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# Effect of melatonin ingestion on physical performance, metabolic responses, and recovery after an intermittent training session

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*Objectives:* Fatigue is a limiting factor for sport performance. For this reason, optimal recovery after training is just as critical as the training program itself, if not more. Indeed, there is a need for strategies that can facilitate recovery after training, and one such strategy is the ingestion of supplements like melatonin (MEL). This study aimed to evaluate if MEL intake could improve recovery of athletes after an intermittent training session (ITS). *Methods:* Fifteen elite female athletes (17.4 ± 0.4 years, 76.4 ± 5.6 kg, 1.76 ± 0.04 m; mean ± standard deviation) participated in two testing campaigns. During each period, they performed a battery of physical and cognitive tests before and after an ITS, as well as after ingesting MEL (6 mg tablet) or placebo in a randomized design. The ITS comprised the modified agility T-test, squat jump, counter movement jump, maximum standing ball-throw velocity test, maximum jump ball-throw velocity test, and 20-m sprint. Oral temperature (OT) and vigilance were evaluated before and after the ITS. Rating of perceived exertion (RPE), blood lactate [La], and glucose [Gl] were recorded after each ITS. *Results:* Short-term performance, recovery of physical performance, and OT were not affected by MEL ingestion after the ITS. Moreover, MEL did not affect cognitive performance or RPE scores after the ITS. However, [La] and [Gl] ($p < 0.05$ for both) were decreased after MEL ingestion. *Conclusion:* MEL has no effect on the recovery of physical performance but may affect glucose utilization and lactate metabolism during the team-handball training session.

**Keywords:** melatonin, recovery, physical performance, lactate, training

## Introduction

Playing handball requires multiple intermittent high-intensity activities during competitions and training sessions (35). This includes a combination of high aerobic and anaerobic capacities and leads to temporary and end-match neuromuscular fatigue (35). Indeed, muscle fatigue is a limiting factor for athletic performance (43) and is associated with increased injury rates (15). Thereby, recovery strategies during periods of intense training or consecutive competitions are

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required in order to (1) relieve athletes' fatigue after exertion, (2) recover performance more quickly, and (3) reduce the risks of injury. In this regard, several studies have reported that optimized nutrition, particularly with an increased dietary content of nutritional antioxidants, may reduce fatigue (32), oxidative stress (13), and muscle damage (13).

Recent findings have highlighted the potential role of melatonin (N-acetyl-5-methoxytryptamine; MEL) as a hormone that enhances the athletes' tolerance to increased training and competition frequencies (16). MEL is a pineal gland hormone classically known to entrain the biological rhythms of mammals (39). Its synthesis and secretion are triggered by the light–dark transition and inhibited during daytime by the light, which acts both as masking and entraining stimuli (33, 39).

According to the literature, even a single dose of MEL ingested just before the exercise prevents inflammation, oxidative stress, and muscle damage (27, 28). This indole has also displayed beneficial effects on tissue repair and skeletal muscle healing (40). MEL has a protective effect on muscle and hepatic glycogen stores by inhibiting their depletion (23, 31, 37) and also it improves lipid metabolism (28). Furthermore, exogenous MEL ingestion has improved short-term and aerobic performances (8, 12). From these observations, MEL seems a potential reasonable ergogenic aid with a considerable protective effect from muscle fatigue after intense exercise.

Thus, the aim of this study was to elucidate the effect of acute MEL ingestion on recovery and specific performance of handball players.

## Materials and Methods

*Participants*

Fifteen young elite female athletes [age: $17.4 \pm 0.4$ years, body mass: $76.4 \pm 5.6$ kg, body height: $176.0 \pm 4.2$ cm; mean $\pm$ standard deviation (SD)], members of the Tunisian team-handball national team, volunteered to participate in this study. All participants reported to be non-smokers, healthy, and without any significant previous medical history. They confirmed that they (1) were not taking any medicine or supplementation, (2) were non-shift-workers, and (3) had not done any transmeridian trips during the past month before the experiment. Indeed, transmeridian trips can impede sport physical performance, because jet lag symptoms peak upon arrival and can still be detected up to 6 days (24).

