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Altered sleep–wake cycles and food intake: The Ramadan model

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Abstract

In this review the effects of diurnal fasting on normal physiological processes are considered. Ramadan is placed in a circadian context, food and fluid ingestion being displaced to the pre-sunrise and post-sunset hours. Over the holy month, negative energy balance is often experienced, though this deficit is not a universal finding. Responses to exercise during the day show influences consistent with hypohydration and an increased reliance on fat as a source of fuel for exercise. Muscle performance and psychomotor performance are impaired as the month of fasting progresses but it is not clear how circadian rhythms in responses to activity are altered. For some measures at rest there is a reduction in amplitude and a delay in acrophase. Health-related benefits are reflected in a rise in high-density lipoprotein cholesterol and individuals with predispositions for coronary heart disease are not at increased risk of cardiovascular disorders due to fasting. The physiological adjustments during the month have some similarities to the disturbances in circadian rhythms experienced in different circumstances. The Ramadan model provides an alternative to those for ageing, nocturnal shift-work and time-zone transitions in understanding the links between behaviour and endogenous circadian rhythms.

Keywords: Circadian rhythms; Exercise; Food intake; Sleep

1. Introduction

Rhythmicity is a fundamental feature of existence and circadian rhythms have been observed in the vast majority of human physiological variables [1]. One of the more fundamental rhythms is that of the sleep–wakefulness cycle which is harmonised with the natural alternation of daylight and darkness in the environment. Patterns of food and fluid ingestion also fit a diurnal rhythm, in time with arrangements for sleeping and being active. The ingestion of food and liquid is highly influenced not only by immediate biological needs but also by external factors such as social circumstances, habit and individual and family choices.

Normal patterns of fluid and food intake are broken when the sleep–wake cycle is disrupted. Different types of disturbance are attributable to time-zone transitions, working on rotating shift systems and sleep deprivation. Sleep–wake cycles are also affected by ageing [1] and so is the autonomic drive to imbibe fluid [2]. The focus of this review is on Ramadan, a holy month for Muslims in which food and fluid ingestion is not permitted during daylight hours. This fasting regimen applies to about 18% of the world's population. It therefore provides a relevant model to study the links between circadian rhythms and their interactions with changes in eating and drinking.

2. Ramadan in a circadian context

The required practice of adherents to Ramadan is to abstain from food and fluid intake between sunrise and sunset. Observance of this religious tenet by Muslims displaces energy intake and hydration to the hours of darkness and partly reverses the normal circadian pattern of eating and drinking. The long duration of diurnal fasting means that hunger, energy levels and subjective fatigue are increased above those habitually experienced at other times of the year. Furthermore, if the period of daytime fasting is fractured by spells of sleeping, the normal sleep–wakefulness cycle associated with the solar day is disrupted. The propensity to participate in physical training and the maximal capability to perform exercise are likely to be impaired, even if the period of training is displaced voluntarily to a time after darkness has fallen.

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In addition to the avoidance of solid food, fluid intake is also eschewed during daylight hours. A gradual dehydration therefore occurs until body water status can be restored after darkness. Since severe hypohydration can lead to impairments in exercise performance, the lack of fluid intake compounds the effects of energy losses during the day. There are likely to be knock-on consequences for renal function as well as endocrine function during daytime, particularly secretion of anti-diuretic hormone and aldosterone [3].

The changes associated with conforming to strict Muslim customs are in part conflicting with the normal circadian cycle of rest and activity that corresponds to the hours of darkness and light. Normally, this cycle has consequences for the regulation of habitual activity in humans and other animals. It has a direct exogenous influence (due to environmental temperature, social factors, exercise and so on) upon measured circadian rhythms in many physiological systems, superimposed upon an endogenous component (due to the so-called body clock). The harmonisation of these internal and external components fixes the circadian rhythm into a 24-h period. In the normal habitual activity of Muslims, the morning call to prayer signals the start of daily routines and this, coupled with physical and social activity, food intake and light exposure, acts to adjust the phase of the body clock relative to the solar day.

Ramadan interferes with the normal circadian rhythms largely by means of disturbing the typical patterns of feeding. Other occasions in which circadian rhythms are perturbed include sleep deprivation, nocturnal shift-work and travel across multiple time-zones [1,4]. The research models based on these sources of circadian desynchronisation provide useful insights into the likely consequences of Ramadan practices on circadian rhythms. However, it should be emphasised that neither model of jet-lag or shift-work on its own provides satisfactory explanations. For example, the syndrome of jet-lag demonstrates what happens when rhythms are desynchronised from the new external environment, but the symptoms disappear once the body clock re-tunes to fit with the new time-zone. More appropriate insights are obtained by considering consequences of displacing diurnal activities into the night-time while local environmental conditions remain unchanged, as occurs in rotating shift-work systems. There is also the observation that the body clock does not readily adjust to night-work, and so the changes experienced are not transient. Another situation for comparison with Ramadan is where sleep is fragmented as might occur when sleep is disrupted due to domestic circumstances. These models will be compared with the fasting during Ramadan, and it will be concluded that the disturbances to the sleep–wake cycle and food intake that are produced are unique.

In order to appreciate how daytime fasting impacts on circadian rhythms, an understanding of key features of the body clock is desirable. The biological basis of circadian rhythms is presented prior to a consideration of rhythms in performance. The relevance of rhythms in performance is explained where appropriate, and individual differences are placed in context. Whilst there is a dearth of literature related to the study of circadian rhythms during Ramadan, their likely impact is discussed from chronobiological principles. The consequences of the intermittent schedules for eating and drinking for health and for human performance are also considered.

