Sport Sciences for Health
https://doi.org/10.1007/s11332-025-01415-9

RESEARCH

Acute and delayed effects of Ramadan intermittent fasting on the postural control of elite judokas: focus on mobility and dynamic balance performance

Nafaa Souissi[1] · Amira Zouita[2] · Salma Abedelmalek[3,4] · Achraf Ammar[5,6,7,8] · Gaith Ezzedine[7] · Khaled Trabelsi[7,9,10] · Katherine Dziri[2] · Cain C. T. Clark[11] · Nizar Souissi[1] · Karim Chamari[12,13]

Received: 30 October 2024 / Accepted: 12 April 2025

Abstract

Background Ramadan intermittent fasting (RIF) induces significant physiologic changes, including alterations in sleep patterns, energy intake, and hydration status, which may affect athletic performance. Given the importance of postural control in judo, understanding the impact of RIF on mobility and dynamic balance is crucial for optimizing performance and injury prevention.

Purpose This study aimed to investigate the acute and delayed effects of RIF on postural control in elite judokas, with a specific focus on mobility and dynamic balance performance**.**

Methods Ten elite judokas (23.5 ± 2.3 years, 172.6 ± 7.4 cm, and 71.6 ± 3.9 kg) completed three morning test sessions assessing postural mobility and dynamic balance using the walk across (WA) and limit of stability (LoS) tests. Assessments were conducted before Ramadan (BR), during the third week of fasting (DR), and 3 weeks after Ramadan (AR). Anthropometric measures and daily energy intake were also recorded.

Results Significant reductions in total daily energy intake, body mass, and body mass index were observed at DR compared to BR and AR ($p < 0.05$). In the WA test, step length, and movement speed significantly decreased during DR ($p < 0.001$), while step width remained unchanged. In the LoS test, reaction time and sway velocity increased ($p < 0.001$), while directional control decreased ($p < 0.001$) at DR compared to BR and AR. No significant differences were found for maximum excursion across conditions.

Conclusion RIF transiently impaired both mobility and dynamic postural control in elite judokas, likely due to a combination of sleep disturbances, reduced energy intake, and dehydration. These impairments resolved 3 weeks after Ramadan. Coaches and athletes should consider targeted nutritional and sleep strategies to mitigate these temporary declines in postural stability during fasting periods.

Keywords Balance impairment · Ramadan observance · Elite athlete · Combat sport

Introduction

Ramadan intermittent fasting (RIF) is the holiest month in the Islamic calendar, during which fasting from dawn to sunset is compulsory for healthy adult Muslims [1]. This fasting period induces a partial reversal of the nychthemeral rhythm, characterized by complete abstention from food and fluids during daylight hours, increased nighttime food and fluid intake, and an extended waking state. To compensate for the altered sleep–wake cycle, individuals often adopt compensation strategies such as fragmented sleep periods and variable daytime naps [2]. These changes influence eating habits, sleep duration, and sleep architecture [3], which, in turn, may compromise both physical and cognitive performance [4].

Despite these physiologic shifts, many Muslim athletes continue to train and compete, as international sporting calendars do not account for religious observances. Consequently, prolonged abstinence from food and fluids during daylight training or competition, combined with disruptions in sleep, may significantly impact athletic performance [5]. Sleep, in particular, plays a crucial role in recovery, training adaptation, and overall performance [6]. Both acute and

Extended author information available on the last page of the article

chronic disturbances in sleep patterns can negatively impact physical and cognitive abilities, as well as emotional well-being and immune function [4].

Several studies have demonstrated that Ramadan disrupts the normal sleep–wake cycle, leading to (i) altered sleep timing and prolonged sleep latency, (ii) reduced total sleep duration and slow-wave sleep, and (iii) increased daytime sleepiness and more frequent episodes of partial sleep deprivation [3, 5, 7]. As a result of these disturbances, athletes may experience impairments in tasks requiring sensorimotor coordination, cognitive function, and physical performance [7, 8]. Balance, an essential component of athletic performance and injury prevention, may also be negatively affected [9]. Smith et al. [10] highlighted that prolonged wakefulness increases the likelihood of balance impairments, which may elevate the risk of falls or other repercussions of decreased postural control.

Postural stability, defined as the ability to maintain proper body alignment and balance during movement, is a crucial component of athletic performance. It plays a fundamental role in injury prevention, movement efficiency, and optimizing strength and coordination across various sports [11]. In the context of sleep disturbances, previous research has demonstrated that postural control is negatively affected by sleep deprivation, with increased postural sway and reduced balance maintenance, particularly in fatigued individuals [12]. Several studies have used stabilometric indices, including center of pressure area, and velocity to evaluate the effects of sleep deprivation on postural stability [13]. Findings indicate that balance performance is generally impaired during nighttime and that postural sway is associated with tiredness [14]. When tests were performed at 18h00 the next day, Bougard and Davenne [9] identified that one night of partial sleep deprivation impaired balance control, particularly in the stance test of the dominant leg. Given the well-established association between circadian rhythms, sleep loss, and postural control, [9, 11, 15] further research is warranted to explore how these factors interact with specific sporting contexts.

In sports requiring precise motor control, postural stability is essential for optimal performance. The somatosensory system plays a dominant role in balance regulation under stable conditions, relying on input from receptors in the skin, muscles, and joints. However, on unstable surfaces or during challenging conditions, such as when an athlete is subject to intersensory conflict, the vestibular system become increasingly dominant [16]. Dynamic postural control, which refers to the ability to maintain the center of mass within the base of support while experiencing internal or external perturbations, is particularly important in combat sports [17]. In Judo, vestibular and proprioceptive inputs play critical roles in balance regulation, and effective postural control is a key determinant of performance [18]. The ability to manipulate an opponent’s balance is central to judo, as throws and takedowns often rely on disturbing an adversary's equilibrium. Notably, the imbalance of an opponent along the eight axes of imbalance provides opportunities for offensive maneuvers [19]. Regular training has been shown to improve the utilization of proprioceptive and somatosensory information, reinforcing postural stability across different skill levels [20, 21]. Recent research also indicates that the nature of training influences static balance, with judo athletes displaying superior balance control compared to dancers, suggesting that different movement patterns stimulate distinct proprioceptive adaptations [22].

