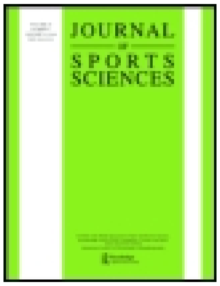

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The effects of Ramadan intermittent fasting on athletic performance: Recommendations for the maintenance of physical fitness

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Abstract

The behavioural modifications that accompany Ramadan intermittent fasting (RIF) are usually associated with some alterations in the metabolic, physiological, and psychological responses of athletes that may affect sport performance. Muslim athletes who are required to train and/or compete during the month-long, diurnal fast must adopt coping strategies that allow them to maintain physical fitness and motivation if they are to perform at the highest level. This updated review aims to present the current state of knowledge of the effects of RIF on training and performance, focusing on key-factors that contribute to the effects of Ramadan on exercise performance: energy restriction, sleep deprivation, circadian rhythm perturbation, dehydration, and alterations in the training load. The available literature contain few studies that have examined the effects of RIF on physical performance in athletes and, to date, the results are inconclusive, so the effects of RIF on competition outcomes are not at present wholly understood. The diverse findings probably indicate individual differences in the adaptability and self-generated coping strategies of athletes during fasting and training. However, the results of the small number of well-controlled studies that have examined the effects of Ramadan on athletic performance suggest that few aspects of physical fitness are negatively affected, and where decrements are observed these are usually modest. Subjective feelings of fatigue and other mood indicators are often cited as implying additional stress on the athlete throughout Ramadan, but most studies show that these factors may not result in decreases in performance and that perceived exercise intensity is unlikely to increase to any significant degree.

Current evidence from good, well-controlled research supports the conclusion that athletes who maintain their total energy and macronutrient intake, training load, body composition, and sleep length and quality are unlikely to suffer any substantial decrements in performance during Ramadan. Further research is required to determine the effect of RIF on the most challenging events or exercise protocols and on elite athletes competing in extreme environments.

Keywords: *athletic performance, coping strategies, training, time-of-day*

Introduction

Ramadan intermittent fasting (RIF) is a model of acute starvation and dehydration that can impose a significant challenge for Muslim athletes who continue to train intensively and/or compete while undergoing the month-long, diurnal fast (Chaouachi, Leiper, Souissi, Coutts, & Chamari, 2009b). The constraining nutritional protocol of this pillar of the Islamic religion requires healthy adolescent and adult Muslims to refrain from, amongst other things, eating and drinking from sunrise to sunset, for approximately 28–30 consecutive days. This can be especially problematic for those living in high latitudes when Ramadan falls during the summer months, when the hours of daylight are greatly extended, as will be the case in the Northern hemisphere over the next decade. Such restrictions lead to several behavioural modifications, including altered eating schedules and sleep patterns that may also result in decreases in sleep time and quality (Chaouachi et al., 2009b; Waterhouse, 2010). These factors can induce acute diurnal dehydration, altered substrate availability and utilisation, sleep

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deprivation, and can alter the body's normal circadian rhythms resulting in many changes to an individual's physiological and biochemical status. Collectively these changes may cause physiological and psychological perturbations that could have detrimental effects on sports performance.

Currently, the governing bodies responsible for the organisation of the major world-wide sports events do not take religious observance into account in scheduling the sporting calendar. For example, the 2011 FIFA U-20 world-cup in Colombia was predominantly played during the holy month of Ramadan, and the 2012 London Olympics will be held entirely during Ramadan. The Islamic calendar is lunar; therefore Ramadan occurs at different times of the solar calendar over a 33-year cycle. For instance, Ramadan in 2012 will occur at the height of summer making the fast duration as long as 16 hours in London, with the added problem of greater environmental stress during this time of the year. Although fasting is not obligatory for several categories of healthy and ill people who may choose to postpone the fast, the list of allowable reasons does not specifically include competitive athletes.

The RIF may have several important performance and physiological implications that may put competitive Muslim athletes at a disadvantage. Even small effects on performance may be sufficient to determine the outcome of sporting contests. Many concerns have been raised regarding the possible influence of RIF on exercise performance, and the question of whether fasting affects sports performance is still a matter of debate (Chaouachi et al., 2009b; Maughan, 2010; Maughan, Fallah, & Coyle, 2010; Mujika, Chaouachi, & Chamari, 2010; Waterhouse, 2010).

The effects of RIF on metabolism, health and performance have become a topic of considerable interest to both the scientific and athletic communities. This question has stimulated a variety of investigations during the past decade, and previous non-systematic reviews (Chaouachi et al., 2009b; Maughan et al., 2010; Mujika et al., 2010; Waterhouse, 2010) have been unable to reach a consensus. This has also led, among other initiatives, some specialised organisations to convene meetings to review the evidence for the probable effects of RIF on athletic performance. For example, the Medical Commission of the International Olympic Committee (IOC) in 2009 assembled a number of international experts to assess the impact of Ramadan on competitive athletes (Maughan et al., 2011). Because of the lack of scientific consensus on this question, a growing number of experts working in this field have suggested that research efforts should be transferred from trying to determine the effect of RIF on athletic performance to the development of strategies for training and competition that counteract the challenges imposed by RIF (Chaouachi et al., 2009b; Mujika et al., 2010; Roy, Ooi, Singh, Aziz, & Chai, 2011; Waterhouse, 2010).

This annual fasting month is not a uniquely stressful condition for athletes training and competing. Football, for example, is played in a variety of extreme environments around the world, including heat, cold, high altitude and travel across time zones (i.e. leading to jet lag). All of these act as stressors that can alter normal physiological function, homeostasis, metabolism, whole body nutrition, and hence human performance (Armstrong, 2006). In these situations, rather than accepting performance decrements as inevitable, athletes, coaches and sport scientists plan strategies for training and competition that offset these challenges. There appear to be good reasons to apply a similar approach in developing plans to reduce the stresses associated with Ramadan fasting without compromising the religious principles of Muslim athletes. To do this there is a need to determine the effects of these obligatory changes in behaviour and lifestyle imposed by RIF, and where required to attempt to alleviate any detrimental consequences.

Research methods

This review integrated studies that examined the impact of RIF on training and performance. The literature review was performed using ASAP, ProQuest 5000, MEDLINE, SPORTDiscus, AUSPORT, ScienceDirect, Web of Science and Google Scholar databases. The databases were selected as they contain extensive relevant literature in the areas of sports science. The electronic databases were searched using a number of key terms as selected by the authors: "athlete", "circadian rhythms", "cognitive function", "coping strategies", "dehydration", "energy intake" "exercise", "fasting", "fluid consumption", "hydration", "hypohydration", "Islam", "long term development", "time factors", "mental processes", "mood", "physical activity", "physical performance", "psychological", "sleep", "short term power output", "time-of-day-effect", "training", and "Ramadan". These keywords were used as separate words or in combination with each other for "title", "keywords" and "in-text search". The bibliographies of all reviewed articles were then searched and any relevant papers revealed by this method were included. Articles referenced by authors online or articles with restricted full text online were found in hardcopy form in library archives. The search ended on 15 January 2012.

Lifestyle and athletic performance

Performance of an athlete depends on the individual's technical, tactical, physiological, and psychological characteristics (Bangsbo, Mohr, Poulsen, Perez-Gomez, & Krustrup, 2006). Under optimum conditions, the demands in sport are closely related to the athlete's physical capacity, which can be divided into the following categories: the ability to perform prolonged exercise (endurance); the ability to exercise at high intensity; the ability to sprint; and the ability to develop a high power output (force) in single actions during competition such as kicking and jumping in football (Bangsbo et al., 2006). The physiological systems that underpin performance can be affected by many external factors, such as nutrition and hydration status (Burke, 2010; Burke & King, 2012; Maughan et al., 2010; Rodriguez, DiMarco, & Langley, 2009), and sleep (Waterhouse, Alabed, Edwards, & Thomas, 2009). Any change in these patterns, such as occurs during Ramadan, has the potential to reduce physical performance. It is well recognised that substrate availability, dehydration, hyperthermia, hypoxia, sleep loss, or resynchronisation of internal biological clocks are primary disrupters of homeostasis (Chaouachi et al., 2009b; Maughan et al., 2010; Waterhouse et al., 2009). Ramadan intermittent fasting imposes constraining nutritional and lifestyle protocols that can affect mental as well as physical performance (Waterhouse et al. 2009).

