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Jeanick Brisswalter, Ezzedine Bouhlel, Jean Marie Falola, Jean-Marc Vallier, Christophe Hausswirth

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Jeanick Brisswalter[1], PhD , Ezzedine Bouhlel[2], PhD, Jean Marie Falola[3], PhD, Jean Marc Vallier [4], MD,PhD, Christophe Hausswirth[5], PhD

[1] University of Nice Sophia Antipolis, Laboratory of Human Motricity, Education Sport and Health, Nice, France.

[2] University of Sousse, Medicine Faculty, Laboratory of Physiology, Tunisia.

[3] University of d'Abomey-Calavi, Porto Novo, Benin

[4] University of South France Toulon Var, Laboratory of Human Motricity, Education Sport and Health, Toulon, France.

[5] National Institute of Sport Expertise and Performance, Paris, France.

Corresponding author:

Prof. Brisswalter Jeanick

University of Nice Sophia Antipolis, Laboratory of Human Motricity, Education Sport and Health, BP 3259 , 06205 Nice, France

🖂 Email: brisswalter@unice.fr

Tel: +33 6 31 79 27 17

Fax: +33 4 92 29 65 49

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ABSTRACT

Objective: To assess whether Ramadan intermittent fasting (RIF) affects 5000m running performance and physiological parameters classically associated with middle distance performance.

Design: Eighteen subjects (age 23.6±2.9 yr, body mass 64 ± 2.3 kg) divided in two experimental groups (Ramadan fasting (n = 9 *vs.* control, n= 9) participated in two experimental sessions, one before RIF and the other the last week of fasting.

Setting: For each session subjects completed four tests in the same order: a maximal running test, a maximal voluntary contraction (MVC) of knee extensor, two rectangular submaximal exercises on treadmill of 6 min duration at an intensity corresponding to the first ventilatory threshold (VT_1) and a running performance test (5000m).

Participants: 18 well-trained middle distance runners

Main Outcome Measurements: Maximal oxygen consumption, maximal voluntary contraction, running performance, running efficiency submaximal VO2 kinetics parameters (basal VO2 : VO2b, time constant : τ, and amplitude : A1) and anthropometric parameters were recorded or calculated.

Results: At the end of Ramadan fasting a decrease in maximal voluntary contraction was observed, **(-3,2%, p< .00001, Eta_2: 0.80)**, associated with an increase in time constant of oxygen kinetics (+51%, **p< .00007, Eta_2: 0.72**) and a decrease in performance (-5%, **p< .0007, Eta_2: 0.51**). No effect was observed on running efficiency or maximal aerobic power.

Conclusions: These results suggest that Ramadan changes in muscular performance and oxygen kinetics could affect performance during middle distance events and need to be considered to choose training protocols during RIF.

Key-words*: muscular strength, VO_2 kinetics, anaerobic performance, running efficiency*

INTRODUCTION

Ramadan, is the ninth month of the Islamic calendar. During Ramadan Muslims refrain from eating and drinking from dawn until sunset. Elderly subjects or those who suffer from a disability or disease could be exempt from fasting, but athletes not. Thus, whether or not Ramadan Intermittent fasting (RIF) affects performance could be important when events take place during Ramadan fasting. During the last decade, several studies have been realised to assess the impact of RIF on physiological or psychological factors of performance [1, 2]. In one of the first study on this topic, Bigard et al[3] have associated a significant decrease in maximum isometric strength of the elbow flexors (-12%), muscular endurance (-22%) and orthostatic tolerance during Ramadan fasting with a decrease in body mass (-2.7%) and a fall in plasma volume (-7%). Moreover, in football players, Zerguini et al[4] have reported a reduction in agility, dribbling speed and endurance related with changes in sleep patterns, food intake, and/or motivation level of the subjects. However, even if Ramadan fasting is often associated with a decrease in performance, descriptive data from recent studies show large individual variations in all measured physiological parameters with relatively little difference between fasting and non-fasting individuals [4-14]. Therefore, studies are still needed to determine the effect of RIF on factors affecting performance among exercises involving different intensities and durations. Within this framework, many of the best endurance performances are realized by athletes from north or east Africa[e.g. 15] where islam is one of the main religions, but to the best of our knowledge, only one recent study has examined the effect of RIF on long duration exercise performance[1] and no study has investigated a possible effect of fasting on middle distance performance.

