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Maintaining Explosive Power Through Motor Imagery Training During Ramadan Fasting

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Abstract

This randomized controlled trial investigated whether a structured motor imagery (MI) program can mitigate Ramadan fasting–related declines in explosive power in adolescent male tennis players. Twenty-seven athletes (16.8 ± 0.6 years) were randomly allocated to a control group (neutral videos; n = 14) or an MI group (MI training; n = 13). Over four weeks, the MI group completed three weekly sessions after regular tennis practice, using a two-stage sequence combining external visual imagery and internal kinesthetic imagery. Imagery ability and engagement were monitored via a Likert-scale questionnaire, and athletes completed a familiarization session before testing. Explosive performance was evaluated at four time points (pre-, beginning, mid-, and post-Ramadan) using validated measures of lower-limb power (countermovement jump) and upper-limb power (3-kg medicine ball throw). Nutritional intake, anthropometrics, and environmental conditions were controlled. Repeated-measures ANOVA revealed significant performance reductions during Ramadan in both groups ($p < 0.001$). However, the MI group showed significantly better performance than controls at mid- and post-Ramadan ($p < 0.01$; $p < 0.001$), suggesting a protective effect. Overall, Ramadan fasting transiently impaired neuromuscular performance, while integrating MI meaningfully attenuated losses in explosive power, offering a practical strategy to support performance during fasting.

Introduction

Ramadan fasting is a widespread and predictable form of intermittent fasting that many Muslim athletes must accommodate within their annual training and competition schedules (Chaouachi et al., 2009; Karasneh et al ., 2022). During this month, practicing Muslims refrain from eating and drinking from sunrise to sunset for 29 or 30 consecutive days (Brisswalter & al., 2010; Maughan, 2010). Depending on geographical location and season, daily fasting duration can extend up to 19 hours in temperate or hot climates, particularly during midsummer. This prolonged abstinence from food and fluid intake induces considerable physiological and psychological stress, including alterations in energy metabolism, circadian rhythms, sleep patterns, and hydration status (Maughan, 2010; Brisswalter et al., 2011). Such changes may, in turn, influence both physical and cognitive performance, posing particular challenges for athletes who must sustain high levels of training, skill execution, and recovery during Ramadan (Authors 2025; Chaouachi et al., 2009; Bouhlel et al., 2013; Memari et al., 2011).

Fasting during Ramadan triggers a complex interplay of metabolic, endocrine, and behavioral adaptations (Makdour et al., 2023; 2025). Reduced caloric intake, altered meal timing, and shifts in macronutrient distribution can affect glycogen stores, blood glucose levels, and lipid metabolism, potentially compromising energy availability for training and competition (Authors 2025; Chaouachi et al., 2009). Concurrently, disruption of sleep patterns—often linked to late-night meals (Iftar), pre-dawn meals (Suhur), and early awakenings—may exacerbate fatigue and impair neuromuscular performance, reaction time, and concentration (Bouhlel et al., 2013; Memari et al., 2011). In addition, hypohydration resulting from prolonged daytime fluid restriction, especially in hot or dry environments, further impairs thermoregulation, muscle contractility, and overall physical capacity (Memari et al., 2011). Collectively,

these factors may lead to increased fatigue, decreased neuromuscular coordination, slower reaction times, and reduced power output, making it difficult for athletes engaged in high-intensity, intermittent sports to maintain optimal performance throughout the fasting month (Ghaffar et al., 2025).

A growing body of research has documented the negative effects of Ramadan fasting on high-intensity physical performance (Abaidia et al., 2020). Athletes in intermittent sports frequently exhibit reductions in sprint capacity, vertical jump height, and upper-limb power during Ramadan, changes that are likely associated with decreased training load, sleep deprivation, and compromised hydration status (Authors 2025; Chaouachi et al., 2009; Aziz et al., 2017; Bouhlel et al., 2013; Ozbay et al., 2024). Subtle declines in neuromuscular coordination and central nervous system excitability have also been reported and may further impair the execution of complex motor skills (Memari et al., 2011). These findings suggest that athletes whose performance relies heavily on short, maximal efforts and rapid neuromuscular activation are particularly vulnerable to fasting-related performance decrements. Thus, identifying strategies that can help maintain explosive power and skill execution during Ramadan represents a practical and scientific priority.