Athletic performance alterations during Ramadan

A great deal of information has been published in the scientific literature on RIF and the effects it has on physical activity (Al-Hourani & Atoum, 2007; Chaouachi et al. 2009b; Leiper, Molla, & Molla, 2003; Waterhouse, 2010), but most of these studies have looked at the effects in either sedentary or slightly-to-moderately active healthy subjects (Chaouachi et al., 2009b). Until 2007, no published data were available on the influence of RIF in competitive or elite athletes. Any Ramadan-related decrement in athletic performance reported in recent studies has been shown to be rather small (see Table I).

Sprint performance. Some studies have shown a reduction in anaerobic performance during Ramadan. One of the first published articles of the present era investigating the effect of RIF on performance was published by Ben Salama and colleagues (Ben Salama et al., 1993). This study showed that fasting reduced physical performance in both 100-m and 800-m races in fasting high-school Tunisian students. One other investigation reported a slight 2.5% increase in cumulative sprint times, but no effect on best time or sprint decrement during RIF in sedentary boys (Girard & Farooq, 2011).

Of the small number of studies that have tested sprint ability in competitive athletes, one has reported a 5.3% decrement in overall 6 x 40-m sprint performance, but no change in individual 20-m or 40-m sprint velocity in youth footballers during Ramadan (Meckel, Ismaeel, & Eliakim, 2008). A group of Algerian professional footballers also retained their sprint speeds over 5-m, 10-m and 30-m (Zerguini, Kirkendall, Junge, & Dvorak, 2007), while Kirkendall and colleagues (Kirkendall, Leiper, Bartagi, Dvorak, & Zerguini, 2008) reported approximately 2% faster 30-m repeated sprint times in both fasting and non-fasting elite Tunisian youth footballers with no alteration in 10-m repeated sprint velocity. A group of elite Tunisian Judokas maintained their 3-m, 10-m and 30-m sprint speeds throughout Ramadan (Chaouachi et al., 2009a). In a study conducted in Senegalese sprinters, Faye and colleagues (Faye et al., 2005) observed a negative effect of fasting on 3 x 150-m and 3 x 250-m sprint performance, but the differences in speeds were not reported in that paper and the athletes were found to be hypoglycaemic immediately before being tested during Ramadan. Studies involving competitive sprint-trained athletes would suggest that single sprint times over the range 5 to 40 m are not affected by RIF, but repeated sprinting with short recovery intervals (30 s) can increase summated time when overall physical training is reduced during Ramadan (Meckel et al., 2008).

It should, however, be recognised that in most of these studies (Chaouachi et al., 2009a; Meckel et al., 2008; Zerguini et al., 2007) there was an apparent slight decrease in mean sprint performance of $\leq$4% over the range of distances tested, but that none of these values reached statistical significance. While athletes and coaches may argue that any measured increase in the time to complete a sprint is significant in competition, variability in group data collection must be robustly and objectively assessed using appropriate statistical analysis. It is also pertinent to highlight that in the study where training load was maintained during Ramadan, sprint speeds were modestly, but significantly faster during Ramadan (Kirkendall et al., 2008).

Power output measure. Wingate performance (peak power and mean power) and maximal power tests appear to be essentially unaffected when tested in the morning during Ramadan (Abedelmalek, Souissi, Takayuki, Hadouk, & Tabka, 2011; Chtourou, Hammouda, Chaouachi, Chamari, & Souissi, 2012b; Karli, Güvenç, Aslan, Hazir, & Acikada, 2007), but anaerobic power was reduced substantially compared with the control period in the

Table I. A summary of the characteristics and results of studies that have investigated the effect of Ramadan on components of sports performance.

Authors	Subjects	Age (years)	Country	Measured parameters	Ramadan effect	Percentage change
Abedelmalek et al. (2011)	9 sport students	22 ± 0	Tunisia	Peak power during the Wingate test	NS	-
				Mean power during the Wingate test	NS	-
Asl et al. (2011)	15 male athletes	23 ± 1	Iran	Mean HR during 2 × 45 min running at 55 and 90 % of $\dot{V}O_{2max}$.	NS	-
				Blood lactate after the running test	↑ at MR	15.1
Aziz et al. (2010)	10 moderately trained runners	27 ± 7	Singapore	Distance during 30-min time trial treadmill running	↓	3.6
				Speed during 30-min time trial treadmill running	↓	NR
				HR during 60-min of endurance treadmill running	NS	-
				RPE	NS	-
				Blood lactate	NS	-
				Subjective readiness to train	NS	-
				Subjective level of tiredness	NS	-
				Subjective level of alertness	↓	17.3
				Subjective level of concentration	↓	15.7
Aziz et al. (2011)	18 footballers FST: $n = 10$ NFST: $n = 8$	18 ± 1	Singapore	20-m multi-stage shuttle run test	NS effects of Ramadan between groups	-
				RPE 20-min after training session	NS effects of Ramadan between groups	-
Ben Salama et al. (1993)	60 high school students	18	Tunisia	100 m run test	↓	20.7
				800 m run test	↓	8.8
Bigard et al. (1998)	11 senior fighter pilots	27 to 49	Morocco	MVC of right elbow flexors	↓	9.3 to 9.6
				MVC of left elbow flexors	↓ at BR	12.1
				MVC of knee extensors	↓ at ER	14.8
				Muscle endurance at 35% MVC	↓ at ER	28.4
				Muscle endurance at 70% MVC	↓ at ER	22.2
Brisswalter et al. (2011)	18 runners FST: $n = 9$ NFST: $n = 9$	24 ± 3	France	Estimated $\dot{V}O_{2max}$	NS	-
				v$\dot{V}O_{2max}$	↓ at ER in FST.	11.9
				Speed at VT1	NS	-
				HRmax	NS	-
				Running economy	NS	-
				MVC	↓ at ER in FST.	3.8
				Running velocity at OBLA in the 20-m shuttle run test	NS	-
				RPE in the 20-m shuttle run test	NS	-
				RPE at 8–12 km · h^{-1} in the 20-m shuttle run test	NS	-

(*continued*)

Table I. (*Continued*).

Authors	Subjects	Age (years)	Country	Measured parameters	Ramadan effect	Percentage change
				Resting lactate in the 20-m shuttle run test	NS	-
				Lactate at 8, 10, 11 and 12 km · h^{-1} in the 20-m shuttle run test	NS	-
				Peak lactate in the 20-m shuttle run test	NS	-
				Resting HR in the 20-m shuttle run test	NS	-
				HR at 8-12 km.h^{-1} in the 20-m shuttle run test	NS	-
				Peak HR in the 20-m shuttle run test	NS	-
Chaouachi et al. (2009a)	15 judo athletes	18 ± 1	Tunisia	SJ (height, force; peak power)	NS	-
				CMJ (height, peak power)	NS	-
				30-s vertical jump test (average height, average power)	NS	-
				Lactate 3-min after the 30-second test	NS	-
				5 m, 10 m and 30 m sprint time	NS	-
				v$\dot{V}O_{2max}$, estimated $\dot{V}O_{2max}$ and HRmax	NS	-
				Lactate 3 min after MSFT Test	NS	
				Total fatigue score	↑	33.3 to 58.3
Chennaoui et al. (2009)	8 middle distance runners	25 ± 1	France	MAV	↓	2.9 to 3.9
				POMS questionnaire	↑ fatigue score	31.5
Chtourou et al. (2011a)	20 footballers	18 ± 1	Tunisia	RPE after the Yo-Yo test	↑	11 to 12.6
				RPE after the RSA test	↑	11.5 to 12.5
				RPE after the Wingate test	↑	9.5 to 12.6
				POMS questionnaire	↑ fatigue	12 to 22.8
				Peak power during the Wingate test	↓	1.6 to 1.8
				Mean power during the Wingate test	↓	2.4 to 2.9
				Fatigue index during the Wingate test	↑	6.8 to 11.4
				Total distance covered in the Yo-Yo test	↓	11.9
				MAV in the Yo-Yo test	↓	3.7
				Total work in the RSA test	↓	3.8
				Peak power in the RSA test	↓	NR
				% decrement of peak power during the RSA test	↓	51.6
Fall et al. (2009)	12 sport students	24 ± 4	Morocco	Maximal aerobic power	↓ at ER	22
				HRmax	NS	-
Girard & Farooq (2011)	18 sedentary boys	13 ± 2	Qatar	Best time in the RSA test	NS	-
				Cumulated sprint times in the RSA test	↑ at ER	2.5
				Sprint decrement score in the RSA test	NS	-

(*continued*)

Table I. (*Continued*).

