 juniors) volunteered to participate in this study. They were regularly training throughout the study period (see below). Their age, anthropometric, and VO2max data were as follows: 21.6±4.8 years (range: 16.3-30.5), 66.8±9.1 kg, 176.1±6.0 cm; 57.7±5.6 $ml \cdot kg^{-1} \cdot min^{-1}$ (all measured one week after Ramadan). For external validity of the results, only athletes with previous experience of Ramadan fasting were selected [15]. Participants began fasting at the age of 12.6±0.7 years and were experienced with fasting during Ramadan. The participants had cycling training experience of 9.6±3.6 years. All participants signed an informed consent form (with signed consent from the parents when appropriate) before participating in the study. The study protocol respected the Helsinki convention, and was approved by the Shafallah-IRB committee, Doha, Qatar.

Experimental procedures

The study was conducted during the summer of 2013. Ramadan occurred from the 9th of July to the 7th of August. The participants were living in a residential training camp for 3.5 months from July to mid-October, preparing for an international competition starting on the 20th of October. Participants spent the pre-Ramadan period and the first week of Ramadan training in the GCC (Middle East), and then relocated to Europe for the overseas summer training camp. When in the GCC, the minimum fasting duration was approximately 15 h 15 min (first day of Ramadan, dawn: 3:16 a.m. to sunset: 6:29 p.m.). In the Europe training camp location, this duration was extended to ~16 h 30 min (last day of Ramadan: dawn: 4:07 a.m. to sunset: 8:36 p.m.). During Ramadan, there was a clear shift of bedtime for all the participants. Indeed, the cyclists shifted pre-Ramadan sleep from night-time to day-time sleep during Ramadan. Most of them stayed awake for the whole night and then took their Sohoor (last meal allowed before starting the fast), had their prayers and then went to bed to start sleeping in early morning.

The cyclists were in a slow-progressively increasing training load period, bringing them to the objective of their training process (the international race, starting on October the 20th, i.e. ~2.5 months after the end of Ramadan). Training was first composed of endurance training, and then intensity training was progressively included. The cyclists started to participate in competitions 2 weeks after the end of the study. Therefore, the measures were performed in a period of exclusive training with a slight progressive increase in training load. Training load and cyclists' wellness were measured daily and are reported for the 2 weeks before Ramadan, the month of Ramadan, and for 2 weeks post-Ramadan. Cognitive function and sleep measures were performed at 4 time points: the last week before Ramadan (BR), at the end of the first week of Ramadan (RA1), at the end of the 4th week of Ramadan (RA4), and at the end of the 2nd week post-Ramadan (PR).

Cognitive function assessment

Participants were familiarized with the cognitive function tests once, 10 to 12 days before Ramadan. During the testing period, each athlete was tested at 2 times of day at BR, RA1, RA4, and PR. The two times of day were chosen taking into account the sleep pattern of the participants and in order to respect an inter-test interval of about 8 hours. Before and after Ramadan the tests were performed at 8-10 a.m. and 4-6 p.m. During Ramadan, the testing times were shifted to 4-6 p.m. and 0-2 a.m., respectively. Thus, participants were tested in the beginning and middle of their awakening time. The only cognitive test that was performed in a fasted state was the first measurement during Ramadan (end of afternoon, 4-6 p.m.), as the fasting break (Iftar) always occurred after 6 p.m. During cognitive function assessment, the cyclists were tested in a quiet room with environmental conditions of 22-23.5°C and 50-60% humidity.

The administered tests were part of the Cambridge Neuropsychological Test Automated Battery (CANTAB). This computerized neuropsychological assessment was developed at Cambridge University in the 1980s [16-18]. Two tests were extracted from the CANTAB battery to assess, Reaction Time (RTI), and Rapid Visual Information Processing (RVP), to assess cognitive processes involved when practising sports [4, 10-14]. The tests were administered using a computer with a touch-sensitive screen. Application of the test and feedback were performed in a standardized manner [16].

Reaction Time (RTI)

RTI is a latency task with a comparative history (the five-choice task) and uses a procedure to separate response latency from movement time.