Tennis is a high-intensity, intermittent sport characterized by repeated bursts of explosive activity interspersed with brief recovery periods (Fernandez et al., 2006; Meckel et al., 2008; Morais et al., 2014). Successful performance in tennis depends on the integration of lower-limb power for sprints, rapid changes of direction, and jumps, as well as upper-limb power for serves, forehands, and backhands, all supported by high levels of agility, speed, and both aerobic and anaerobic conditioning (Abaidia et al., 2020; Fernandez et al., 2021; Guo et al., 2024; Kolman et al., 2018). Precise neuromuscular coordination and fine motor control are also essential for stroke accuracy and tactical execution under time pressure. Given these demands, even modest reductions in explosive strength, reaction time, or neuromuscular coordination may compromise match outcomes and elevate injury risk (Lui et al., 2025). The documented impact of Ramadan fasting on sprinting, jumping, and upper-limb power (Authors 2025; Chaouachi et al., 2009; Bouhlel et al., 2013; Memari et al., 2011). suggests that tennis performance may be particularly susceptible to fasting-induced perturbations, making it a relevant model for investigating mitigation strategies (Bougrine et al., 2023; Authors 2020).

Motor imagery (MI), defined as the mental rehearsal of motor actions without overt physical execution, has emerged as a promising neurocognitive tool to enhance athletic performance (Eaves et al., 2022; Grosprêtre, 2024; Moran et al., 2012; Prasomsri et al., 2024). Neuroimaging and electrophysiological studies indicate that MI activates cortical and subcortical regions that overlap with those involved in actual movement, including the primary motor cortex, supplementary motor area, cerebellum, and basal ganglia (Ebben et al., 2002; Hardwick et al., 2018; Guillot et al., 2009; Loze et al., 2006). Through repeated mental simulation of specific movements, MI can strengthen neural pathways associated with motor planning and execution, improve proprioceptive awareness, and potentiate neuromuscular coordination (Mulder, 2007; Ruffino et al.,2017; Ebedden et al., 2002). In athletic populations, MI has been shown to improve vertical jump performance, sprinting ability, and upper-limb explosive strength, even in the absence of concurrent physical practice (Fekih, 2020; Guillot et al., 2015). These characteristics make MI

particularly attractive in situations where the capacity to perform high-intensity physical training is constrained (Gippert et al., 2025; Prasomsri et al., 2024; McNeil et al., 2024).

During Ramadan, coaches often reduce training volume or intensity to manage fatigue, altered recovery, and hydration issues (Belamjahad et al., 2025). In this context, MI offers a low-fatigue, non-invasive, and easily implementable adjunct to physical training that may help maintain neuromuscular activation and performance-related motor patterns. Through neurocognitive stimulation of motor pathways and task-specific strategies, MI could partially compensate for decreased physical training loads and attenuate fasting-induced reductions in explosive power (Authors2020).

Despite the accumulating evidence supporting MI in sports performance enhancement (Bonin et al., 2025; Robin et al., 2007), its application in the specific context of Ramadan fasting remains largely unexplored, particularly in adolescent athletes. Adolescence is a critical period for neuromuscular and physiological development, characterized by growth-related changes in body composition, motor control, strength, and coordination (Williams et al., 2021). At the same time, adolescents may be especially sensitive to energy restriction, altered sleep–wake cycles, and other stressors associated with fasting (bakhsh et al., 2024). These factors may not only increase susceptibility to performance decrements during Ramadan but also influence responsiveness to MI-based interventions. To date, however, there is a notable lack of randomized controlled trials evaluating whether MI can preserve explosive lower- and upper-limb performance during Ramadan in adolescent athletes.

Given its reliance on frequent high-intensity efforts and both upper- and lower-limb explosive power, tennis represents an appropriate model for examining the compensatory potential of MI under fasting conditions. Preserving these physical qualities during Ramadan is crucial not only for sustaining competitive performance but also for reducing injury risk, as neuromuscular fatigue and impaired coordination are recognized contributors to musculoskeletal injuries (Abaidia et al., 2020; Fernandez et al., 2012; Meckel et al., 2008). Investigating MI in adolescent tennis players during Ramadan may therefore yield insights of both scientific and applied relevance.

Accordingly, the present study aims to determine whether a structured motor imagery-based training program can preserve lower- and upper-limb explosive power in adolescent tennis players during Ramadan fasting. Two primary hypotheses guide this investigation. First, it is hypothesized that fasting during Ramadan will negatively affect the explosive power of both lower and upper limbs in adolescent tennis players, reflecting the cumulative impact of energy restriction, sleep disruption, and hypohydration. Second, it is hypothesized that integrating a motor imagery-based training program into the regular training regimen will attenuate or prevent this decline, providing a practical, evidence-based strategy for maintaining performance under fasting conditions.