Authors	Subjects	Age (years)	Country	Measured parameters	Ramadan effect	Percentage change
				Resting energy expenditure in the RSA test	NS	-
Gueye et al. (2003)	12 sport students	23 ± 2	Senegal	Systolic and diastolic blood pressure during the 60-min cycling test at 75% HRmax	NS	-
				Resting and mean HR during the 60-min cycling test at 75% HRmax	NS	-
Güvenç (2011)	16 youth footballers	17 ± 1	Turkey	Peak running distance in the 20-m shuttle run test	NS	-
				Peak running time in the 20-m shuttle run test	NS	-
				Peak running velocity in the 20-m shuttle run test	NS	-
				Running velocity at OBLA in the 20-m shuttle run test	NS	-
				RPE in the 20-m shuttle run test	NS	-
				RPE at 8–12 km · h^{-1} in the 20-m shuttle run test	NS	-
				Resting lactate in the 20-m shuttle run test	NS	-
				Peak lactate in the 20-m shuttle run test	NS	-
				Resting HR in the 20-m shuttle run test	NS	-
				HR at 8–12 km · h^{-1} in the 20-m shuttle run test	NS	-
				Peak HR in the 20-m shuttle run test	NS	-
Karli et al. (2007)	10 athletes	22 ± 1	Turkey	Peak power during the Wingate test	↑	NR
				Mean power during the Wingate test	↑	NR
				Fatigue index during the Wingate test	↑	NR
				Resting lactate	NS	-
				Peak lactate	NS	-
				Lactate half-time	NS	-
				Resting HR	↓	NR
				Peak HR	NS	-
Kirkendall et al. (2008)	85 youth footballers FST: $n = 53$ NFST: $n = 32$	18 ± 1	Tunisia	30-m repeated sprint time	↑ FST > NFST	0.7 to 1.4 2.07
				10-m sprint time	↑ at BR NS effects between groups	1.67 -
				Fatigue index during the 7 × 30-m repeated sprint test	↑ NS effects between groups	16.9 to 20.8 -
				Dribbling time during the Loughborough football dribbling test	↓ NS effects between groups	5.4 to 6.6 -
				CMJ height	↑ FST > NFST	1.7 to 2.4 4.5

(*continued*)

Table I. (*Continued*).

Authors	Subjects	Age (years)	Country	Measured parameters	Ramadan effect	Percentage change
				Agility time during the 4-line agility test	↑ at ER NS effects between groups	1.4 -
				Passing time during the Loughborough Soccer Passing test	↓ at BR NS effects of groups	3.8 -
				Running distance during the 20-m multistage shuttle run test	↑ at ER NS effects between groups	8.4 -
Kordi et al. (2011)	34 athletes	22 ± 4	Iran	Broad jump	NS	-
				Agility test	NS	-
Lotfi et al. (2010)	9 resistance athletes	23 ± 3	Morocco	Resting HR during 1000 m run	↓ at ER	14.3
				HR 15-min after a 1000 m	NS NS	- -
				Resting diastolic blood pressure		
				Diastolic blood pressure 15-min after a 1000 m run	NS ↓ at ER	- NR
				Resting motor time		
				Motor time 15-min after a 1000 m run	NS	-
				Resting recognition time	NS	-
				Recognition time 15-min after a 1000 m run	NS	-
				Resting total reaction time	NS	-
				Total reaction time 15-min after a 1000 m run	NS	-
				Resting critical flicker fusion	NS	-
				Critical flicker fusion 15-min after a 1000 m run	↑ at BR	3.7
Meckel et al. (2008)	19 youth footballers	14 to 16	Israel	Agility (4 × 10-m shuttle run)	NS	-
				CMJ jump height	↓ at ER	1.8
				Summated run time during the 6 × 40-m sprints exercise with a 30-s rest in-between	↓ at ER	0.8
				Performance decrement during the 6 × 40-m sprints exercise with a 30-s rest in-between	↓ at ER	5.3
				2 × 20-m sprint	NS	-
				3000-m run	↓ at ER	0.9
Memari et al. (2011)	12 female taekwondo athletes	15 to 27	Iran	Agility time	↑	5.1 to 7.3
				Vertical jump height	NS	-
				Balance time	NS	-
Stannard & Thompson (2008)	8 physically active men	26 ± 6	Australia	HR during a 3 × 10-min exercise at 45 & 60% $\dot{V}O_{2max}$	NS	-
				$\dot{V}O_2$ during a 3 × 10-min exercise at 45 & 60% of $\dot{V}O_{2max}$	↓	5% & 6% respectively
Sweileh et al. (1992)	Sedentary			Submaximal $\dot{V}O_2$	↓ at BR	-

(*continued*)

Table I. (*Continued*).

Authors	Subjects	Age (years)	Country	Measured parameters	Ramadan effect	Percentage change
Zerguini et al. (2007)	48 professional footballers	17 to 38	Algeria	Vertical jump height	NS	-
				Dribbling time	↑ at ER	9.4
				Agility time	↑ at ER	6.8
				5 m, 10 m and 30 m sprint time	NS	-
				12 min run distance	↓ at ER	15.9
				HR after the 12-min run	↓ at ER	22.7
				HR 5 min after the 12-min run	NS	-

Note: $\dot{V}O_{2max}$: maximal oxygen uptake; MAV: Maximal Aerobic Velocity; MSFT: multi-stage fitness test; POMS: Profile of Mood States; CMJ: Countermovement Jump; NS = No significant Change during Ramadan; HR: Heart Rate; SJ: Squat Jump; $v\dot{V}O_{2max}$: velocity associated with $\dot{V}O_{2max}$; HRmax: maximal heart rate; RPE: Rating of Perceived Exertion; MVC: Maximal Voluntary isometric Contraction; VAS: Visual Analogue Scale; VT: Ventilator Threshold; RSA: Repeated Sprint Ability; BR: beginning Ramadan; MR: middle Ramadan; ER: end Ramadan; FST: fasting group; NFST: non-fasting group; OBLA: onset of blood lactate accumulation (4 mmol · L^{-1})

afternoon and evening (17:00 and 21:00) during Ramadan (Table II).

Training and time-of-day effects. There is evidence that time-of-day affects performance in a range of sports and/or sport-related tasks such as time trials in cycling, swimming, badminton skills, dribbling or juggling in football, and serving in tennis (Reilly & Waterhouse, 2009; Chtourou et al. 2011b).

Single jump and countermovement jump (CMJ) height, force and peak power appear to be unaffected by the Ramadan fast in competitive adult male Judokas and footballers (Chaouachi et al., 2009a; Zerguini et al., 2007), and female athletes (Memari et al., 2011). A small (1.8%) decrease in CMJ height was measured in fasting adolescent Israeli football players (Meckel et al., 2008), while in a similar age-group of more talented Tunisian footballers, fasting participants appeared to jump slightly higher (4.5%) during Ramadan than their non-fasting peers (Kirkendall et al., 2008). The most likely reason for the difference in performance between the two fasting groups in these two studies is that the Tunisian group maintained their training load during Ramadan, while the Israeli players reduced theirs. Ramadan fasting did not appear to affect performance of the 30 s vertical jump test (Chaouachi et al., 2009a), or broad jump test (Kordi, Abdollahi, Memari, & Najafabadi, 2011).

Maximum voluntary contraction. There are few studies that have examined the potential effects of RIF on skeletal muscle strength. An early article on this subject was published by Bigard, Boussif, Chalabi, and Guezennec (1998). They illustrated a significant decrease in maximum isometric contraction (MVC) strength of elbow flexors muscles (10–12%) and knee extensors (15%), and muscular endurance at both 35% and 55% of MVC (-22% and -28%, respectively, by the end of Ramadan) in fighter pilots. Brisswalter, et al. (2011) reported a more modest, approximately 3%, decrease in MVC in their fasting compared with their non-fasting middle-distance runners. Weight training has been used in two other studies as part of the training load carried out by the participants before and during Ramadan (Chaouachi et al., 2009a; Karli et al., 2007). While changes in muscle strength were not measured in either of these investigations, the authors reported that training loads were maintained throughout their studies, which would suggest that there was no noticeable reduction in muscle strength reported by the fasting participants. The paper of Bigard and colleagues (Bigard et al., 1998) does not give enough detail of their study conditions to draw any conclusions as to why their participants lost so much muscle strength during Ramadan, but we can assume that none of these senior fighter pilots were undertaking rigorous athletic training and they had lost an average of 2.5% of body mass over the month of intermittent fasting.