Task: The test is divided into five stages, which require increasingly complex chains of responses. In each stage, the participant has to react as soon as possible to a yellow dot that appears on the screen. In the simple reaction time task the dot appears in the only circle appearing on the screen. For the multiple reaction time, the dot may appear in one of five locations present on the screen. To that, the participant must respond by (1) touching the screen, (2) using the press pad, and finally by (3) using both actions.
Outcome measures: The four outcome measures in RTI are divided into reaction time (simple and five-choice) and movement time (simple and five-choice).
Administration time: around 3 min.

Rapid Visual Information Processing (RVP)
RVP is a test of sustained attention, has proved to be useful in many studies, and is a sensitive measure of general focusing performance [12].
Task: A white box appears in the computer screen, inside which digits (from 2 to 9) appear in a pseudo-random order, at the rate of 100 digits per minute. Participants are requested to continuously focus on the screen to detect target sequences of digits and to register responses using the press pad. The digit sequences (2-4-6, 3-5-7, 4-6-8) are continuously displayed on the side of the screen in order to be seen and remembered by the assessed subject.
Outcome measures: The RVP outcome measures cover latency, probabilities and sensitivity (calculated using signal detection theory), hits, misses, false alarms and rejections.
Administration time: around seven minutes.

Both RTI and RVP were performed with a few seconds of rest in between. Therefore the battery testing time ranged from 10 to 11 min.

Training load and wellness assessment

The rating of perceived exertion (RPE) method was used to assess training load. The 'subjective' feeling of the athlete translates all the physiological and psychological variables into one rating, which is multiplied by the training duration to provide a single value of training load. TL = RPE x training duration (min). Weekly training load (TL) was also calculated as the sum of the week' daily TLs.

The RPE training load monitoring tool was first validated by [19] in sport, and has been specifically used in cyclists by [20-22], among others.

In addition to the RPE tool, the 'Hooper Questionnaire' was administered every morning to each cyclist to assess their Wellness score. This method presented by [7, 8] allows one to follow four variables: 1 – perceived sleep quality; 2 – perceived quantities of (a) stress, (b) delayed onset muscle soreness (DOMS), and (c) general fatigue.

Sleep measures

Ambulatory EEG (ZEO Sleep System, Zeo Inc, Newton MA) was used to estimate sleep duration, sleep macro-architecture, namely the specific sleep stages (light, deep, rapid eye movement (REM)), and periods of sleep interruption (i.e. awakenings). These were assessed during the primary sleep (nights before and after Ramadan, and day-time sleep during Ramadan) at BR, RA1, RA4, and PR. Cyclists were required to wear a light-weight headband which contains a single-channel, soft sensor to detect EEG activity. The device is easy to use, and provides rapid but validated results [23]. Participants always slept in quiet and dark bedrooms with air conditioning temperature set between 20 and 22°C. As the ambulatory devices were placed only during primary sleep, this study did not take into account the naps of the participants.

Statistics

All data were analysed with SPSS version 21.0, and expressed as mean±SD. A one-way within-subject analysis of variance (ANOVA) for repeated measures was used to assess the main effects of time (time points: BR, RA1, RA2, and PR) on changes in TL, Hooper index, and sleep parameters. A two-way ANOVA for repeated measures was performed to determine the effects of time and time-of-day on the cognitive function (RTI and RVP). Whenever a significant main effect or interaction effect was observed, post-hoc pairwise comparisons were performed using Šidák correction. The level of statistical significance was set at $p<0.05$.

RESULTS

Cognitive function

RTI
Reaction and movement times (simple and complex) and mean latency time were not significantly affected either by RIF or by time of day.