Material and Methods

Study Design

The present study was designed as a randomized controlled trial to investigate the efficacy of a structured motor imagery (MI) program in mitigating the negative effects of Ramadan fasting on the explosive power of upper and lower limbs in adolescent tennis players. The study adhered to CONSORT 2010 guidelines to ensure methodological rigor, transparency, and reproducibility. An a priori power analysis was conducted using G*Power 3.1 software to determine the required sample size (Faul et al., 2007). Based on a repeated-measures ANOVA with two groups and three measurement points, assuming a medium effect size (f = 0.25), alpha of 0.05, and desired power of 0.80, a minimum of 24 participants was required. To account for potential attrition, 27 participants were recruited. Ethical approval was obtained from the Ethical Committee for the Protection of People of the South (C.P.SUD), Sfax, Tunisia (Protocol Reference: N_0057/2023), and written informed consent was secured from all participants and their legal guardians in accordance with the Declaration of Helsinki.

Participants

Twenty-seven adolescent tennis players (mean age: 16.8 ± 0.6 years) were recruited from a regional tennis club. Participants engaged in structured tennis training for at least six hours per week, typically in three two-hour sessions. Inclusion criteria required a minimum of two years of continuous tennis experience, regular weekly engagement in structured training, and willingness to observe fasting during Ramadan. Participants were excluded if they had recent musculoskeletal injuries, chronic medical conditions, or were using medications or supplements that could influence performance. Randomization was performed using a computer-generated sequence with block randomization and stratification for age, training experience, and baseline performance. Allocation concealment was ensured via sequentially numbered, opaque, sealed envelopes prepared by an independent researcher. Participants were allocated to a control group (Cont-G, n = 14) or an experimental group receiving MI training (EXP-G, n = 13). Baseline characteristics, including age, years of training, height, body mass, and BMI, did not differ significantly between groups, confirming homogeneity (Table 1).

Table 1
Descriptive statistics of the recruited sample.

Variables	**Control Group**	**Imagery Training Group**	***P***
	Mean (SD)	**Mean (SD)**	
Age (years)	16.7 ± 0.59	16.9 ± 0.64	0.41
Number of years of training	5.7 ± 1.18	5.4 ± 1.2	0.48
Height (m)	1.74 ± 0.06	1.75 ± 0.04	0.70
Body mass (kg)	66.12 ± 6.83	67.5 ± 2.96	0.50
BMI (kg/m2)	21.73 ± 0.87	22.02 ± 0.58	0.31

Note. SD = standard deviation; BMI = body mass index.

Procedure and Motor Imagery Intervention

All participants, regardless of group allocation, followed a standardized physical and technical tennis training program throughout the four-week study period. Training sessions were conducted under the supervision of the same qualified coach to ensure consistency in intensity, volume, and technical content across all participants. Each training session lasted approximately two hours and included a combination of physical conditioning, technical drills, and tactical exercises, designed to replicate the demands of competitive tennis and align with established guidelines for adolescent athlete development (Dirienzo et al., 2015; Authors 2020).

Motor Imagery Training Protocol

The experimental group (EXP-G) engaged in a structured motor imagery (MI) training program in addition to the regular training protocol. Based on previously validated procedures (Feki et al., 2020), MI sessions were implemented three times per week for a total of four weeks, with each session lasting 15 minutes immediately following the physical/technical training. This timing was selected to optimize mental rehearsal when neuromuscular activation patterns were most recently engaged, facilitating the consolidation of sensorimotor memory (Dirienzo et al., 2015; Authors 2020).

The MI program employed a two-stage, sequential approach integrating both external and internal imagery modalities, in accordance with cognitive motor imagery frameworks (Dirienzo et al., 2015).

Stage 1 – External Visual Imagery

Participants were instructed to observe short video clips of expert tennis players performing technically correct movements, including fast lateral movements, powerful groundstrokes, and high-velocity serves. Using an external visual perspective, players imagined themselves as if watching their own performance on a video screen, mentally rehearsing movement patterns with emphasis on timing, trajectory, and velocity. Participants were encouraged to replicate match-like scenarios, anticipating ball placement, footwork adjustments, and stroke execution in the first-person perspective.

Stage 2 – Internal Kinesthetic Imagery

Following external visualization, participants engaged in internal, first-person kinesthetic imagery. During this stage, they were instructed to mentally simulate the proprioceptive and somatosensory sensations associated with each movement, such as muscle contraction, joint angle adjustments, and force application. The focus was placed on replicating the neuromuscular and tactile experience of match-specific actions, including explosive leg extension for jumps, rotational core engagement for strokes, and coordinated upper-limb movements for ball propulsion. This two-stage approach is consistent with evidence demonstrating that combined visual-kinesthetic MI enhances both cortical activation and peripheral motor unit recruitment, thereby improving neuromuscular performance (Feltz et al., 1983; Holmes et al., 2008; Trabelsi et al., 2022; Waterhouse et al., 2010).

