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Effects of Ramadan Fasting on Health and Athletic Performance

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Exercise Responses and Training during Daytime Fasting in the Month of Ramadan and its Impact on Training-Induced Adaptations

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Abstract

During the month of Ramadan, restriction of food and fluid intake for many hours before and during exercise, together with other Ramadan-associated negative factors such as sleep and mood swings can be a real challenge for fasting Muslim athletes to perform at their optimum level. Numerous studies have looked at the effects of Ramadan fasting on exercise responses and performances but these studies were mostly focused on the effects of the religious fast on acute training sessions. This review aims to present studies that analyzed the effects of fasting during the daytime period on chronic training and on the magnitude of training-induced adaptations over the Ramadan month. These studies were selected based on a set of criteria laid out by the authors to ensure valid comparison. The results from the small number of validated studies chosen, in contrast to our initial hypothesis, have indicated equivalent improvements in the magnitude of training-induced adaptations by both fasted and non-fasted individuals during post-Ramadan testing. The data suggest that in order for optimal training-induced adaptations to take place in Muslim fasted athletes during Ramadan, a training programme imposing a sufficient training load or stimulus with the presence of optimal nutrition and rest-recovery are key factors.

Key words

Acute exercise, Adaptations, Chronic Exercise, Intensity, Training Load

Introduction

Exercise can be a real challenge for fasting Muslim athletes during the daytime in Ramadan. The inability to consume nutrients for many hours before and during exercise means that the athletes face the possibility of reduced levels of endogenous fuel as well as dehydration towards the later part of the exercise or training session; see reviews [1,2]. The situation is further exacerbated with other Ramadan-associated negative factors, such as daytime sleepiness and feelings of increased malaise and lethargy with undesirable mood swings [1,2]. These subjective feelings are due to chronic sleep debt and/or a drastic shift in the individual's daily circadian rhythm [1,2], which alone or when summed, can create a less than ideal "psycho-physiological" situation within the athlete during training.

Effects of Ramadan on acute exercise training session

Although the physical conditions of the Ramadan fasted individuals is less than optimal, the effects of Ramadan fasting on exercise quality and quantity have been inconsistent [3]. The quantity of exercise has been shown to be compromised [4-6], while the quality of training, i.e., the fasted individual's responses to acute exercise physiological stress, has been less affected. For example, blood glucose concentration, which is an important source of fuel during exercise and is likely to be compromised only if the individual's blood

glucose falls < 3.5 mmol·L-1, i.e., to levels that could be deemed as hypoglycemic. Although some studies have shown a lower pre-exercise blood glucose concentration during Ramadan [7], particularly if measured in the late afternoon period, the glucose values were clearly within the normal range that would have minimal influence on the fasted individual's subsequent exercise capacity [4,8,9]. In these same studies, post-exercise blood glucose concentrations have been shown to be higher than pre-exercise levels. This indicates that the fasted individual is more than able to mobilize or breakdown their liver glycogen stores to produce the needed blood glucose for brain and muscle functions. Post-exercise blood lactate concentration has been used previously as an indirect indicator of muscle glycogen usage or breakdown during exercise [10]. Studies have also shown that post-exercise blood lactate concentration seem to increase to levels equivalent to that observed in the non-Ramadan fasted state [4,8,9]. These data indicates that Ramadan fasting did not have a negative effect on muscle glycogenolysis process during exercise and has little impact on exercise variables such as post-exercise blood glucose and blood lactate concentrations [3]. Therefore, Ramadan fasting has minimal impact on muscle metabolic functions during exercise. However this is a different case for exercise Heart Rate (HR) where several studies have shown a lower or no difference in HR during exercise of submaximal intensity in Ramadan vs. non-Ramadan periods [11-14]. In contrast, Leiper et al. [15] observed a higher HR (average of ~5 b•min-1) in Ramadan fasted vs. non-fasted players during a football training session. The authors argued that dehydration was one of the possible reasons for the observed differences.

While objective measures of acute exercise or training responses do not seem to be adversely affected, there is substantial evidence to indicate a negative impact of Ramadan fasting on subjective Ratings of Perceived Exertion (RPE) during acute exercise in fasted Muslims. Many studies indicate that RPE was always higher when exercising in the Ramadan fasted state when compared to the same exercise in the non-fasted state [16-19]. In retrospect, the adverse impact on perceived subjective effort of exercise is expected due to the individual's inability to ingest foods and fluids over a prolonged duration. As a result, fasted individuals usually present themselves in a hypohydrated state, with possibly low levels of endogenous fuels and higher levels of sleepiness and fatigue before the start of the exercise, particularly in the late afternoon period [16,19-21]. These less than ideal conditions could substantially limit the individuals' capacity or reduce their physiological ability to exercise at the same intensity, relative to what they are actually capable of performing when they are in the non-fasted state. In other words, whilst external training load imposed on the fasted athletes may be similar to that during the non-Ramadan period, in reality, the internal training load or stimulus experienced by these individuals are perceived or felt to be relatively greater during the Ramadan period. Thus, the same amount or rate of work seemed to be more "intense" or "difficult" in the Ramadan fasted state.