RVP
The false alarms log count was significantly reduced at RA1 (0.7±0.4, p=0.007), and RA4 (0.3±0.3; p=0.001) compared with baseline (n=1.1±0.5). Overall accuracy was significantly increased at: RA1

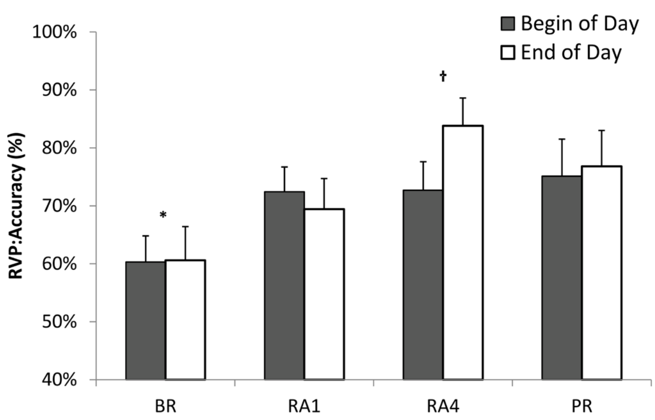

FIG. 1.
RVP test: Accuracy changes over the study period. For legend see figure 2. * mean daily measure (averaged measures of 2 times of day) significantly different compared to other time points. † two measures of the day significantly different from each other.

(+10%±3, p=0.042), RA4 (+18%±2, p=0.001), and PR (+16%±4, p=0.026) compared to baseline (Figure 1). At RA4, the accuracy was higher at the end of day compared to the beginning of day (p=0.002).

Training load

Figure 2 shows the average weekly training load over the 2-month study. There was no significant change of TL throughout Ramadan. Nevertheless, there was a significant increase in TL over the 2-month study period, with TL of 2 weeks BR and that of 2 weeks PR being significantly different than the rest of the measures. The Hooper index (sum of 4 scores) did not differ during Ramadan compared to BR. Nevertheless, the Hooper index at RA4 was significantly higher than that of RA1. Within the Hooper index score, the perceived DOMS was significantly higher at RA4 compared to RA3 and RA1. Likewise, perceived fatigue was significantly higher at RA4 and 2 weeks-PR compared to RA3.

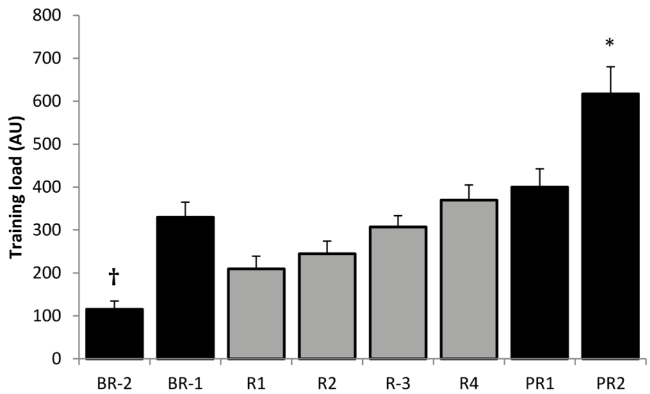

FIG. 2. Daily training load (mean ± SE) for 8 weeks of training. BR-2: two weeks before Ramadan; BR-1: one week before Ramadan; RA1; RA2, RA3, RA4: first to fourth weeks of Ramadan, respectively. PR1; PR2: weeks 1 and 2 post-Ramadan, respectively. † significantly lower compared to other time periods, * significantly higher compared to other time periods.

Sleep measures

With respect to baseline (one week before Ramadan – BR), the total sleep duration of the main/primary sleep did not change significantly over the study period (see Figure 3). Bed time shifted from 2:50 a.m. before Ramadan to 5:04 a.m. at RA1, 6:14 a.m. at RA2, then strongly shifted back to 00:21 a.m. after Ramadan. At RA1, 25% of the participants had very long sleep durations (more than 9 hours) [24]. This was inverted during the last week of Ramadan, with 25% of the participants having very short sleep durations (shorter than 6 hours) [24]. Although mean sleep duration decreased from around 7 h at baseline and at RA4 to less than 6 h at 2 weeks post-Ramadan, the high heterogeneity of the data resulted in no significant difference between values. The number of awakenings during sleep tended to increase during the first (4.3±2.6, p=0.013) and last week of Ramadan (3.9±3.6, p=0.033) compared to pre-Ramadan (1.9±1.7), and 2 weeks post-Ramadan (2.4±1.7) values, being similar to baseline. Sleep architecture was also impacted during the study (Figure 4). Light sleep duration significantly increased at RA1 and RA4 and then turned back to baseline values at post-Ramadan, while deep and REM sleep stages duration progressively decreased during the study to reach significantly lower values than baseline at 2 weeks PR.