All MI sessions were conducted in a quiet environment, with minimal distractions, and were closely monitored by the research team to ensure adherence, concentration, and correct execution of imagery instructions. Participants reported their subjective imagery vividness and perceived effort after each session using a standardized Likert scale (1–7), ensuring engagement and quality control, as recommended in contemporary MI research protocols (Dirienzo et al., 2015; Guillot et al., 2015).

Performance Measures

Physical performance assessments focused on the explosive power of the lower and upper limbs and were conducted at three time points: before Ramadan (baseline), during the mid-point of the fasting period, and at the end of the four-week intervention.

Lower-Limb Explosive Power

The counter-movement jump (CMJ) test was used to evaluate lower-limb power. Participants performed three maximal vertical jumps on a Takei Kiki Kogyo (TKK) Abalakov vertical jump meter, with two minutes of rest between trials to minimize fatigue effects. The highest jump height among the three attempts was recorded for statistical analysis. This standardized protocol is widely recognized for its reliability and sensitivity to detect changes in lower-limb explosive performance (Cohen, 2013; Guillot et al., 2015; Stockbrugger et al., 2001).

Upper-Limb Explosive Power

Upper-limb explosive power was assessed using a 3-kg medicine ball throw, inspired by Stockbrugger et al.,'s methodology (2001). Participants executed a movement pattern simulating a vertical jump combined with a forward ballistic throw, emphasizing maximal distance and velocity. Each participant performed three trials, with the greatest throw distance retained for analysis. Standardized instructions, warm-up routines, and consistent environmental conditions were maintained to ensure reproducibility.

Nutritional and Control Measures

To control for potential confounding effects of dietary intake, all participants completed a 3-day food consumption diary at baseline and at the end of Ramadan. Nutritional data were analyzed by a registered nutritionist using the Tunisian food composition tables, assessing total caloric intake and macronutrient distribution (carbohydrates, proteins, fats). This procedure ensured that any observed performance changes could be attributed to fasting and/or MI intervention rather than differences in energy availability (Battaglia et al., 2014; Stockbrugger et al., 2001).

Environmental and temporal factors were standardized across testing sessions. All measurements were conducted in the same indoor tennis facility under similar lighting and temperature conditions, and

participants were tested at consistent times of day to minimize circadian variability in neuromuscular performance. Participants were instructed to avoid vigorous physical activity or caffeine consumption 24 hours prior to testing.

Data Quality and Reliability

All testing procedures were conducted by trained assessors blinded to group allocation to minimize observer bias. Equipment was calibrated prior to each session, and standardized verbal encouragement was provided across trials to ensure maximal effort without differential influence on performance outcomes. The reliability of CMJ and medicine ball throw measures has been validated in adolescent athletic populations, with intra-class correlation coefficients exceeding 0.90 (Cohen, 2013; Guillot et al., 2015).

This comprehensive protocol, integrating standardized physical training, structured motor imagery, controlled dietary monitoring, and robust performance assessments, ensures methodological rigor, reproducibility, and validity of the findings. It allows for precise evaluation of the effectiveness of MI training in mitigating the negative impact of Ramadan fasting on adolescent tennis players' explosive power.

Statistical Analysis

All data were analyzed using STATISTICA 10.0 software (StatSoft, Maisons-Alfort, France). Descriptive statistics, including mean ± standard deviation (SD), were computed for all variables. Normality of distributions was tested using the Shapiro–Wilk test, and assumptions of sphericity were verified before performing inferential statistics.

A repeated-measures analysis of variance (ANOVA) was conducted to examine the effects of Ramadan fasting (before, beginning, middle, end) and motor imagery intervention (with or without) on both lower- and upper-limb explosive power. When significant interactions or main effects were observed, post hoc pairwise comparisons were performed using Student's t-tests with Bonferroni correction to adjust for multiple comparisons. Effect sizes were calculated using partial eta-squared (ηp^2), with values of 0.01, 0.06, and 0.13 representing small, moderate, and large effects, respectively (Cohen, 2013). Statistical significance was set at $p < 0.05$ for all analyses.

Results

Nutritional Intake

Analysis of dietary intake revealed no significant changes in total caloric intake or macronutrient composition between baseline (pre-Ramadan) and the end of Ramadan (Table 2). Daily caloric intake remained consistent (pre-Ramadan: 2956 ± 133 kcal/day; end of Ramadan: 2947 ± 154 kcal/day), as did the proportion of carbohydrates (52.3 ± 5.1% vs. 52.1 ± 4.6%), lipids (31.2 ± 3.9% vs. 30.5 ± 4.1%), and

proteins (18.7 ± 2.8% vs. 19.2 ± 2.2%). These findings indicate that the observed changes in physical performance were not confounded by variations in energy or macronutrient intake (Table 2).