Furthermore, after being thoroughly informed of the possible risks and discomforts associated with the experimental procedures, the participants and tutors for minors signed a written informed consent to take part in the experiment. The experimental design of this study was approved by the local institutional review board and performed in accordance with the bioethical rules of the Declaration of Helsinki.

*Experimental design*

All the involved athletes were participating in an 8-day training camp for the preparation of the Africa Nations Championship 2015. During the experimental period, average ambient temperature ranged from 30 to 34 °C, humidity from 48% to 56%, sunrise and sunset timing at ~5:00 a.m. and at ~7:36 p.m., respectively. Climatic data were provided by the National Institute of Meteorology. During the training camp, participants were trained twice a day (i.e., morning sessions started at 9:00 a.m. and the afternoon sessions at 4:00 p.m.). In the morning of the fifth day, they participated in a tactical technical training session. Then, in the

afternoon, they performed a battery of physical and cognitive tests after ingesting 6 mg of quick release vegetable MEL (Jamieson Laboratories Toronto, Montreal, Canada) or placebo (PLA) (i.e., composition of lactose, starch, and cellulose) in a double-blind randomized design. MEL or PLA tablets were taken between 4:00 and 4:30 p.m. (i.e., to respect a latency of 30 min between supplement administration and performance measurement for all participants). The MEL dose was determined according to the dosing preference of Arendt and Deacon (2) and previous related studies (16). After ~30 min of ingestion, resting oral temperature (OT) and vigilance test (VT) were measured. Thereafter, the participants made their usual team's warm-up, consisting of patterned collective movements along the entire court without opposition during 10 min, followed by 10 min of dynamic stretching (44).

About 1 h after ingestion, a testing battery was performed in the following order: modified agility T-test (MAT), squat jump (SJ), counter movement jump (CMJ), maximum standing ball-throw velocity test (MSBVT), maximum jump ball-throw velocity test (MJBVT), and 20-m sprint (20m-Sp). A passive recovery of a minimum of 90 s separated the repetitions of each physical test. All players had already been familiar with the testing procedure as it was part of their normal fitness-assessment program.

After this first testing battery, the participants performed an intermittent training session (ITS). This session started ~90 min after MEL ingestion and consisted of a physical training based on technical tasks composed of three bouts of $12 \times 15$ s of high-intensity runs interspersed by a 15-s passive recovery period. Consecutive bouts were interspersed by 150 s of passive recovery. During ITS, every three players had to cover the required distance by passing ball between them (crisscross drill). The required distance during 15 s was determined in order to incite the players to run at an intensity between 95% and 100% of their maximum aerobic speed (MAS). MAS had been measured 1 week before the training camp, with the Yo-Yo intermittent recovery test level-1 (25). The heart rate (HR) of the participants was continuously monitored during all the training sessions using HR monitors (Polar Team System, Polar Electro Oy, Kempele, Finland). It is used to check whether the HR of each player during the exercise was above 90% of the maximum HR. This had also been verified during preexperimental trials using the same patterns of exercises (i.e., crisscross). The coaches of the participants were present and they encouraged during all the ITS, as it was also the case in common practice. OT and rating of perceived exertion (RPE) were measured immediately after the ITS. Moreover, glucose [Gl] and blood lactate [La] levels were assessed in 3- to 5-min period after the ITS (Fig. 1). Then, all the physical and cognitive tests were repeated in the same order. Two weeks later, the same protocol was repeated to allow each participant to achieve the experiment once with MEL and once with PLA. The recorded HR during the second session of ITS verified that the intensity of the two sessions was similar.

*Oral temperature (OT)*

Digital thermometers (Rossmax TG 380; accuracy 0.1 °C, Rossmax International Ltd., Taipei, Taiwan) were used to measure OT. After cleaning, the thermometer was kept under the tongue of the participant until the digital thermometer beeps signaled a constant temperature that was considered as the OT for each participant (21).