Despite extensive research on the influence of training on postural stability, limited attention has been given to the effects of external factors, such as Ramadan intermittent fasting (RIF), on balance performance in judokas. Aloui et al. [23], demonstrated that RIF leads to significant impairments in physical performance in judo-specific and generic tests conducted in the afternoon. Given that judo performance is highly dependent on dynamic balance and rapid postural adjustments, understanding the effects of RIF on postural control is crucial. However, previous research investigating the impact of RIF on postural stability in elite judokas has been limited in scope. The only study to date examining RIF's effects on dynamic balance failed to assess the eight axes of imbalance, which are fundamental to judo techniques [24]. Given the strategic role of balance manipulation in judo, understanding how RIF affects postural stability across all eight imbalance directions is crucial.

RIF leads to significant disruptions in sleep and circadian rhythm, which have been shown to impact postural control in non-fasting conditions, suggesting a potential impact on balance regulation in fasting athletes. Moreover, dynamic balance is a key determinant of judo performance, influencing both the execution and defense against throws. Despite this, previous research on RIF and postural control has primarily relied on general balance assessments, which may not fully capture the sport-specific demands of judo. Therefore, examining postural stability through assessments tailored to the unique biomechanical and tactical requirements of judo will provide more relevant insights into the effects of RIF on athletic performance.

The present study aims to investigate the acute and delayed effects of RIF on postural control in elite judokas by utilizing dynamic and mobility tests that specifically evaluate balance performance in all eight imbalance directions relevant to judo techniques. We hypothesize that RIF will impair postural stability, particularly in conditions requiring heightened vestibular and proprioceptive engagement.

Methods

Study design

This study followed a repeated-measures design to investigate the effects of RIF on postural control in elite judokas. Each participant was evaluated across three experimental sessions: 1 week before Ramadan (BR) (19–20 May 2017), during the third week of Ramadan (DR) (16–17 June 2017), and 3 weeks after Ramadan (AR) (14–15 July 2017). Testing sessions were scheduled at the same time between 08:00 and 09:00 to minimize diurnal variation effects on postural control [5]. The temperature of the testing room was held at 26 ± 1 °C, with a relative humidity of 45 ± 4% during all the experimental sessions. The study was conducted in Tunisia, where sunrise and sunset times changed throughout Ramadan (first day: 05:03 and 19:29, last day: 05:01 and 19:42).

Participants performed two postural control assessments: (i) the walk across test (WA) and (ii) the Limit of Stability test (LoS), with each test comprising three trials separated by a 15-s rest interval. To reduce potential learning effects, all participants completed two familiarization sessions before data collection [26]. After receiving a description of the protocol, risks, and benefits of the study, they all provided written informed consent. The study adhered to the principles of the Declaration of Helsinki and received ethical approval from the National Institute of Orthopedics Kassab of Tunis.

Participants

The required sample size was determined using G*Power 3.1 software for repeated-measures ANOVA within-subjects design. Based on a previous study by Souissi et al. [24] and discussion between authors, an effect size of $f = 0.5$ was estimated. With a significance level of $\alpha = 0.05$, statistical power of 0.85, three repeated measurements (pre-, mid-, and post-Ramadan), and an assumed correlation of 0.5 among repeated measures, the power analysis indicated that a minimum of nine participants would be required to detect significant effects. Given these considerations, ten elite judokas were recruited for this study. Ten elite judokas (age: 23.5 ± 2.3 years; body mass: 71.6 ± 3.9 kg and height: 172.6 ± 7.4 cm) volunteered to participate in the present study (Table 1). Participants were classified as elite judo athletes based on the taxonomy established by Jaworski and Lech [22], with a mean experience of 12 ± 3.6 years in judo. To be included in the study, participants had to meet the following criteria: (i) holding a first Dan black belt, (ii) competing at a national or international level, (iii) training at least 16 h per week, (iv) regularly participating in official judo tournaments, and (v) following a structured training regimen six days per week, with two training sessions per day, except for Saturdays (one session per day). Participants were not undergoing a weight-cutting phase or actively reducing weight for competition one month prior and during the experimental period. All judokas competed in the -73 kg weight category. Furthermore, participants were selected based on their chronotype, assessed via the validated Horne and Ostberg sleep questionnaire [27]. All judokas were classified as having an intermediate chronotype, with habitual sleep occurring between 22:30 ± 1:23 and 07:00 ± 1:16. Participants reported no history of medical conditions, no use of medication, and no smoking habits. Since all ten participants met the inclusion criteria, were enrolled, and completed the study without dropout or exclusion, and considering that all collected data were included in the final analysis, a CONSORT flowchart was deemed unnecessary.

Table 1 Characteristics of the participants ($n = 10$)

Parameters	M ± SD
Age (year)	23.5 ± 2.3
Height (cm)	172.6 ± 7.4
Judo level	Black belt
Time of judo practice (year)	12 ± 3.6
Level of competition	International
Weight category	− 73 kg
Trained per week	16 h

Procedures

To ensure standardized sleep conditions throughout the study, participants adhered to a controlled sleep schedule, with a nocturnal rest period set between 23:00 ± 1:00 and 07:00 during the BR and AR periods. During RIF (DR period), they consumed Suhour before sleeping and went to bed before 01:30, waking up at 07:00 after an uninterrupted sleep cycle. Sleep patterns were continuously monitored using wrist actigraphy (Actiwatch Sleep and Activity software, version 5.32, Cambridge Neurotechnology, UK) to objectively track variations in sleep duration and quality. The average (Mean ± SD) sleeping time of the participants was 01:54 ± 00:25 less DR compared with BR and 01:38 ± 00:18 less compared with AR. In addition, a 7-day dietary record was maintained to assess nutritional intake, analyzed using Nutrisoft-Bilnut (ver. 4, Paris, France) [28] and food composition tables issued by the Tunisian National Institute of Statistics in 1978 [29, 30]. Reference dietary intakes for physically active individuals were used to compare estimated nutrient intakes. Participants were instructed to maintain their habitual dietary habits while abstaining from caffeine and caffeinated products for 48 h before each testing session to prevent potential confounding effects on physiological responses [25]. To ensure hydration consistency, they were only permitted to drink a single glass of water (15–20 cl) before testing in the BR and AR sessions [31]. Furthermore, participants were instructed to refrain from engaging in any vigorous physical activities outside their regular training regimen throughout the experimental period to minimize potential confounding effects. They were advised to maintain only their usual judo training sessions while avoiding additional strenuous exercise that could influence physiologic and performance-related outcomes.