3. The Body Clock

There is a considerable body of evidence favouring the suprachiasmatic nuclei cells (SCN) of the hypothalamus as the site of the body clock (see Ref. [1]). This cluster of cells is linked neurally to the eyes via the retinohypothalamic tract and receives humoral input from the pineal gland. These pathways provide a means of responding to light and to its absence. The pineal gland secretes the hormone melatonin during the hours of darkness, and there are melatonin receptors in the SCN. The secretion is inhibited by natural daylight or bright artificial light. Therefore the profile of melatonin in the blood or saliva in dim light is a strong indicator of the phase of the circadian rhythm. Outputs from the SCN are transmitted to hypothalamic nuclei that control body temperature and hormone secretion, to the raphe nucleus which is involved in sleep regulation, and to the sympathetic nervous system. Feedback from the sympathetic nervous system contributes to the control of melatonin production [5].

Melatonin has a myriad of effects throughout the body and these have been reviewed in an exercise physiology context by Atkinson et al. [6]. One of melatonin's attributes is that it is a potent vasodilator and therefore promotes heat loss. The body temperature falls in the evening as melatonin is secreted and begins to rise again in the morning as secretion is inhibited. The core temperature, also used as a reliable marker of circadian rhythms (see Fig. 1A), has a peak-to-trough variation of about 0.6 °C over the solar day when environmental conditions are constant. Melatonin also induces drowsiness which increases the feelings of sleepiness as the body temperature decreases towards its nadir.

Many physiological systems exhibit circadian rhythmicity, closely in phase with the curve in body temperature. Some of the effects are due directly to the change in core temperature; Reilly and Brooks [7] calculated that about one-third of the circadian amplitude in oxygen uptake ($\dot{V}_{O_2}$) could be explained by the change in core temperature. A minor sub-harmonic in $\dot{V}_{O_2}$ is attributable to food intake, referred to as the specific dynamic activity of food. A sub-harmonic in the circadian variation in alertness occurs in the afternoon and has been termed the 'post-lunch dip'. The phenomenon is evident even when lunch is missed and has been explained as a corollary of the 90-min stages in brain-wave activity that characterise sleep but are subliminal in the daytime [1]. Existence of this sub-harmonic would likely promote daytime sleep when fasting but prolonged naps might impair nocturnal sleep. Such interactions are evident as effects of ageing whereby total night-time sleep is reduced but afternoon or early evening napping is increased. A consequence is that ageing is associated with a movement towards a 'morningness' profile [8]; whether adherence to Ramadan (and any typical napping patterns) displaces circadian rhythms in phase, or alters their amplitudes, is open to question. There is also the problem that changes in the overt circadian rhythm in these circumstances might reflect the direct effect of exogenous influences rather than any change in phase or amplitude of the

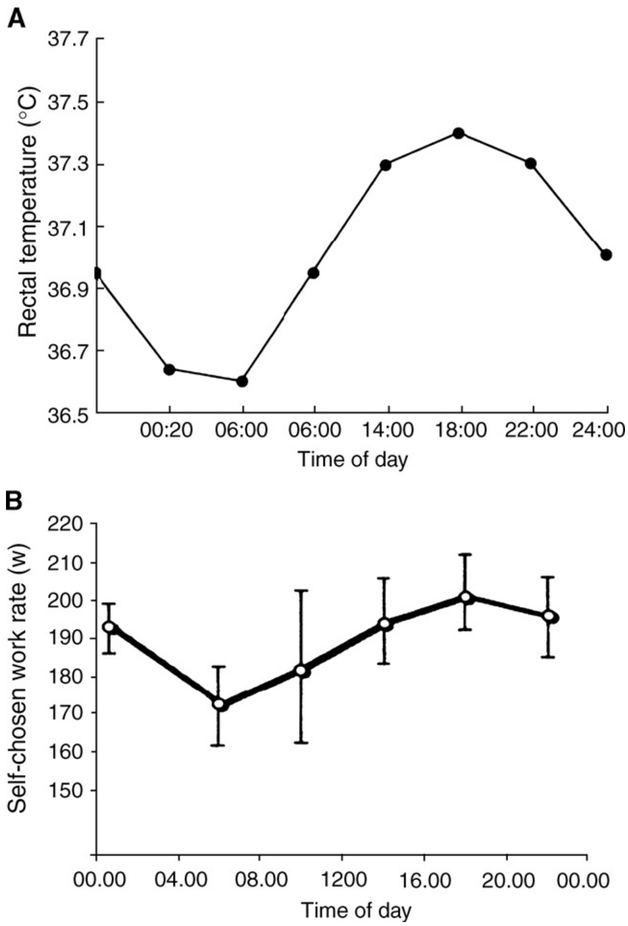

Fig. 1. The circadian rhythm in rectal temperature (A) and in self-chosen work-rate (B).

output from the body clock. It is likely that any profound changes that occur in behaviour and lifestyle have implications for human performance. Again, these changes are not yet unambiguously associated with a change in the body clock itself rather than with changes secondary to altered sleep pressure and food intake.

The typical pattern of food ingestion is that meals are distributed more or less evenly throughout the day for reasons of comfort, ease of digestion, social factors, daily schedule, and maintenance of energy levels. An overnight fast during a sleep following supper means an absence of energy intake for almost 40% of the 24-h solar day. This pattern applies in normal conditions in the majority of societies, although details differ according to culture, climate, season and food availability. It is this regularity that is broken in instances of circadian disruption such as nocturnal shift-work, travel across multiple time-zones and with religious practices, notable among which are those associated with Ramadan.