DISCUSSION

This study investigated cognitive function measures in trained cyclists from the Middle East who fasted during Ramadan. Simple and com-

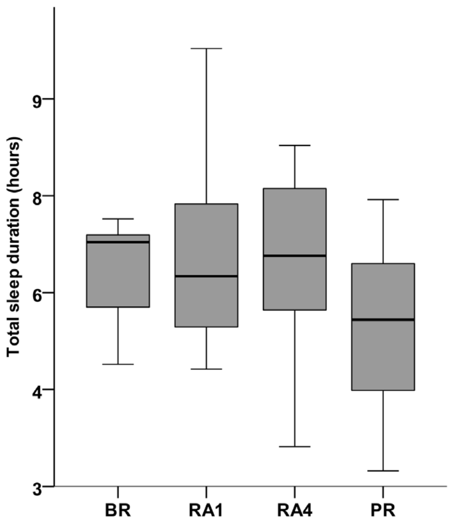

FIG. 3. Box plot of total sleep duration. Total sleep duration of the participants over the study period.
BR: one week before Ramadan; RA1: end of first week of Ramadan; RA4: end of fourth week of Ramadan; PR: end of 2nd week post-Ramadan.

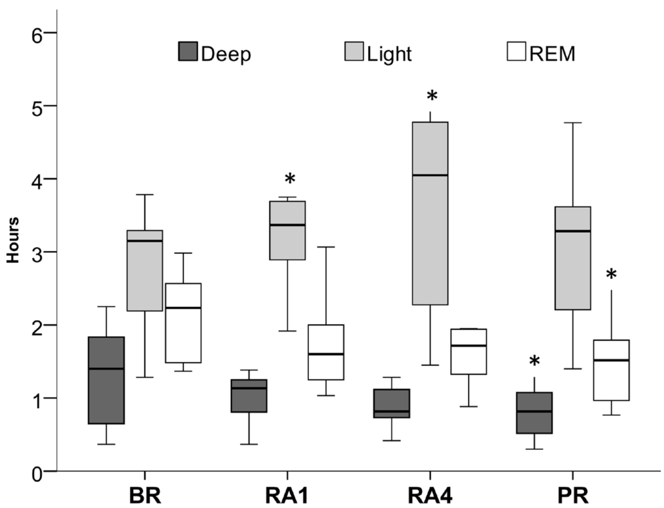

FIG. 4. Sleep architecture measures over the study period.
*: significantly different from baseline. For other legends, see fig. 2.
* significantly different compared to BR.

plex reaction and movement times did not vary over the study period, whereas false alarms decreased on the sustained attention task during Ramadan. Overall rapid visual information processing accuracy was higher at 0 2 h a.m. compared to 4-6 p.m. at the end of Ramadan.

Reaction and mean latency times on simple and complex tasks were neither affected by RIF nor time of day. This is consistent with some studies and conflicting with others. Green et al. [25] found no effect of fasting on simple reaction time and sustained attention. These findings are inconsistent with other studies [4, 26] that have shown that tasks requiring rapid reaction (detection and identification tasks) are sensitive to fasting. Bouhlel et al. [27] observed a complex effect of RIF with a negatively impacted simple reaction time at the end of Ramadan and no effect on complex reaction time. Roky et al. [28] reported a delay in movement reaction time only during the first week of Ramadan. In sum, the set of findings suggests that the relationship between fasting and RTI performances is complex because it is context- and moment-dependent [27].

The sustained attention accuracy was significantly increased during Ramadan (RA1 and RA4) as compared to baseline. This is in accordance with Tian et al.'s findings [4] that showed that detection performances were better during Ramadan, supporting the hypothesis that fasting increases detection abilities. Along with these findings, the obtained wellness index value showed that self-reported fatigue significantly increased over the Ramadan period. Consequently, the increase in accuracy during Ramadan seems robust enough to not be negatively impacted by a reported fatigued state. The accuracy increase could also be explained by a potential test-habituation effect or other physiological factors such as blood glucose [29]. In this context, it should be noted that such tests have been shown to be insensitive to any habituation effect [17, 18].

