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Synergetic effects of a low caffeine dose and pre-exercise music on psychophysical performance in female taekwondo athletes

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ORIGINAL PAPER

Abstract

The ergogenecity of caffeine (CAF) and pre-exercise music have been studied extensively in male and mixed-gender groups, but there is limited information on their synergistic effects in females. This study assessed the effects of combining a low dose of CAF with warm-up music on taekwondo specific performance, perceived exertion (RPE), and psychological aspects in female athletes. In a double-blinded, randomized, placebo-controlled crossover study, 16 female taekwondo athletes ($M \pm SD$; age: 17.69 ± 0.60 years) performed the taekwondo-specific agility test (TSAT), 10 s frequency speed of kick test (FSKT-10s) and its multiple version (FSKT-mult) under the following conditions: 1) no supplement with music (NS+M); 2) no supplement without music (control); 3) CAF without music (CAF+NM), 4) placebo without music (PL+NM), 5) CAF with music (CAF+M), 6) PL with music (PL+M). After each test, athletes rated their RPE, feeling scale (FS), felt arousal scale (FAS) and physical enjoyment (PACES). CAF+M induced better physical performance than other conditions on the FSKT-10s, FSKT-mult, and more desirable psychophysiological responses including RPE post_TSAT, RPE post_FSKT-10s, PACES post_FSKT-10s, FS, FAS post_warm-up, FAS post_FSKT-10s and FAS post_FSKT-mult (all $p < 0.05$). Except for PL+M, CAF+M also elicited more desirable responses than other conditions for FAS post_TSAT ($p < 0.05$). Furthermore, CAF+M and CAF+NM conditions enhanced TSAT, PACES post_TSAT, RPE post_FSKT-mult greater than the other conditions ($p < 0.05$). Preceding warm-up music stimulus with a low dose of CAF may be a more efficient strategy to enhance physical performance and affective valence in female taekwondo athletes compared with using either strategy in isolation.

Keywords: Martial arts; combat sports; taekwondo; performance; ergogenic effect; supplementation; music preference.

Efectos sinérgicos de una dosis baja de cafeína y de la música previa al ejercicio sobre el rendimiento psicofísico en atletas femeninas de taekwondo

Resumen

La ergogenicidad de la cafeína (CAF) y la música previa al ejercicio se han estudiado ampliamente en grupos de hombres y en grupos mixtos, pero existe poca información sobre sus efectos sinérgicos en mujeres. Este estudio evaluó los efectos de combinar una dosis baja de CAF con

Efeitos sinergéticos de uma dose baixa de cafeína e da música pré-exercício no desempenho psicofísico de atletas de taekwondo do sexo feminino

Resumo

A ergogenecidade da cafeína (CAF) e da música pré-exercício foi amplamente estudada em grupos masculinos e mistos, mas existe pouca informação sobre os seus efeitos sinérgicos no sexo feminino. Este estudo avaliou os efeitos da combinação de uma dose baixa de CAF com

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música de calentamiento en el rendimiento específico de taekwondo, el esfuerzo percibido (RPE) y los aspectos psicológicos en atletas femeninas. En un estudio cruzado doble ciego, aleatorizado y controlado con placebo, 16 atletas femeninas de taekwondo (*M* ± *DE*; edad: 17,69 ± 0,60 años) realizaron la prueba de agilidad específica de taekwondo (TSAT), la prueba de velocidad de frecuencia de patada de 10 s (FSKT-10s) y su versión múltiple (FSKT-mult) en las siguientes condiciones: 1) ningún suplemento con música (NS+M); 2) ningún suplemento sin música (control); 3) CAF sin música (CAF+NM), 4) placebo sin música (PL+NM), 5) CAF con música (CAF+M), 6) PL con música (PL+M). Después de cada prueba, las atletas valoraron su RPE, la escala de sensaciones (FS), la escala de excitación sentida (FAS) y el disfrute físico (PACES). CAF+M indujo un mejor rendimiento físico que otras condiciones en el FSKT-10s, FSKT-mult, y respuestas psicofisiológicas más deseables incluyendo RPE post_TSAT, RPE post_FSKT-10s, PACES post_FSKT-10s, FS, FAS post_calentamiento, FAS post_FSKT-10s y FAS post_FSKT-mult (todas $p < 0,05$). Excepto para PL+M, CAF+M también provocó respuestas más deseables que otras condiciones para FAS post_TSAT ($p < 0,05$). Además, las condiciones CAF+M y CAF+NM mejoraron TSAT, PACES post_TSAT, RPE post_FSKT-mult más que las otras condiciones ($p < 0,05$). Preceder el estímulo musical de calentamiento con una dosis baja de CAF puede ser una estrategia más eficaz para mejorar el rendimiento físico y la valencia afectiva en atletas femeninas de taekwondo en comparación con el uso de cualquiera de las dos estrategias de forma aislada.