4. Energy balance during Ramadan

Energy balance is determined by the correspondence between energy expenditure and energy intake. The expenditure of energy is affected by the level of habitual activity and the cost of resting metabolism. Energy intake is influenced by the quantity and quality of food available and the opportunities for ingestion. There is also a need to maintain hydration status by drinking fluids. The main influences on the decision to eat are hunger and habit, both of which are affected in nocturnal shift-workers, in those travelling across multiple time-zones [9] and during Ramadan. Fluid intake is due to thirst and to habit and is often less likely to be decreased during night-work because drinks are more readily available. During time-zone transitions, long-haul flights and long car journeys, however, dehydration can arise due to the dry cabin air (in flights) and decreased availability of suitable fluids. (Alcohol and tea are unsuitable, due to their diuretic and diaphoretic properties, respectively). In Ramadan, feelings of thirst in the daytime have to be ignored and alcohol does not constitute a problem, since devout Muslims do not take drinks that contain it.

In the short-term, the maintenance of body water stores is the more important of these homeostatic processes controlling food and fluid intake. Leiper et al. [10] concluded that Muslims undoubtedly become dehydrated during the daylight hours of Ramadan but it is unclear whether they are chronically hypohydrated during the holy month. Some forms of exercise performance may be affected when the loss of body water exceeds 2% of body mass, at least in endurance activities [11]. It may be possible to produce all-out performance in anaerobic activities over a few seconds with body mass losses of up to 5%. Athletes may lose sweat at a rate of $2\,l\,h^{-1}$ during strenuous exercise [12], especially in the heat. In contrast, imbalances in energy do not occur nearly as fast nor do they have the same potential to threaten health. Nevertheless, weight gained or lost over a sustained period might influence performance capability and have consequences for health. When energy intake is inadequate and the diet is deficient in nutrients, a shortage of the appropriate macronutrients could have an adverse effect on physical activity, both in training and competitive contexts. Leiper et al. [10] considered that a reduction in body mass is a common but not a universal finding during Ramadan but there was no evidence of an adverse effect on health due to the negative water and energy balances that are experienced during Ramadan.

5. Implications for gastrointestinal function

Quite apart from the disturbance of the normal regularity of eating, there is potential for health-related problems to be experienced when normal dietary habits are perturbed. For example, eating particular types of food at inappropriate times may be a factor in gastrointestinal complaints among those on unorthodox daily work-schedules and may predispose individuals to becoming overweight. Iraki et al. [13] showed that gastric acidity was increased during Ramadan, mainly in the diurnal phase but without any adverse digestive symptoms. Similarly, eating at night after a day-time fast can disrupt sleep due to intestinal discomfort from eating too much or as a sequel to hunger from having eaten too little earlier on.

Fig. 2 shows the mean hunger and indigestion in a group of 12 subjects during the course of a constant routine. In this routine, subjects were kept awake in a constant environment (temperature, humidity and lighting) for 25 h, starting after a full night's sleep

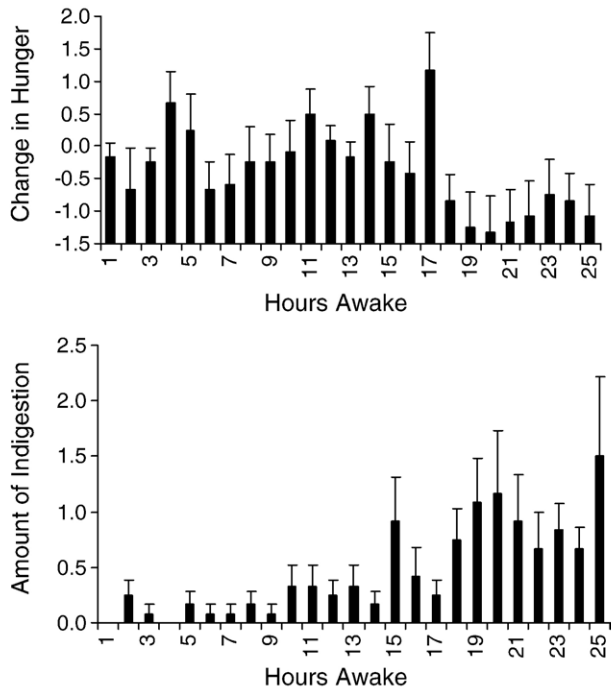

Fig. 2. Top: the mean (+SE) change from normal of hunger measured at hourly intervals during a constant routine in a group of 12 subjects. Bottom; mean (+SE) amount of indigestion felt at the same times.

that ended at 08:00 h. At the end of each hour awake, the subjects were given a small sandwich and drink of fruit juice. Immediately before these snacks, they were asked to rate their hunger on a scale from −5 (not at all hungry), through 0 (as hungry as normal) to +5 (very hungry). They were also asked to rate any feelings of indigestion or feeling overfull from 0 (none) to +5 (marked). It is clear that during their normal waking hours (the first 16 h of the constant routine) their hunger was normal and they suffered little from indigestion or feeling overfull. However, during the night (hours 17+), their hunger fell and their sense of indigestion and feeling over-full increased.

6. Patterns of food intake

It should be recognised that the pattern of meals and activity varies between different countries; nevertheless religious dictates during Ramadan create a profound change from habitual food intake in the circadian profile due to these exogenous factors. The pattern of feeding during the day reflects an exogenous aspect of normal circadian variation but with an ultradian component. An ultradian rhythm is one with a period less than 20 h and in the context of meal times is about 3 h [14]. Ultradian rhythms reflect lifestyle (external) and endogenous (internal) factors. These patterns of feeding are partly related to individuals' habits and social norms and are determined in part also by biological needs. However, they may be overridden, for example during the holy month of Ramadan [15]. This change contrasts with meal times in Muslims at other times of the year and in dwellers at high latitudes, in all of whom food intake patterns are fairly consistent throughout the year even though there are wide variations in the number of daylight hours [14].