Whilst the impact of Ramadan fasting on training quality has been contentious, the available evidence on the effect of Ramadan fasting on training quantity is much more convincing. Studies have indicated that Muslim athletes were negatively affected by Ramadan fasting as, they tend to produce a lower level of exercise performance or complete a lower amount of work compared to what they are actually capable of performing in the non-Ramadan state [1,2]. In this regard, the study by Aziz et al. [4] is worth highlighting. Previous Ramadan-related exercise or training studies have usually employed an exercise protocol that resembles an exercise or a sport-specific performance measure. This is the only study, to our knowledge, that was specifically designed to examine the impact of Ramadan fasting on an acute exercise protocol that resembles a typical training-like session. The study's exercise protocols included six repeated 30-s Wingate anaerobic test all-out effort cycling bouts (with 4 min of recovery between each bout), followed by 6 min of recovery before cycling to exhaustion, which lasted between 8 and 20 min [4]. Exercise protocols were akin to the routine intense high-intensity interval workout session that taxed both the aerobic and anaerobic components of the individual's energy systems, which is typically undertaken by the well-trained athletes. The investigators showed that exercise in the daytime was adversely affected during Ramadan compared to the same exercise performed at the same time of the day in the non-Ramadan period [4]. Additionally, the use of pre-packaged meals helped to ensure that participants' maximal compliance to standardized micronutrients and energy intake over the 24 h period prior to the testing sessions further strengthened the validity of the results obtained in the Aziz et al. study [4].

The reasons for the decline in training quantity during acute exercise in the Ramadan fasted state are currently unknown, but there are several possibilities. Firstly, there may be a drastic shift in the energy metabolism during exercise as a result of the Ramadan fast. Indeed, Ramadan fasting can lead to a predominant use of lipids or fat rather than carbohydrate oxidation during exercise [6,22,23]. As a result, the Ramadan fasted working muscles are compelled to use lipids, which is clearly not suited for high-to-maximal intensity sustain work and thus leading to less than efficient muscular contractions, i.e., lower power output. Secondly, there is also a possibility of progressive muscle glycogen depletion in selective muscle fibres, such as on the fast twitch fibres rather than across the entire muscles, over the period of Ramadan. The glycolytic energy system can only utilize carbohydrates (i.e., glucose from blood glucose or from stored intramuscular glycogen), and since high-intensity exercise primarily recruits fast twitch fibres to a greater extent than slow fibres, it may be that high power-strength contractions may lead to a rapid depletion of the available endogenous substrate within these working fibres. This results in the early onset of fatigue, i.e., a lowering of power output in subsequent bouts of maximal exercise. A previous non-Ramadan study has also showed decreased levels of phosphocreatine (PCr) concentration in muscles due to a slower rate rephosphorylation particularly of PCr, within the fast twitch fibres, during the recovery periods from prior bout of intense exercise [24]. This inability to replenish PCr concentration levels quickly or as effectively during the inactive recovery period will have an adverse impact in the subsequent bouts of maximal efforts during high-intensity intermittent exercise protocol. In addition, dehydration of as much as 1% of pre-exercise body mass may also lead to some internal disturbances within the muscular cells milieu which could interfere with the proper or optimal functioning of neuromuscular system and negatively influence exercise performance [25,26]. Alternatively, the onset of fatigue might originate from the brain or central nervous system leading to an attenuated recruitment of muscle fibres during sustained efforts. This centrally-mediated fatigue could be simply due to the individual's poor self-motivation as an outcome of drastic shifts in moods swings or due to placebo effects from observing the Ramadan fast. In summary, the literature is currently unclear as to the exact mechanism(s) for the adverse effects of Ramadan fasting on sustained high-intensity exercise performance; nonetheless it does appear that this early fatiguing of the fasted individual involves a combination of, or contribution from several factors, rather than a single factor.

The substantial reduction in overall training stimulus has also been touted as one of the major contributing factors for the decline in exercise performance towards the later period of the Ramadan month in fasted individuals [27]. For instance, there may be a direct decrease in the total external training load or stimulus during the early part of the Ramadan month, which is due to the fact that fasted athletes might consciously or unconsciously reduce their work capacity because of their own subjective feelings on the prevailing levels of fatigue or tiredness. Fasting is held only once a year, thus individuals possibly require some time to adapt or make adjustment to

the drastic change in daily behavior patterns or circadian rhythm in Ramadan. In short, during the early part of Ramadan, the fasting Muslims may find themselves struggling to cope with the perturbations associated with the Ramadan fast [28]. As a result, many Muslim athletes experienced relatively higher levels of fatigue and perceived effort when completing the same amount of work or exercise during Ramadan as compared to the non-Ramadan period. Ramadan fasted individuals would possess minimal levels of tolerance to sustain moderate- to high-intensity of efforts for prolonged periods of time [5,8]. Alternatively, anecdotal evidence suggests that coaches deliberately reduce the team's or athlete's training load or intensity because of the heightened (*mis*)perception that Muslim athletes are not able to sustain high workload in the fasted state [29,30]. This means that the higher perceived effort during exercise experienced by Ramadan fasted individuals is simply due to the lowering of exercise stimulus over the early part of the Ramadan month and this may lead to a loss of some level of physical conditioning or detraining effects during the later part of the Ramadan month [27].