Palabras clave: Artes marciales; deportes de combate; taekwondo; rendimiento; efecto ergogénico; suplementación; preferencia musical.

música de aquecimento no desempenho específico do taekwondo, perceção de esforço (RPE) e aspectos psicológicos em atletas do sexo feminino. Num estudo cruzado, duplamente cego, aleatorizado e controlado por placebo, 16 atletas de taekwondo do sexo feminino (M ± DP; idade: 17,69 ± 0,60 anos) realizaram o teste de agilidade específico do taekwondo (TSAT), o teste de velocidade de pontapé de frequência de 10 s (FSKT-10s) e a sua versão múltipla (FSKT-mult) nas seguintes condições 1) sem suplemento com música (NS+M); 2) sem suplemento sem música (controlo); 3) CAF sem música (CAF+NM), 4) placebo sem música (PL+NM), 5) CAF com música (CAF+M), 6) PL com música (PL+M). Após cada teste, os atletas classificaram a sua RPE, a escala de sensações (FS), a escala de excitação sentida (FAS) e o prazer físico (PACES). O CAF+M induziu um melhor desempenho físico do que as outras condições no FSKT-10s, FSKT-mult, e respostas psicofisiológicas mais desejáveis, incluindo RPE pós_TSAT, RPE pós_FSKT-10s, PACES pós_FSKT-10s, FS, FAS pós_warm-up, FAS pós_FSKT-10s e FAS pós_FSKT-mult (todos $p < 0,05$). Exceto para PL+M, CAF+M também provocou respostas mais desejáveis do que outras condições para FAS pós_TSAT ($p < 0,05$). Além disso, as condições CAF+M e CAF+NM melhoraram o TSAT, PACES pós_TSAT, RPE pós_FSKT-mult mais do que as outras condições ($p < 0,05$). Preceder o estímulo musical de aquecimento com uma dose baixa de CAF pode ser uma estratégia mais eficiente para melhorar o desempenho físico e a valência afectiva em atletas femininas de taekwondo, em comparação com a utilização de qualquer uma das estratégias isoladamente.

Palavras-chave: Artes marciais; desportos de combate; taekwondo; desempenho; efeito ergogénico; suplementação; preferência musical.

1. Introduction

Sports professionals and coaches are constantly searching for strategies to improve physical performance through different means of intervention (Filip-Stachnik et al., 2022). The consumption of nutritional ergogenic aids is one strategy, among others, attracting sports professionals' attention (López-Torres et al., 2023). This approach seems justified, given the array of research demonstrating improvements in physical performance in a variety of sports settings following ingestion of various nutritional ergogenic aids (López-Torres et al., 2023). Caffeine (CAF),1,3,7-trimethylxanthine, is the most commonly used central nervous system stimulant, which is capable of enhancing athletic performance and cognitive function (McLellan et al., 2016). Whilst the mechanisms underpinning caffeine's ergogenicity are yet to be fully elucidated (Grgic & Varovic, 2023), CAF may improve athletic performance through a variety of mechanisms, including binding to adenosine receptors, indirect release of neurotransmitters, reducing perceived exertion (RPE), and enhancing muscle contractile properties, possibly via improved intramuscular metabolic milieu (Davis & Green, 2009; Lima-Silva et al., 2021; McLellan et al., 2016).