Another important finding of the present study is that at the end of Ramadan, even though the cyclists reported to feel more fatigued, the second measure of the day (0-2 a.m.) RVP accuracy was significantly higher compared to the start of the day measure (4-6 p.m.). This unexpected finding could be explained by a circadian shift and/or higher concentration of blood glucose, because previous studies showed that higher blood glucose tended to preserve visual processing tasks, at the expenses of speed [30]. Owen et al. [29] found in that regard a glucose facilitation effect for certain cognitive tasks and not others, with a specific effect according to the glucoregulatory status of the subjects. For instance, participants with good glucose regulation actually felt calmer and performed better and faster in several cognitive tests compared to those with poor glucose regulation. As no blood glucose measures were taken and no nutritional logs were collected in the present study, this remains pure speculation that should be further investigated in the future. In this context, it is not clear why this improvement in accuracy was significantly higher for the second measure of the day only at the end of Ramadan and not at the other time points. Consequently, further studies should replicate the study while controlling blood glucose and variables linked to circadian rhythm, such as body temperature.

The variables that might have an impact on cognitive function measures will be discussed hereafter, in order to better understand the study conditions. The cognitive tests were administered to the participants at 2 times of day (TOD), before, during and after Ramadan. This was done because several studies have reported conflicting results when the TOD of the measures was not consistent. To be able to detect possible changes that would occur in the middle of the 'day' and 'later' when comparing Ramadan with non-Ramadan periods, the present study protocol was set to assess the cyclists at 2 different TOD, keeping a 'common' time for absolute comparisons purposes (see methods). This allowed us to detect changes at certain time points, that were not observable at another time of day (see discussion above). We recommend that Ramadan study protocols take into consideration the chronobiology effects in their measures.

Cognitive function measures were collected while training load (TL) varied over the whole 2-month period. Nevertheless, the evolution of weekly TL did not concern the Ramadan period for which the TL was held constant. Therefore, any modification of the measures during Ramadan could not be directly caused by the TL. Despite no significant increase in TL during Ramadan, at the last week of Ramadan, cyclists reported increased perceived fatigue and DOMS. This result is in accordance with previous studies showing increased fatigue at the end of Ramadan [31-33]. When interpreting the data, another factor should be taken into account. Ramadan fasting has also been shown to be accompanied by a possible increase in the exercise perceived exertion [27, 31, 34]. Therefore, even if the RPE method has been validated and used in cyclists [20, 21], the progressive but still non-significant increase in TL observed during Ramadan (fig. 2) could be due to a slight increase in external training load and/or to a progressively impacted exercise perceived exertion. In any case, the results of the present study will have to be interpreted keeping in mind an increase in the reported fatigue towards the end of Ramadan. Also, the measures at post-Ramadan were performed when the TL significantly increased with a concomitant related significant increase in perceived fatigue.

