Effects of Fasting During Ramadan Month on Cognitive Function in Muslim Athletes

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Abstract

Purpose: Our study aimed to profile the effect of fasting during the Ramadan month on cognitive function in a group of healthy Muslim athletes.

Methods: Eighteen male athletes underwent computerized neuropsychological testing during (fasting) and after (non-fasting) Ramadan. Diet was standardized, and tests were performed at 0900h and 1600h to characterize potential time-of-day (TOD) interactions. Psychomotor function (processing speed), vigilance (visual attention), visual learning and memory, working memory (executive function), verbal learning and memory were examined. Capillary glucose, body temperature, urine specific gravity, and sleep volume were also recorded.

Results: Fasting effects were observed for psychomotor function (Cohen's d=1.3, P=0.01) and vigilance (d=0.6, P=0.004), with improved performance at 0900h during fasting; verbal learning and memory was poorer at 1600h (d=-0.8, P=0.03). A TOD effect was present for psychomotor function (d=-0.4, P<0.001), visual learning (d=-0.5, P=0.04), verbal learning and memory (d=-1.3, P=0.001), with poorer performances at 1600h. There was no significant fasting effect on visual learning and working memory.

Conclusions: Our results show that the effect of fasting on cognition is heterogeneous and domain-specific. Performance in functions requiring sustained rapid responses was better in the morning, declining in the late afternoon, whereas performance in non-speed dependent accuracy measures was more resilient.

INTRODUCTION

Fasting is a practice that is observed by many cultures and religions. In Islam, during the month of Ramadan, able-bodied Muslims abstain from food and fluid for 12-14 hours daily. They rise early for prayers, eat before sunrise, retire later and consume large meals after sunset to replenish energy and fluid levels. This leads to alterations in feeding habits, sleep duration, pattern and architecture [1,2]. As major

sporting calendars do not take religious observances into account, many athletes continue to train or compete while fasting.

Well-documented effects of Ramadan fasting include changes in circadian rhythms [3,4], physiological [5], metabolic and endocrine function [6-8], as well as reductions in daytime hydration, blood glucose and body temperature [6,9,10]. Physical and cognitive performances are also affected [11].

Cognition allows the athlete to pay attention, learn, remember new skills and solve problems. It enables the athlete to react appropriately to stimuli, and is crucial in disciplines such as shooting, martial arts, road cycling and motorsports, where impairment can change the outcome of a contest or result in injury. Several studies have demonstrated that psychomotor performance, subjective alertness and memory are adversely affected during Ramadan [10,12-14]. However, evidence also exists regarding the relative robustness of memory, attention, executive function, information processing and verbal function during fasting [15-19]. The conflicting findings may be due to methodological differences and the unavailability of sensitive computerised neuropsychological instruments in some studies.

Cognitive function is also subject to the influence of circadian rhythms, with performance fluctuating over the day [4,9,20,21]. Thus far, to the best of our knowledge, only two published studies on cognitive performance during fasting have considered this [10,22].

Meal timing and macronutrient composition can also affect cognitive function [23,24]. They may either impair reaction time and attention or improve memory and learning ability [23,25]. High protein meals can slow memory scanning and increase susceptibility to distraction [23]. The effects are attributed to diet-induced changes in neurotransmitter activity, sympathetic activation, hypothalamic-pituitary-adrenal axis function and serum glucocorticoid levels [24].

Hence, our study was designed to examine the effect of fasting during Ramadan on cognitive function, taking into account the influence of circadian rhythms, meal composition and timing. We posit that the alterations in feeding and sleep schedules may affect cognitive function via changes in blood glucose levels, body temperature and circadian rhythms.

METHODS AND SUBJECTS

Subjects:

Eighteen healthy male volunteers were recruited from the national pencak silat squad. Pencak silat is a traditional Southeast Asian martial art form that is currently practised worldwide with regular sanctioned competitions. The participants' weekly training volume during Ramadan [8.9 (±2.8) hours; range, 3-14 hours] was not significantly different from the non-Ramadan period (P=0.8). To enhance external validity, only Muslim athletes with previous fasting experience during Ramadan were selected. Written informed consent was obtained and the study conducted in 2009 after approval by the Ethics Committee of the Singapore Sports Council.

Experimental procedure:

To characterize potential interactions between the time-of-day (TOD) and fasting, testing was carried out at two diurnal time points (0900h and 1600h), with each participant attending two sessions during (fasting) and two sessions after Ramadan (non-fasting) (Fig. 1). To minimize any potential carryover effect of Ramadan fasting, the non-fasting sessions were conducted two weeks after the end of Ramadan. Participants served as their own controls. Familiarization with all test procedures was performed before Ramadan, and the test sequence was identical throughout all sessions. To minimize fatigue, each session for the same participant was separated by an interval of at least 24 hours.