Another area that has an impact on exercise performance in the Ramadan fasted state but has received little research attention is the thermoregulation during exercise. The fasted individual commences exercise in the hypohydrated state due to the inability to consume fluid many hours before exercise. This hypohydrated situation is further exacerbated with the inability to ingest fluid during exercise which can further lead to excessive dehydration, particularly if the duration of exercise is prolonged and/or the exercise is performed in a hot environment. How such a situation affects the fasted individual's thermoregulatory processes is unknown, but will most likely have a negative impact on the fasting individual's exercise capacity and/or performance. To our knowledge, only two studies have investigated the impact of Ramadan fasting on exercise in a hot environment and interestingly, both showed that thermoregulation was not influenced by Ramadan fasting [31,32]. Gueye and colleagues [31] showed that there were no observed differences either in rectal or skin temperature at the end of the exercise between fasting and non-fasting conditions in the same Muslim individuals. However, the study's findings are limited because the cycle exercise was of relatively low intensity (<75% HR_{max}). Moreover, the prevailing environmental conditions where the cycle exercise was conducted were not reported in the study [31]. In the other study, professional Muslim football players training for eight weeks (4 weeks of Ramadan month and 4 weeks of non-Ramadan) showed similar peak body core temperature, and did not exhibit any heat-stress incidents during the Ramadan month [32]. This field study also has several shortcomings, for instance, training sessions during the Ramadan month were conducted in the evening period after the breaking of the days' fast in the non-fasted state and moreover, core temperature were assessed in only two players [32]. Thus, there are methodological issues that limit the findings of both the cited Ramadan and thermoregulatory studies. Clearly additional research is required to closely examine the impact of Ramadan fasting on thermoregulation process in fasted individuals and the consequent physiological responses and performances, especially when exercising in the hot environment.

Effects of Ramadan on chronic exercise training sessions

The packed international sporting calendar and the fact that the organizing sports bodies does not take into account of the Ramadan month in their competition scheduling implies that Muslims athletes must often train through the Ramadan month in preparation for competitions. Optimal training-induced adaptations often takes place as a result of systematic and progressive exercise that are of sufficient frequency, intensity, duration, in the presence of optimal nutrition, appropriate rest-recovery duration and high quality of effort during the preceding sessions [33]. Henceforth, given the less than optimal conditions that the fasted individuals encountered or experienced, it is possible that the quality and/or quantity of exercise performance of the athletes during an exercise or training session in the daytime during the month of Ramadan may be poor or even compromised [4]. Thus, if such 'inferior' training sessions persistent throughout the Ramadan month, it would then be expected that the magnitude or percentage of improvements, i.e., training-induced physiological adaptations derived from the Ramadan month exercise sessions, would be lower as compared to that in non-Ramadan month. Similarly, if the same training or exercise programme are being performed by two different groups of individuals, i.e., fasted and non- fasted individuals, it would also be expected that the non-fasted group will produce a relatively better quality or higher output of training, which would then lead to improvement of greater magnitude in physiological adaptations as compared to the fasted group.

Therefore, the purpose of this short review is to examine the literature on the effects of fasting on chronic training during the daytime period in the month of Ramadan on the magnitude of training-induced adaptations. The studies in this review must fulfill several criteria to ensure fair and valid comparison. Firstly, studies should be compare the individuals' performances or sporting measures which were taken "before" and "after" the Ramadan month and where both of these pre- and post-Ramadan test sessions or performance measures are performed in the non-fasted state. The studies chosen should also involve two groups of subjects. One of the groups should be Muslim individuals who are both training and observing the Ramadan fast (i.e., FAS group) and the other group should consist of either Muslim or non-Muslim individuals who are training but not performing the Ramadan fast (i.e., non-FAS group). In addition, both groups should be maintaining their normal or planned training program throughout the entire Ramadan month. Since training across the investigative period may differ or is periodized as would be the case in a coach-driven training programme, the non-FAS group would serve as acontrol to account for potential differences in training load/stimulus experienced by both groups across the study period. Another important methodological consideration is that training sessions during the Ramadan month must be performed during the daytime period (i.e., in the Ramadan fasted state for the FAS group) rather than in the evenings (i.e., after *iftar*). The studies selected should then be compared for improvements made from pre- to post-Ramadan test between the FAS and non-FAS groups as the criterion measure of the effectiveness (or non-effectiveness) of training-induced adaptations in the Ramadan fasted state.

Based on the four criteria set for this review, it was apparent that many of the Ramadan exercise and training studies previously published does not meet all the four criteria required for further analysis (Table 1). Only seven of them attained the necessary four criteria to be included but one of these studies, [34] is omitted as blood markers were the only responses measured and no exercise performance measure was taken in the investigation and thus, this does not allow the evaluation of the effectiveness of the study's training programme. The six remaining studies are listed in Table 2 with the details of each of the study prominently highlighted. It is interesting to note that five of the six studies in Table 2, except Kordi et al. [35], involved fasted individuals or players who were members of the same squad. This is advantageous because it further ensures that the overall or total training stimuli between the FAS and non-FAS groups during the Ramadan period of the study are more likely to be equivalent.