Thus, whether Ramadan fasting could affect middle distance performance remains unclear especially in well trained subjects. In middle distance events, maximal oxygen uptake, anaerobic power, running economy or muscle strength, are often suggested to represent the main factors of performance[16-19]. Therefore, the aim of this study was to assess the effect of

RIF on 5000m running performance and factors classically associated with middle distance performance. **We hypothesise that alteration in muscular performance or long duration performance previously reported in the literature would lead to a decrease in middle distance performance with fasting.**

METHODS

Experimental Approach to the Problem

Each subject completed four tests during 2 sessions during August and September : one session the week before Ramadan (S1), and the other one, the last week of the fasting period (S2). During each session, four tests were performed, in the same order. The first one was a test for the determination of maximal oxygen consumption (VO_2max), and ventilatory threshold, during the second test, the subject realised a maximal test of leg extension-flexion on an isometric ergometer to record maximal torque during leg extension, and EMG parameters of the vastus lateralis. During the third test subjects underwent two 6 min running exercise at an intensity corresponding to the first ventilatory threshold (VT_1) and the last one was a performance test (5000-m). Each subject had performed the four tests at the same period of the day. **During the period of the study a quantitative assessment of dietary intake was provided by means of a 7-day food record. The food records were analyzed using a computer dietary analysis (Nutrilog 1.20b software, Marans, France) employing the Ciqual table of food composition. This analysis takes into account the loss of the vitamins induced by the cooking preparation but not those induced by the transport, the storage and the reheating of the food.**

Subjects

Eighteen well trained Muslims runners (age 23.6±2.9 yr) participated in this study. Mean values for height, and body mass were: 179 ± 2.6 cm, and 64 ± 2.3 kg respectively. They were chosen according to their religious practice and **thus non-randomly** divided in one Fasting group (n = 9) and one control group (n = 9). The individuals selected were well trained distance runners regularly competing in 1500m, 5000m or 10 000 m events; Subjects were all training and living in France. During the testing period, training of the subjects was standardized **with three training sessions per week composed for the first one by slow running (30min) and intermittent run (30s-30s) at the maximal aerobic speed (100% MAS); the second one was composed by slow running (30min) and 2x6x300m at 100% MAS and the last one by slow running (20min) and 4x4 min at the specific competition running speed of each athlete.**

Maximal running test

Prior to the experiment, each subject underwent a running test on a treadmill to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and ventilatory thresholds (VT1) where the increment of speed was fixed at 1 km.h^{-1} each 3 minutes[20]. The first running speed was fixed at 12km.h^{-1}. Oxygen uptake ($\dot{V}O_2$) and expiratory flow ($\dot{V}_E$) were recorded breath by breath with a telemetric gas exchange measurement system (Cosmed K4b², Rome, Italy). Heart rate values (HR) were monitored every second using a Polar unit (RS800sd, Polar Electro, Kempele, Finland). Expired gases and HR values were subsequently averaged every 5 s. $\dot{V}O_{2max}$ was determined according to the following criteria described by Howley et al.[21] that is, a plateau in $\dot{V}O_2$ despite an increase in running speed, a respiratory exchange ratio value of 1.15, or a Heart rate (HR) over 90% of the predicted maximal HR. $\dot{V}O_{2max}$ was then determined as the highest value of $\dot{V}O_2$ achieved during a period of 30-sec. Moreover, the first ventilatory thresholds (VT1) was determined according to criteria previously described by Wasserman[22]. **VT1 was defined as an increase in the ventilatory equivalent for oxygen** ($\dot{V}E/\dot{V}O_2$) **with no concomitant increase in the ventilatory equivalent for carbon dioxide** ($\dot{V}E/\dot{V}CO_2$) **and**

the departure from linearity of $\dot{V}E$. VT2 was established using the criteria of an increase in both $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$. Visual determination was performed by two investigators in a blinded manner. If there was disagreement, the opinion of a third investigator was sought.