Outcomes

Anthropometric measures

Body mass was measured before each session using a Tanita digital scale (Tanita, Tokyo, Japan) with an accuracy of 0.1 kg.

Posturographic assessments

Postural control was evaluated as mobility and dynamic balance tests using the NeuroCom® Balance Master (NBM: NeuroCom International; Software Version 7). Data from three trials for each test were averaged to enhance reliability. The NBM has been validated as a reliable tool for assessing postural stability across various populations. Studies have reported test–retest reliability with intraclass correlation coefficients (ICCs) ranging from 0.48 to 0.82, depending on the specific balance parameter assessed [32]. The system has demonstrated high reliability, particularly in complex balance tasks and in populations with neurologic impairments [33] supporting its suitability for evaluating dynamic postural control in elite athletes.

The walk across test (WA) The WA test was used to assess gait characteristics, including step width (cm), step length (cm), and speed (cm/s). The judoka began the test positioned approximately 90 cm in front of the platform, ensuring alignment with the surface level of the platform.

During normal gait, the center of gravity (COG) moves forward while also shifting mediolaterally, creating an "S"-shaped pattern. These right/left shifts occur due to the transfer of weight from foot to foot, while forward motion is generated through toe-off propulsion and momentum [34]. To complete the test, the participant took three consecutive steps on the 2.5-m-long platform, maintaining natural gait mechanics, before immediately jumping off the platform. The NeuroCom Balance Master™ system recorded and analyzed key gait parameters, providing an objective assessment of dynamic stability and movement control.

The limit of stability test (LoS) The LoS test is a dynamic balance assessment that measures the participant's ability to intentionally control their COG while maintaining a standing position with feet together. Participants were instructed to shift their weight toward eight designated targets, arranged in an elliptical pattern at 100% of their theoretical stability limit [35], calculated by the NeuroCom™ system based on individual body dimensions (Fig. 1). The test required participants to initiate movement from a central position and sequentially shift their weight toward each eight target directions, following a clockwise sequence: (1) forward, (2) forward-right, (3) right, (4) backward-right, (5) backward, (6) backward-left, (7) left, and (8) forward-left. Participants were instructed to keep their gaze straight ahead, remain calm and immobile in the anatomic stance, and maintain their feet in a standardized position on the force plate. The task began when participants heard a tone signal and saw a blue circle appear on the screen at the outermost highlighted target. They were instructed to shift their weight as quickly as possible to move the on-screen icon toward the target and hold their position until a second tone was heard. Participants were allowed to use any movement strategy (e.g., ankle or hip-based shifts) without lifting or moving their feet. Each trial lasted 8 s and started with the participant standing at the center square of the force plate.

Statistical analysis

Statistical analyses were conducted using STATISTICA Software (StatSoft, France), and all data were reported

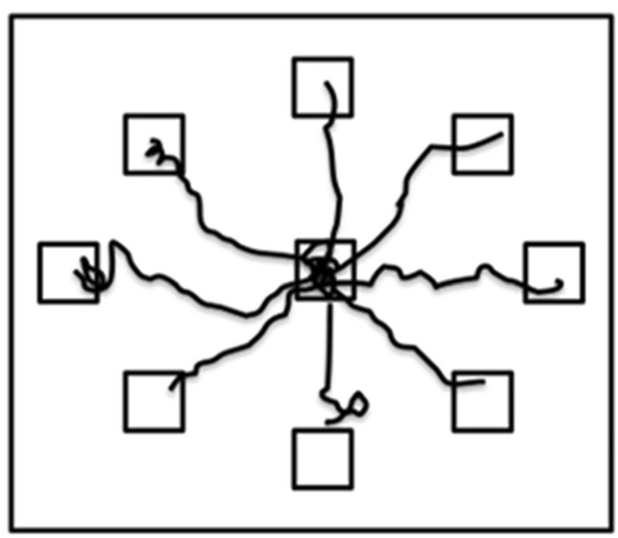

Fig.1 Limit of stability test

as mean ± SD. The assumption of normality was verified using the Shapiro–Wilk *W*-test, and homogeneity of variances (homoscedasticity) was assessed using Levene's test. To meet the assumptions required for repeated-measures analysis of variance (RMANOVA), sphericity was also tested using Mauchly's test. All parameters of the WA test (i.e., step width, step length, and speed) and the LoS test (i.e., reaction time, sway velocity, maximum excursion and directional control) were analyzed using one-way RMANOVA across the three testing periods (BR, DR, and AR). For anthropometric measures and dietary data, RMANOVA was used to detect significant differences between the three sessions. Where appropriate, significant differences among means were tested using the Bonferroni post-hoc test. To assess the practical significance of the data, effect sizes were computed as partial eta-squared (ηp^2). The interpretation of effect sizes followed the commonly used thresholds: small ($\eta p^2 = 0.01$), medium ($\eta p^2 = 0.06$), and large ($\eta p^2 = 0.14$), as suggested by Cohen [36] and expanded upon by Lakens [37] for research in behavioral and sports sciences. A test–retest for posturographic assessments was conducted 1 month before Ramadan, with intraclass correlation coefficients (ICC) computed to verify measurement consistency. Statistical significance was accepted, a priori, at $p < 0.05$.

Results

The impact of RIF on the measured outcomes.

Table 2 presents the impact of RIF on anthropometric characteristics, daily nutrient consumption, and postural control, as assessed by the mobility (WA test) and dynamic balance (LoS test) measures.