Study	Criterion 1 Were the exercise or test measures performed "before" and "after" the Ramadan month	Criterion 2 Was a control group (i.e., training but non-FAS) included in the study?	Criterion 3 Was the subjects' training load or stimuli was maintained during Ramadan?	Criterion 4 Was the subjects' acute exercise responses to the training stimuli/ load described in the study?
Aloui et al., 2013 [16]	√	X	√	√
Aloui et al., 2013 [17]	X	X	X	√
Aloui et al., 2013 [59]	X	X	X	X
Aziz et al., 2010 [8]	X	X	√	X
Aziz et al., 2010 [60]	X	X	√	√
Bigard et al., 1998 [61]	√	X	X	X
Bouhlel et al., 2006 [22]	X	X	X	√
Bouhlel et al., 2013 [62]	X	√	√	X
Brisswalter et al., 2011 [5]	X	√	√	√
Chaouachi et al., 2009 [19]	√	X	√	√
Chennaoui et al., 2009 [63]	X	X	√	X
Chtourou et al., 2011 [18]	X	X	√	√
Chtourou et al., 2012 [21]	X	X	√	√
Fall et al., 2007 [64]	X	X	X	X
Faye et al., 2005 [7]	X	X	X	X
Girard & Farooq, 2011 [65]	√	X	X	X
Gueye et al., 2003 [31]	X	√	√	√
Guvenc, 2011 [20]	√	X	√	√
Hammouda et al., 2012 [66]	X	X	√	√
Hosseini et al., 2013 [67]	√	X	√	X
Karli et al., 2007 [68]	√	X	√	√
Lofti et al., 2010 [69]	√	X	X	X
Meckel et al., 2008 [30]	X	X	√	X
Memari et al., 2011 [70]	√	X	√	X
Mirzaei et al., 2012 [71]	√	X	√	√
Ramadan et al., 1999 [11]	X	X	X	√
Ramadan & Barac-Nieto, 2002 [12]	X	X	X	√
Ramadan et al., 2002 [13]	X	X	X	√
Rebaï et al., 2013 [72] ‡	√	X	√	√
Souissi et al., 2007 [43]	√	X	X	X
Stannard & Thompson, 2008 [6]	X	X	X	√
Sweileh et al., 1992 [42]	X	X	X	X
Sweileh et al., 1990 [73]	X	X	X	X
Tayebi et al., 2010 [74]	X	√	√	X
Trabelsi et al., 2013 [34]	X	√	√	√
Trabelsi et al., 2012 [75] ‡‡	√	√	√	√
Trabelsi et al., 2012 [76]	X	√	√	X
Wilson et al., 2009 [32]	√	X	X	√
Zarrouk et al., 2012 [77]	X	X	√	X
Zerguini et al., 2007 [78]	√	X	√	X

Key: FAS = Ramadan fasting group; non-FAS = non-fasting group; √ = criterion met, X = criterion was not met
‡There was no control group since both of the training groups in the study exercised in the fasted state.
‡‡No exercise performance measures were taken in the study.

Table 1: Ramadan training-related studies that did not meet the all the four criteria set to be included as a validated study in this review.

Studies examining the effects of Ramadan on training-induced adaptations

Given the potential negative effects of Ramadan observance on training-induced adaptations, it is rather surprising that in the sic studies that have fulfilled the criteria set (Table 2), majority of them have indicated equivalent improvements in training-induced adaptations by both FAS and non-FAS individuals [9,36-38].

Kirkendall and colleagues [38] were among the first to examine the impact of Ramadan fasting on exercise performance across the Ramadan period. Their study showed that Ramadan fasting did not negatively affect the different variables tested in their subjects, which consisted of a large sample of young soccer players undergoing a coach-designed training programme. Physical performances in speed, power, agility and aerobic endurance significantly improved when tested after Ramadan and more importantly, the magnitude of improvements were similar in both FAS and non-FAS groups. The investigators suggested that the changes in exercise performance observed in both groups were most likely due to training-induced effects and familiarity to the tests [38]. In another study, after 4 weeks of training together as a group, FAS subjects improved to a greater extent, albeit not significantly, than non-FAS subjects during a 2-mile run time-trial [37]. There was no significant differences in both groups' dietary intake, but the authors argued that the higher fitness level at pre-Ramadan reduction in the FAS subjects' body mass may have contributed to the greater improvements made in the FAS group [37]. Nonetheless, it could be reasoned that the equivalent improvements made by FAS and non-FAS subjects in Kirkendall et al. [38] and Havenetidis [37] studies were due to the fact that these studies were conducted in training camp conditions where all of the subjects' food, fluid, sleep and training load were well managed and monitored closely by the management and coaching staff. Thus in such situations, it can be argued that the FAS subjects' Ramadan negative-associated behaviors such as chronic sleep debt, poor dietary intake and low

training load were averted, or at least minimized, which resulted in equivalent improvements in FAS compared to the non-FAS group.