Technical ability. Technical ability is an individual's facility to perform the basic movements or pattern of movement required for a sport. They are a combination of psychomotor skills and technique required for that sport.

While three studies found that Ramadan fasting did not have any noticeable effect on footballers' agility (Kirkendall et al., 2008; Kordi et al., 2011; Meckel et al., 2008), two other investigations reported slight (5.1–7.3%) increases in the time to complete these tests in female athletes (Memari et al., 2011) and professional footballers (Zerguini

Table II. Studies that have investigated Ramadan fasting and time-of-day effects on sports performance.

Authors	Times of measurement	Measured parameters	Acrophase		RIF modifications	Amplitude	
			Before RIF	During RIF		Before RIF	During RIF
Souissi et al. (2007)	- 07:00 h	Oral temperature	21:00 h	21:00 h	↓ at 17:00 and 21:00 h	0.9 ± 0.28°C	0.6 ± 0.38°C
	- 17:00 h	Pmax	17:00 h	NS	↓ at 17:00 h	NR	NR
	- 21:00 h	F_0	17:00 h	NS	↓ at 17:00 h	NR	NR
		V_0	NS	NS	NS	NR	NR
		Ppeak	17:00 h	NS	↓ at 17:00 and 21:00 h	NR	NR
		Pmean	21:00 h	21:00 h	NS	NR	NR
		FI	NS	NS	NS	NR	NR
Hamouda et al. (2012)	- 07:00 h	Oral temperature	17:00 h	17:00 h	↓ at 17:00 h	0.71 ± 0.32°C	0.4 ± 0.28°C
	- 17:00 h	RPE after the YYIRT and the RSA tests	NS	NS	↑ at 17:00 h	NR	NR
		PP	17:00 h for the first two sprints	NS	↓ at 17:00 h	NR	NR
		Pdec	NS	NS	NS	NR	NR
		Wtotal	17:00 h	NS	↓ at 17:00 h	NR	NR
		TD	17:00 h	NS	↓ at 17:00 h	NR	NR
Chtourou et al. (2012b)	- 07:00 h	RPE after the Wingate test	NS	17:00 h	↑ at 17:00 h		
	- 17:00 h	Ppeak	17:00 h	NS	↓ at 17:00 h	3.14 ± 3.64	0.65 ± 2.62
		Pmean	17:00 h	NS	↓ at 17:00 h	2.9 ± 3.47	1.02 ± 4.51
		FI	17:00 h	NS	↑ at 17:00 h	10.59 ± 12.12	20.13 ± 10.33

Note: NS: no-significant; NR: not reported; Pmax: maximal power during the force-velocity test; F0: the braking force corresponding to zero velocity during the force-velocity test; V0: maximal velocity at zero braking force during the force-velocity test; Ppeak: peak power during the Wingate test; Pmean: mean power during the Wingate test; FI: fatigue index during the Wingate test; PP: peak power during each sprint of the repeated sprints (RSA) test; Pdec: decrease of PP over the repeated sprints; Wtotal: the total work; TD: the total distance covered during the Yo-Yo intermittent recovery test (YYIRT); RPE: Rating of perceived exertion.

et al., 2007). In the study of Memari et al. (2011), energy intake and body mass were reduced during Ramadan, and although this was associated with slightly improved vertical jumping and single leg balance performance, it may have adversely affected the agility tests.

The time taken for footballers to complete a dribbling test was increased by about 9% in the study of Zerguini et al. (2007) during Ramadan, while the younger players in the study of Kirkendall et al. (2008) reported a 5–7% improvement in this test, but there was no difference between the fasting and non-fasting groups in this study. The footballers in this latter study also improved their time to complete the Loughborough passing test during Ramadan, but again there was no difference between the fasting and non-fasting groups.

Blood lactate concentration. Peak lactate concentration in the circulation, time to peak blood lactate levels and blood lactate concentration at a fixed time point are sometimes used as measures of aerobic and anaerobic fitness (Billat, 1996). Before and after the Wingate test, blood lactate concentrations were not affected by the Ramadan fast in a group of Turkish power athletes (Karli et al., 2007), or following a 60 min treadmill run in moderately trained Singaporean runners (Aziz, Wahid, Png, & Jesuvadian, 2010). No effects of Ramadan fasting on blood lactate concentrations were seen during or 3 min after a 20-m shuttle run test in middle-distance runners and young footballers (Brisswalter et al., 2011; Güvenç, 2011), or during the 30 s vertical jump test or the 30-m multiple shuttle fitness test in Judokas (Chaouachi et al., 2009a). However, one study has recently reported an approximately 15% greater blood lactate concentration during Ramadan following two bouts of exercise, each at a different percentage of the competitive runners' maximum oxygen uptake ($\dot{V}O_{2max}$) (Asl, 2011). Unfortunately, from the poorly reported description of the methodology used in this study it is not clear what the exercise mode was or for how long the participants exercised, and no conclusions can be drawn from this investigation.

Heart rate. Both resting and submaximal exercise heart rates have been used as measures of athletic capacity, and changes in these parameters are considered to be indicative of alterations in physical fitness (Bangsbo et al., 2006). Improvements in aerobic power are often associated with a slower resting pulse and/or a lower rate of submaximal heart rate for a given workload.

Resting heart rate has been found to be slightly slower in some studies that have measured this parameter during Ramadan (Leiper, Watson, Evans, & Dvorak, 2008a; Ramadan & Barac-Nieto, 2000; Sweileh, Schnitzler, Hunter, & Davis, 1992). In some competitive athletic groups, resting heart rate appears to be essentially similar before and during Ramadan (Brisswalter et al., 2011; Gueye et al., 2003; Güvenç, 2011), but Lotfi et al. (2010) found resting heart rate to be about 14% slower at the end of the fasting month in collegiate resistance-trained athletes. Karli et al. (2007) stated that heart rate before exercise was slightly lower during than before Ramadan, but they did not present data to support this. It is not clear why there was a mean 9 bpm slower resting heart rate at the end of Ramadan compared with that recorded one week before Ramadan in the study of Lotfi et al. (2010). There appears to have been no familiarisation to the study protocol, therefore the participants' initial resting heart rate measurement may have been affected by a mild stress-related tachycardia. A more likely explanation, however, is the alterations in biorhythms associated with Ramadan (Waterhouse, 2010).

Submaximal heart rate (HR) for a given exercise intensity has been reported to be faster (Leiper et al., 2008a) for a young competitive athletic group, and about 5% slower for a sedentary group (Ramadan & Barac-Nieto, 2000). In other studies, heart rates at submaximal workloads have been reported to be unaffected by Ramadan fasting in physically active (Stannard & Thompson, 2008) and competitive athletes (Brisswalter et al., 2011; Gueye et al., 2003; Güvenç, 2011). It appears surprising that submaximal exercise should appear to cause less strain in Ramadan fasting individuals who are likely to be acutely hypohydrated during RIF (Chaouachi et al., 2009b; Maughan et al., 2010). It is not clear from the study of Ramadan and Barac-Nieto (2000) whether the participants voluntarily reduced the submaximal exercise intensity during testing and hence caused a decrease in heart rate, but the reported submaximal oxygen consumption ($\dot{V}O_2$) levels would argue against this suggestion.

Peak heart rate during exercise does not seem to be affected by Ramadan fasting in athletic groups (Aziz et al., 2010; Brisswalter et al., 2011; Chaouachi et al., 2009a; Fall et al., 2007; Güvenç, 2011; Karli et al., 2007).

Aerobic performance. Aerobic performance for recreationally active individuals and for competitive athletes is described below.

Recreationally active individuals. Submaximal VO_2 during prolonged aerobic exercise has been reported to decrease significantly over the month of Ramadan and there may be a substantial reduction in $\dot{V}O_{2max}$ within the first week in sedentary subjects when they are acutely hypohydrated (Sweileh et al., 1992). However, the values were observed to return to pre-fasting levels during the last week of Ramadan when hydration status was improving. In another group of physically active Australians, VO_2 was reduced by a mean of 5% and 6% during Ramadan at exercise intensities calculated to elicit 45% and 60% of $\dot{V}O_{2max}$, respectively (Stannard & Thompson, 2008). However, the decrements appeared only near the end of Ramadan when the participants had lost approximately 1.8% of body mass.