One-way RMANOVA (Table 2) indicated significant effects of "period" on total daily energy intake ($p = 0.026$, $\eta p^2 = 0.32$;), daily total fat content ($p < 0.001$, $\eta p^2 = 0.88$), and daily protein ($p < 0.001$, $\eta p^2 = 0.62$) and carbohydrate ($p = 0.033$, $\eta p^2 = 0.32$) intake; with lower values DR compared to BR and AR ($p < 0.05$). Similarly, a significant effect of "period" was noted for body mass ($p = 0.006$, $\eta p^2 = 0.43$), body fat ($p < 0.001$, ηp2 = 0.66) and BMI ($p < 0.006$, $\eta p^2 = 0.43$); with lower values DR vs, AR and FR ($p < 0.05$).

Concerning the WA test, RMANOVA showed a significant effect of "period" on step length ($p < 0.001$, $\eta p^2 = 0.50$) and speed ($p < 0.001$, $\eta p^2 = 0.007$) with lower values during DR compared to BR and AR ($p < 0.001$). However, no significant difference was found for step width between BR, DR, and AR ($p > 0.05$).

For the LoS test, a significant effect of "period" was observed on reaction time ($p < 0.001$, $\eta p^2 = 0.78$), sway velocity ($p < 0.001$, $\eta p^2 = 0.48$), and directional control

Table 2 The impact of Ramadan intermittent fasting on anthropometric characteristics, daily nutrient consumption, and mobility (WA test) and dynamic (LoS test) balance measures

Parameters	BR	DR	AR	$F(2, 18)$	p value	ηp^2
Body mass (kg)Bo	Anthropometric characteristics and daily nutrient consumption					
Body mass (kg)	71.60 ± 3.9	69.78 ± 4.4[¥]	71.44 ± 2.5	6.79	0.006	0.43
Body mass index (kg·m^2)	24.01 ± 1.3	23.40 ± 1.5[¥]	23.96 ± 0.9	6.88	0.006	0.43
Body fat (kg)	11.37 ± 1.12	9.52 ± 1.03[¥]	11.00 ± 1.07	17.17	< 0.001	0.66
Energy (kcal/day)	2916 ± 85	2805 ± 132[¥]	2864 ± 100	4.53	0.026	0.33
Protein (g/day)	104.53 ± 13.63	80.52 ± 10.84[¥]	97.17 ± 8.40	14.91	< 0.001	0.62
Fat (g/day)	117.22 ± 8.31	91.73 ± 8.17[¥]	112.09 ± 9.34	67.33	< 0.001	0.88
Carbohydrates (g/day)	480.7 ± 25.2	423.6 ± 55.1[¥]	456 ± 48.9	4.14	0.033	0.32
	WA's step width, step length, and speed					
Step width (cm)[a]	19.41 ± 4.93	19.80 ± 3.28	19.82 ± 2.48	–	0.836	0.018
Step length (cm)	69.80 ± 11.56	60.05 ± 10.09[¥]	70.72 ± 6.16	9.16	0.001	0.50
Speed (cm/s)	85.18 ± 8.28	76.13 ± 7.69[¥]	83.58 ± 9.13	0.07	0.001	0.007
	LoS' s reaction time, movement velocity, maximum excursion, and directional control					
Reaction time (s)	0.63 ± 0.22	0.79 ± 0.20[¥]	0.62 ± 0.15	24.87	0.001	0.78
Sway velocity (deg/s)	4.81 ± 1.14	5.99 ± 1.46[¥]	4.78 ± 1.31	8.49	0.001	0.48
Maximum excursion (%)	100.69 ± 3.45	98.54 ± 5.00	100.78 ± 2.36	1.78	0.05	0.16
Directional control (%)	77.35 ± 4.30	72.40 ± 4.78[¥]	77.71 ± 5.21	20.65	0.001	0.69

BR before Ramadan, *DR* during Ramadan, *AR* after Ramadan, *WA* walk across test, *LoS* limit of Stability test

[¥]($p < 0.05$) Significant difference compared to BR and AR

[a]Nonparametric test (Friedman test with Chi-2 = 0.359). Results presented as mean ± SD

($p < 0.001$, $\eta p^2 = 0.69$), with an increased reaction time and movement velocity, and a lower directional control DR compared to BR and AR. ($p < 0.001$). However, no significant difference was found for the maximum excursion during the LoS test BR, DR, and AR ($p > 0.05$).

No significant difference was noted between BR and AR in all tested parameters of WA and LoS.

The reliability of the mobility and dynamic balance measures

Test–retest reliability analysis demonstrated that the WA test outcomes exhibited poor to moderate reliability, with ICC values ranging from 0.53 for step length to 0.67 for step width. In contrast, the LoS test outcomes showed high to excellent reliability, with ICC values ranging from 0.83 for maximum excursion to 0.98 for reaction time. Directional control and movement velocity also showed excellent reliability, with ICCs of 0.95 and 0.89, respectively.

Discussion

The present study aimed to investigate the acute and delayed effects of RIF on postural control in elite judokas, using both mobility and dynamic balance assessments. Specifically, postural mobility was evaluated using the WA test, while dynamic balance was assessed through the LoS test. Results suggest that RIF significantly affected postural control, with impairments observed in multiple parameters of both the WA and LoS tests DR compared to BR and AR. Notably, step length and movement speed in the WA test were reduced, while reaction time and sway velocity in the LoS test increased, indicating compromised postural control. These effects were transient, as postural stability measures returned to baseline values after Ramadan.