*Vigilance test (VT)*

This test is used to measure vigilance. It consisted of identifying a particular sign (a figure composed of three numbers) and circulating it as much as possible in a limited time (1 min), working line by line, from left to right, leaving aside all the other figures, which were not

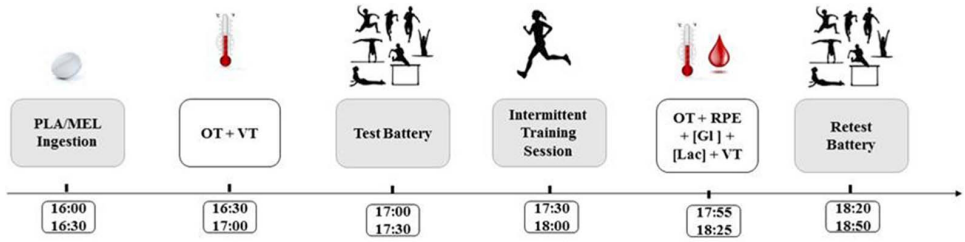


*Fig. 1.* Schematic illustration of the experimental protocol. PLA: placebo; MEL: melatonin; OT: oral temperature; VT: vigilance; RPE: rating of perceived exertion; [Gl]: glucose; [La]: lactate

composed of three numbers. The paper contained 600 signs divided into 36 lines. The total circling number was considered to determine vigilance performance for each participant (45).

*Modified agility T-test (MAT)*

The MAT was used to determine speed with respect to changes of direction. Based on the protocol modified by Sassi et al. (38), each participant sprinted 5 m forward and touched the base of a cone with the right hand. Facing forward and without crossing feet, the participants shuffled to the left to the second cone located 2.5 m to the left of the first cone and touched its base with the left hand. They then shuffled to the right to the third cone located 2.5 m to the right of the first cone and touched its base with the right hand. They shuffled back to the left to the first cone and touched its base. Finally, they ran backward as quickly as possible and returned to the starting line. The recorded score for this test was the better result from the two trials. The MAT performances were recorded using an electronic timing system (Globus, Microgate, SARL, Italy). One pair of the electronic timing system sensors mounted on tripods were set approximately 0.75 m above the floor and positioned 3 m apart facing each other on either side of the starting line. The participants were instructed to begin with their preferred foot forward, placed from 0.2 to 0.5 m behind the starting line.

*Squat jump (SJ) and counter movement jump (CMJ) tests*

Participants were asked to perform a maximal vertical SJ and CMJ without any load on an infrared jump system (Opto jump, Microgate, Bolzano, Italy) interfaced with a microcomputer. They stood between two 1-m infrared sensor bars to perform SJ and CMJ. This system is developed to measure with a$10^{-3}$-s precision of all flying and ground-contact times, from which the jump's height was calculated. In the SJ, players lowered themselves into a squat position (90°) and, after a brief pause, jumped upward as quickly and high as possible. No downward motion immediately prior to jumping was allowed. In the CMJ, they initiated the jump from an extended leg position, descended to a 90° knee flexion, and immediately performed an explosive concentric action to achieve maximum height. Jumping height was calculated from the flight time. During SJ and CMJ, participants performed three jumps interspersed with 15 s of rest; the peak value was used for further analysis (11).

*Maximum standing ball-throw velocity test (MSBVT) and maximum jump ball-throw velocity test (MJBVT)*

Maximum ball-throwing velocity was measured using a radar gun (Sports Radar 3300, Sports Electronics Inc., Dayton, OH, USA), with a range of 10 to 199 ± 2.3 km/h and accuracy

at ±0.1 km/h. The players had to shoot the ball to the middle of the goal at a distance of 7 m from frontal radar position, as previously described (29). After warm-up, players began to throw at full velocity using the standing-throw technique (MSBVT) or jump-throw technique (MJBVT) and using their dominant arms. This was performed until three valid throws were recorded for each participant. The best throw was used for subsequent analysis. Coaches supervised the throws throughout the test to ensure that participants were using the proper technique.