During this session, anthropometric parameters were also recorded **by the same investigator** (body mass, body weight, skinfold thikness) to determine the fat mass, and the fat-free mass. Subjects wearing light clothing but no shoes were weighed using a AMTI force platforms (Biometrics France, Orsay). Skinfold thicknesses (biceps, triceps, subscapular and suprailiac) were measured in triplicate at the left side of the body as described by Durnin and Womersley[23] using Holtain skinfold calipers (Holtain Ltd, Crosswell, UK).

Maximal voluntary isometric contraction (MVC) testing

On their second visit to the laboratory the subjects were placed in a seated position and were securely strapped into the test chair with a 110° hip angle and a 90° knee angle (0° was full leg extension) to perform a maximal voluntary isometric (MVC) knee extension of their dominant leg using an isometric ergometer (Biodex medical, Shirley, NY, USA.). Before MVC assessment, a 5 min isometric warm up was performed. The intensity of the warm up contractions was self-selected but gradually increased to improve the following MVC generation. The subjects were asked to perform three maximal isometric contractions of 5-s duration, each separated by 2-min rest period. The best performance of the three trials was defined as the maximal isometric voluntary contraction (MVC, in Newton).

Electrical recording

EMG recordings were taken from vastus lateralis muscle (VL). In order to replicate the same measure, predetermined landmarks were used as a guideline for electrode placement (15cm from the superior border of the patella 12cm for VL)[24].

The subjects were prepared for placement of EMG electrodes by shaving the skin of each electrode site, cleaning it carefully with alcohol swab and lightly abrading it to maintain a low inter-electrode resistance of < 1000Ω. Pairs of Ag/AgCl pre-gelled surface electrodes (Medicotest, type Blue Sensor, Q-00-S, Copenhagen, Denmark) of 40 mm diameter with a center to center distance of 25mm were applied. A ground electrode was placed on a bony site over the right anterior superior spine of the iliac crest. EMG signals were pre-amplified closed to detection site (Common Mode rejection Ratio, CMRR = 100 dB; Z input = 10G'Ω; gain = 600, bandwidth frequency = from 6 Hz to 1600 Hz). Prior to acquisition, a third order, zero lag butterworth antialiasing filter at 500 Hz was applied. Data were digitized through an acquisition board (DT 9800-series, Data Translation, Marlboro, VT, USA) and stored on a computer to be analyzed using custom-written add-on software (Origin 6.1®, OriginLab, Northampton, USA). The power spectrum density function was calculated by a fast Fourier transformation algorithm for each MVC. To standardize analysis, the spectrum was computed over a 500 msec plateau after the peak force had been reached. The final result of this signal analysis includes root mean square (RMS) and median frequency (MF).

Running efficiency and running performance

In order to calculate running efficiency, subjects performed two running exercise separated by 20 minutes. Each running exercise was composed by 5-min running at 60% VT_1, followed after 5 min rest by a 6-min running exercise at VT_1. One hour after running, subjects performed the 5000-m running performance on the 400-m track. During the running bouts, race strategies were free, the only instruction given to the athlete being to run as fast as possible during the entire 5000-m. **Three minutes after** the end of the 5000m run, capillary blood samples were collected from subjects's ear lobes and blood lactate was assessed using the Lactate Pro system

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Data analysis

Classically, changes in locomotion efficiency can be evaluated during dynamic exercise by analyzing oxygen uptake during a submaximal exercise[25]. Within this framework, during the last decade it has been well documented that the characteristics of VO_2 kinetics could reflect more accurately the aerobic response to exercise and thus efficiency[26-28]. In this study gas exchanges were measured using the K4b² portable gas analyser (COSMED, Rome, Italy). Cardio-respiratory data were collected breath-by-breath during the constant-load transitions of the two exercises. The gas analyser was calibrated before each test according to the manufacturer's guidelines. For each subject and each exercise, the breath-by-breath data were interpolated to 1s interval and ensemble averaged to yield to a single response for each subject. Resting data were obtained by averaging the values recorded over the 3-min rest period prior to exercise. In order to reduce the noise we used a technique of superimposing and averaging values of the two sessions performed at the same period of the day[26,28]. The VO_2 kinetics were evaluated by fitting a monoexponential function of the type:

$$Y(t) = Y(b) + A*[1-e^{(-t-TD/\tau)}],$$

where Y represents VO_2 at any time (t), b is the baseline value of Y (VO_{2b}), A is the amplitude of the increase in Y above the baseline value, τ is the time constant defined as the duration of time through which Y increases to a value equivalent to 63 % of A, and TD is the time delay . **The time delay (TD) is a parameter allowed to vary in order to optimize the fit, representing the time between onset of exercise and the start of the mono- exponential increase of VO2.** Parameters values of the model were determined that yielded the lowest sum of squared residuals. In this study running efficiency (*i.e* oxygen consumption for a given submaximal speed) was assessed using amplitude of oxygen kinetics[27] (A).

Statistical analysis

All data were expressed as mean ± standard deviation (SD). **Normality was verified for all data samples using the Kolmogorov-Smirnov test . A two-way analysis of variance (group x period) for repeated measures was performed** using oxygen kinetics, running performance, MVC and EMG values as dependent variables. Tukey post-hoc test was used to determine any differences among the different sessions. A p value of ≤ 0.05 was accepted as the level of statistical significance for all analyses.

ETHICAL CONSIDERATIONS

Risks and benefits of the study had been described to the subjects; written informed consent was obtained from the participants, and the study was conducted according to the declaration of Helsinki. This study was approved by the local Ethics Committee (Nice, France) before its initiation.

RESULTS

Total daily energy intake remained unchanged. It represents respectively for the Ramadan and the control group: 135.2 ± 8.4 vs. 140.5 ± 6.2 $kJ.kg^{-1}.day^{-1}$. On the opposite, the qualitative components of nutrients were modified in 5 subjects of the Ramadan group with an increase in lipid and carbohydrate intake. For these five subjects the increase in the contribution of carbohydrates and lipids was respectively 8.5 ± 2.2% and 5.7 ± 2.5 1.1% Estimated mean daily water intake was about 2.2 l in the entire group throughout the study.

Body composition and Maximal cardio-respiratory parameters.

Results are shown in Table 1. No effect of Ramadan was observed on body composition in our well trained subjects**. A significant interaction effect (period x group) was observed in maximal running speed at VO_{2max} with a significant decrease** in the Ramadan group (-12%, **p< .00001, Eta_2: 0.88**) . No changes were recorded in VO_{2max},VE_{max}, HR_{max} or VT_1.

Maximal voluntary contraction. **Before fasting no significant effect of group was reported on muscular parameters whereas a significant interaction effect (period x group) was**

observed. After fasting, a significant decrease in Maximal voluntary contraction was observed, **(-3,2%, p< .00001, Eta$_2$: 0.80).** This decrease in MVC was associated with a decrease MF (-5,6%, **p< .00001, Eta$_2$: 0.68**), and a decrease in VL RMS (- 18%, **p< .00001, Eta$_2$: 0.87**). (table 2)

Running economy and running performance. **No effect of group was reported on running economy or performance before Ramadan fasting**. Furthermore, no effect of Ramadan fasting was observed on running efficiency (*i.e;* amplitude of oxygen kinetics) **whereas a significant interaction effect (period x group)** was observed for time constant of oxygen kinetics with a significant increase in time constant in the Ramadan group. (+51%, **p< .00007, Eta$_2$: 0.72**). **Furthermore, a significant interaction effect (period x group)** was also reported for performance with a slight but significant decrease in 5000 m running performance in the RIF group (-5%, **p< .0007, Eta$_2$: 0.51**) associated with an increase in blood lactate values (table 3).

DISCUSSION

The main finding of this study was that Ramadan fasting was associated with a significant reduction in 5000m performance, in maximal strength and changes in oxygen kinetics. This result is in agreement with a recent study indicating that Ramadan fasting could lead to a slight but significant decrease in long distance performance[5].