Our study expands on prior research by examining sport-specific postural control adaptations in elite judokas during RIF. Previous studies have predominantly focused on the general effects of RIF on motor performance, strength, and endurance [23, 36, 37], with limited attention given to sport-specific balance assessments. In judo athletes, existing studies have reported RIF-induced impairments in both static and dynamic postural control tests [24, 35]; however, these studies did not incorporate mobility assessments, and their dynamic balance tests failed to evaluate all eight axes of imbalance, which are fundamental to judo techniques. Indeed, the concept of linearity, a fundamental facet in the early years of judo, forms the basis for the system of Happō-no-kuzushi or "Eight basic directions of unbalance" [19]. All of these directions represent a linear symmetry in a biomechanical plane parallel to the tatami [19]. The use of specific and appropriate actions is needed to increase the imbalance in an opponent, grapple, and thereby facilitate specific moves or throws. The present study is among the first to comprehensively assess postural control across all eight imbalance directions that are directly relevant to judo performance. Furthermore, previous research on postural control in judo has emphasized the role of vestibular and proprioceptive training in enhancing balance [20, 21, 38]. Our findings suggest that RIF temporarily impairs these balance mechanisms, potentially compromising an athlete's ability to maintain stability during throws and counterattacks. Unlike studies that have primarily focused on static balance assessments ([24]), our research underscores the dynamic nature of postural adjustments in judo, reinforcing the necessity for sport-specific balance evaluations that align with the unique biomechanical and tactical demands of the sport.

Postural mobility, as assessed by the WA test, was significantly impaired during DR, with reductions in step length and movement speed. These findings suggest that RIF negatively impacts locomotion efficiency and gait stability, which could affect an athlete's ability to execute rapid, coordinated movements during combat. Previous studies have demonstrated that alterations in neuromuscular coordination and proprioception due to sleep deprivation and energy deficits may contribute to impaired gait performance [9, 14]. Given that prolonged fasting may lead to decreased glycogen availability, known to contribute to neuromuscular fatigue [39], reduced movement efficiency in the WA test could reflect lower muscle energy stores and diminished coordination during Ramadan. Furthermore, prior research has indicated that postural mobility is highly dependent on vestibular and proprioceptive integration, both of which may be affected by sleep deprivation and altered circadian rhythms during RIF [7, 14]. Since judokas rely on rapid footwork and precise weight shifts, even subtle impairments in mobility could influence their ability to execute defensive maneuvers and counterattacks. Our results align with findings from studies examining the effects of sleep restriction on gait dynamics, which have shown that sleep disturbances lead to slower walking speed, shorter step length and lower sensorimotor control of gait [40, 41].

The LoS test revealed significant impairments in dynamic balance during DR, as evidenced by increased reaction time, swaying velocity, and reduced directional control. These results indicate that athletes exhibited slower responses to balance perturbations and greater instability when shifting their COG. The decline in directional control suggests compromised coordination and reduced ability to maintain balance under dynamic conditions, which could increase the risk of falling or being thrown off balance in a judo match. Several mechanisms may explain these findings. First, sleep disturbances associated with RIF are known to impair sensorimotor function, alter reaction time, functional attention and delay neuromuscular responses, leading to reduced postural stability [3, 7, 12, 42]. Previous studies have asserted that the increase in postural sway following sleep deprivation may be due to a reduction in vestibular system efficiency [43] and/or the integration of several sensory inputs [44]. Indeed, the maintenance of a stable base of support during a balance control task necessitates the integration of sensory inputs to elicit the appropriate motor responses required to make limb corrections [45]. Since judokas frequently rely on anticipatory and reactive balance adjustments to counter an opponent's movements, any delay in postural reactions could be detrimental to performance. Second, reductions in total energy intake and macronutrient availability during DR may have contributed to neuromuscular fatigue and altered psychomotor performance; thereby altering his ability to generate rapid corrective movements [2, 42]. Given that carbohydrate availability plays a crucial role in maintaining motor performance [46], lower glycogen stores during fasting could impair balance-related neuromuscular responses. Previous research on sleep deprivation and balance control has demonstrated that prolonged wakefulness increases postural sway and reduces reaction time in balance tasks [9, 14]. In line with these studies, our findings suggest that the combination of fasting, sleep disturbances, and potential dehydration may have compounded the effects on dynamic balance during Ramadan.

In addition to postural control, the present study examined the effects of RIF on anthropometric characteristics and daily nutrient intake. Our results showed significant reductions in body mass, BMI, and body fat percentage during DR compared to BR and AR, likely reflecting the influence of fasting-induced caloric restriction. Moreover, total daily energy intake, as well as macronutrient consumption (fat, protein, and carbohydrates), were significantly lower during DR. This aligns with previous findings that RIF leads to reduced caloric intake and alterations in body composition among athletes [2, 47]. These results further reinforce our previous discussion regarding the potential role of nutritional shifts in neuromuscular fatigue and reduced energy availability, which could contribute to compromised postural control. Given the high metabolic demands of judo, ensuring adequate nutritional intake during Ramadan is crucial to maintaining optimal performance, particularly in balance-related tasks.

Taken together, sleep disturbances and altered energy intake appear to be the primary contributors to the observed impairments in postural balance during RIF among elite judokas. Future research should explore strategies to mitigate these effects, such as targeted sleep interventions (e.g., naps) and adjusting training and competition schedules to optimize performance under fasting conditions. In addition, future studies could examine the efficacy of targeted nutritional strategies, including ergogenic supplementation and optimizing Suhoor timing, to counteract the effects of energy restriction on postural stability. Recent studies by Bougrine et al. [48, 49] and Pickerill & Harter [32] demonstrated that consuming Suhoor closer to pre-dawn helps preserve morning cognitive function, prevent impairments in the fasted state at midday and afternoon, and minimize declines in physical performance during short-term high-intensity exercise, ultimately enhancing overall athletic performance.

Practical applications for judo athletes observing Ramadan

To mitigate the impact of RIF on postural control, several practical strategies can be implemented. First, optimizing sleep schedules and incorporating strategic naps could help counteract sleep deprivation effects. Research suggests that short naps during the day can enhance cognitive and motor performance in sleep-restricted individuals [42, 50]. Second, judokas should focus on maintaining adequate hydration and energy intake during non-fasting hours, prioritizing slow-digesting carbohydrates and high-quality protein sources to support neuromuscular function. Athletes may consider delaying their Suhoor to maximize energy availability and sustain cognitive and physical performance throughout the fasting period [48, 49]. Similarly, coaches may adjust training schedules to align with periods of peak alertness and physical readiness, such as late afternoon or evening sessions, when athletes are closer to breaking their fast. These adjustments could help mitigate performance declines, optimize training adaptations, and support postural stability and neuromuscular function during Ramadan fasting [3, 51]. In addition, integrating balance-specific drills into training routines may help maintain postural stability during Ramadan. Proprioceptive and vestibular exercises, including unstable surface training and reaction-based balance drills, could help athletes compensate for fasting-induced impairments [20]. Nevertheless, as previously mentioned, future research should explore the effectiveness of these interventions either separate or in combination with preserving judoka's balance performance during RIF.