In combat sports, CAF ergogenic effect has recently been evidenced via improvements in some physical and physiological aspects following different ingestion strategies (Delleli et al., 2022). Although existing research has considered caffeine's ergogenic potential within different athletic populations and levels of training experience, female athletes have rarely been considered, despite evidence for potentially lower efficacy in this population (Mielgo-Ayuso et al., 2019). In female combat sports athletes, little is known about CAF effects on their physical performances and associated psychological responses (Delleli et al., 2022). For instance, it has been reported that 5 and 6 mg/kg of CAF both ingested 60 min before exercising did not improve subsequent performances in female karatekas (Arazi et al., 2016) or influence the special judo fitness test performance and heart rate responses in female judo athletes (Pereira et al., 2010). The exact mechanism underlying the different responses to the supplement remains unknown, but body size and body composition could be mediating factors (Domaszewski, 2023). In addition, Temple and Ziegler (2011) suggest that responses induced by CAF may be related to changes in steroid hormone levels. In fact, hormone levels' fluctuation through the menstrual cycle phases alters CAF metabolism and neuromuscular function (Temple & Ziegler, 2011). In addition, the use of oral contraceptives in some cases interferes with CAF metabolism and excretion and inhibits the activity of CYP1A2, an enzyme responsible for the metabolism of CAF (Lara et al., 2020). Such factors may explain the higher effect of CAF in male than female athletes in producing higher power, total weight lifted and improved sprint performance despite the same dose being administered (Mielgo-Ayuso et al., 2019). Moreover, in a study investigating the moderating effects of sex and competition level, Ouergui et al. (2023) reported that, under CAF condition, male taekwondo athletes performed better than their females counterparts in both elite and sub-elite level. However, these findings should be taken with caution since the ergogenic effect of a low dose of CAF (3 mg/kg) has been evidenced during anaerobic exercise in an all-female sample, regardless of their menstrual cycle phase (Lara et al., 2020; Lara et al., 2021). Based on these inconsistent findings, generalizing results from one sample sex to another would generate biased approaches.

In high-level competition, athletes experience high physiological stress and anxiety, with females often reporting levels of anxiety or nervousness, which are more than three times higher than their male counterparts (Domaszewski, 2023). Although relatively low CAF doses have been reported to improve several aspects of performance in combat sports (Delleli et al., 2022), its use in combination with other strategies might elicit additive effects when compared to being used in isolation (Delleli et al., 2023; Ouergui et al., 2022). Since physical and physiological performance is supported by psychological state (Bridge et al., 2014), improving athletes' behaviors is a fundamental requirement. Music is a psychoactive stimulus proven to be effective in improving mood, affective valence as well as physical performance in various sports settings and populations (Chtourou et al., 2017; Terry et al., 2020). Regarding combat sports, listening to music during warm-up is considered to be the optimal time to facilitate ergogenic performance effects (Ibrahim Ouergui, Arwa Jebabli, et al., 2023; I. Ouergui et al., 2023). With inconsistent findings being reported on warm-up music effects, personal and situational factors have been postulated to explain the variation in an individual's responsiveness to such stimulus (Karageorghis et al., 2021). Specifically, when it is played under preference, warm-up music elicited higher effect on affective valence and related effort (Ballmann, 2021). It is pertinent to note that sex is a modulating factor, with male listeners presented greater sensitivity to such stimulus than their female counterparts (Ibrahim Ouergui, Arwa Jebabli, et al., 2023; I. Ouergui et al., 2023). However, the benefits attained from using 'warm-up music' cannot be negated since its effects on an all-female athletic population has been revealed through various stages of their menstrual cycle (Ghazel et al., 2022). This evidence collectively infers that existing data generated from male populations cannot be generalized to female athletes, due to the existence of several moderating factors on both CAF (Grgic & Varovic, 2023) and music (Karageorghis et al., 2021) effects. Moreover, in both music and CAF investigations, female athletes received less consideration with inconsistent findings being reported.

To the authors' current knowledge, only one previous study (Delleli et al., 2023) that addressed the combined effects of CAF and warm-up music on specific performances and related psychological responses in male taekwondo athletes. However, there have been no concerted attempts to study the synergistic effects of CAF and warm-up music on psychophysical aspects using only female athletes. Therefore, this study was designed to assess the combined effects of preceding preferred warm-up music by a low dose of CAF on the sports-specific physical performance and related psychological responses in female taekwondo athletes. Based on the interconnection of athletes' psychological state and physical performance (Bridge et al., 2014), it was predicted that such combination would result in greater effects than the independent use of either intervention alone.