In another Ramadan training study, investigators showed no difference in aerobic performance between pre- and post-Ramadan in young soccer players [36]. In this study, the players involved were not residing in a training camp setting, but were "free-living". Ratings of perceived intensity, an indirect indicator of the subjects' internal training load, that were taken at the end of the high-intensity interval training sessions performed throughout the study, showed no significant differences between FAS and non-FAS subjects [36]. This finding of equivalent perceived effort during training sessions is however not universally observed [9,37]. It should also be mentioned that the study's investigators had taken deliberate and specific steps to ensure that FAS and non-FAS subjects performed their exercise runs to equivalent effort as much as possible [36]. This included organizing the training as a single group session to exert peer-pressure on the FAS subjects; and providing feedback on their running times to ensure correct pacing and effort during the runs. The investigators also ensured that the duration of session was shortened (< 60 min) to prevent the influence of insufficient endogenous muscle glycogen as a possible limiting factor to exercise performance. The session was also conducted towards the later part of the day and was deliberately timed to end close to *iftar* (time to break day's fast) so as to provide somewhat of a "psychological" edge to the FAS subjects [36]. Nonetheless, a major limitation of this study [36] study was that only ~40% of the total number of training sessions was controlled while the other 60% consisted of sports-specific training sessions which was under the purview of the team's coaching staff. Hence, it cannot be ascertained that training intensity is the only factor that primarily influenced the outcome of the study's observations.

Study	Subjects' characteristics	Detailed training programme during Ramadan month		Magnitude (in %) and direction of change (↑, ↓ or ↕) from Pre- to Post-Ramadan test			Remarks / Conclusion
				Test	FAS	Non-FAS	
Aziz et al. [36]	Males, 18 ± 1 y. National youth soccer players. FAS (*n* = 10) and non-FAS (*n* = 8). Players were free-living subjects. They were from the same squad and trained together.	F	6 sessions per week	Beep (number of shuttles)	0.9, ↔	0.9, ↔	No significant improvements made in both the FAS and non-FAS groups as a result of training. No significant differences between FAS and non-FAS for Beep test at pre- and post-RAM. Training stimuli (external): Similar between groups Training responses (internal): Session-RPE post aerobic and sprint sessions were similar between FAS and non-FAS groups Dietary intake: Similar between groups Sleep pattern: Not reported Note: Only 40% of study's total training sessions were controlled.
		I	High to maximal				
		Ti	Progressive duration of 30-50 min per session				
		T	Football-specific, high-intensity aerobic runs, and short all-out sprints				
Aziz et al. [9]	Males, 18 ± 1 y. College and club level team-sports athletes. FAS (*n* = 10) and non-FAS (*n* = 10). Players were free living subjects. They were from the same squad and trained together.	F	3 sessions per week	Aerobic power (ml·kg·-1min-1)	12, ↑	11, ↑	Significant improvements made by both FAS and non-FAS as a result of training. No significant differences in improvements made for aerobic and anaerobic performance between FAS and non-FAS groups. Training stimuli: Similar between groups Training responses: Blood lactate, HR and RPE were generally similar between FAS and non-FAS groups Dietary intake: Similar between groups Sleep pattern: Not reported Note: Players were training for 7 weeks where Ramadan month falls within this period.
		I	Maximal efforts, >100%$VO2_{max}$	Anaerobic power (work done during 4 x 30 s Wingate cycle in kJ)	8, ↑	10, ↑	
		Ti	Progressive duration of 30–60 min per session				
		T	Repeated 30 s Wingate cycle bouts (from 4 to 10 bouts with 2-4 min recovery)				
Havenetidis [37]	Males, 23 ± 3 y. Military cadets who were club runners. FAS (*n* = 10) and non-FAS (*n* = 10). Cadets were residing in a military camp and were from the same club and trained together.	F	4 sessions per week	2-mile running time (min)	2.9, ↑	1.6, ↑	Significant improvements made by both FAS and non-FAS as a result of training. The 2-mile run time performance was better in FAS than non-FAS but the difference was not statically significant. Training stimuli: Similar between groups Training responses: Not reported Dietary intake: Similar between groups Sleep pattern: Not reported
		I	~70% individual's HR_{max}				
		Ti	Progressive duration of between 45-55 min				
		T	Continuous steady-state runs				
Kinugasa et al. [41]	Males, 13-14 y. Trained soccer players. FAS (*n* = 9) and non- FAS (*n* = 11). Players were residing in a sports school environment. They were from the same squad and trained together.	F	5 sessions per week	20m sprint (s)	-0.3, ↔	-1.2, ↔	No significant differences between FAS and non-FAS for 20 m sprint and Beep test. Broad jump decreased to a greater extent in FAS than non-FAS. Training stimuli: Similar between groups Training responses: Not reported Dietary intake: Similar between groups Sleep pattern: Not reported
		I	Not reported	Beep (number of shuttles)	3.4, ↓	3.9, ↓	
		Ti	Not reported	Standing broad jump (cm)	3.9, ↓	-0.4, ↕	
		T	Football-specific sessions, aerobic conditioning and strength training				