Study limitations

The present study was conducted on a relatively small sample of elite judokas. However, given the inherently limited number of available athletes at this competitive level, increasing the sample size was operationally challenging. Importantly, a priori sample size calculation confirmed that the inclusion of ten elite athletes was sufficient to achieve the required statistical power. Nevertheless, we acknowledge that the sample size remains a limitation, and results should be interpreted with caution, particularly regarding their generalizability to broader populations. In addition, as with many studies on Ramadan conducted in Muslim-majority countries, the current study is lacking the presence of a non-fasting comparator group. To address this, we considered the assessments performed before and after Ramadan as control conditions, despite the inherent methodological constraints. Future studies are advised to integrate a dedicated non-fasting control group to strengthen comparative analyses and provide more robust reference standards. Furthermore, study focused exclusively on well-trained male judokas, limiting the applicability of the findings to other populations, including sedentary individuals, female athletes, recreational judokas, or patient populations. Future research should aim to expand the participant pool to assess the broader implications of Ramadan fasting on postural stability across different demographic and athletic groups. Lastly, future studies should incorporate biomechanical assessments, such as electromyography and motion capture analysis, to gain deeper insights into the neuromuscular mechanisms underlying fasting-related balance impairments.

Conclusions

The present findings suggest that both mobility and dynamic postural control was significantly impaired during Ramadan in elite judokas. These effects appear to be transient, as postural control measures returned to baseline after Ramadan. The combination of sleep disturbances, reduced energy intake, and potential dehydration likely contributed to these impairments. Given the critical role of balance in judo performance, athletes and coaches should consider implementing targeted strategies to mitigate these impairments, including optimizing sleep schedules, incorporating strategic naps, maintaining proper nutrition and adequate nutritional intake, and incorporating balance-specific training. Future research should further explore the interaction between fasting, sleep, and postural control across different athletic populations and competition settings along with their underlying mechanism, as well as assess the efficacy of countermeasures to support performance during fasting periods.

Author contributions Conceptualization, Nafaa Souissi, Achraf Ammar, Khaled Trabelsi, Nizar Souissi and Karim Chamari; Formal analysis, Nafaa Souissi; Funding acquisition, Achraf Ammar; Investigation, Nafaa Souissi; Methodology, Nafaa Souissi, Amira Zouita and Achraf Ammar; Project administration, Achraf Ammar; Software, Amira Zouita and Katherine Dziri; Supervision, Nizar Souissi and Karim Chamari; Validation, Nafaa Souissi, Amira Zouita, Salma Abedelmalek, Achraf Ammar, Ghaith Ezzedine, Khaled Trabelsi, Katherine Dziri, Cain C.T. Clark, Nizar Souissi and Karim Chamari; Visualization, Achraf Ammar; Writing—original draft, Nafaa Souissi and Achraf Ammar; Writing—review and editing, Amira Zouita, Salma Abedelmalek, Achraf Ammar, Ghaith Ezzedine, Khaled Trabelsi, Katherine Dziri, Cain C.T. Clark, Nizar Souissi and Karim Chamari.

Funding Open Access funding enabled and organized by Projekt DEAL. This research received no external funding.

Data availability statement Data are available from the first author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest

References

1. Al Wakeel J, Mitwalli AH, Alsuwaida A, Al Ghonaim M, Usama S, Hayat A, Shah IH (2013) Recommendations for fasting in Ramadan for patients on peritoneal dialysis. Perit Dial Int 33(1):86–91. https://doi.org/10.3747/pdi.2010.00095
2. Chtourou H (2015) Effects of Ramadan fasting on health and athletic performance. Omics Group eBooks
3. Roky R, Chapotot F, Benchekroun MT, Benaji B, Hakkou F, Elkhalifi H, Buguet A (2003) Daytime sleepiness during Ramadan intermittent fasting: Polysomnographic and quantitative waking EEG study. J Sleep Res 12(2):95–101. https://doi.org/10.1046/j.1365-2869.2003.00341.x
4. Venter RE (2012) Role of sleep in performance and recovery of athletes: a review article. S Afr J Res Sport Phys Educ Recreat 34(1):167–184
5. Chamari K, Briki W, Farooq A, Patrick T, Belfekih T, Herrera CP (2016) Impact of Ramadan intermittent fasting on cognitive function in trained cyclists: a pilot study. Biol Sport 33(1):49–56. https://doi.org/10.5604/20831862.1185888
6. Knufinke M, Nieuwenhuys A, Geurts SAE, Coenen AML, Kompier MAJ (2018) Self-reported sleep quantity, quality, and sleep hygiene in elite athletes. J Sleep Res 27(1):78–85. https://doi.org/10.1111/jsr.12509
7. Waterhouse J (2010) Effects of Ramadan on physical performance: chronobiological considerations. Br J Sports Med 44(7):509–515. https://doi.org/10.1136/bjsm.2007.071712
8. Reilly T, Waterhouse J (2009) Sports performance: is there evidence that the body clock plays a role? Eur J Appl Physiol 106(3):321–332. https://doi.org/10.1007/s00421-009-1066-x
9. Bougard C, Davenne D (2012) Effects of sleep deprivation and time-of-day on selected physical abilities in off-road motorcycle riders. Eur J Appl Physiol 112(1):59–67. https://doi.org/10.1007/s00421-011-1948-6
10. Smith SS, Cheng T, Kerr GK (2012) The effect of extended wake on postural control in young adults. Exp Brain Res 222(3):329–335. https://doi.org/10.1007/s00221-012-3175-8
11. Hrysomallis C (2011) Balance ability and athletic performance. Sports Med 41(3):221–232. https://doi.org/10.2165/11538560-000000000-00000