The normal circadian and ultradian patterns of eating in adults are reflected in similar rhythms of gut motility, secretion of digestive juices, absorption of digested food, blood concentrations of glucose, amino acids and lipids [16]. The gastrointestinal and metabolic effects produced by meals also display circadian variation [17]. Metabolic responses to a glucose load, for example, are less rapid in the evening than in the morning. Gastric emptying and blood flow are greater in the daytime than at night, leading to a faster absorption of foodstuffs from the gastrointestinal tract [18]. By contrast, the absorption of some drugs from the gastrointestinal tract is greater in the hours after waking due to an empty stomach. The result of eating a large meal after night-fall is that the strict Muslim will feel bloated during the night (compare with the results obtained during the night, 17–25 h, in a constant routine, Fig. 2). A significant correlation between the number of calories ingested during a meal and the duration of subsequent sleep has been reported in rats [19] but the relationship is less clear in humans. On studying humans living in isolation, Bernstein et al. [20] did report a positive correlation between meal size and the interval to the next meal, suggesting that metabolic factors, as well as habit and an endogenous clock, normally determine the choice to eat, appetite and amount of food ingested at different times of the day.

The first meal of the day during the holy period is, for most Muslims, before sunrise (and referred to as 'scoor'). Physical training in the morning 2–3 h afterwards would lead to fluid and energy losses, with no opportunity for their rapid restoration following cessation of activity as normally occurring with athletes in training. There would be further impact on the diurnal endocrine responses to the developing state of hypohydration. The first intake of solids after sunset (footor) is typically in the form of dates taken with water, and sometimes soup. There is therefore a window of time for absorption to take place after 'footor' and subsequent prayer at the mosque, but before the major meal, when physical activity such as exercise training could be performed.

7. Energy balance

The changes in energy balance during Ramadan are not consistent between studies. Yucel et al. [21] have reported no change in body mass, the subcutaneous and visceral distribution of fat (assessed using computer tomography), or waist, hip and thigh circumferences, implying an equivalence of energy intake and expenditure during the holy month. In young females there was a reduction in the visceral fat compartment, attributed to their daily physical activity. Gharbi et al. [22] reported that the energy intake of their subjects actually increased, due to the meal eaten after sunset which contributed 65% to the total daily diet. The extra energy was contained in fat and protein, but not carbohydrate, and it was not clear if an overall energy balance was achieved. Beltaifa et al. [23] found no overall effect on energy intake or on body mass. A similar observation was reported by Finch et al. [24] on Muslims living in the United Kingdom, despite the increase in hunger during the daily fast. The higher ratings of hunger by women during the early days of

Ramadan were attributed to their proximity to eating-related cues caused by preparing food to be eaten after sunset.

In contrast to these observations of an overall energy balance, the majority of studies indicates less energy intake than energy expended in both males and females [10,25]. This deficit in energy intake would occur despite the fall in energy expenditure associated with a lower habitual activity profile in the daytime during Ramadan. It may also be accompanied by adoption of a less healthy diet. Karaagaoglu and Yucecan [25] noted that whereas the pre-dawn meal consisted of foods that were usually eaten at breakfast, those consumed after sunset were far more variable. Calcium was the nutrient that was missing most from the food eaten after sunset, raising questions about the overall quality of the diet. Ennigrou et al. [26] found that Muslim residents in Tunis increased the consumption of animal proteins in their diet and decreased the consumption of vegetables. They concluded this trend was a negative result of custom, and was to be corrected by means of an educational programme.

8. Health-related implications

Whilst detrimental effects on health are possible during Ramadan fasting, there is no substantive evidence for major concerns across the studies in the literature. Compliance with drug therapies seems to fall during Ramadan, leaving these patients vulnerable to their underlying medical conditions [10]. Patients with diabetes presenting in emergency departments of hospitals in Izmir, Turkey were significantly younger during Ramadan than those attending in the rest of the year [27], implying a connection between the disease and the fasting regimen and that young individuals susceptible to diabetes experience particular problems when observing the fasting regimen. For other diseases, Ramadan did not appear to be a risk factor, a finding that Al Suwaidi et al. [28] extended to congestive heart failure. Indeed Chamsi-Pasha and Ahmed [29] concluded that the majority of patients with stable cardiac disease can fast during Ramadan without detrimental effects. It is not known whether similar advice can be applied to the continuing of exercise programmes by such individuals, without an extra cautionary note. The major concern may be the discontinuation of previous medications, for example in treated hypertensives [30].

There are potential consequences of gastric acidity associated with the hours of fasting for individuals who previously had duodenal ulcers. Patients healed of this condition were considered to have an increased risk of relapse due to a continuously low gastric pH and high plasma gastrin concentrations during the hours of fasting [31].

The intermittent fasting regimen imposed by adherence to religious practices can have beneficial effects on health-related haematological and biochemical profiles. An increase in plasma high-density lipoprotein cholesterol has been a consistent observation [32–34]. Aksungar et al. [35] found that the increases in high-density lipoprotein levels during Ramadan persisted 20 days after the fast. Improvement in coagulation status was reflected in a reduced concentration of D-dimer. These positive alterations were attributed to the missing of daytime meals when the body's metabolic activity is normally greatest and blood viscosity is low. Beneficial effects of the Ramadan fast have also been reported for apolipoprotein metabolism [36] and for serum leptin and neuropeptide Y [37], both of which are thought to play a long-term role in energy balance. However, Lennernas et al. [38] wondered if there was a link between the amount of glucose ingested at night and one of the cholesterol fractions (in non-Muslim night-workers), and this was a risk factor for cardiovascular morbidity.