Kirkendall et al. [38]; Leiper et al. [15] and [79]	Males, 18 ± 1 y. Club level soccer players. FAS (*n* = 53) and non- FAS (*n* = 32). Players were residing in a training camp for 10 weeks where Ramadan month falls within this period. Players were from two squads. Players from each squad trained together.	F	6-8 sessions per week	7 x 30-m repeated sprint (s) Beep (number of shuttles) Vertical jump (cm) Agility (s)	-1.4, ↑ 25.3, ↑ 6.8, ↑ -2.3, ↑	-0.6, ↔ 16.8, ↑ 4.7, ↑ -3.2, ↑	Most performance measures showed significant improvements in both FAS and non-FAS as a result of training and/or learning effects. Performance in Beep and dribbling tests were similarly improved in FAS and non-FAS. FAS improved to a greater extent in repeated sprint and vertical jump than in non-FAS group. Training stimuli: Similar between group Training responses: HR and RPE were generally similar between groups Dietary intake: Similar between groups Sleep pattern: Minimal disruption to sleep hours and pattern in FAS Note: Performance data are combined from tests conducted in the morning and afternoon.
		I	Low to high				
		Ti	60-90 min per session				
		T	Football-specific with several sessions of aerobic conditioning and strength training				
Kordi et al. [35]	Elite male athletes at local and national level from volleyball, karate, taekwondo and football. FAS (i.e., athletes training during daytime; n = 14) and non-FAS (athletes training in the evening period, n = 20).	F	Not reported	Agility (s) Standing broad jump (cm)	0.5, ↔ 0.8, ↔	5.7, ↑ 0.9, ↔	There was minimal change in performance measures across Ramadan in both FAS and non-FAS groups, except for a significantly better improvement in agility in non-FAS than in FAS group. Training stimuli: Not reported Training responses: Not reported Dietary intake: Not reported Sleep pattern: Not reported Note: Participants were not training together as a group; therefore with greater likelihood of differences in the internal training load or stimulus between groups.
		I	Not reported				
		Ti	Remained unchanged during Ramadan				
		T	Sport-specific skills				

Key: FAS = Ramadan fasted subjects group; non-FAS = non-Ramadan fasted subjects group; RAM = Ramadan month; CON = Control period; HR = heart rate; ↑ = increase; ↓ = decrease; ↔ = no change; F = frequency, I = intensity, Ti = time, T = type (of exercise).

Table 2: Ramadan fasting and training-induced studies

The investigators followed up their earlier study [36] with a more controlled and systematic training program where the loading of exercise intensity was progressive and incremental in nature [9], . The training programme has also been shown to be effective in enhancing the training individual's aerobic and anaerobic systems. Further more, compared to their previous study, all exercise sessions throughout the later study were under the control and scrutiny of the investigators [9]. This study showed that the improvements made by both the FAS and non-FAS groups were similar. Several indicators of training responses such as blood lactate concentration, HR and RPE, were assessed in all subjects during the last session of each training week which allowed a fair comparison between the FAS and non-FAS groups in their responses to the training stimuli. The training responses between FAS and non-FAS groups were not significantly different and the total caloric intake from dietary records taken throughout the study period was similar in both groups. The authors concluded that aerobic and anaerobic adaptations to a high intensity-training program were not adversely affected as a result of Ramadan fasting, possibly because training intensity and daily nutritional intake during the Ramadan month were not compromised [9].

This factor of training intensity and/or load as the key to enhancing training-induced adaptations during Ramadan was further reinforced with the observations from a longitudinal field-study [39]. In that study, five FAS and five non-FAS professional football players were tracked over a total of 12 weeks period (four week before-, four week during- and four weeks after-Ramadan month). The players' aerobic fitness (as determined from HR and blood lactate post-intermittent running at submaximal intensity) was assessed at the end of every four weeks and their training load (i.e., session-RPE x exercise duration; [40]) was recorded throughout the period. All players were training together as a team throughout the 12 weeks. The FAS players' aerobic fitness increased from before- to during-Ramadan, followed by a decreased from during- to after-Ramadan periods. The FAS players' up- and down-swings in aerobic fitness levels paralleled closely to their training load pattern throughout the 12 weeks while no such trends was observed in the non-FAS players. The study's authors rationalized that the changing in aerobic fitness in FAS subjects was mostly influenced by the changes in players' internal training load and therefore recommended that coaches should try to maintain the intensity of training sessions during Ramadan fasting to alleviate the perturbations of Ramadan fast on players' physical condition [39].

The more recent studies have provided persuasive evidence that improvements of similar magnitude could also be made in FAS as compared to non-FAS subjects, who were not residing in a training camp setting i.e., "free-living" [9,35,36]. These research indicated that the fundamental similarities or the consistent underlying themes of these studies that have shown equivalent degree of training-induced adaptations or improvements in FAS individuals as compared to non-FAS individuals during Ramadan are that: i) total dietary intake over the Ramadan was similar compared to the non-Ramadan period in FAS subjects, ii) FAS individuals' sleep hours over the Ramadan period were minimally affected, and iii) training load or stimuli in FAS individuals throughout the Ramadan period were high and/or were maintained at the same levels as in the non-Ramadan period, or was equivalent to the non-FAS subjects. This indicates that when these conditions remain stable, the impact of Ramadan fasting and its associated perturbations will be minimized so that fasted training Muslim athletes can obtain the same training-induced benefits as their non-fasting training counterparts.