Meal schedule and composition:

A standardized meal with 2g of carbohydrate/kg body mass, 0.5g of protein/kg body mass and 200ml of fluid was consumed between 0530h–0630h for the 0900h test sessions and between 1230h–1330h for the non-Ramadan 1600h session. The menu was identical throughout the experiment. Outside of the test occasions, the athletes were allowed to consume a free diet. However, they had to inform the investigators if they were ill or consuming medication, and they were not allowed to consume caffeinated products, sedatives, stimulants, alcohol or smoke in the 24 hours prior to testing.
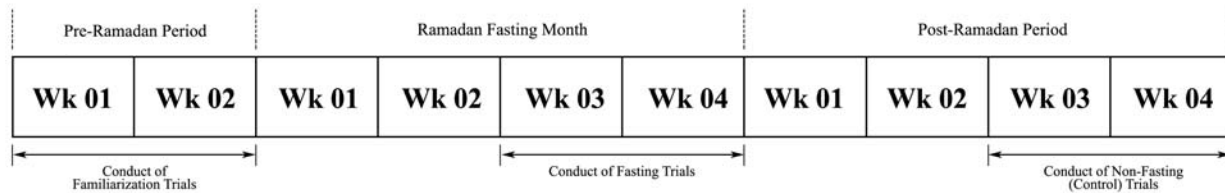
Fig. 1: Study design

Protocol and physiological measurements:

Upon arrival at the laboratory, participants rested quietly for 20 minutes, during which they answered questionnaires regarding their past 24 hours diet and sleep duration. A urine sample was collected and specific gravity measured using a digital refractometer (UG-1, Atago, Japan). Oral temperature was recorded using a digital thermometer (accuracy, 0.5^0C; Terumo Corporation, Japan) and blood glucose level measured via a finger-prick sample (Accu-check, Roche Diagnostics, Germany).

Cognitive function:

Neuropsychological testing was performed using CogState software (version 1.0, Cogstate Ltd., Melbourne, Australia). Computerised testing was used as it allows standardised and accurate recording of reaction times, electronic data capture and processing, thus minimising human error and response bias. The entire battery required 25-30 minutes to complete and consisted of 5 different tasks (Table 1), detailed descriptions of which have previously been published [26]. The tests were selected because of their parametric properties and demonstrated utility for within-subject experimental designs [27]. These could also be administered at short intervals without significant practice effects [28, 29].

Each task was in the form of a card game presented in succession against a green background. Prior to each task, written instructions were presented and participants were given an interactive demonstration. Once they had successfully given a sufficient number of correct responses to demonstrate their awareness of the rules, the task began. Participants used the same computer for each session, and the battery was always administered in the same order.

Statistical analysis:

This was performed using SPSS software (version 15.0; SPSS Inc., Chicago, Illinois). Comparison of quantitative data between Ramadan (fasting) and non-Ramadan (non-fasting) was performed using paired t-tests if normality assumptions were satisfied; otherwise non-parametric tests were used. The fasting and TOD effects were assessed using 2 x 2 repeated measures ANOVA, with (0900h, 1600h) and (fasting, non-fasting) as factors. If a significant interaction was present, single factor pair-wise comparison was performed to determine its direction. Effect size was quantified using Cohen's d, which was computed as the difference of the two group means expressed as a function of the pooled variance associated with each individual mean. Change scores for performance differences were computed for both fasting and non-fasting states as well as between the two diurnal time-points. Two-tailed statistics were used and statistical significance set at $P<0.05$.

RESULTS

Eighteen healthy male volunteers aged between 17 and 29 years [20.9 ($\pm$3.3) years] with a mean education level of 11.8 ($\pm$1.4) years (range, 10-15 years) were enrolled in this study.

Cognitive function:

Performance differences were observed in the detection ($P=0.01$), identification ($P=0.02$), and international shopping list recall ($P=0.03$) tasks during Ramadan (Table 1). There were also significant performance

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Table 1: Performance measures for CogState tests and change scores (negative values indicate performance decline)