Competitive athletes. Estimated $\dot{V}O_{2max}$ has been reported as being unchanged during Ramadan in competitive runners (Brisswalter et al., 2011) and elite Judokas (Chaouachi et al., 2009a). Running velocity and distance during shuttle running tests, and hence estimated $\dot{V}O_{2max}$ appear unaffected by Ramadan fasting (Aziz, Slater, Chia, & Teh, 2012; Guvenç, 2011; Kirkendall et al., 2008) in competitive team sport athletes in the majority of studies. The total distance and maximum aerobic velocity during the Yo-Yo test, however, was reduced by approximately 12% and 4%, respectively, in one group of Tunisian youth footballers (Chtourou et al., 2011a) and time to complete a 3-km run was approximately 1% longer in a group of Israeli adolescent footballers (Meckel et al., 2008). The distance run during a 30 min time-trial was also marginally (3.6%) reduced during Ramadan in a group of Singaporean runners (Aziz et al., 2010).

In the study of Meckel et al. (2008) the training load of the participants was decreased during Ramadan. Although the group of Tunisian adolescent footballers recruited for the study of Chtourou et al. (2011a) were members of local junior squads that were affiliated to professional football clubs, no measure of training load or energy intake was reported in this study. The runners in the time-trial study had lower blood glucose levels and were in a poorer hydration status before exercising in the fasting compared with the non-fasting state (Aziz et al., 2010). The possible effects of detraining during Ramadan may be the cause of these small reductions in aerobic capacity.

Maximum aerobic velocity and velocity associated with $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) have been reported to be slower (3.7–12%) during Ramadan in competitive middle-distance runners and footballers (Brisswalter et al., 2011; Chtourou et al., 2011a), but $v\dot{V}O_{2max}$ has been found to be similar in motivated Tunisian Judokas (Chaouachi et al., 2009a).

At relatively low exercise intensities, there is a greater reliance on fat oxidation during the Ramadan intermittent fasting (Bouhlel et al., 2006; Ramadan, Telahoun, Al-Zaid, & Barac-Nieto, 1999; Stannard & Thompson, 2008). This metabolic adaptation might explain some of the observed ventilatory changes, but carbohydrate metabolism does not seem to be compromised at high intensities (Stannard & Thompson, 2008). Nevertheless, whereas statistically significant reductions in aerobic performance have been detected in the early stages of the RIF, the decrements are usually small and tend to disappear in the second half of Ramadan (Kirkendall et al., 2008; Sweileh et al., 1992).

In summary, any decrements in exercise performance during Ramadan are usually very slight and often within the error of measurement for the test. These measured reductions in physical proficiency are associated with either significant loss in body mass, as a result of acute dehydration and/or energy restriction or diminution in training load. Where performance measurements have been made at different weeks during Ramadan, most studies have found the largest numerical changes to occur in the early part of the month-long intermittent fast.

Rating of perceived exertion and mood scores. The rating of perceived exertion (RPE) was introduced by Borg in 1970. While there are several variants used in sports exercise and medical practice, the most common is the 15 point 6–20 scale (Borg, 1970). The subjective evaluation of perceived effort is known to be correlated with several exercise parameters such as heart rate and $\%\dot{V}O_{2max}$ (Noble, Borg, Jacobs, Ceci, & Kaiser, 1983) and have been used as measures of individual's assessment of their somatic stress. Similarly, a person's subjective feelings or mood can be appraised by use of validated questionnaires that rate the psychological well-being of the individual (McNair & Droppleman, 1971).

Many studies have shown that sleep loss produces a general decline in performance (Reilly & Edwards, 2007). The trend is not the same for everyone or for all the components of performance. Mood, psychomotor and cognitive functions deteriorate more quickly than physical capabilities (Chaouachi et al., 2009b). The complexity, duration, and boredom produced by the task can also accelerate this decline (Reilly & Edwards, 2007). Furthermore, sleep deprivation can reduce the amplitude of the diurnal fluctuation in performance (Souissi et al., 2008) due to a reduction in exercise capability at the time when the maximum values of performance are normally recorded. Thus, sleep deprivation modifies the rhythm of performance, reducing both the mean level of performance (mesor) and the peak-to-peak amplitude.

The RPE scores throughout and at the end of the 20-m shuttle run test were reported to be similar at the same velocities in Ramadan-fasting and non-fasting runners (Brisswalter et al., 2011) and before and during Ramadan in youth footballers (Güvenç, 2011). Perceived exertion reported 20 min after training sessions, as a measure of overall subjective feeling of exercise intensity, was similar between Ramadan-fasting and non-fasting Singaporean (Aziz, Chia, Singh, & Wahid, 2011) and Tunisian (Leiper, Junge, Maughan, Zerguini, & Dvorak, 2008b) youth footballers, and essentially the same before and during Ramadan in a group of Singaporean runners (Aziz et al., 2010). However, in another group of youth football players reported RPE scores that were greater during Ramadan following their Yo-Yo test (11–13%), after the repeated sprint (12–15%) (Hamouda, Chtourou, Farjallah, Davenne, & Souissi, 2012) and after the Wingate test (10–13%) (Chtourou et al., 2011a). In the few studies that have looked at the perceived exertion of competitive athletes training or exercising during Ramadan, where increases in effort have been reported by athletes, the differences have been rather small and not likely to reduce performance to any real extent (Chaouachi et al., 2009b).

Similarly, subjective mood profiles reported by competitive athletes while exercising during Ramadan are usually little different from that recorded outside Ramadan (Chaouachi et al., 2009b). Descriptors used in this type of visual analogue scale (Likert scale) are used to define such subjective mood states as 'anger', 'tension', 'depression', 'vigour', 'fatigue/tiredness' and 'confusion' (McNair & Droppleman, 1971). Other factors, such as hunger, thirst, alertness, headache etc. are sometimes included (Leiper et al., 2008b).

In the small number of studies that have examined the effect of Ramadan fasting on the mood states of competitive athletes, only fatigue levels and tiredness are usually greater during the fast (Chaouachi et al., 2009a; Chennaoui et al., 2009; Leiper et al., 2008b). In the study of Leiper and colleagues (2008b), fasting players reported that they were also marginally more thirsty and hungry, and slightly less able to concentrate before training during than before or after the end of Ramadan. The questionnaire data collected in the study of Algerian professional football players, indicated that 15% more of the players felt tired and 8% reported difficulty in concentrating during than before Ramadan (Zerguini et al., 2007). There was also a 50% increase in the numbers of these players who rated their quality of training as being poorer than usual and 31% more who perceived their performance in matches as being worse than normal at the end of Ramadan compared with before the fast.

The slightly negative changes in mood state in the limited number of mental status indicators reported are unlikely to greatly affect exercise performance. However, the increase in the number of individuals in the study of Zerguini and colleagues (2007) who considered that their physical performance in training and during competition was adversely affected during Ramadan must give rise to concern. As there were no performance measures made in conjunction with the training or competitive play of these professional footballers, it is impossible to ascertain whether or not any appreciable decrements did occur.

The elite Tunisian youth footballers investigated by Leiper et al. (2008a), reported no real change in their perception of training effort and difficulty before during and following Ramadan, and there were no differences in these parameters between the fasting and non-fasting groups before, during or after Ramadan. During this study, which lasted for nine consecutive weeks, at least one competitive match was played each week, and while no specific questions were asked regarding their performance or perception of effort during these matches, the participants were told to regard these games as training sessions and to record them as such. For this group of footballers the Ramadan fast did not noticeably reduce their exercise performance (Kirkendall et al., 2008; Leiper et al., 2008a). Sedentary subjects also reported decreases in their mood and motivation at the end of Ramadan (Roky, Houti, Moussamih, Qotbi, & Aadil, 2004) and Ramadan fasting is reported to negatively affect a number of psychosomatic factors in otherwise healthy, normal Muslims.

In conclusion, athletes show diverse views in their perception of changes in their training, sleep and dietary patterns during the Ramadan fast. These individual differences probably indicate difference in the athlete's adaptability and coping strategies during fasting and training during Ramadan. Changes in sleeping habits, resynchronisation of biorhythms, acute hypohydration and withdrawal symptoms due to the daytime restriction on caffeine and tobacco have been suggested as the most likely effectors of this decrease in mental wellbeing (Leiper et al., 2003). Individuals who normally find training hard, or moderate or easy, tend to rate the degree of difficulty during Ramadan in the same general category each time (Leiper et al., 2008b; Tian et al., 2011).