Readers should however be aware of the inherent limitations of studies listed in Table 2. For instance, although the training program in the Aziz et al. [9] study was well-designed, the exercise sessions were held merely three times a week, on every alternate day, and performed indoors under cool environmental conditions. This meant that subjects had ample time to recover adequately (both physiologically and mentally) from the previous exercise session and thus the overall physical stress imposed on the athletes throughout the period of study might not be as intense as that expected of some elite athletes who could be training twice a day on most days of the week. Hence, it is still not known if similar magnitude of improvements can be obtained in subjects who fast during Ramadan under more 'elite-like' or very intense training programme. For example, frequency of training could be up to six days a week with two sessions

a day, which is clearly the norm for majority of elite athletes. It is foreseeable that such a regime would then challenge or even sap the fasted individual's physiological and psychological resources at a faster rate, and possibly exert pressure on the individual's recovery capability – which in turn could lead to excessive stress or overtraining during Ramadan month. This could result in adverse training-induced adaptations. This hypothesis certainly warrants further research. Several of the studies listed in Table 2 [e.g., 35,41] also provided insufficient information about their training program and therefore the training volume or load that the FAS and non-FAS subjects had been exposed to is not known. Instead, authors simply stated that both the FAS and non-FAS groups performed their "normal" or typical training during the Ramadan month. More importantly, these studies did not provide any information about the exercise responses of both groups who were presumably exposed to the "same" training program and thus, the subsequent training loads experienced by both the FAS and non-FAS subjects was assumed to be equivalent. The internal stimuli (i.e., physical and mental stress) experienced by different individuals vary widely from the same external training load (i.e., quantity of training) imposed upon the individuals [36]. Therefore, training responses information such as HR, blood lactate and RPE are important before determining that FAS and non-FAS subjects' training loads were equivalent. The differences in responses during exercise for the same training stimuli are even more important when it is an accepted fact that FAS subjects are possibly at a physiological and/or mental disadvantage as compared to non-FAS subjects at pre-, during and post-exercise during daytime fasting in Ramadan. Hence, future research need to take into account subjects' exercise responses when examining the impact of daytime fasting during Ramadan on the magnitude of training-induced adaptations during Ramadan, before arriving at their conclusions.

From Table 2, only one study showed a decline in training-induced adaptations during Ramadan [41]. This study was conducted on young footballers where the student-athletes showed reduction in aerobic endurance (via Beep test) and lower limb power (via standing broad jump test) after the Ramadan month compared to before the Ramadan month. The decline in performance is an unexpected finding since the players in the study were all full-time residents in the sport-school and thus should be coping well with the perturbations of Ramadan or at least, being monitored closely such as the participants in the study of Kirkendall et al. [38]. Explanations for these differences are not apparent but noted that subjects in Kirkendall et al. [38] were in the competitive phase and were thus training for a major competition to be held just after the Ramadan month and players in the study of Kinugasa et al. [41] were in their post-competition mode. It is plausible that the motivation levels of the fasted individuals (i.e., competing for a place in the final squad vs. routine training) may play a major part in contributing to the observed difference between findings of the cited studies. Additionally, in Kinugasa et al. [41] study, the training programme, training responses and other important variables such as dietary intake were not adequately reported and thus further limit the applicability of the study's findings.

The study reported by Kirkendall et al. [38] is worthy of close research scrutiny. Apart from pre- and post-Ramadan tests, the investigators undertook additional test measures within the Ramadan month, which provided some interesting observations of effects of Ramadan fasting on exercise performance. The authors showed that exercise performance during Ramadan was poorer during the first week of the Ramadan month but progressed and improved towards the later part of the month, followed by improvements in performance above pre-Ramadan levels at post-Ramadan [38]. These data indicates that fasted individuals were primarily affected by the perturbations of Ramadan during the early part and they were able to cope well with fasting as the Ramadan days progressed. This argument is in line with previous studies which showed that performances and other measures such as metabolic and physiological variables stabilized during the last week of Ramadan as compared to the performances observed during the early part of Ramadan [22,41-43]. It is apparent that individuals learn to better adjust their behaviors and adopt various coping strategies as Ramadan progresses, i.e., a habituation effect [28,38,42]. The practical implication here is that coaches should be aware of such physical and/or physiological trends on the fasted individual's exercise response and performances during training in early Ramadan and therefore to be more flexible in their training program. Coaches and fasting athletes themselves should not be overly concerned with the relatively poorer quality of exercise performance, especially during the first week Ramadan month training sessions as performance will be expected to improve to baseline or pre-Ramadan levels during the later part of the Ramadan month.

Explanations for equivalent training-induced adaptations whilst observing Ramadan fasting

It would be of interest to speculate how it was possible for the FAS subjects to achieve the same degree of improvements as to their non-FAS counterparts, given the less than ideal conditions of the FAS subjects whilst exercising throughout the Ramadan month. In both Aziz et al. studies [9,36], training sessions ended very close to the time of the day's breaking of fast such that the fasted athletes were able to get access to food and fluid without restriction within an hour post-exercise for all the sessions, i.e., *iftar* meals. Thus, whilst the exercise or training sessions were conducted in the less than ideal 'physiological' conditions of fasting, the post-recovery situations of these sessions were not compromised. Rather, this ability to consume nutrients within the "window of opportunity" period for recovery [44] is important as the process of adaptations does not commence until nutrients and rest period are available [45]. Indeed muscle biopsy studies have clearly demonstrated that the intracellular signaling mechanisms regulating muscle protein synthesis and hence the subsequent cellular adaptations from aerobic and resistance exercise are enhanced during recovery in the fed vs. in the fasted state [46,47]. In summary, in both Aziz et al. studies [9,36], even though the actual 'physical' performance of the training sessions were not ideal, the recovery process of the exercised muscles in these studies was, however, close to optimal, which consequently might have led to the similar magnitude in training-induced adaptations between the FAS and non-FAS subjects in the two studies. This finding has important implications for athletes and coaches when they plan their daytime training session during the Ramadan month.