9. Indirect effects upon sleep, endocrines and menstrual cycle

Metabolic factors are also linked with the sleep phase of the circadian rhythms. There is evidence that monoamines, principally serotonin, modulate both sleep and metabolism. Tryptophan is the biochemical precursor of serotonin and must be supplied in the diet: plasma tryptophan rises after ingesting carbohydrate, and it has been argued that a high-carbohydrate meal would induce drowsiness, thereby promoting sleep. Only minute changes in the electroencephalograph have been reported in athletes using a high-carbohydrate diet [39] and, besides, it has not been firmly established that precursor uptake is the rate limiting step for serotonin release, or that such changes are responsible for the fall in alertness [40]. Nevertheless, Minet-Ringuet et al. [41] reported that a protein diet rich in tryptophan restored sleep after food deprivation in the rat. They suggested this diet could be used to improve sleep in adults subjected to nutritional disturbances such as occur in shift-work and during Ramadan.

Serotonin may have a role also in regulating the secretion of insulin by the pancreatic islets of Langerhans. Inhibition of serotonin has been shown to inhibit insulin secretion also [42], and sleep is reduced when subjects are deprived of food. The diurnal regimen of abstinence during Ramadan would render it more difficult to sleep during daytime when insulin levels have fallen. This difficulty may be partly offset by the so-called 'sleep debt' likely to be carried into each new day when nocturnal sleep is inadequate for sleep homeostasis [43].

It cannot be assumed that findings of circadian disruption in male subjects apply equally to females. Secondary amenorrhea has been associated with disruption of the normal circadian rhythm such as that occurring in multiple time-zone transitions. Such disturbances in the normal menstrual cycle have been linked to the influence of alterations in melatonin on luteinizing hormone and progesterone [44]. Menstrual disorders can be worsened by nocturnal shift-work and there are also possible negative influences of shift-work on reproductive health (for review, see [45]). Since a prolonged negative calorie balance may also lead to an anovulatory circamensal cycle, the menstrual health status of women fasting during Ramadan is worthy of investigation.

10. Human performance

There is fairly comprehensive evidence of circadian rhythms in many aspects of human performance. The circadian variation in athletic performance has been reviewed previously [46]. In the main, rhythms in performance have been closely related to the circadian variation in body temperature, although some measures (notably single 'explosive' maximal efforts) reflect the rhythm in arousal which tends to peak earlier in the day than does body temperature and is associated with plasma adrenaline levels. There are psychological as well as physiological determinants of these performance rhythms: for example, the spontaneously chosen pacing of exercise intensity demonstrates a circadian function that resembles that of body temperature (see Fig. 1B). In fasting individuals, this rhythm is likely to be reduced in amplitude, due to the length of time without food at the time of day that performance capabilities should be at their zenith. There are also likely to be peripheral (local muscular) as well as central (cerebral) influences on the variations in muscle performance over the solar day, both of which are likely to be impaired by food deprivation. All these expected changes in performance with time of day are likely to be due not only to the body clock [6] but also to exogenous influences including lifestyle and nutrition.

A factor that is obviously relevant to the fasting athlete during the period of Ramadan is the timing of training. Normally, high-intensity exercise is best tolerated at the time that resting core temperature is at its high-point [46]. Dehydration and lack of food intake are likely to mean that the quality of the training stimulus will be impaired if training is conducted in the middle or towards the end of a diurnal fast. There is some suggestion of habituating to training at a particular time of day, Edwards et al. [47] reporting that competitive performance in cycle time-trials is influenced positively by training at that time in the days before racing. Whilst exercising in the daytime during Ramadan may lead to such a habituation effect, performance is still likely to be impaired by nutritional restrictions after sunrise. The alternative of changing the schedule to accommodate training at night-time is also likely to be sub-optimal for securing physiological adaptations, since the timing will have by-passed the normal circadian peaks in temperature, adrenaline and performance. The effectiveness of training is related to work done rather than to perceived effort and the training stimulus is likely to be low when participants are poorly motivated towards activity (Fig. 1B). There should also be some time in between the breaking of the fast (footor) and the start of training to allow digestion to proceed. Besides, there are some benefits to exercising after darkness has fallen: in hot climates the high environmental temperature outdoors is avoided. Even if the exercise intensity is low due to the decline in physiological measures towards their minimum, the practice of game skills will have obvious value over the total exclusion of training.

Whether there is a systematic decline in the physiological variables related to exercise performance during the month of fasting is not yet clear. Ramadan [48] reported no adverse effects on sedentary subjects exercising at about 70% $\dot{V}_{O_2\ max}$ under thermoneutral conditions during the holy month in Kuwait, but there were increases in systolic blood pressure in response to exercise, attributable to mild dehydration, by the end of Ramadan. In a separate report [49], a decrease in the respiratory exchange ratio during submaximal exercise reflected the increased reliance on fat as a source of fuel during Ramadan. An increased plasma osmolarity was suggestive of mild hypohydration.

Bigard et al. [50] concentrated on measuring maximal voluntary contraction (MVC) of elbow flexion muscles. Maximum isometric strength decreased by 10–12% whilst muscle endurance at 35% and 55% MVC had decreased by 28 and 22%, respectively by the end of Ramadan. There was a decrease in orthostatic tolerance to a head-up tilt test with changes in heart rate and pulse pressure that were associated with a 7% fall in plasma volume.