CogState test	Cognition domain	Performance measure (unit)	Change score (fasting vs non-fasting) 0900h	1600h	Change score (0900h vs 1600h) Fasting	Non-fasting
Detection task	Psychomotor function (processing speed)	Speed (Log10 milliseconds)[1]	0.124* (0.033)	- 0.028 (0.014)	0.138[#] (0.02)	- 0.014 (0.02)
Identification Task	Vigilance (visual attention)	Speed (Log10 milliseconds)[1]	0.044* (0.017)	0.028 (0.017)	- 0.006 (0.015)	- 0.022 (0.02)
One Card Learning	Visual learning & memory	Accuracy (arcsine proportion)[2]	- 0.004 (0.024)	- 0.071 (0.038)	0.085[#] (0.035)	0.018 (0.033)
One Back Memory	Executive function (working memory)	Accuracy (arcsine proportion)[2]	- 0.062 (0.039)	- 0.026 (0.043)	0.006 (0.003)	0.093 (0.04)
International Shopping List Recall	Verbal learning & memory	Number of correct responses[3]	0.444 (0.544)	-1.557* (0.682)	2.28[#] (0.51)	0.28 (0.522)

[1]Mean of the log10 transformed reaction times for correct responses;
[2]Arcsine transformation of the square root of the proportion of correct responses;
[3]Total number of correct responses made in remembering the list after a delay;
*Significant change in performance between fasting and non-fasting
[#]Significant change in performance between 0900h and 1600h

differences between the 0900h and 1600h sessions for the detection ($P<0.001$), one-card learning ($P=0.02$), and international shopping list recall ($P<0.001$) tasks (Table 1). The TOD effect was significant only during the fasting sessions.

Repeated-measures ANOVA analysis revealed a significant fasting effect on the speed-dependent detection and identification tasks (Table 2). These assess psychomotor function/processing speed and visual attention/vigilance. Performance was significantly better at 0900h during fasting when compared to the non-fasting period (Fig. 2a, b). The magnitude of the fasting effect was relatively large (Cohen's d=1.3) for the detection task and moderate

(d=0.6) for the identification task. Performance in the international shopping list recall task, which assesses verbal learning and short-term memory, was also adversely affected by fasting (d=-0.8). There was no significant fasting effect on the one-card learning and one-back memory tasks, both of which are non-speed dependent accuracy measures.

A significant TOD effect was present for the psychomotor function/processing speed, visual learning, verbal learning and memory tasks (Table 2). Performance was significantly poorer at 1600h compared to 0900h and the magnitude of the effect was greater during fasting. The largest effect size was observed for verbal learning and memory (d=-1.3,

**Table 2:** Effect of Time-of-Day (TOD) and Fasting on CogState task performance

Cogstate task	Time-of-day effect $F_{(1,34)}$	P-value	Fasting effect $F_{(1,34)}$	P-value	Fasting & time-of-day interaction effect $F_{(1,34)}$	P-value
Detection task	15.19	0.001[1]	6.95	0.01[2]	17.51	<0.001[3]
Identification task	1.26	0.27	9.40	0.004[2]	0.46	0.5
One Card Learning	4.59	0.04[1]	2.79	0.10	2.19	0.15
One Back Memory	4.03	0.05	0.40	0.53	2.27	0.14
International Shopping List Recall	12.24	0.001[1]	5.23	0.03[2]	5.26	0.03[4]

[1]Significant time-of-day effect
[2]Significant fasting effect
[3]Better performance at 0900h during fasting
[4]Poorer performance at 1600h during fasting

a. Detection task

b. Identification task
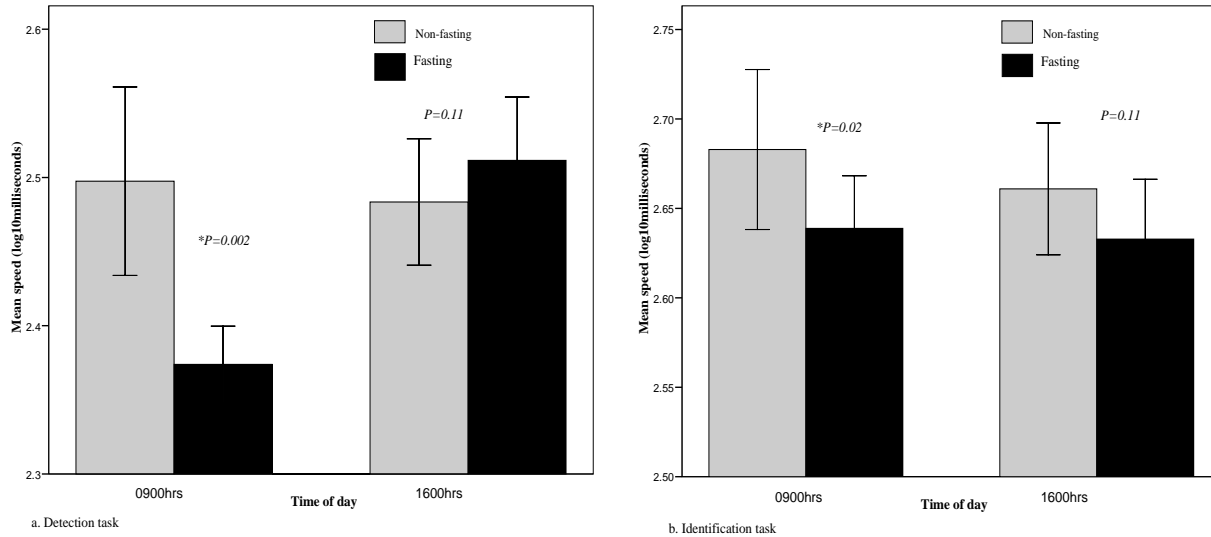
Fig. 2a: Detection task during fasting and non-fasting, 0900hrs *vs* 1600hrs. Lower scores indicate better performance.
Fig. 2b: Identification task during fasting and non-fasting, 0900hrs *vs* 1600hrs. Lower scores indicate better performance.