*20-m sprint (20m-Sp)*

Sprint time over 20 m was measured using photocells (Globus, Microgate). The participant had to run the whole distance as fast as possible. The best trial was used for the subsequent statistical analysis. The athletes decided themselves when to start the test, from the static position, 30 cm behind the photocell (starting line) and with the time being recorded from when the participant broke the first photocell beam (44).

*Rating of perceived exertion (RPE)*

The RPE scale allows participants to give a subjective exertion rating for the physical task. It consists of a 10-point scale ranging from 0 (rest) to 10 (very very hard) (18). The RPE scale is a reliable indicator of physical discomfort, has sound psychometric properties, and is strongly correlated with several other physiological measures of exertion (18). In this study, the participants were instructed to give an overall perception about how hard they felt the ITS according to RPE scale. RPE scores were recorded immediately after the ITS.

*Measurements of blood lactate [La] and glucose [Gl]*

Small pinprick blood samples were taken from the fingertip. The area was cleaned first using a dry tissue to remove sweat and then using an alcohol swab. Once the area was dry, the lancet (often with a spring-loaded apparatus) was used to pierce the skin. With only 5 μl of blood and simple operation, Lactate Pro (LP, Arkray KDK, Japan) analyzer, which has previously been validated (17), provides the accurate [La] level in 60 s. [La] in the sample reacts with potassium ferricyanide and lactate oxidase to form potassium ferrocyanide and pyruvate. Similarly, [GL] was measured from the fingertip using a glucometer (Accu-Chek® Active, Roche Diagnostic Corporation, Germany). A drop of blood is placed on a small strip inserted in the glucometer. The meter calculates and displays the [GL] level within 15 s (41).

*Statistical analysis*

Data were presented as mean ± SD. All statistical tests were processed using STATISTICA 10 software (StatSoft, Maisons-Alfort, France). The Shapiro–Wilk test revealed that the data were normally distributed. OT, VT, MAT, SJ, CMJ, MSBVT, MJBVT, and 20m-Sp were analyzed using a two-way (Condition × Exercise) analysis of variance with repeated measures for the two factors. Both factors were "within-participants" by definition and included two "levels" (MEL/PLA) in the condition factor and two "levels" (before/after) in the exercise factor. When appropriate, significant differences among means were tested using the Tukey's honestly significant difference *post-hoc* test. Effect sizes were calculated as partial eta-squared ($\eta^2_p$) to estimate the meaningfulness of significant findings. $\eta^2_p$ values of 0.01, 0.06, and 0.13 represent small, moderate, and large effect sizes, respectively. 95% confidence intervals (95% CIs) were calculated for each measured variable. RPE, [Gl], and [La] values were analyzed with dependent paired *t*-test. A probability level of 0.05 was selected as the criterion for statistical significance.

## Results

*Oral temperature (OT)*

There was a significant effect of Condition [$F_{(1.14)} = 6.0$, $p < 0.05$, 95% CI: (0.01, 0.23)] and Exercise [$F_{(1.14)} = 213$, $p < 0.001$, 95% CI: (−1.01, −0.75)] for OT. However, the interaction Condition × Exercise is not significant. In addition, there was no significant difference for OT between MEL and PLA (Fig. 2).

*Psychocognitive performances*

Data of psychocognitive performances are presented in Table I. Statistical analysis revealed a significant interaction Condition × Exercise [$F_{(1.14)} = 5.87$, $p < 0.05$] for the VT.