Training

Effect of RIF on training and the impact on subsequent exercise performance

A well-cited study showed that nearly 70% of 55 professional Algerian football players felt that their training quality was adversely impacted by Ramadan fasting, although it was unclear which aspects of the players' "training quality" were affected (Zerguini et al., 2007). In support of this study's finding, a large scale investigative survey ($n = 900$) of Junior and Senior level national athletes, found that $\sim$30% of those questioned considered that their training sessions were unfavourably affected by the Ramadan fast (Ooi et al., 2010; Singh et al., 2011). This section of surveyed athletes stated further that they felt that all aspects of training variables (i.e., frequency, duration and intensity) were adversely impacted (Singh et al., 2011). Overall, however, the majority of the athletes questioned either thought that Ramadan had no impact on their training or were unsure if there was any effect (Singh et al., 2011). The studies of Ooi et al. (2010) and Singh et al. (2012) were surveys and no objective tests of physical performance were carried out.

The impact of Ramadan fasting on training can be significant because a reduction in training load (Chennaoui et al., 2009) and intensity (Meckel et al., 2008) from the pre-Ramadan to the Ramadan period, has previously been shown to result in poorer physical performance measures by the end of the Ramadan month in well-trained athletes. Many coaches believe that fasting Muslim athletes are unable to cope with normal training and thus deliberately reduce their athletes' training load during the Ramadan period (Mujika et al., 2010; Meckel et al., 2008). Previous studies have also shown that many fasted Muslims reported an increase in subjective feelings of fatigue, malaise, lethargy and alterations in mood, which they felt resulted in their inability to sustain physical efforts, particularly during high-intensity exercise (Roky et al., 2004; Waterhouse, 2010; Zerguini et al., 2007). Thus an overall reduction in training quality, rather than the act of fasting *per se*, could lead to a detraining effect in fasted Muslim athletes. However, other studies have, in contrast, indicated that many Muslim athletes are able to cope well with their usual training load while fasting (Bouhlel et al., 2006; Chaouachi et al., 2009a; Karli et al., 2007; Kirkendall et al., 2008). A number of reasons might account for the disparity in findings between the studies that have investigated the influence of Ramadan on training.

Firstly, many authors did not report a detailed explanation of the training programme that their athletes had undergone. They merely stated that the athletes continued with their 'normal' training or maintained their 'normal' training schedule. Such brief one-line descriptions of the entire four weeks of training are clearly inadequate as they does not provide important information on the quality or quantity of training stimulus that the fasted participants have experienced over the study period (Bouhlel et al., 2006; Chaouachi et al., 2009a; Chennaoui et al., 2009; Karli et al., 2007; Kirkendall et al., 2008; Meckel et al., 2008). The latter is clearly critical because the variable of exercise intensity is the key factor that influences the quality of effort and thus the overall efficacy of the training programme (Mujika et al., 2010).

Secondly, and most importantly, many of the above cited studies have adopted repeated measure cross-over design using a single-study group. With such a design, it is possible that the training for the non-Ramadan (i.e., control period) and Ramadan months were different, as is usually the case since coaches typically periodised their training programme over the longer term (Mujika et al., 2010). Thus it is clearly important for Ramadan research to include a control group (i.e. participants who are training but not fasting) to account for the training stimuli across the investigation period.

There are only a limited number of Ramadan exercise studies that have included a control group of non-fasting athletes who trained with their fasting peers (Table III). Further, only four of these have reported in some detail their studies' training programmes. One example is that of Kinugasa and colleagues (Kinugasa, Nair & Aziz, 2010), who examined the impact of Ramadan fasting on a squad of pre-adolescent (14.0 $\pm$ 0.5 years) sports school students specialising in football. The squad was split into those that normally underwent the Ramadan fast (FAS) and those who did not fast during Ramadan (non-FAS) groups. The boys trained together once a day for 120 min per session for 5 days per week; which consisted of football-specific sessions, aerobic conditioning and resistance exercises. To assess the impact of the Ramadan fast, the boys were assessed using standardised physical tests, such as the beep test, 20-m sprint, and standing broad jump, on four occasions: at pre-, 2nd week-, 4th week- and post-Ramadan. Compared with the non-FAS group, the FAS participants showed a 2.7% decrease in their aerobic capacity during the first half of the Ramadan month, which had begun to recover by the 4th week of Ramadan. The study concluded that Ramadan fasting had an adverse impact on some aspects of exercise performance (Kinugasa et al., 2010). Although both groups underwent the same training programme, the lack of information on the player's exercise responses limits the interpretation of the study's findings. It could be argued that whilst external load (the coach's planned programme) might be similar in both groups, the internal load (the actual physical stress that was experienced by the player) could have been different between the FAS and non-FAS groups Other information such as food and fluid intake were not reported although these were apparently measured via a 3-day food diary. The same limitations or short-comings are also evident in some of the other studies in Table III. These studies did not measure the exercise responses

Table III. Ramadan fasting and training studies (that have specifically included a control non-fasting group to account for the training load and/or training stimuli in both groups during the Ramadan month).

Study	Participants' characteristics	Is dietary intake and sleep hours controlled?	Training programme during study	Participants' responses to exercise training	Outcome of performance variable(s)	Training intensity and other remarks
Afyon & Micoogulari (2003)	Males, age = NR University football players FAS (n = 20) and non-FAS (n = 20)	Dietary intake = NR Sleep = NR	NR	NR	Aerobic capacity was decreased in FAS but not in non-FAS. No difference in strength between groups	Unable to ascertain with confidence that training load and/or training stimuli was equal between FAS and non-FAS. Abstract only.
Aziz et al. (2011)	Males, 18 ± 1 year National youth football players FAS (n = 10) and non-FAS (n = 9)	Dietary intake = No, but the iftar meals during post-exercise sessions were catered for both FAS and non-FAS. Sleep = NR	3 sessions per week of sports-specific sessions + 2 sessions per week of aerobic conditioning sessions consisting of high-intensity interval runs and sprints	Session RPE post-interval run training sessions were similar between FAS & non-FAS	Post-RAM Beep performance was maintained in FAS and were similar to that of non-FAS	Training intensity throughout RAM was equivalent between groups.
Aziz et al. (2012)	Males, 17.5 ± 0.5 year College & club level team sports athletes FAS (n = 10) and non-FAS (n = 10)	Dietary intake = No, but were similar between groups. Sleep = NR	3 sessions per week consisting of repeated 30 s Wingate cycle bouts with 2 to 4 min recovery. The number of bouts progressed from initial 4 to 10 bouts per session.	Mean exercise HR, post-exercise blood lactate and RPE were generally similar between FAS and non-FAS throughout the training sessions.	Post-RAM aerobic and anaerobic performance capacities were improved in FAS that were similar in magnitude to that of non-FAS group.	Training load and intensity throughout RAM was equivalent between groups.
Brisswalter et al. (2011)	Males, 24 ± 3 years Well-trained middle distance runners FAS (n = 9) and non-FAS (n = 9)	Dietary intake = No, but were similar between groups. Sleep = NR	3 sessions per week consisting of 30 min of slow run followed by either 30 s intermittent runs at maximal aerobic speed (MAS), or 12 x 300 m runs at MAS, or 4 x 4 min runs at competition speed	NR	MAS, oxygen kinetic and strength were lowered in FAS vs. non-FAS	Unable to ascertain with confidence that training load and/or training stimuli was equal between FAS and non-FAS.
Havenetidis (2011)	Males, 23 ± 3 years Military cadets who were club runners FAS (n = 10) and non-FAS (n = 10) Note: Cadets were from the same club and residing during study period.	Dietary = No, but were similar between groups. Sleep = NR	4 sessions per week consisting of progressive duration of between 45–55 min of continuous steady-state runs at 70% individual's HR	NR	Time to run 2-mile was improved in FAS which was greater in magnitude than that of non-FAS	Unable to ascertain with confidence that training load and/or training stimuli was equal between FAS and non-FAS.

(*continued*)

Table III. (*Continued*).