In this study we have not found any changes in body composition during fasting in our well trained runners. In the literature a small body mass loss associated with dehydration is a frequent, but not universal, outcome of Ramadan[1, 3, 6, 7, 9, 11]. Some studies have reported an increase in body mass[14] or no changes[12]. Furthermore if recent reports have indicated that practising Muslims are undoubtedly dehydrating, it is not clear whether they are chronically hypohydrated during the month of Ramadan[10, 13]. This apparent inconsistancy of results could be mainly related to difference in eating previously reported during Ramadan fasting between countries[10,11]. The present study was realised on young healthy Muslims living in France without any poverty problems. In our study we have observed an increase in protein carbohydrate intake whereas others have reported an increase in lipid and protein and a decrease in carbohydrate intake[1, 4, 10]. Thus food behaviour of our subjects, and physical activity during fasting should be taken in consideration to interpret our data.

To the best of our knowledge no studies have previously analysed the effect of Ramadan fasting on maximal voluntary contraction performed during leg extension. The detrimental effect of fasting on MVC is smaller than reduction reported by previous studies on upper body muscle[3]. This difference could be explained by the characteristics of lower limb muscle largely involved in running training, with higher initial values of strength, which could limit the detrimental effect of Ramadan fasting. In our study, the MVC alteration could be explained in part by the decrease in MF and the decreased of RMS. **Classically, muscle fatigue can be quantified by following the shift in the electromyography (EMG) spectral density towards lower frequencies, using the median frequency (MF), whereas the decrease in RMS could, be explained by the decrease of motor unit firing rate indicating to some extent, a main role of central fatigue[29]**

One interesting finding of this study is the effect of Ramadan fasting on oxygen kinetics with an increase in time constant. For a moderate exercise below ventilatory threshold the VO_2 response is essentially mono-exponential and time constant represents a parameter that describes the rate at which VO_2 rises toward the steady state classically called "oxygen deficit" at the beginning of exercise. Within this framework, for same amplitude of VO_2 kinetics, a short time constant is often reported as an effect of training that could enhance performance[28]. In our study, no effect was observed on kinetics amplitude (A1), therefore, the greater value for the time constant observed in our study after Ramadan fasting (+ 16%) results in a latter attainment of a same steady state. This could be physiologically important because it means that the lag in VO_2 (i.e. the oxygen deficit) would be greater, and thus the requirement for ''anaerobic'' energy provision during the transition from rest to exercise is increased. Therefore we can hypothesize that during Ramadan fasting performing the same exercise intensity than before Ramadan would lead to an increase in anaerobic metabolism contribution and thus to an increase metabolites classically associated with the fatigue process (i.e. adenosine diphosphate, inorganic phosphate, and hydrogen ions). This hypothesis could also explain the decrease in the maximal speed at VO_{2max} observed in our study without any changes in VO_{2max}.

In our study, no changes in running efficiency (oxygen kinetics amplitude) or VO_{2max} was reported. This result is similar with those reported recently by Aziz et al[5] for long distance performance and indicates that RIF has little effect on aerobic performance.

In conclusion, the present study showed that Ramadan intermittent fasting alters middle distance performance with a decrease in muscular performance and increase in oxygen kinetics time constant but without any effects on maximal oxygen consumption or running efficiency. During middle distance events over 1500 m pacing strategies seems to be regulated by the prevailing anaerobic store at each instant of the race[30]. **Recently it has been proposed model of a central neural governor preventing the risk of anaerobiosis on oxygen-sensitive organs during maximal exercise[31]. This "central governor" model proposes that the subconscious brain regulates power output (pacing strategy) by modulating motor unit recruitment to preserve body homeostasis**. Therefore an increase in anaerobic contribution and a decrease in muscle strength must lead to different strategies during the race.

During training, middle distance runners use mainly interval training[32]. Interval training involves repeated short to long bouts of moderate to high intensity exercise interspersed with short or long recovery periods, and thus the form of interval training used elicits differently aerobic or anaerobic metabolism. The detrimental effect of Ramadan fasting on muscle performance or oxygen kinetics needs to be taken into account to choose the appropriate interval training method.

One limitation of this study has to do with the extent to which the findings can be generalized beyond the cases studied. In our work we have studied healthy Muslims living and training in France, then RIF, habits and effects could be slightly different for runners

living and training in north or east Africa. Secondly, a large inter individual variability is classically observed in RIF studies and may be could be responsible, with a small sample size and two non randomly divided group of the lack of any significant effect of RIF on some classical factors of running performance such as running economy.