Table 2

Averages (± SD) of daily calorie intake and percentages of carbohydrates, fats and proteinsrecorded before and during the month of Ramadan.

Variables	Before Ramadan	End of Ramadan
	Mean (SD)	**Mean (SD)**
Calorie intake (kcal/day)	2956 ± 133.4	2947 ± 154.3
Carbohydrate (%)	52.3 ± 5.1	52.1 ± 4.6
Lipids (%)	31.2 ± 3.9	30.5 ± 4.1
Protein (%)	18.7 ± 2.8	19.2 ± 2.2

Note. SD = standard deviation.

Anthropometric and Body Composition Changes

Repeated-measures ANOVA revealed significant main effects of time on body mass ($F(3,108) = 28.59$, $p < 0.001$, $\eta p^2 = 0.443$) and BMI ($F(3,108) = 25.70$, $p < 0.001$, $\eta p^2 = 0.416$) in both groups. Post hoc analysis indicated significant reductions in body mass and BMI at the middle and end of Ramadan compared to pre-Ramadan values in both groups ($p < 0.001$). Specifically, the experimental group showed a decrease in body mass from 67.52 ± 2.96 kg at baseline to 66.45 ± 2.87 kg at the end of Ramadan, and in BMI from 22.02 ± 0.58 to 21.68 ± 0.57. The control group exhibited similar trends (Table 3). These findings are consistent with prior studies demonstrating hypohydration and potential lean mass reduction during prolonged fasting periods (Aloui et al., 2013; Stockbrugger et al., 2001) (Table 3).

Table 3. *Averages (±SD) of body mass and body mass index (BMI) recorded before and during Ramadan.*

Parameters	Groups	Before Ramadan	Beginning of Ramadan	Middle of Ramadan	End of Ramadan
		Mean (SD)			
Body mass (kg)	Experimental group	67.52 ± 2.96	67.16±2.85	66.82 ± 2.83 *	66.45 ± 2.87 *
	Control group	66.12±6.83	65.67 ± 6.88	65.35 ± 6.86 *	64.94 ± 6.89 *
BMI (kg/m2)	Experimental group	22.02 ± 0.58	21.91 ± 0.59	21.80 ± 0.57 *	21.68 ± 0.57 *
	Control group	21.73 ± 0.87	21.58 ± 0.94	21.47 ± 0.93 *	21.33 ± 0.94 *

Note. SD = standard deviation; BMI = Body mass index; * Significantly different from before Ramadan at $p < 0.001$.

Lower-Limb Explosive Power

Vertical jump performance, assessed via CMJ, demonstrated a significant interaction between Ramadan period and motor imagery intervention ($F(3,108) = 24.94$, $p < 0.001$, $\eta p^2 = 0.409$). Both groups exhibited a decline in jump height at the beginning, middle, and end of Ramadan compared to baseline ($p < 0.001$). However, participants in the EXP-G consistently outperformed the control group, with statistically significant differences observed at the end of Ramadan. This suggests that motor imagery mitigated, but did not entirely prevent, the decline in lower-limb explosive power associated with fasting.

Upper-Limb Explosive Power

Medicine ball throw distance revealed a significant Ramadan period × motor imagery interaction ($F(3,108) = 33.62$, $p < 0.001$, $\eta p^2 = 0.483$). Both groups showed reduced throwing distances during Ramadan relative to pre-Ramadan measures ($p < 0.001$). Notably, the experimental group maintained higher performance levels than the control group at both the mid-point ($p < 0.01$) and end of Ramadan ($p < 0.001$). These results indicate that motor imagery training had a protective effect on upper-limb explosive power, consistent with literature demonstrating enhanced neuromuscular recruitment and cortical activation following imagery-based interventions (33–36).

Discussion

The present study investigated the effects of a motor imagery-based training program on the explosive power of the lower and upper limbs in adolescent tennis players during the month of Ramadan. Our findings demonstrate that fasting during Ramadan negatively affected explosive performance in both

limbs, confirming the first hypothesis. Notably, the experimental group engaging in motor imagery training exhibited a significantly attenuated decline in performance, suggesting that mental imagery may serve as a practical intervention to mitigate the adverse effects of fasting on neuromuscular performance. This discussion contextualizes these findings within the current literature, explores potential underlying mechanisms, and highlights the practical implications for coaches and athletes.

Effects of Fasting During Ramadan

Our results indicate a significant decrease in lower-limb explosive power, as assessed via the counter-movement jump (CMJ), and in upper-limb explosive power, as measured by the medicine ball throw, in the control group throughout Ramadan. These findings are consistent with previous studies. Bouhlel et al. (2013) reported reductions in maximal upper- and lower-limb power in physical education students during the first and fourth weeks of Ramadan, suggesting that even short-term fasting can impact neuromuscular performance. Similarly, Meckel et al. (2008) observed a decline in CMJ height in young football players toward the end of Ramadan, while Aloui et al. (2013) documented decreases in jump height during the fasting period, highlighting the sensitivity of explosive power to nutritional and temporal constraints.