Study	Participants' characteristics	Is dietary intake and sleep hours controlled?	Training programme during study	Participants' responses to exercise training	Outcome of performance variable(s)	Training intensity and other remarks
Khalil et al. (2010)	Males ($n = 6$) and Females ($n = 2$). Trained endurance runners FAS ($n = 4$) and non-FAS ($n = 4$). This is a crossed-over study design with subjects exercising in the fasted and non-fasted state.	Dietary intake = NR Sleep = NR	NR	NR	Time taken to run 2.4 km was not significantly different in the fasted and non-fasted state ($P > 0.05$) but effects size indicated small meaningful differences between conditions.	Unable to ascertain with confidence that training load and/or training stimuli was equal between FAS and non-FAS.
Kinugasa et al. (2010)	Males, 13–14 years Trained football players FAS ($n = 9$) and non- FAS ($n = 11$). Note: Players were from the same squad and residing in sports school environment.	Dietary intake = NR Sleep = NR	5 sessions per week consisting of sport-specific training, aerobic conditioning and strength training	NR	No significant different between FAS and non-FAS for 20 m sprint but Beep test and standing broad jump performance were lower in FAS.	Unable to ascertain with confidence that training load and/or training stimuli was equal between FAS and non-FAS.
Kirkendall et al. (2008)	Males, 18 ± 1 year Clubs football players FAS ($n = 53$) and non- FAS ($n = 32$) Note: Players were residing in a training camp for 10 weeks	Dietary intake = No, were similar between groups. Sleep = No, but were relatively equivalent in both FAS and non-FAS.	6-8 sessions per week consisting mainly of sport-specific training with few sessions of aerobic conditioning and strength training. Note: all training sessions were designed and run by the club coaching staff.	Training impulse, load, and intensity, as well as subjective feelings (RPE & training difficulty) during sessions were similar between groups. Mean exercise HR was higher in FAS vs. non-FAS.	Physical performance in jump, agility, sprint and Beep test were similarly improved in FAS and non-FAS	Training intensity was maintained throughout.
Mirza et al. (2011)	Males, 25 ± 2 years Professional football players FAS ($n = 5$) and non- FAS ($n = 5$) Note: Players were from the same club	Dietary intake = NR Sleep = NR	5 sessions per week consisting of sports specific training + 2 sessions per week of strength and aerobic conditioning. Note: all training sessions were designed and run by the club coaching staff.	Mean daily training load (session RPE x training duration) over the study period tended to be lower in the FAS vs. non-FAS	Mean HR, blood lactate, RPE during 8 min of submaximal run in the Yo-Yo Intermittent Recovery Test Level 1were higher in FAS vs. non-FAS	Training stimuli during Ramadan was lower in FAS compared to non-FAS group. Conference presentation only.

Note: FAS = Ramadan fasted subjects group; non-FAS = non Ramadan fasted subjects group; RAM = Ramadan period; CON = Control period; NR = not reported in the study; RPE = ratings of perceived exertion; HR = heart rate of the participants during training, and hence it cannot be assumed that the training stimulus experienced by both the FAS and non-FAS players was equivalent during the study period.

In contrast to the findings of Kinugasa et al. (2010), the investigation by Kirkendall and colleagues (Kirkendall et al., 2008) found that Ramadan fasting had no effect on a variety of physical performance tests in well-trained adolescent football players undergoing 10 weeks of training in a residential camp environment. This study showed that the FAS footballers had similar improvements in their physical performance capabilities such as speed, agility, power, speed endurance and aerobic endurance to that of non-fasting peers. Importantly, the various indices of training such as training impulse, session-RPE and mean exercise HR showed minimal differences between FAS and non-FAS players, which implied that the internal training load experienced by both exercising groups was equivalent (Leiper et al., 2008a). Thus the findings of Kirkendall et al. (2008) demonstrated that when the training stimuli (load) in FAS participants were maintained (i.e., equal to that of non-FAS participants), the physical performances of those who trained while fasting are apparently not adversely affected. It is important, however, to highlight that the players in Kinugasa et al. (2010) and Kirkendall et al. (2008) were all residing in a school and training camp, respectively, where the players' food and fluid intake, sleep, and training programme were rigorously monitored by the administrative and coaching staff. Thus it could be argued that the impact of RIF on the players' exercise performances was ameliorated by the ideal conditions of the residential living and training environments. Such conditions are clearly not always readily available to many teams and athletes.

To resolve this issue, Aziz et al. (2011) performed a 4 week (i.e., an actual Ramadan month) training study on elite-level National youth football players (18 ± 1 year) who were preparing for a major competition. In contrast to the previous two studies, the players were not residing in a school or training camp (i.e. they were free-living). The squad was split into FAS and non-FAS groups and their training regimen, which was fully described in the paper, consisted of specific football exercises, drills and fitness training. The training consisted of mainly high-intensity interval running and short sprints. Perceived ratings of exercise intensity during the fitness training sessions were not significantly different between the FAS and non-FAS footballers, which indicated that the internal training load was equivalent in both groups. Subsequently, the aerobic endurance performance of the FAS group was maintained at the end of Ramadan month, and was similar to that of the non-FAS group. The authors concluded that training to preserve maximal aerobic performance is viable during the Ramadan fasting month provided the appropriate exercise stimulus is imposed during training. Thus the previous finding of the Kirkendall et al. (2008) study was experimentally supported in free-living subjects.

A major limitation of the investigation of Aziz et al. (2011) was that only 40% of the study's total training sessions were controlled. This group followed up their previous work (Aziz et al., 2011) with a study that endeavoured to tightly control participants' training programme by monitoring all training sessions (Aziz, Slater, Chia & Teh, 2012). This subsequent work, although carried out with college and club-levels team sports athletes (18 ± 1 year) rather than well-trained athletes, examined the effects of 7 weeks of high-intensity training, in which the Ramadan fast fell within week 3 to 6 of the programme (Aziz et al., 2012). The thrice weekly exercise programme was a deliberately and carefully planned training regimen. The programme was progressive, with a gradual systematic increase in both duration and intensity of the exercise protocol throughout the 7 week period, developed to elicit specific fitness improvements in the players. At the end of the 7 weeks of training, both groups showed similar improvements in their aerobic and anaerobic capabilities. Again, the indices of quality of training, such as mean exercise heart rate, post-exercise blood lactate and RPE measured during sessions were generally similar in both FAS and non-FAS groups. The investigators concluded that aerobic and anaerobic performances were not adversely affected as a result of Ramadan fasting, possibly because training intensity and daily energy and fluid intake during the Ramadan month were not compromised (Aziz et al., 2012).

In a recent longitudinal study, 10 professional football players (FAS, $n = 5$ and non-FAS, $n = 5$) were monitored for a total of 12 weeks (4 weeks before, 4 weeks during, and 4 weeks after Ramadan) (Mirza, Aziz, Wahid, & Chia, 2011). The investigation was carried out during the middle of the league season by recording the players' training load (i.e., session RPE x duration of session) in every single training session (Mirza et al., 2011). In FAS players, indicators of aerobic fitness (i.e., mean HR, post-exercise blood lactate and RPE during 8-min of continuous intermittent shuttle runs at submaximal velocities), were elevated (i.e., impaired) from the pre- to the during-Ramadan period, and then lower (i.e., improved) from the during-Ramadan to the after-Ramadan period. The non-FAS players' aerobic fitness, in contrast, did not show any change throughout the same period. The FAS players' mean weekly training load followed a similar pattern of down- and up-swing to their aerobic fitness. The authors concluded that the perturbations of fasting caused a lower training stimulus during Ramadan, which had a small adverse impact on the aerobic fitness levels of these professional football players. They recommended that the coaches should make conscious efforts to maintain the intensity of training sessions at the optimum competitive level for fasting Muslim players during Ramadan (Mirza et al., 2011).

In conclusion, the key to preserving or possibly improving physical fitness during RIF is the maintenance of the training stimulus (exercise load and/or intensity) at levels appropriate to the fasting athlete's ability throughout the month of Ramadan. At the same time, the athlete's food and fluid intake, as well as sleep patterns must be managed to prevent any adverse effect on the individual's ability to train.

Training and time-of-day effects. There is evidence that time-of-day affects performance in a range of sports and/or sport-related tasks such as time trials in cycling, swimming, badminton skills, dribbling or juggling in football, and serving in tennis (Reilly & Waterhouse, 2009). These measures of sports performances have been found to be optimal in the late afternoon between 17:00 h and 19:00 h and poorer in the early morning between 05:00 h and 07:00 h, with the test differences ranging from 3% to 21% (Nicolas, Gauthier, Bessot, Moussay, & Davenne, 2005). Many of these sports performance rhythms parallel the circadian rhythm of body temperature and a causal link has been suggested (Reilly & Waterhouse, 2007). Indeed, the circadian rhythm of body temperature could exert a passive warm-up effect enhancing metabolic reactions, increasing the extensibility of connective tissue, reducing muscle viscosity, and increasing the conduction velocity of action potentials (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005).