These decreases in muscle performance were corroborated for psychomotor measures [51]. There is also evidence of increased incidence of traffic accidents occurring in the month of Ramadan [51]. Whether these events are related to changes in insulin, blood glucose, low energy levels or mood changes, or a combination of these factors, is unclear. Irritability has been found to increase during Ramadan [52,26], peaking at the end of the month.

Siddiqui et al. [53] implemented a series of pulmonary tests on healthy subjects during Ramadan. There were no significant changes in vital capacity (a measure of lung capacity), FEV_1, peak expiratory flow (a measure of lung power), FEF (25–75%) (a measure of mid-flow) or maximum voluntary ventilation. The authors noted a decrease in vital capacity when measurements were repeated post-Ramadan, which was associated with an increase in body mass. This rebound effect after fasting is finished has not been explored in terms of consequences for physical fitness.

Kirkendall et al. [54] focused on two professional teams in Algiers in their investigation of the impact of Ramadan on biochemical and performance indices of soccer players. By the end of the period of fasting, the players displayed decreases in sprinting speed, agility, speed of dribbling and 12-min run performance. These changes were accompanied by reductions in blood cholesterol, low-density lipoproteins, triglycerides and glucose. Most players felt they had poorer quality of sleep, training and match performance during the period of fasting. These negative states would in turn have an adverse effect on motivation for exercise. When players were re-examined 2 weeks after the end of Ramadan, many of the blood variables had recovered to normal but performance measures were still below initial baseline values.

The studies completed so far are of limited value in helping to understand how exercise performance is affected by the intermittent fasting practised during Ramadan. A fall in performance may be caused by alterations in circadian rhythms, fatigue due to disturbances of the sleep–wake cycle or a reduction in energy reserves — or, more likely, by an interaction of all these factors. The time of day at which testing has been conducted, the fitness levels of subjects and the measurements made may be critical. In certain circumstances, athletes may be exempt from the fast and so may not experience the same dietary discomfort as strict religious adherents. Dispensations apply when athletes are ill or are travelling. For those reasons it is not clear how practising Muslims might best maintain their training programmes in harmony with altered circadian rhythms during Ramadan. Different examples are shown in Fig. 3, which vary in the

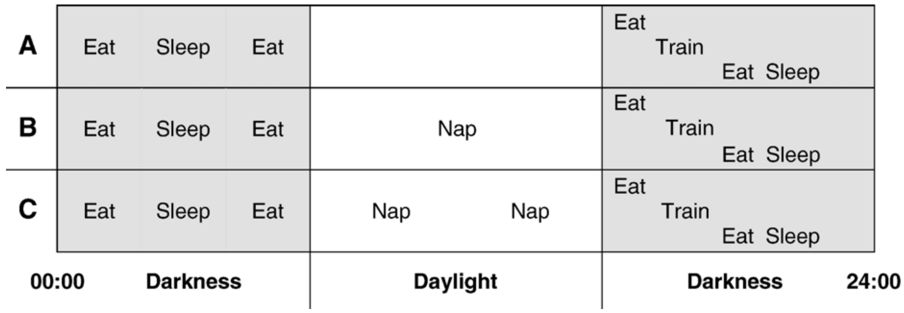

Fig. 3. Different examples of Muslim athletes during Ramadan. Example A is strictly adherent, B incorporates a single nap to overcome daytime fatigue, whilst C is not strictly adherent and is most likely to flatten circadian rhythms due to the repetitive naps.

degree of conformity to strict religious practices and in their likelihood to preserve performance capability.

11. Circadian rhythms during Ramadan

The most obvious likely consequences of daytime fasting are the altered metabolic responses during the day, the failing energy levels due to absence of food intake, and disturbances of sleep due to a late evening meal. Impairments of normal sleep could have knock-on consequences for the sleepiness experienced the following day. Whilst eating and drinking form exogenous factors influenced by habit and social variables, they may alter the shape or phase of the overt circadian rhythms.

The rhythms of cortisol and testosterone normally display a peak in the morning around or prior to wakening. Bogdan et al. [55] reported a shift of secretion onset in both of these hormones. They also observed an enhanced peak in prolactin and a diminished and delayed peak in melatonin. These findings would be consistent with an increased drowsiness and a tendency towards an ‘evening-type’ behavioural profile.

Changes in eating and sleeping schedule were found to reduce cortisol levels in the morning and raise levels in the evening. In control conditions, morning (08:00 h) values were 3.84 times higher than at 20:00 h, a difference that was reduced to 2.02 times during Ramadan. Adrenal sensitivity to corticotrophin stimulation (using exogenous ACTH) did not appear to be impaired during Ramadan [56].

The confinement of eating to the early and late parts of the day seems to have an effect on the acrophase of serum leptin levels. Bogdan et al. [57] reported no significant change in the amplitude of the circadian variation but a significant shift of 5.5 h in the peak and trough values had occurred by the 23rd day of fasting. Roky et al. [58] reported a diurnal decrease in oral temperature between the hours of 09:00 and 20:00 h and an increase at 23:00 and 24:00 h during Ramadan. These results suggest a decrease in circadian rhythm amplitude of body temperature and a phase delay. They would probably decrease the ability to train effectively in the daytime, though it might promote training after footor (see above). Subjective alertness decreased at 09:00 and 16:00 h compared to normal conditions whilst the time taken for rapid limb movement increased at 16:00 h by the sixth day of fasting. Negative effects upon mood at the same time as the fall in alertness and impairment in movement time would suggest a sub-harmonic in the circadian rhythm analogous to the post-lunch dip noted in normal conditions [59]. In a later review, Roky et al. [51] recorded reduced amplitudes and phase shifts in rhythms of body temperature, cortisol and melatonin, concluding that major chronobiological and behavioural changes occurred during Ramadan fasting.