Interestingly, our dietary analyses revealed no significant changes in caloric intake or macronutrient composition (carbohydrates, lipids, proteins) before and during Ramadan, aligning with previous research (Aloui et al., 2013a; Authors 2020). Therefore, the observed decline in explosive performance is unlikely to be explained solely by changes in energy intake. Rather, multiple physiological and behavioral factors may interact to reduce performance during fasting.

One potential contributor is hypohydration, a well-documented consequence of prolonged fasting without fluid intake (Aloui et al., 2013b). Fluid restriction can impair thermoregulation, reduce plasma volume, and limit muscle contractility, thereby diminishing power output in both upper and lower limbs. Additionally, reductions in body mass observed in both groups during Ramadan suggest a combination of fluid loss and possible muscle catabolism, which may directly affect the capacity for force generation. These findings are in agreement with Fekih et al. (2020), who also reported decreases in body mass during Ramadan, potentially linked to both fluid depletion and transient reductions in muscle mass.

Sleep disruption may further exacerbate the decline in explosive performance. During Ramadan, alterations in meal timing, such as late-night Suhur meals and early morning awakenings, can interfere with normal circadian rhythms and reduce total sleep duration (Trabelsi et al., 2020; 2021; Waterhouse, 2010). Sleep loss has been shown to impair neuromuscular function, reaction time, and psychomotor performance, which may partially explain the reductions observed in both CMJ height and medicine ball throw distance. Fatigue induced by sleep disturbances may also reduce motivation and central nervous system drive, contributing to the observed declines.

Moreover, hormonal changes during fasting may influence physical performance. Previous research has highlighted alterations in cortisol, testosterone, and insulin-like growth factor-1 (IGF-1) levels during

Ramadan, which can affect muscle protein synthesis, energy metabolism, and recovery processes (Bouhlel et al., 2013; Chaouachi et al., 2009). These endocrine adaptations, combined with reductions in glycogen availability due to restricted meal timing, likely contribute to the decreased explosive power observed in our study. Collectively, these findings underscore the multifactorial nature of performance decrements during fasting, implicating hydration, sleep, endocrine function, and neuromuscular integrity as key determinants.

Effects of Motor Imagery Training

The present study provides novel evidence that incorporating motor imagery (MI) training into the regular training routine can attenuate the decline in explosive power during Ramadan. The experimental group, which engaged in structured MI sessions three times per week, demonstrated significantly higher CMJ and medicine ball throw values at the middle and end of Ramadan compared to the control group. These findings support the second hypothesis and align with prior research demonstrating that MI can enhance strength and power performance (Authors 2020). Motor imagery is known to activate neural networks overlapping with those involved in actual movement execution, including the primary motor cortex, supplementary motor area, cerebellum, and basal ganglia (Feltz et al., 1983; Holmes et al., 2008). Repeated mental rehearsal strengthens motor planning circuits and enhances neuromuscular coordination without the fatigue associated with physical training. This is particularly advantageous during periods when high-intensity training is constrained, such as fasting. The observed maintenance of explosive power in the experimental group suggests that MI can compensate for reductions in physical load, maintaining neuromuscular efficiency and movement pattern optimization.

Furthermore, MI may exert beneficial effects on muscle activation and recruitment. Slimani et al. (2016) demonstrated that motor imagery can increase electromyographic activity in both proximal and distal muscles, leading to enhanced force production. In our study, the experimental group maintained superior CMJ heights and medicine ball throw distances, suggesting that MI preserved or enhanced motor unit recruitment during Ramadan. Players may have maintained the sensorimotor integration necessary for explosive movements by simulating real-match situations through both external (visual) and internal (kinesthetic) imagery, thereby stabilizing performance despite fasting-related stressors.

Beyond neuromuscular mechanisms, MI may influence psychological factors, including motivation, confidence, and focus, which are critical determinants of performance in intermittent sports like tennis (Feltz et al., 1983, Sariati et al., 2021). Mental rehearsal can enhance self-efficacy, reduce anxiety, and improve readiness to perform under fatigue or caloric restriction, contributing to the superior outcomes observed in the experimental group. Therefore, MI appears to confer both physiological and cognitive advantages that collectively mitigate the negative impact of Ramadan fasting on explosive power.