The effect of the time-of-day-specific training has been rarely investigated even during normal conditions in competitive athletes. The few previous studies that have investigated the temporal specificity of endurance training (Hill, Cuerton, & Collins, 1989, Hill, Leiferman, Lynch, Dangelmaier, & Brut, 1998; Torii, Shinkai, & Hino, 1992) have reported that the improvement of parameters of performance (i.e., the ventilatory anaerobic threshold (Hill et al., 1989), $\dot{V}O_{2max}$ (Torii et al., 1992), and work capacity (Hill et al., 1998)) was greater at the time-of-day at which training was regularly performed. However, these studies suffered from several methodological limitations, such as testing was performed at only one time point (i.e., the afternoon) both before and after training, or only after the training programme. More recent studies have investigated the temporal specificity of resistance training (Chtourou et al., 2012a; Sedliak, Finni, Cheng, Lind, & Häkkinen, 2009; Souissi et al., 2012) and have confirmed that adaptations to resistance training are greater at the time-of-day at which training was conducted than at other times.

Time-of-day training coping strategies. One of the many strategies taken by coaches to circumvent the possible impact of Ramadan on exercise performance is to alter their usual training sessions to specific times of the day (Wang, 2008). For example, training or exercising sessions have been rescheduled for the morning, 3–4 hours after *sahour,* when the athletes would be relatively fuel and fluid replete. However, this results in the athletes not eating or drinking immediately after training, and having to wait until the breaking of the day's fast that will be at least 6–8 hours later. This could result in a situation where exercise recovery is marred (e.g., impaired protein resynthesis; inadequate recovery of muscle glycogen stores) that could hamper the training-induced adaptation process (Burke, 2010).

Other coaches have suggested that training should ideally be conducted in the late afternoon, just prior to the breaking of the day's fast (i.e., between ~17:00 h to 18:00 h). It is argued that although the fasted-athlete would have been without fuel and fluid for the last 10–12 hours up to this point in time, it is believed that athletes would be more likely to exert themselves to a greater extent during this session (Aziz et al., 2011). This is because the athlete knows that food and fluid will be available almost immediately upon completion of training, which is something of a "psychological edge"; although paradoxically, the athletes are in the worst physiological state since they have fasted for 10–12 hours. Alternatively, it makes sense for fitness training to be conducted in the evening, several hours after the athlete has broken the day's fast (Waterhouse, 2010). At this time the athlete would be in a non-fasted state, and moreover, food and fluid could be consumed during and after training without restriction (Grantham, 2010). However, the effects of late evening training, particularly high-intensity sessions, impacting sleep cannot be discounted for there is evidence suggesting that prior intense exercise can result in reductions in sleep time and/or poor quality of sleep (Reilly, 2007). There is also a concern that the already decreased sleep time during Ramadan could be further exacerbated because athletes need to wake-up before dawn to consume the *sahour* meal.

To the authors' knowledge, no study has been published that directly aimed to investigate the temporal specificity of training and the optimum time of day for exercise during the Ramadan month. Although it is logical to assume that training in the evening, after breaking the day's fast is the ideal time for Muslim athletes to train during Ramadan (Mujika et al., 2010; Waterhouse, 2010), the question then arises how to counteract the evening decrease or the circadian rhythm shift of sports performances. Recently, we have examined (*unpublished data*) the effect of training at a specific time-of-day (i.e. by comparing two training groups: 'morning', 'evening', and a 'control' group (who completed all test sessions, but who did not undertake any specific time-of-day training) on short-term maximum performance (Wingate test) of football players. Peak power during the Wingate test was recorded in the morning (i.e., at 08:00 h) and in the evening (i.e., 17:00 h) at the beginning (i.e., before training) and at the end (i.e., after training) of Ramadan fasting. The results indicated: (i) for the morning training group, the improvement in performance was significant only at 08:00 h, and peak power was higher in the morning than in the evening at the end of Ramadan; however, the chronotype of the participants was unchanged (i.e., moderate morning type). This suggests that morning training blunted the Ramadan shift in the sleep-wake cycle. (ii) For the evening training group, there was no significant improvement in performance, and peak power was not affected by the time-of-day of testing both at the beginning and at the end of Ramadan (i.e., morning = evening); however, the chronotype of the participants was modified from "moderate morning type" to "evening type" indicating a significant shift in the sleep-wake cycle. (iii) In the control group, there was no significant change in peak power by the time-of-day of testing, or alteration of the chronotype of the participants. The results of this study suggest that training in the morning hours may significantly improve morning performances, but no effect was found for peak power measured in the evening. In addition, morning training may blunt the sleep-wake cycle shift during Ramadan. In contrast, training in the evening produced no significant changes in short-term maximal performance at the two times of testing, but the chronotype of these participants was altered indicating a significant shift in the sleep-wake cycle (i.e., participants slept later and woke up later).

From a practical point of view, if the time of competition is known, training sessions before a major event should be conducted at the same time-of-day at which the critical performance is scheduled. However, if the time of competition is not known, training sessions should be programmed in the morning to counteract a possible shift in the sleep-wake cycle and its effect on sports performance.

Overall summary of coping strategy to maintain performance during Ramadan

Athletes who maintain their energy and macronutrient intake, training load, body composition, and sleep are unlikely to suffer any substantial decrements in performance during the month-long Ramadan fast. The most significant perturbations that are due to RIF have been reported to occur in the first week of Ramadan. Therefore at least two weeks before the start of Ramadan the appropriate coping strategy should be gradually introduced. Sleep deprivation and disruption to the normal circadian cycles can adversely affect physical performance. In this period before Ramadan, athletes should progressively establish a new sleep-wake cycle, with regular sleeping and eating schedules that match that followed during Ramadan. Sleep loss should be minimised, and regular daytime naps may be required to sustain hard physical activity (Chaouachi et al., 2009b; Roy et al., 2011; Waterhouse, 2010).

Part of the coping strategy must include a diet that is composed of high carbohydrate (60–70% of total energy intake) foods, with sufficient energy to meet the athlete's energy and nutrient requirements of their training and competition schedules (Rodriguez et al., 2009). The meals should be healthy, balanced meals presented in an appetising form. Athletes should be encouraged to meet the normal energy and nutrient requirements of their training and competition. A trained nutritionist may be required to monitor the energy and nutrient requirements of the athletes and to suggest suitable meals to be eaten. However, the timing of food and drink ingestion may not be optimal for the Muslim athlete during Ramadan because of the daylight fast. Acute hypohydration will occur during daylight hours especially during bouts of strenuous physical activity in the heat. Sensible dietary strategies that ensure adequate fluid intake especially just before dawn, coupled with behavioural adaptations that minimise daytime fluid losses before training will help preserve hydration status and physical performance. Fluid intake should be monitored daily and pre-training urine concentration and body mass should be checked in order to ascertain that individual athletes are not already significantly dehydrated before training. As a guide, it is suggested that individuals who are hypohydrated by 3% or more of body mass should not undertake strenuous, prolonged ($\geq$60 min) exercise, especially in hot environments.

Training loads should be suitable to progress the required fitness and performance levels of the athletes, or they should be that usually carried out in the lead up to the competition. Heavy training sessions should be rescheduled either in the early evening or the late afternoon, so that players can replenish their glycogen stores and rehydrate immediately after training. Technical or light training can be carried out at the usual time. Players should be allowed cool water to rinse out their mouth, whenever they require, which will alleviate their thirst without breaking their daytime fast. Where possible, sweat loss should be minimised by reducing non-training activity, staying in the shade or air conditioned areas.

Even modest decrements in performance could seriously affect an individual's ability during an athletic event, therefore all athletes should be regularly monitored to ensure that mood and/or performance is not progressively deteriorating. These checks should be made on a daily basis from two weeks before Ramadan and throughout Ramadan. Any obvious loss of performance/playing ability should be immediately investigated by the team scientific expert, doctor, physiotherapist, conditioning coach etc. Athletes will vary greatly in their adaptability to coping strategies during fasting and training during Ramadan, and some may not be able to sustain their exercise performance during the RIF. This may affect team selection for a competition during or immediately following Ramadan.

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