Bahammam [60] reported delayed bedtime and waking time in fasting subjects during Ramadan and an increased tendency towards ‘eveningness’ behaviour. As non-fasting individuals also displayed displaced bedtimes during Ramadan, the author concluded that factors other than fasting may play a role in modifying an individual’s behaviour during the month. The tendency to delay going to sleep and increase evening-type activity has been reported by others, accompanied by late waking and increased daytime sleepiness [61]. In a study in the United Arab Emirates, Margolis and Reed [62] reported that observant Muslims avoid a rise in daytime somnolence by increasing daytime sleep hours during Ramadan. The corollary to this change would be an increase in activity during the hours of darkness. It is also possible that the prime factor is the delay in eating or joining friends and family for the evening meal which decreases sleep time and subsequently causes an increase in daytime sleep.

Roky et al. [63] allowed Muslim subjects an opportunity for daytime naps during which electroencephalographic recordings were analysed. Subjective alertness decreased at mid-day towards the middle of the month’s fast, accompanied by a reduced sleep latency during the permitted naps. They concluded that the increases in daytime sleepiness were associated with the transient diurnal fall in rectal temperature.

Roky and colleagues [64] also examined the nocturnal sleep of Muslims during Ramadan, on the 11th and 25th night of the month and compared polysomnographic recordings with pre-Ramadan baselines. Their main findings were an increase in sleep latency and a modification of sleep architecture. The total sleep time decreased but the proportion of non-rapid eye movement (non-REM) sleep increased during both phases of the fast. Within non-REM sleep, there was an increase in Stage 2 and a decrease in slow-wave sleep. The changes in sleep parameters were associated with raised rectal temperatures at night. This elevation would lead to a delay in the acrophase of rectal temperature of 2–3 h and a reduction in its amplitude. The changes in body temperature and sleep characteristics were attributed to the inversion of the drinking and meal schedule rather than changes in total 24-h energy intake, which was preserved at normal values in these subjects.

It seems that there are different patterns of adjustment to the regimen of fasting during Ramadan. Alterations in metabolic and endocrine function are due both to changes in the rest–activity diurnal rhythm and to the displacement of food and fluid intake to night-time. The consequent reduction in daytime activation and tendency towards 'eveningness' would have a negative impact on performance capability and disposition towards high-intensity exercise in the daytime.

Table 1
Circadian rhythms in gut motility

▪ Daytime velocity of migratory motor complex is 50% faster than nocturnal velocity.
▪ Gastric emptying rate is faster in daytime than at night (after 20:00 h).
▪ Secretion of gastric acid is higher in evening/night compared to morning.
▪ Shift-workers eating at night place a burden on the gastrointestinal tract that conflicts with its circadian rhythm.

12. A Circadian Model for Ramadan

It is clear that the normal circadian rhythms are disrupted during Ramadan, changes in activity being secondary to the alterations in patterns of meal times. What is less clear is which other model of circadian perturbation best applies to those fasting during the holy month of Ramadan. This fast is essentially different from the Christian period of Lent, which does not necessarily entail abstaining from food during the hours of daylight. The effects of fasting during Ramadan on the circadian system overlap (but only in part) those induced by transmeridian flight, nocturnal shift-work and the ageing process. These conditions are referred to below as the jet-lag, shift-work and ageing models, respectively.

13. The jet-lag model

Long-haul flights across multiple time-zones are associated with digestive discomfort and constipation, together with decreased daytime alertness and ability to train maximally. These are some of the symptoms of jet-lag and are due to circadian desynchronisation between the body clock and the times of light and dark and food intake in the new environment [65]. Also, the dry cabin air during long flights can lead to a gradual dehydration that persists until rehydration after arrival at the destination [66]. Circadian rhythms become re-synchronised to the new time zone after a few days, mainly through