Practical Implications

The findings of this study have several practical implications for coaches, sports scientists, and athletes, particularly in intermittent sports demanding high levels of explosive power. First, the results suggest that traditional physical training alone may not be sufficient to maintain peak performance during fasting

periods. Incorporating MI into training schedules offers a low-cost, low-fatigue, and easily implementable intervention capable of preserving neuromuscular performance. Coaches can structure MI sessions using video demonstrations, external visualization, and kinesthetic imagery, aligning mental rehearsal with the specific technical and tactical demands of the sport.

Second, MI can serve as a strategic tool to maintain both lower- and upper-limb explosive power, essential for tennis performance. Preserving these capacities during Ramadan may reduce the risk of injury associated with neuromuscular fatigue and impaired coordination. Additionally, MI training can be applied in other intermittent sports such as football, basketball, and volleyball, where high-intensity efforts are critical and fasting may compromise performance.

Finally, the study highlights the importance of considering multifactorial influences on performance during Ramadan. While MI mitigates some declines, optimizing hydration, sleep hygiene, and nutrient timing remains essential. Integrating MI with these complementary strategies could provide a holistic approach to sustaining performance during periods of intermittent fasting.

Limitations and Future Directions

Despite its strengths, this study has several limitations. First, sleep patterns were not objectively measured, precluding detailed analyses of sleep duration or quality, which may moderate the effects of fasting on performance. Second, performance testing occurred in the afternoon, whereas most competitions occur in the morning; time-of-day effects may have influenced results. Third, the sample comprised exclusively adolescent tennis players, limiting the generalizability of findings to adult athletes or players from other sports. Future studies should investigate MI efficacy across different age groups, competitive levels, and sports disciplines.

Additionally, while the study controlled for caloric intake and macronutrient composition, other factors such as hydration status, hormonal fluctuations, and psychological stress were not directly measured and may have contributed to performance variability. Future research could employ more comprehensive physiological monitoring, including electromyography, heart rate variability, and endocrine profiling, to elucidate the mechanisms underlying MI-mediated performance maintenance. Longitudinal studies examining the cumulative effects of repeated MI interventions across multiple fasting periods would further strengthen the evidence base.

Conclusion

This study represents a pioneering investigation into the use of motor imagery training to mitigate fasting-induced declines in lower- and upper-limb explosive power in adolescent tennis players. Our results demonstrate that Ramadan fasting negatively affects physical performance, likely through a combination of hypohydration, altered sleep, and neuromuscular fatigue. Importantly, structured MI training significantly attenuated these declines, preserving both vertical jump and medicine ball throw performance. These findings underscore the value of integrating MI into training regimens during fasting

periods, offering coaches and athletes a scientifically supported strategy to maintain performance, enhance neuromuscular function, and optimize competitive readiness.

In conclusion, motor imagery training constitutes a viable, practical, and effective intervention for sustaining explosive power during Ramadan and potentially other periods of reduced training load. We recommend that coaches of intermittent sports incorporate MI protocols alongside conventional training, emphasizing both external and internal imagery techniques. Further research is warranted to explore the neurophysiological, hormonal, and psychological mechanisms underpinning MI effects, and to extend these findings to diverse athletic populations and competitive contexts.

Declarations

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Competing interests

The authors declare that they have no competing interests.

Authors contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by HM, BZ and AK. The first draft of the manuscript was written by HM and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data :

Data supporting the findings of this study can be requested from the corresponding author upon reasonable justification. The data are not publicly available due to privacy concerns related to the inclusion of sensitive personal information.