2. Methods

2.1. Participants

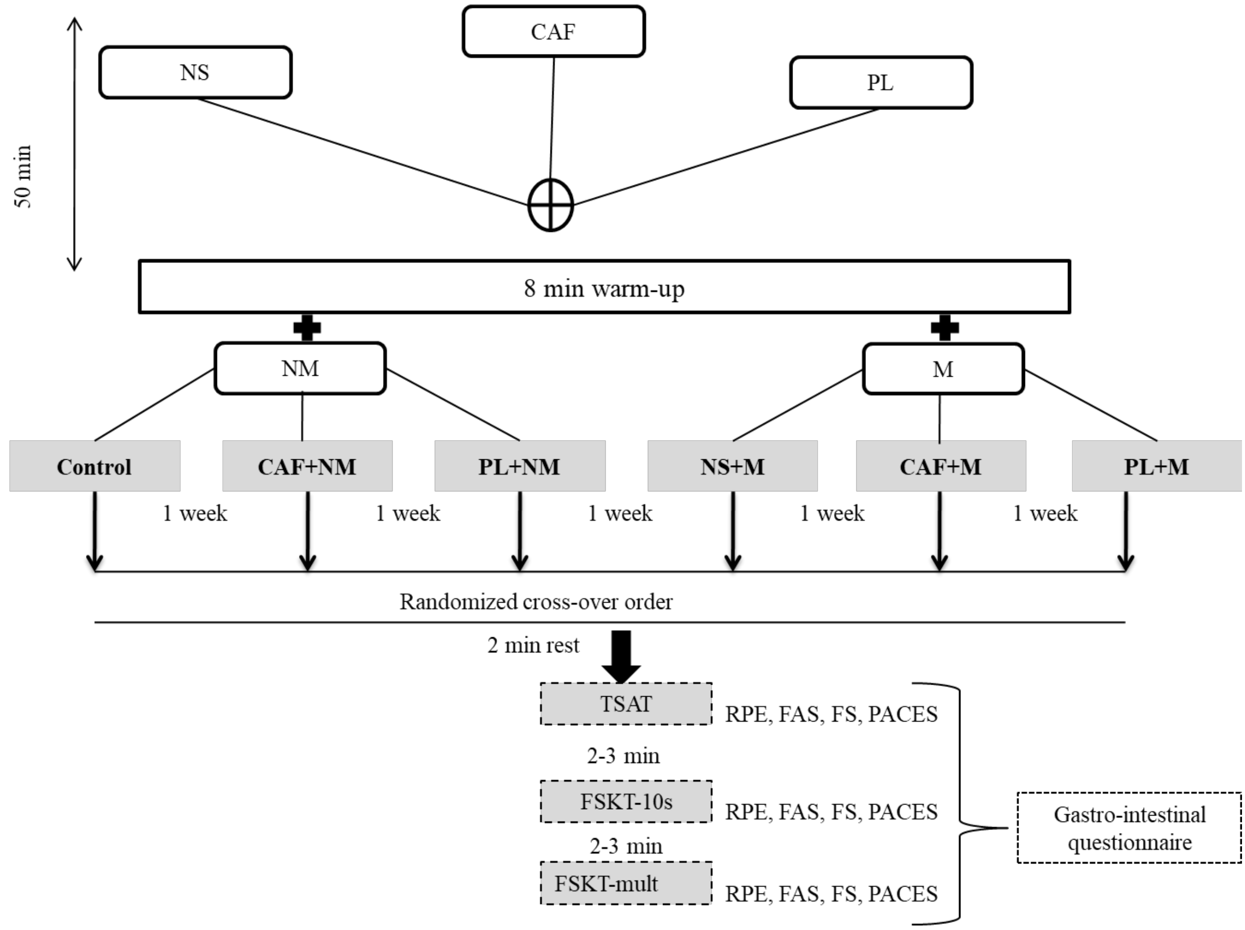
A priori power analysis was conducted to determine the required sample size using the G*Power software (Version 3.1.9.4, University of Kiel, Kiel, Germany). The repeated measures