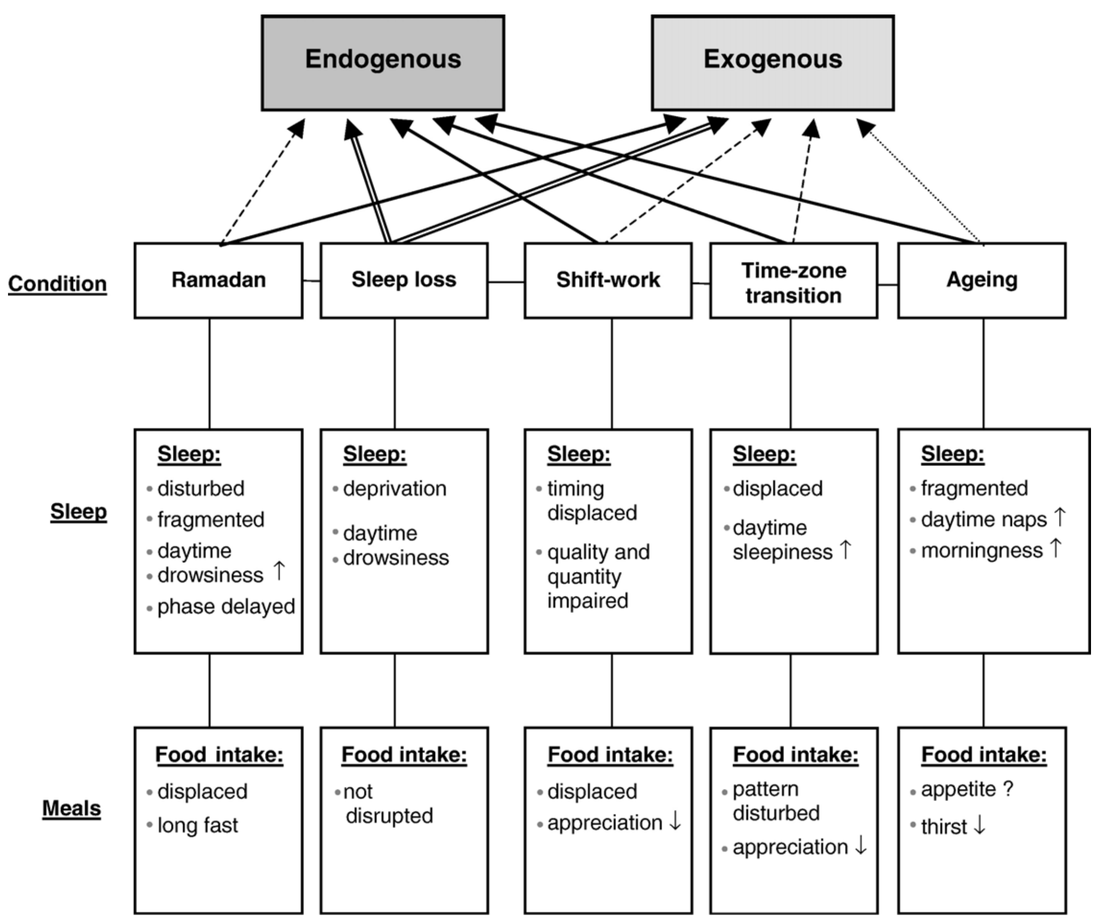

Fig. 4. Schematic illustration of effects of conditions on endogenous and exogenous factors in circadian rhythms. The broken lines denote minor influences, the bold lines main influences and the double lines equal influences.

exposure to the new light–dark cycle. Whilst dehydration and energy depletion occur in Ramadan, and the pattern of rest and activity is altered, the major external signal of natural light is not altered. Therefore, the jet-lag model is a poor fit to the circumstances of diurnal fasting (see Fig. 4).

14. The shift-work model

The nocturnal shift-worker alters meal times and the size of meals [9], as does the strict Muslim. For both, the circadian rhythm in gut motility is highly relevant (see Table 1). Indigestion, gastric ulcers and irregularity of bowel movement are more common in night-workers than they are in their counterparts working normal daylight hours [67]. However, unlike in Muslims, where Ramadan occurs only occasionally, changes in mealtimes in shift-workers can affect a large proportion of their working days and cover successive months or years. In both Ramadan and those working shifts, the timing of sleep is altered. For those on night-shifts, sleep is delayed by about 8 h and is attempted in the daylight, a change that is far greater than during Ramadan. In Ramadan, some may also become early risers, and this brings them more into line with shift-workers on the morning shift (06:00–14:00 h); in both groups, sleep loss is likely to occur. For Muslims, this sleep loss may be more marked, due to the later retiring times in addition, particularly if daytime naps (which can be taken after work by those on the morning shift) are not taken. Whereas the nocturnal shift-worker unable to tolerate disturbances of circadian rhythms may opt out of working nights, this choice is not open to the discretion of the Muslim. The value of the shift-work model is very limited, therefore.

15. Napping and the ageing model

The movement towards early rising (for breakfast) on the one hand and an ‘eveningness’ behavioural activity profile on the other is tolerable when recuperative naps are taken during the day. Long-distance sailors and rowers survive for periods similar to the duration of Ramadan by a ‘cluster napping’ strategy in which a sleep ration of say 6 h in every 24 h is broken into smaller fragments [68]. However, this strategy applies throughout the 24 h and so makes it different from sleep habits during Ramadan where a longer consolidated sleep period during the night remains.

With regard to sleeping, it seems that the model that best fits the period of fasting is a hybrid, is bi-modal in shape and resembles the circadian variations that occur with ageing [8]. Its key characteristics are shortened sleep at night, a tendency towards eveningness (due to the main meal and social events being after sunset) despite arising for breakfast before sunrise, and a sub-harmonic with a nap in the afternoon. However, this model has several inadequacies. First, strict adherents to Ramadan will not nap during the daytime. Second, for many older people, the changed habits reflect a deterioration in an effective output from the body clock, difficulties with mobility and the ability to maintain concentration in the daytime, and the need to empty the bladder at night (due to the lack of decreased nocturnal urine production). These changes are not present in healthy Muslims. Third, ageing individuals do not adjust their habitual pattern of meal times, and therefore their energy levels do not experience the daytime slump concomitant with avoiding food. Further, the thirst mechanism is blunted in ageing individuals [2] who tend to underestimate their rehydration needs after strenuous physical activity. The consequences of the reversal in the typical circadian pattern of fluid intake during Ramadan have not been thoroughly investigated. Their impact will place the Muslim athlete at a considerable disadvantage when competing abroad and the newly adopted habitual cycles are further disrupted by jet-lag.

In conclusion, it seems that Ramadan provides a set of circumstances with elements of ageing, jet-lag and shift-work but also with requirements that are unique to this behaviour pattern. The behavioural responses of Muslims in conforming with religious requirements is not uniform. These responses provide a highly complex context for the investigation of circadian rhythms and their adjustment to the endogenous sleep–wake cycles. Whilst there is a myriad of research questions yet to be resolved, the Ramadan model provides an alternative to ageing, nocturnal shift-work and time-zone transitions for understanding the links between behaviour and endogenous circadian rhythms.

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