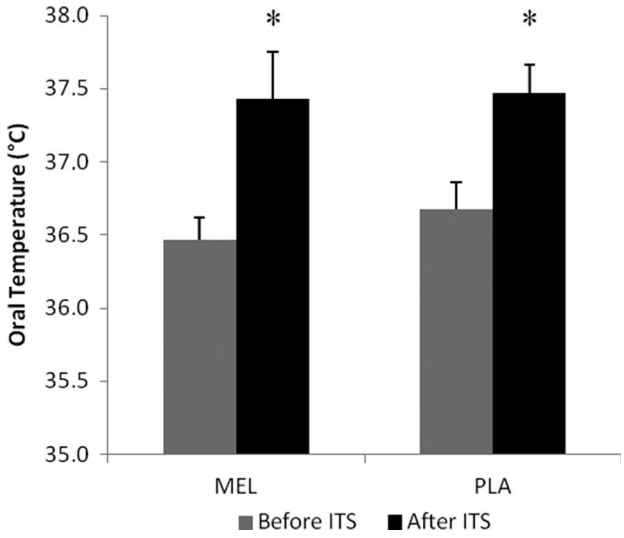


*Fig. 2.* OT measures during MEL and PLA conditions before and after the ITS. OT: oral temperature; MEL: melatonin; PLA: placebo; ITS: intermittent training session. *Significant difference compared to rest ($p < 0.001$)

*Table I.* Psychocognitive and physical performances (mean ± SD) measured before and after the ITS, with either MEL or PLA ingestion

| | Placebo | | Melatonin | |
|---|---|---|---|---|
| | **Before ITS** | **After ITS** | **Before ITS** | **After ITS** |
| VT (AU) | 71.1 ± 14.3 | 67.1 ± 10.4 | 67.8 ± 13.4 | 69.7 ± 13.0 |
| MAT (s) | 6.1 ± 0.7 | 5.9 ± 0.5 | 6.0 ± 0.4 | 6.0 ± 0.3 |
| SJ (cm) | 26.5 ± 3.9 | 26.3 ± 3.8 | 26.0 ± 3.6 | 25.6 ± 4.2 |
| CMJ (cm) | 28.8 ± 4.1 | 28.1 ± 3.9 | 28.7 ± 4.2 | 28.3 ± 4.5 |
| MSBVT (km/h) | 80.3 ± 6.2 | 78.5 ± 7.6 | 79.9 ± 5.24 | 77.9 ± 6.01 |
| MJBVT (km/h) | 76.3 ± 6.4 | 76.7 ± 7.3 | 77.4 ± 5.3 | 76.0 ± 5.8 |
| 20m-Sp (s) | 3.4 ± 0.2 | 3.4 ± 0.2 | 3.5 ± 0.1 | 3.5 ± 0.2 |

SD: standard deviation; MEL: melatonin; PLA: placebo; ITS: intermittent training session; VT: vigilance test; MAT: modified agility T-test; SJ: squat jump; CMJ: counter movement jump; MSBVT: maximal standing ball-throw velocity test; MJBVT: maximal jump ball-throw velocity test; 20m-Sp: 20-m sprint

However, there was no significant effect of Condition or Exercise. In addition, no significant effect of MEL on RPE was found. RPE was $6.7 \pm 1.9$ and $6.3 \pm 2.4$ after PLA and MEL ingestion, respectively.

*Physical performances*

Data of physical performances are displayed in Table I. Statistical analysis (Table II) showed only a significant effect of Exercise for MSBVT [$F_{(1.14)} = 8.69$, $p < 0.05$, 95% CI: (0.57, 3.63)]. However, there was no significant effect of Condition, Exercise, and the interaction Condition × Exercise for MAT, SJ, CMJ, MJBVT, and 20m-Sp ($p > 0.05$).