12. Bougard C, Davenne D (2014) Morning/evening differences in somatosensory inputs for postural control. Biomed Res Int 2014:287436. https://doi.org/10.1155/2014/287436
13. Gribble PA, Hertel J (2004) Changes in postural control during a 48-hour sleep deprivation period. Percept Mot Skills 99(3):1035–1045. https://doi.org/10.2466/pms.99.3.1035-1045
14. Nakano T, Araki K, Michimori A, Inbe H, Hagiwara H, Koyama E (2001) Nineteen-hour variation of postural sway, alertness, and rectal temperature during sleep deprivation. Psychiatry Clin Neurosci 55(3):277–278. https://doi.org/10.1046/j.1440-1819.2001.00858.x
15. BaHammam A, Alrajeh M, Albabtain M, Bahammam S, Sharif M (2010) Circadian pattern of sleep, energy expenditure, and body temperature of young healthy men during the intermittent fasting of Ramadan. Appetite 54(3):426–429. https://doi.org/10.1016/j.appet.2010.01.011
16. Peterka RJ, Loughlin PJ (2004) Dynamic regulation of sensorimotor integration in human postural control. J Neurophysiol 91(2):410–423. https://doi.org/10.1152/jn.00516.2003
17. Winter DA, Patla AE, Frank JS (1990) Assessment of balance control in humans. Med Prog Technol 16(1–2):31–51
18. Itamar N, Schwartz D, Melzer I (2013) Postural control: differences between youth judokas and swimmers. J Sports Med Phys Fit 53(4):483–489
19. Kudō K (1967) Dynamic judo: grappling techniques, vol 2. Japan Publications, Tokyo
20. Paillard T, Montoya R, Dupui P (2007) Postural adaptations specific to preferred throwing techniques practiced by competition-level judoists. J Electromyogr Kinesiol 17(2):241–244. https://doi.org/10.1016/j.jelekin.2006.01.006
21. Paillard T, Costes-Salon C, Lafont C, Dupui P (2002) Are there differences in postural regulation according to the level of competition in judoists? Br J Sports Med 36(4):304–305. https://doi.org/10.1136/bjsm.36.4.304
22. Jaworski J, Lech G (2022) Influence of training and selection on postural stability and its relationship with sport level in judo practitioners aged 11–14 years. Front Psychol 13:1–8. https://doi.org/10.3389/fpsyg.2022.1053426
23. Aloui A, Chtourou H, Masmoudi L, Chaouachi A, Chamari K, Souissi N (2013) Effects of Ramadan fasting on male judokas' performances in specific and non-specific judo tasks. Biol Rhythm Res 44(5):645–654. https://doi.org/10.1080/09291016.2012.722454
24. Souissi N, Chtourou H, Zouita A, Dziri C, Souissi N (2013) Effects of Ramadan intermittent fasting on postural control in judo athletes. Biol Rhythm Res 44(2):237–244. https://doi.org/10.1080/09291016.2012.667980
25. Ammar A, Chtourou H, Souissi N (2017) Effect of time-of-day on biochemical markers in response to physical exercise. J Strength Cond Res 31(1):272–282. https://doi.org/10.1519/JSC.0000000000001481
26. Souissi W, Hammouda O, Ayachi M, Ammar A, Khcharem A, De Marco G, Souissi M, Driss T (2020) Partial sleep deprivation affects endurance performance and psychophysiological responses during 12-minute self-paced running exercise. Physiol Behav 227:113165. https://doi.org/10.1016/j.physbeh.2020.113165
27. Horne JA, Östberg O (1976) A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol 4(2):97–110
28. Abedelmalek S, Chtourou H, Souissi N, Tabka Z (2015) Caloric restriction effect on proinflammatory cytokines, growth hormone, and steroid hormone concentrations during exercise in judokas. Oxid Med Cell Longev 2015:1–8. https://doi.org/10.1155/2015/809492
29. Bezrati-Benayed I, Nasrallah F, Feki M, Chamari K, Omar S, Alouane-Trabelsi L, Ben Mansour A, Kaabachi N (2014) Urinary creatine at rest and after repeated sprints in athletes: a pilot study. Biol Sport 31(1):49–54. https://doi.org/10.5604/20831862.1086732
30. Romdhani M, Hammouda O, Chaabouni Y, Mahdouani K, Driss T, Chamari K, Souissi N (2019) Sleep deprivation affects post-lunch dip performances, biomarkers of muscle damage, and antioxidant status. Biol Sport 36(1):55–65. https://doi.org/10.5114/biolsport.2018.78907
31. Chtourou H, Trabelsi K, Ammar A, Shephard RJ, Bragazzi NL (2019) Acute effects of an 'energy drink' on short-term maximal performance, reaction times, psychological and physiological parameters: insights from a randomized double-blind, placebo-controlled, counterbalanced crossover trial. Nutrients 11(5):992. https://doi.org/10.3390/nu11050992
32. Pickerill ML, Harter RA (2011) Validity and reliability of limits-of-stability testing: a comparison of 2 postural stability evaluation devices. J Athl Train 46(6):600–606. https://doi.org/10.4085/1062-6050-46.6.600
33. Hebert JR, Manago MM (2017) Reliability and validity of the computerized dynamic posturography sensory organization test in people with multiple sclerosis. Int J MS Care 19(3):151–157. https://doi.org/10.7224/1537-2073.2016-027
34. Suttanon P, Hill KD, Dodd KJ, Said CM (2011) Retest reliability of balance and mobility measurements in people with mild to moderate Alzheimer's disease. Int Psychogeriatr 23(7):1152–1159. https://doi.org/10.1017/S1041610211000639
35. Souissi N, Zouita AB, Chtourou H, Ferchichi H, Dziri C, Abedelmalek S, Souissi N (2014) The effect of Ramadan intermittent fasting on dynamic postural control in judo athletes. Biol Rhythm Res 45(1):27–36. https://doi.org/10.1080/09291016.2013.787759
36. Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd edn. Lawrence Erlbaum Associates, Mahwah
37. Lakens D (2013) Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front Psychol 4:863. https://doi.org/10.3389/fpsyg.2013.00863
38. Paillard T, Bizid R, Dupui P (2007) Les manipulations sensorielles affectent-elles différemment les sujets selon leurs capacités posturales? Br J Sports Med 41:435–438. https://doi.org/10.1136/bjsm.2006.032904
39. Murray B, Rosenbloom C (2018) Fundamentals of glycogen metabolism for coaches and athletes. Nutr Rev 76(4):243–259. https://doi.org/10.1093/nutrit/nuy001
40. Wang L, Zou B (2022) The association between gait speed and sleep problems among Chinese adults aged 50 and greater. Front Neurosci 26(16):855955. https://doi.org/10.3389/fnins.2022.855955
41. Umemura GS, Pinho JP, Duysens J et al (2021) Sleep deprivation affects gait control. Sci Rep 11:21104. https://doi.org/10.1038/s41598-021-00705-9
42. El Moutawakil B, Hassounr S, Sibai M, Rafai MA, Fabrigoule C, Slassi I (2007) Impact du jeûn du Ramadan sur les fonctions attentionnelles. Biol Rhythm Res 163(1):60. https://doi.org/10.1016/S0035-3787(07)90595-0
43. Avni N, Avni I, Barenboim E, Azaria B, Zadok D, Kohen-Raz R, Morad Y (2006) Brief posturographic test as an indicator of fatigue. Psychiatry Clin Neurosci 60(3):340–346. https://doi.org/10.1111/j.1440-1819.2006.01511.x
44. Teasdale N, Simoneau M (2001) Attentional demands for postural control: the effects of aging and sensory reintegration. Gait Posture 14(3):203–210. https://doi.org/10.1016/S0966-6362(01)00134-5
45. Gribble PA, Tucker WS, White PA (2007) Time-of-day influences on static and dynamic postural control. J Athl Train 42(1):35–41
46. Mata F, Valenzuela PL, Gimenez J, Tur C, Ferreria D, Domínguez R, Sanchez-Oliver AJ, MartínezSanz JM (2019) Carbohydrate