fasting; d=-0.1, non-fasting) (Fig. 2c). Smaller effect sizes were present for psychomotor function (d=-0.4, fasting; d=-0.1, non-fasting) and visual learning (d=-0.5, fasting; d=-0.2, non-fasting).

There was also a significant interaction between TOD and fasting for both the detection and international shopping list recall tasks.

Physiological parameters:
During Ramadan, both mean body mass and capillary glucose levels were significantly lower at 1600h (P=0.001, Table 3). There was a 0.8mmol/l reduction in mean capillary glucose level and a 0.9kg decrease in mean body mass at 1600h. A significant TOD (F=11.93, P<0.001) and fasting effect (F=8.06,

c. International shopping list recall
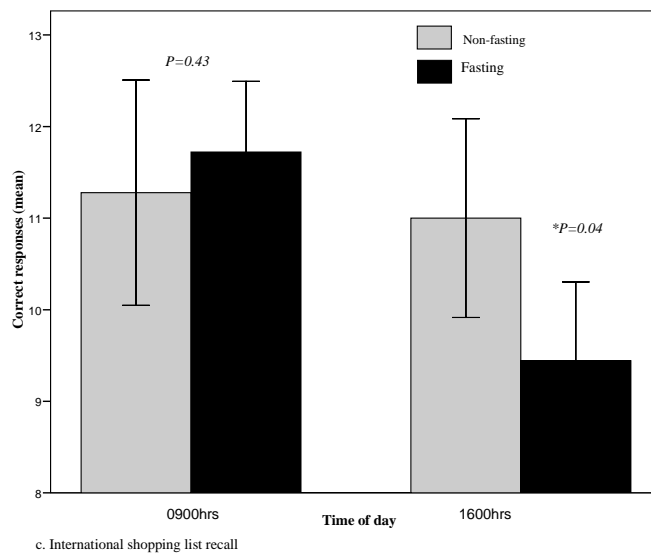
Fig. 2c: International shopping list recall task during fasting and non-fasting, 0900hrs *vs* 1600hrs. Higher scores indicate better performance.

Table 3: Physiological parameters and sleep volume

Parameters	Time	Non – fasting	Fasting	P-value (Fasting vs non-fasting)
Body mass *(kg)*	0900h	69.8 (16.8)	69.3 (16.3)	0.6
	1600h	69.8 (17.0)	68.4 (16.1)	<0.001
Capillary glucose level *(mmol/l)*	0900h	5.8 (1.2)	5.4 (0.6)	0.3
	1600h	5.4 (0.9)	4.6 (0.3)	0.001
Temperature *(^{o}C)*	0900h	36.6 (0.2)	36.5 (0.3)	0.07
	1600h	36.7 (0.3)	36.6 (0.2)	0.05
Urine specific gravity	0900h	1.020 (0.009)	1.021 (0.009)	0.8
	1600h	1.021 (0.007)	1.023 (0.004)	0.3
Total nocturnal sleep *(h)*		7.0 (1.7)	5.3 (1.8)	0.005
Total daytime nap *(h)*		0.3 (0.4)	3.0 (2.1)	0.001

P=0.008) was observed for blood glucose levels. A significant TOD effect was also present for oral temperature (F=6.79, P=0.01), but the fasting effect was not significant (F =3.88, P=0.06).

Sleep

The mean duration of nocturnal sleep during Ramadan was significantly shorter (P=0.005, Table 3). The duration of daytime naps was also increased (P=0.001).