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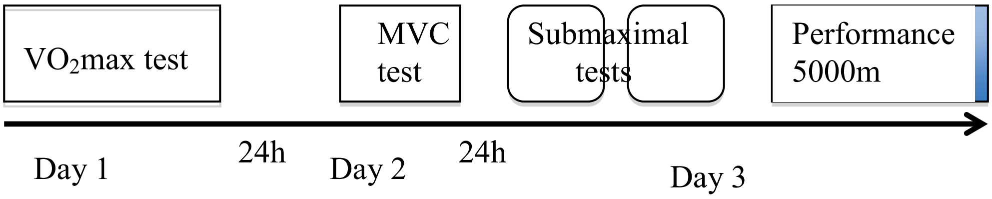

Figure 1. Experimental protocol

Table 1: Changes in Body composition and Maximal cardio-respiratory parameters during RIF.

		Before	After
Body mass, kg	RIF group	62.6 ± 3.2	61.8 ± 4.1
	Control group	65.2 ± 2.8	64.6 ± 3.7
Fat mass, %	RIF group	11.4 ± 2.8	10.6 ± 2.7
	Control group	12.5 ± 1.6	11.2 ± 2.1
VO_2max, $ml.min^{-1}.kg^{-1}$	RIF group	64.4 ± 2.8	65.1 ± 3.2
	Control group	66.1 ± 1.4	65.3 ± 2.2
Speed at VO_2max	RIF group	21.9 ± 1.3	19.3 ± 1.2*
	Control group	21.6 ±1.4	22.2 ± 0.8
Speed at VT1 % VO2max	RIF group	66.2± 2.6	61.1± 4.6
	Control group	67.6± 1.8	66.8± 2.2
VEmax, $l.min^{-1}$	RIF group	113.4 ± 6.6	116.5 ± 7.2
	Control group	118.6 ± 4.7	117.1 ± 7.6
HRmax, $l.min^{-1}$	RIF group	189.6 ± 5.5	187.6 ± 6.1
	Control group	186.7 ± 3.1	185.4 ± 4.1

Mean ±SD, * when a difference between the previous session was significant at $p< 0.05$

Table 2: Changes in maximal voluntary contraction (MVC, Newton), Root Mean Square (RMS, µV), Median Frequency (MF, Hz) during MVC test of knee extensors during RIF .

		Before	After
MVC, N	RIF group	205.2 ± 17.3	197.5 ± 11.7*
	Control group	211.3 ± 10.6	210.6 ± 14.7
RMS (µV)	RIF group	0.17 ± 0. 03	0.14 ± 0. 02*
	Control group	0.20 ± 0. 03	0.19 ± 0. 05
MF (Hz)	RIF group	62.6 ± 1.9	59.1 ± 2.2*
	Control group	60.4 ± 2.4	61.2 ± 1.8

Mean ±SD, * when a difference between the previous session was significant at $p < 0.05$

Table 3: Changes in Oxygen kinetics during submaximal exercise at VT_1 and 5000m running performance during RIF.

		Before	After
Performance (min.sec)	RIF group	14.18 ± 8.3	15.03 ± 7.7*
	Control group	14.23 ± 6.1	14.21 ± 8.1
Blood lactate concentration ($mmol.l^{-1}$)	RIF group	7.6 ± 1.2	8.4 ± 2.4*
	Control group	7.1 ± 0.8	7.4 ± 2.1
VO2b $ml.min^{-1}$	RIF group	350.12 ± 28.7	364.26 ± 32.4
	Control group	412.08 ± 16.5	399.32 ± 19.1
τ (sec)	RIF group	22.3 ± 2.6	33.9 ± 3.2*
	Control group	23.1 ± 2.8	21.7 ± 1.9
A1 ($ml.min^{-1}$)	RIF group	2653.7 ± 271.9	2756.5 ± 252.1
	Control group	2678.3 ± 299.6	2689. 8± 327.6

VO2b is the baseline value of Y, A1 is the amplitude of the increase in Y above the baseline value and , τ is the time constant defined as the duration of time through which Y increases to a value equivalent to 63 % of A.

Mean ±SD, * when a difference between the previous session was significant at $p< 0.05$