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Figures

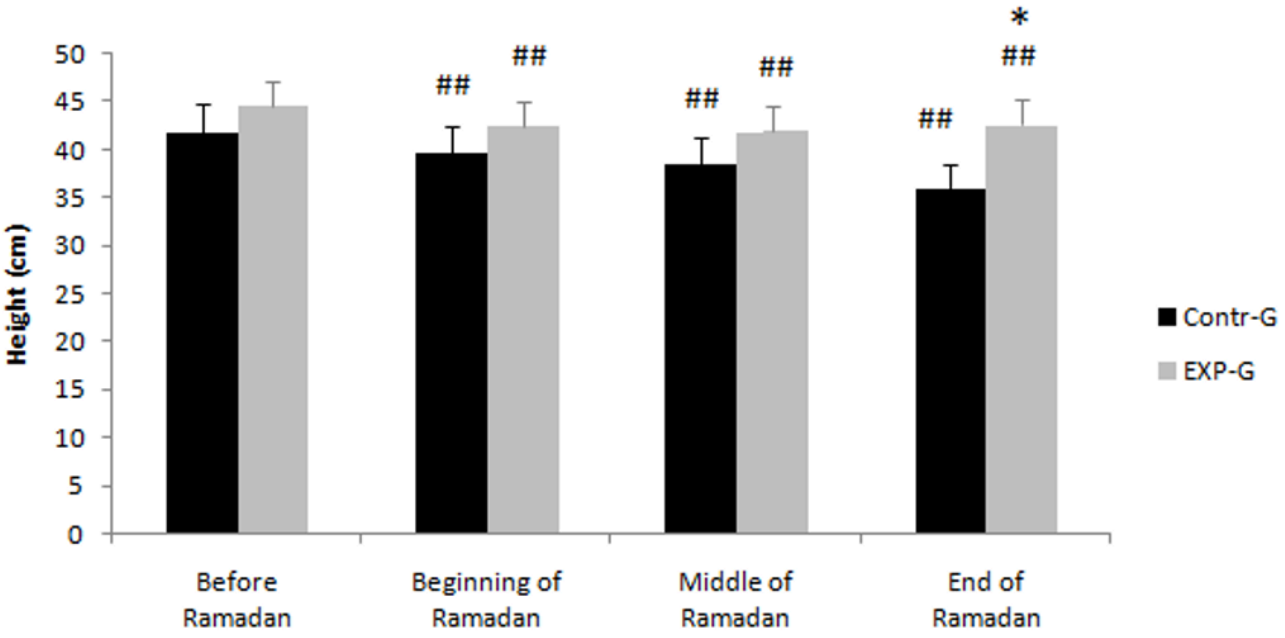


Figure 1

*Means and standard deviations of the vertical jump test scores, before, at the beginning, in the middle, and at the end of Ramadan for the two groups (control group, versus experimental group). Contr-G : control group, Exp-G : experimental group. ##: Significantly different from before Ramadan at p < 0.001. *: Significantly different from the control group at p < 0.01.*

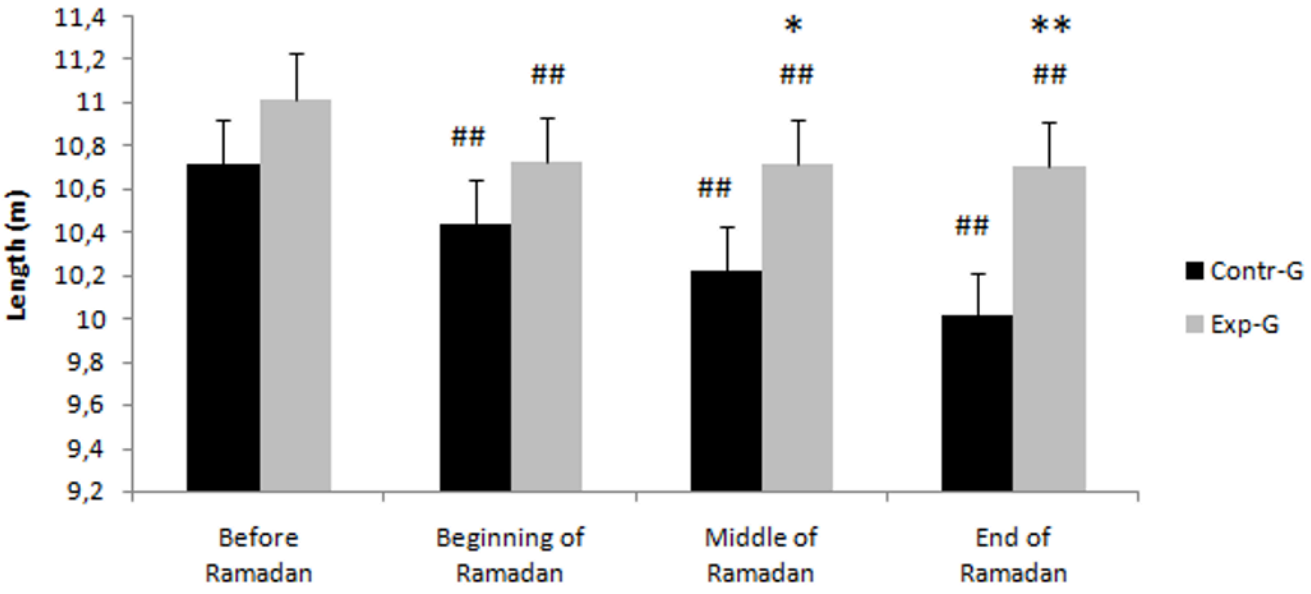


Figure 2

*Means and standard deviations of the medicine ball throwing test scores, before, at the beginning, in the middle, and at the end of Ramadan for the two groups (control group, versus experimental group). Contr-G : control group, Exp-G : experimental group. ##: Significantly different from before Ramadan at p < 0.001; *, **:Significantly different from the control group at p < 0.01 and p < 0.001, respectively.*