availability and physical performance: physiological overview and practical recommendations. Nutrients 11(5):1084. https://doi.org/10.3390/nu11051084
47. Shephard RJ (2012) The impact of Ramadan observance upon athletic performance. Nutrients 4(6):491–505. https://doi.org/10.3390/nu4060491
48. Bougrine H, Salem A, Nasser N, Ammar A, Chtourou H, Souissi N (2023) Ramadan fasting and short-term maximal physical performance: searching for optimal timing of the last meal "suhoor" in female pre-university handball players. Eur J Investig Health Psychol Educ 13(10):2160–2178. https://doi.org/10.3390/ejihpe13100152
49. Bougrine H, Ammar A, Trabelsi K, Belgacem A, Salem A, Chtourou H, Souissi N (2024) The effect of last meal "suhoor" timing on diurnal variations in cognitive performance during Ramadan fasting among female athletes. Front Nutr 11:1373799
50. Waterhouse J, Atkinson G, Edwards B, Reilly T (2007) The role of a short post-lunch nap in improving cognitive, motor, and sprint performance in participants with partial sleep deprivation. J Sports Sci 25(14):1557–1566. https://doi.org/10.1080/02640410701244983
51. Chtourou H, Hammouda O, Chaouachi A, Chamari K, Souissi N (2012) The effect of time-of-day and Ramadan fasting on anaerobic performances. Int J Sports Med 33(2):142–147. https://doi.org/10.1055/s-0031-1286251

Authors and Affiliations

Nafaa Souissi[1] · Amira Zouita[2] · Salma Abedelmalek[3,4] · Achraf Ammar[5,6,7,8] · Gaith Ezzedine[7] · Khaled Trabelsi[7,9,10] · Katherine Dziri[2] · Cain C. T. Clark[11] · Nizar Souissi[1] · Karim Chamari[12,13]

✉ Achraf Ammar
acammar@uni-mainz.de

Nafaa Souissi
nafaa.souissi@isseps.usf.tn

Amira Zouita
amira_zouita@yahoo.fr

Salma Abedelmalek
s_abedelmalek@yahoo.fr

Gaith Ezzedine
ghaith.ezzedine@isseps.usf.tn

Khaled Trabelsi
trabel-sikhaled@gmail.com

Katherine Dziri
dziri_kas@yahoo.fr

Cain C. T. Clark
cain.clark@bcu.ac.uk

Nizar Souissi
n_souissi@yahoo.fr

Karim Chamari
karim.chamari66@gmail.com

1 Physical Activity Research Unit, Sport and Health (UR18JS01), National Observatory of Sports, Tunis, Tunisia

2 Research Laboratory (LR23JS01) "Sport Performance, Health & Society", ISSEP KS, University of Manouba, Biomechanics Laboratory, National Institute of Orthopedics M.T., Kassab, Tunisia

3 Laboratory of Physiology and Functional Exploration, Faculty of Medicine, Sousse, Tunisia

4 Department of Sport Science and Physical Activity, Colfoote of Education, University of Hail, Hail, Saudi Arabia

5 Department of Training and Movement Science, Institute of Sport Science, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany

6 Research Laboratory, Molecular Bases of Human Pathology, LR19ES13, Faculty of Medicine of Sfax, University of Sfax, 3029 Sfax, Tunisia

7 High Institute of Sport and Physical Education Sfax, University of Sfax, Sfax, Tunisia

8 Interdisciplinary Laboratory in Neurosciences, Physiology and Psychology: Physical Activity, Health and Learning (LINP2), UFR STAPS (Faculty of Sport Sciences), UPL, Paris Nanterre University, Nan-Terre, France

9 Research Laboratory: Education, Motricité, Sport et Santé, EM2S, LR19JS01, High Institute of Sport and Physical Education of Sfax, University of Sfax, Sfax, Tunisia

10 Department of Movement Sciences and Sports Training, School of Sport Science, The University of Jordan, Amman Amman 11942, Jordan

11 College of Life Sciences, Birmingham City University, Birmingham B15 3TN, UK

12 Naufar, Wellness and Recovery Center, Doha, Qatar

13 Higher Institute of Sport and Physical Education, ISSEP Ksar Saïd, Manouba University, Manouba, Tunisia