Total sleep duration did not change over the study period, but sleep architecture showed clear disturbances. Indeed, a significantly increased number of awakenings and light sleep duration during Ramadan (RA1 and RA4), and decreased durations of deep and REM sleep stages at post-Ramadan were observed. Previous studies [35, 36] reported reduced sleep durations during Ramadan. In Herrera's [35] study, PSQI questionnaires were used to assess the average sleep duration/patterns in Qatari football players involved in rehabilitation programmes (assessed players were in a free-living setting). In the study of BaHammam et al. [36], armband accelerometry was used. Both studies showed a reduction of total sleep time of about 1 hour. Conversely to these, the present study cyclists were continuously monitored by their technical/medical staff during their training camps. Therefore, the training camp related discipline ensured that a minimum amount of sleep was kept by the cyclists with resulting constancy in total sleep time. In addition, the present study also confirms what has already been suggested by others [1-3, 37, 38], with the 'living setting' having an important impact on the measures performed during Ramadan. For instance, the above mentioned authors stressed that when the athletes were living in training camps, with monitored sleep, nutritional and hydration patterns, many physical performance measures were not or only slightly affected by Ramadan fasting. Nevertheless, even though mean total sleep duration was not affected in the majority of the cyclists of the present study, some of them (25%) had long primary sleep in the first week of Ramadan and also 25% of them had short primary sleep durations at the end of Ramadan. This shows some sleep disturbance, which was confirmed by the sleep architecture measures. Indeed, Ramadan was accompanied by a significant increase in the duration of light sleep. BaHammam et al. [39] observed in healthy volunteers that Ramadan was accompanied by a decrease in REM sleep percentage, with no difference in sleep latency and non-REM sleep percentage. The increase in light sleep stage duration observed in the present study could be explained by the increase in the number of awakenings reported during Ramadan. This increase in sleep interruptions could be due to the increased metabolism that can take place due to late Sohoor (last meal before starting the fast) and/or increased food-seeking behaviours observed during periods of fasting that can disturb sleep [24]. It should be noted that the ambulatory sleep device used was validated for sleep architecture assessment, with a relative weakness at the level of the number of awakening times count. Nevertheless, even though the number of awakenings could be questioned, their number roughly doubled during Ramadan, suggesting robust changes at the level of this variable. Two weeks after Ramadan, the deep and REM sleep stages significantly diminished compared to baseline while light sleep returned to baseline values. These observed effects could be due to the training load increase effect and/or to a delayed effect of Ramadan. Unfortunately, the design of the present study does not allow these effects to be distinguished due to absence of a control group. Overall, the discussed sections about training and sleep show that the training load was constant, with increased fatigue towards the last week of Ramadan, concomitantly to significant negative effects on sleep architecture. It is important to note that despite reporting impacted sleep architecture/schedule in Muslims fasting during Ramadan, previous investigators [36, 39] reported no effect on the arousal index or daytime sleepiness. Another study also showed no impact of RIF on daytime sleepiness, drowsiness or vigilance [40], suggesting no potential major effect of these variables on cognitive function. In the light of the present study results, it is speculated that the cyclists were probably not in negative alertness and vigilance states. Nevertheless, it has to be noted that other authors contrasted this by reporting a decreased subjective alertness during Ramadan daytime followed by an increase of this variable at night [28]. This increase of night-time alertness could explain the end-of-Ramadan increase in RVP accuracy observed at 0-2 a.m. in the present study. It should be noted that this particular study showed impacted sleep duration in these subjects. The reason there were no significant changes in cognitive performance and likely no negatively impacted alertness in the present study is probably that the participants of the present study maintained total sleep duration. Therefore, it seems that fasting young athletes are able to maintain their cognitive performances when total sleep duration is maintained in the fasting period.

It is important to note that the cognitive function tests were all performed in resting conditions and not during effort. In that regard, it would be worth studying the effects of Ramadan fasting on the cognitive function of athletes' measures while exercising, for better ecological validity of the measures. As the duration of the present study cognitive tests was quite short (around 10 min), cognitive tests of longer duration should also be studied to be able to draw conclusions on tasks requiring long concentration. It is also important to point out that the present study did not include a 'control group'. This limitation is a main characteristic of many experiments about Ramadan fasting [1, 2, 41]. Indeed, when research about Ramadan fasting is performed in a Muslim majority country like in the GCC, it is quite problematic and ethically challenging to find non-fasting counterparts to the participants. Therefore, in such cases, the Ramadan measures are compared to the pre-Ramadan baseline as reference values, as usually reported in the literature.

CONCLUSIONS

The present study conducted in Muslim trained cyclists showed stable RTI performances (simple and complex reaction time and movement speed) throughout Ramadan when the training load was held constant. RTI performances were also unaffected even after Ramadan, when training load and fatigue were significantly increased. RVP (rapid visual information processing) performances suggest lower impulsivity of the cyclists during Ramadan, and even improved accuracy towards the end of Ramadan for the second measure of the day. Therefore, the effects of Ramadan intermittent fasting seem to depend on the type of assessed task, time of day of measurement, with no negative impact on the studied selected cognitive measures in the cyclists of the present study.

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