DISCUSSION

The physiological measurements we obtained are in line with published data showing lower blood glucose levels and body temperature in the afternoon during Ramadan [3,7,8,10]. The main findings from our neuropsychological test panel suggest that the influence of Ramadan fasting on cognitive function is not homogeneous. During Ramadan, performance in the domains of psychomotor function/processing speed and visual attention/vigilance was better at 0900h. By late afternoon, there was a significant decrease in psychomotor function/processing speed, verbal learning and memory performance. This may be attributed to the combination of food, fluid and sleep restriction.

As glucose is an essential substrate for the central nervous system, with an increase in its metabolism documented in specific brain areas during cognitive activity [30,31], the performance impairment we observed at 1600h may be due to lowered blood glucose levels. The brain cannot manufacture its own glucose and is dependent on a continual peripheral supply, which will be limited in the late afternoon in fasted subjects.

The effect was not uniform across all the domains tested. This may be due to the different susceptibility of the various cognition domains. Doniger's study, performed during a 12-16 hour Jewish religious fast [22], showed that both time-dependent (attention and information processing) and spatial relation perception (non-verbal recognition memory, problem solving, verbal naming, visual-spatial skills) tasks were more likely to be adversely affected during fasting [23].

Electroencephalogram (EEG) studies provide further support for the domain specific effect. These show that although performance decrements and slower reaction times were present in fasted participants carrying out frontal-parietal dominant tasks requiring decision determination and response implementation, there was no significant effect on simple attention tasks involving stimulus encoding, memory retrieval and decision making [32].

Alpha frequency activity in the occipital cortex, which is the primary area associated with visual sensory stimuli processing and integration, was also not significantly altered during fasting [32]. This is consistent with our findings of a lack of any significant performance decline in the non-speed dependent, predominantly occipital cortex centred one-card learning and one-back memory tasks, which supports

the previously demonstrated robustness of these domains [15-17,22].

The improved performance in the visual attention/vigilance and psychomotor function/processing speed tasks at 0900h in our participants may be the result of post feeding neural activity enhancement as well as reduced sleep inertia due to earlier awakening for prayers. In Pivik's study, frontal lobe activity was enhanced in fed participants performing frontal dominant processes related to stimulus encoding, memory retrieval, decision making and motor response execution [32].

In line with Dinges's study [33], sleep deprivation may be associated with the late afternoon decline in working memory and sustained attention observed in our participants. In sleep restricted subjects, Blood Oxygenation Level Dependent functional MRI (BOLD-fMRI) studies show a decrease in both global and task-specific brain activation during cognitive activity [34]. EEG data also demonstrate reductions in intraparietal sulci and superior parietal lobe activation during short-term memory related tasks [34-36]. BOLD-fMRI studies suggest that compensatory mechanisms exist to aid attention focus and suppress extraneous mental processes in sleep restricted individuals [37,38]. This may ameliorate some of the adverse effects of sleep deprivation and explain the resilience of tasks involved in vigilance and simple reaction.

The reduction in mean body mass and increase in urine specific gravity indicates that the participants in our study were mildly dehydrated (1.3%) at 1600h. Dehydration has a dose-dependent effect on cognitive function. Speed and accuracy dependent tasks are adversely affected within 3 hours of fluid deprivation [39], and mathematical ability, short-term working memory, perceptive discrimination and eye-hand coordination are affected by levels of dehydration between 1% - 4% [40,41]. The effects may be mediated via altered cerebral neurotransmission due to hyperosmolality and electrolyte shifts and/or changes in blood brain barrier permeability. Current theories include alterations in the activity of nitric oxide synthase, which is a key enzyme facilitating learning and memory, and changes in central dopaminergic and noradrenergic pathways [42,43]. The reticular activating system subserving attention and wakefulness; the autonomic structures regulating psychomotor functions; and the cortical and mid-brain structures responsible for thought, memory and perception appear most vulnerable, thus contributing to the late afternoon performance decline.

Our study was limited to a small group of athletes from a single martial art discipline. Furthermore, the participants' lifestyle and training in between test sessions were not controlled. Other potential confounders include the duration of the previous night's sleep and daytime naps, as well as the time of awakening, which were not regulated in this study.

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CONCLUSION

Our results suggest that during Ramadan fasting, performance in cognitive functions requiring sustained rapid responses was better in the morning, declining in the late afternoon, whereas performance in non-speed dependent accuracy measures was more resilient. Although the tests were laboratory based and may not reflect cognitive ability during training or competition, our findings suggest that during Ramadan, skill-based or training requiring high levels of psychomotor, learning or memory ability should be performed in the morning. This will help Muslim athletes and their coaches avoid the late afternoon performance nidus and circumvent the potentially detrimental effects of fasting.

ACKNOWLEDGMENTS

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