*Table II.* Statistical results from analysis of variance

| | **Condition** | **Exercise** | **Condition × Exercise** |
|---|---|---|---|
| OT | $F_{(1.14)} = 5.87$ | $F_{(1.14)} = 213.26$ | $F_{(1.14)} = 1.92$ |
| | $p = 0.03$ | $p < 0.001$ | $p = 0.19$ |
| | $\eta^2_p = 0.3$ | $\eta^2_p = 0.94$ | $\eta^2_p = 0.12$ |
| | ESR: large | ESR: large | ESR: large |
| VT | $F_{(1.14)} = 0.02$ | $F_{(1.14)} = 0.7$ | $F_{(1.14)} = 5.87$ |
| | $p = 0.90$ | $p = 0.42$ | $p = 0.03$ |
| | $\eta^2_p = 0.001$ | $\eta^2_p = 0.05$ | $\eta^2_p = 0.3$ |
| | ESR: small | ESR: small | ESR: large |
| MAT | $F_{(1.14)} = 0.00$ | $F_{(1.14)} = 4.46$ | $F_{(1.14)} = 0.37$ |
| | $p = 0.99$ | $p = 0.05$ | $p = 0.55$ |
| | $\eta^2_p = 0.00$ | $\eta^2_p = 0.24$ | $\eta^2_p = 0.03$ |
| | ESR: small | ESR: large | ESR: small |
| SJ | $F_{(1.14)} = 2.65$ | $F_{(1.14)} = 0.43$ | $F_{(1.14)} = 0.16$ |
| | $p = 0.13$ | $p = 0.52$ | $p = 0.69$ |
| | $\eta^2_p = 0.17$ | $\eta^2_p = 0.03$ | $\eta^2_p = 0.01$ |
| | ESR: large | ESR: small | ESR: small |
| CMJ | $F_{(1.14)} = 0.02$ | $F_{(1.14)} = 3.33$ | $F_{(1.14)} = 0.13$ |
| | $p = 0.90$ | $p = 0.09$ | $p = 0.73$ |
| | $\eta^2_p = 0.001$ | $\eta^2_p = 0.19$ | $\eta^2_p = 0.01$ |
| | ESR: small | ESR: large | ESR: small |
| MSBVT | $F_{(1.14)} = 0.45$ | $F_{(1.14)} = 8.69$ | $F_{(1.14)} = 0.18$ |
| | $p = 0.51$ | $p = 0.01$ | $p = 0.68$ |
| | $\eta^2_p = 0.03$ | $\eta^2_p = 0.38$ | $\eta^2_p = 0.01$ |
| | ESR: small | ESR: large | ESR: small |

*Table II.* Statistical results from analysis of variance *(Continued)*

| | Condition | Exercise | Condition × Exercise |
|---|---|---|---|
| MJBVT | $F_{(1.14)} = 0.02$ | $F_{(1.14)} = 0.49$ | $F_{(1.14)} = 1.24$ |
| | $p = 0.88$ | $p = 0.50$ | $p = 0.28$ |
| | $\eta^2_p = 0.002$ | $\eta^2_p = 0.03$ | $\eta^2_p = 0.08$ |
| | ESR: small | ESR: small | ESR: moderate |
| 20m-Sp | $F_{(1.14)} = 4.5$ | $F_{(1.14)} = 0.28$ | $F_{(1.14)} = 0.52$ |
| | $p = 0.05$ | $p = 0.61$ | $p = 0.48$ |
| | $\eta^2_p = 0.24$ | $\eta^2_p = 0.02$ | $\eta^2_p = 0.04$ |
| | ESR: large | ESR: small | ESR: small |

OT: oral temperature; VT: vigilance test; MAT: modified agility T-test; SJ: squat jump; CMJ: counter movement jump; MSBVT: maximal standing ball-throw velocity test; MJBVT: maximal jump ball-throw velocity test; 20m-Sp: 20-m sprint; ESR: effect size rating