Perhaps, it may be argued that there is minimal impact of Ramadan fasting on acute exercise performance and subsequently, there is no adverse influence on training-induced adaptations over the Ramadan month, albeit specifically in trained individuals only. This view is supported by the findings of a study examining the impact of Ramadan fasting on acute endurance exercise consisting of a 60 min time-trial run [8]. In the study, it was elegantly demonstrated that relatively less fit fasting Muslim individuals performed much poorly compared to fasting Muslims who were aerobically fitter [8]. Indeed, there is support to suggest that well-trained individuals do possess enhanced cardiovascular and metabolic reserve capabilities to be utilised during exercise. For example, they have enhanced muscle glycogen storage, higher body water stores and greater physical tolerance level [48] and/or greater psycho-physical attributes such as self-motivation, determination, etc., than less fit or less trained individuals [49]. Thus, it may be reasoned that fitter fasting individuals were able to cope, both physiologically and mentally, better with the perturbations associated with chronic Ramadan fasting. This will consequently put these same individuals, as compared to their less fit counterparts, in excellent position to possibly counteract or at least minimize the adverse impact of Ramadan fasting on training-induced adaptations.

Interestingly, within the context of metabolism during acute exercise and impact on the subsequent training-induced adaptations, there is evidence to indicate that exercise and training conducted in the fasted state may even be beneficial [46]. Exercising in the fasted

state or more specifically, in the low endogenous carbohydrate state, can enhance oxidative or cellular adaptations although the actual amount of work done during the fasted session is expected to be relatively less as compared to the amount of work done in the non-fasted state. It was reasoned that when the muscle exercises in a 'carbohydrate-filled' condition, there is less of an energy imbalance during the exercise which means less metabolic activation of signalling pathways. On the other hand, the "fasted" muscles are compelled to produce the same amount of work with much less endogenous resources and thus would experience a greater metabolic stress and/or homeostatic disturbances relative to the muscle of non-fasted individuals. This would then create relatively stronger stimuli within the fasted muscles that could accelerate and/or amplify the cellular adaptations processes. This concept of "working harder with less resources" is akin to other training ergogenic modalities such as low-to-moderate exercises in hypoxia or occlusion resistance training using low loads [50,51].

This view of the possibility of high efficacy of training-induced adaptations in Ramadan fasted muscles is supported by experimental studies in humans. Stannard and colleagues [52] discovered that overnight-fasted training had greater training-induced increase in peak power and maximal aerobic power (or $VO2_{max}$) than acutely carbohydrate-fed state, mostly likely via enhanced muscle oxidative capacity. They also showed that chronic exercise in the fasted state enhanced storage of resting muscle glycogen concentration, which is clearly beneficial to fasted exercising individuals during Ramadan [52]. De Bock and colleagues [53] also showed similarities in the percentage of improvements made in $VO2_{max}$ whether the subjects were training in the fasted or carbohydrate-fed state over a period of 6 weeks. The mechanisms for the above observations are unclear but muscles functioning in the fasted or glycogen depleted state seems to promote exercise-induced intramyocellular lipid degradation, which could indirectly enhance exercise performance adaptations by reducing the usage of the limited availability of endogenous muscle glycogen within fasted muscles [54,55]. Additionally, others have also shown that exercising with low endogenous carbohydrate state will lead to a greater activation of signaling proteins and pathways (e.g., peroxisome proliferator-activated receptor-γ coactivator-1, adenosine-5'-phosphate-activated protein kinase) involved in increasing the activities of enzymes, which are contributors to energy metabolism and mitochondrial biogenesis [56,57]. Nonetheless, it should be kept in mind that these cited studies were non-Ramadan related studies and hence were conducted in exercising fasted subjects who were solely deprived of food but not fluids. The impact of Ramadan fasting and all of its associated perturbations such as dehydration, sleep and mood swings were also, not accounted for in these studies, and as such, further experimental studies in actual Ramadan fasting individuals are needed to confirm the assertion that exercise in this state could potentially be advantageous.

Conclusion

Much of the Ramadan fasting literature has primarily focused on acute exercise performance rather than on chronic exercise training programme and the subsequent impact on training-induced adaptations. Based on the findings of the few studies that met the criteria established in this review, it can be concluded that adaptations to training whilst observing Ramadan could be of the same percentage or magnitude as that of non-Ramadan periods if nutrients intake and training stimuli (exercise load/intensity) were maintained at levels that are similar to that in non-Ramadan period. Coaches and fasting Muslim athletes must take the appropriate steps and measures [58] to ensure that these factors are not compromised during Ramadan so as to maximize their training-induced adaptations. Further studies are required to examine the chronic effects of training while observing daytime fasting during Ramadan in well-trained Muslim athletes.

Disclaimer

The above statements are those of the personal views of the authors (NFD and VTWL) and are not the official view of the Ministry of Defence, Brunei Darussalam.

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