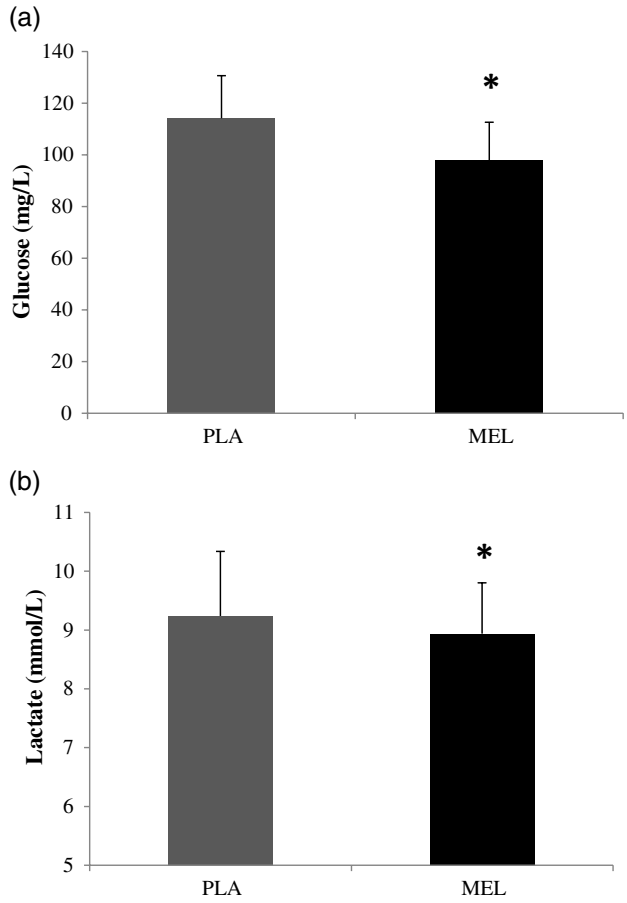


*Fig. 3.* (a) Blood [Gl] response to MEL or PLA ingestion measured after the ITS. (b) Blood [La] response to MEL or PLA ingestion measured after the ITS. [Gl]: glucose; [La]: lactate; MEL: melatonin; PLA: placebo; ITS: intermittent training session. *Significant difference between MEL and PLA group ($p < 0.05$)

*Lactate and glucose*

MEL ingestion resulted in a significant decrease in [Gl] and [La] levels after the ITS ($t = 2.57$, $p < 0.05$ and $t = 2.32$, $p < 0.05$, respectively) (Fig. 3a and b, respectively).

## Discussion

The aim of this study was to verify whether acute MEL ingestion had a positive effect on physical performance recovery after an ITS in junior female elite team-handball players. In other words, does the multiple beneficial effects of MEL decrease athletes' fatigue and enhance the recovery process after an intensive exercise session?

The main findings proved that MEL does not affect short-term performances (i.e., before the ITS) and performance recovery (i.e., after the ITS) during ITS in young elite female handball players.

Previous research works obtained conflicting results regarding the acute effects of exogenous MEL on athletic performance. In congruity with the present findings, some previous researches concluded that MEL ingestion had no effect on short-term ("anaerobic") (19, 20, 33) and endurance ("aerobic") (6, 10) performances. However, other studies have found that MEL administration had adversely affected some athletic performances (19, 20). In these latter studies, which were carried out on football players, the authors found that nocturnal (i.e., 9:00 p.m.) ingestion of 8 mg of MEL, but not 5 mg of MEL, decreased short-term maximal performances (i.e., SJ and CMJ) measured 30 min after MEL ingestion (19). Moreover, morning (i.e., 07:30 a.m.) ingestion of MEL (5 mg) decreased only morning (i.e., 08:00 a.m.) short-term maximal performances but not performances achieved at 12:00 a.m. and 4:00 p.m. (20). However, more recent studies (8, 12) have shown that MEL ingestion improved short-term and aerobic performances. In addition, another study in rats (9) found that MEL ameliorates aerobic performance during a swimming exercise until exhaustion. Several factors may be at the origin of the discrepancy between studies, such as time of ingestion, latency between ingestion of MEL and exercise, dose, level of physical fitness of the participants, and/or the type of exercise performed (4, 5, 8–10, 12, 19, 20, 33).

This study showed no significant effect of MEL on OT. The lack of effect stems from the absence of significant interaction (Condition × Exercise). The present results agree with Brandenberger et al. (10) who found that 5 mg of MEL did not impact rectal temperature during a 32.2-km cycling exercise in a thermoneutral environment. However, previous researches (5, 14, 20) have found a significant decrease in core temperature after ingesting MEL. Marrin et al. (30) reported, in a meta-analysis, a logarithmic dose–response relationship between MEL and its hypothermic effect. MEL doses of 2–5 mg lowered core temperature by ~0.2 °C. However, higher doses did not substantially increase this hypothermic effect. The lack of MEL effect on OT in this study may be due to a low latency time between MEL ingestion and temperature measurement (i.e., 30 min) compared to other studies (i.e., more than 75 min) (5, 14).

This study showed a slight but non-significant decrease in vigilance 30 min after MEL ingestion. Similarly, previous studies (19, 20) have found that the effect of MEL concerned cognitive performances rather than physical ones. In these studies, MEL affected alertness but also the reaction time and short-term memory. The debilitative effects are better marked when the task is complex (6) and performance of mentally demanding tasks is impaired for 5–6 h after MEL ingestion (6). Nevertheless, a recent study conducted in soccer players (20) found that morning MEL ingestion affects vigilance only in the morning and has no deleterious effect in afternoon cognitive performances. In contrast, other studies showed that MEL ingestion has no

effect on cognitive performance (1, 5) or has a facilitative influence on short-term memory (3). Several factors may be at the origin of the discrepancy between studies, such as time of ingestion; latency between ingestion of MEL and exercise, dose, level of physical fitness of the participants; and/or the type of exercise performed (4, 19, 20).

Overall, the results of this study showed that MEL did not affect physical performance recovery after an intensive training. This may be due to the lack of effect of the ITS on physical performance. The players were on the fifth day of the training camp and performed a morning session on the day of the experiment in a warm climate. This has likely led to a state of fatigue that affected and decreased performance especially before the ITS and probably mitigated the effect of MEL on recovery. To the best of the authors' knowledge, only one study investigated the acute effect of MEL on performance recovery (33). It has been shown that MEL ingestion prior to a resistance training session did not affect the recovery of short-term performance (33). Moreover, according to previous studies (5, 6, 10), MEL did not affect the RPE score after ITS. This provides some evidence that MEL has no inherent psychological impact on physical performance.

Otherwise, this study results showed that MEL decreased [Gl] levels after the ITS. This is in agreement with Kaya et al. (23), who also found that MEL lowers blood [Gl] in rats after a 30-min swimming exercise. In contrast, other studies (31, 37) have found that MEL attenuates the decrease of plasma [Gl] observed after exercise. Else, Rohr and Herold (36) found that [Gl], which increases after intravenous glucose supplementation, decreases during sleep. This has been related to a hypoglycemic role of MEL and elucidated the relationship between the pineal gland and the mechanisms of carbohydrate use. A more recent study showed that MEL ingestion 30 min prior to an aerobic exercise bout elevates carbohydrate use during exercise (42). Nevertheless, some studies did not depict an effect of MEL during the recovery period post-exercise (i.e., 48 h after exercise) in rats (34). This discrepancy of results may be due to the differences in exercise types, duration of supplementation, differences between humans and animals but also the time of the experiment as it has been shown that [Gl] levels in the blood follow a diurnal variation (26).

In the same vein, the present findings showed that [La] levels decreased after MEL ingestion. This is consistent with previous studies in rats (22, 31), which also found that decreased [La] levels, due to a single dose (31) or chronic ingestion (22) of MEL, were associated with increased liver and muscle glycogen stores. This can be due to a modification of substrate utilization (31) and can improve endurance capacity (22). Accordingly, pinealectomy in rats induced an increase in [La] levels after exercise (7), which can explain enhanced fatigue and decreased performance. Thus, the ability of MEL to promote a reduced lactatemia may improve the performance during high-intensity exercise. Therefore, future studies should investigate MEL ingestion effects on repeated exercise tasks highly involving the glycolytic pathway.

In this study, the little effect of MEL on performance recovery may be due to the short-term MEL ingestion period. The players who participated in this study were in an intensive training camp, and a supplementation during the whole period of the training period could have been more effective. In addition, in future studies, it might be wise to give more recovery before ITS to prevent the effect of fatigue on performance and subsequently hide the effect of MEL. Furthermore, physical and cognitive performances had to be measured at different times after the ITS and not only immediately after the training session. Moreover, we did not measure resting [Gl] and [La]. The measurement of

biochemical parameters, before and after ITS, is necessary for future studies, especially those of oxidative stress, inflammation, and muscle damage, since they have been accused for the onset of fatigue (13).

In conclusion, the acute effect of MEL intake before an ITS is particularly evident for [La] and [Gl]. However, it seems to have no significant effect on recovery, probably due to the effect of fatigue on physical performance.

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