ANOVA, within factors test, with six conditions revealed that a total sample size of 14 would be sufficient to find medium significant effects of condition (effect size f = 0.30, α = 0.05) with an actual power of 83%. Following convenience sampling, athletes were recruited as long as they met the following inclusion criteria: a) classified as an elite athlete with at least 8 years of taekwondo experience; b) not suffering from any restrictions related to sports practice or hearing loss; c) aged at least 17 years old; d) were not taking any form of contraceptives and; e) have a regular duration of their menstrual cycle, defined as a variation lower than 3 days in the range of their menstrual cycles' length (Lara et al., 2020) for the previous 2 months. Taking into consideration the risk of participant drop-out, 16 elite female taekwondo athletes (Mean ± SD; age: 17.69 ± 0.60 years; body mass: 49.75 ± 5.36 kg; height: 166.81 ± 10.12 cm) were eligible and volunteered to participate in the present study. Based on the questionnaire of Bühler et al. (2014), athletes were considered as low CAF consumers (i.e., mean habitual CAF consumption = 0.96 ± 0.50 mg/kg) with a menstrual cycle duration of 28 ± 1 days. The participants were in the follicular phase (8 athletes) or luteal phase (8 athletes) with no more than two days difference in-between. The participants were asked to follow the same diet, avoid alcoholic substances and vigorous exercise, and restrain from CAF consumption (in drinks and supplements) 48h before each experimental session. All participants and their parents were informed about the procedures, the possible risks and side effects involved in the investigation and they signed a written informed consent form. This study was conducted in accordance with the last Declaration of Helsinki and the protocol was fully approved by the Committee of protection of southern persons (CPP SUD N◦ 0332/2021) before starting the experimentation.

2.2. Experimental design

A double-blind, counterbalanced, placebo-controlled crossover study design was implemented to investigate the acute effects of CAF supplementation combined with listening to music during warm-up on the subsequent performance and psychophysical responses in elite female taekwondo athletes. The present study shares some procedures (i.e., experimental conditions) previously used in the study of Delleli et al. (2023). After familiarization with the testing procedure and anthropometric measurements, athletes were submitted to six testing sessions. In fact, following the same randomized cross over order across experimental sessions, athletes performed the taekwondo specific agility test (TSAT) (Chaabene et al., 2018), 10 s frequency speed of kick test (FSKT-10s) (da Silva Santos et al., 2015), and its multiple version (FSKT-mult) (Da Silva Santos et al., 2016) under six different conditions: 1) no supplement and no music (control), 2) no supplement with music (NS+M), 3) placebo and no music (PL+NM), 4) CAF and no music (CAF+NM), 5) placebo with music (PL+M) and 6) CAF with music (CAF+M). Specifically, in a double-blind fashion, athletes ingested 3 $mg{\cdot}kg^{-1}$ of CAF or placebo (PL) -for all-purpose bleached flour, both diluted in 200 ml of water. Fifty min after supplementation, athletes performed two warm-up protocols, consisting of a standard warm-up (i.e., 8 min of running and taekwondo-specific techniques execution) without music (control), or performing warm-up while listening to their preferred music (i.e., 8 min warm-up with music), both followed by two min of rest. For each athlete, the listened music was self-selected and rated as motivating based on the Brunel Music Rating Inventory-2 (Karageorghis et al., 2006). The mean tempo of the selected music from all participants was 144 ± 18.6 bpm (i.e., all > 120 bpm), while the music volume was standardized at the same level (i.e., 80 db) for all participants. When the music was shorter than the 8 min warm-up session, it was looped. For NM conditions, each participant wore their headphones while warming-up with no music played. In each testing session, arousal was measured after the warm-up using the felt arousal scale (FAS) (Svebak & Murgatroyd, 1985), and after each test, athletes rated their feeling scale (FS) (Hardy & Rejeski, 1989), FAS, physical enjoyment (PACES) (Kendzierski & DeCarlo, 1991), and RPE (Borg, 1985). To monitor any possible side effects of CAF supplementation, a gastrointestinal discomfort questionnaire was adapted and used (Pereira et al., 2014). To check the success of blinding, each subject was asked to identify which supplement they believed they had consumed. Verbal questioning after every session indicated that almost all participants were unable to distinguish between the supplements. Since CAF (Lara et al., 2020; Lara et al., 2021) and warm-up music (Ghazel et al., 2022) reports showed no impact of the menstrual cycle phase on the stimulus potential, the experiment was conducted throughout the menstrual cycle. The sessions were separated by an interval of one week to allow sufficient recovery between sessions and to ensure CAF washout (Chtourou et al., 2019). All sessions were performed at the same time of day (17:00-18:00 p.m).

Figure1. Schematic presentation of the study. NS: no supplement, CAF: caffeine, PL: placebo, M: music, NM: no music, TSAT: taekwondo specific agility test, FSKT-10s: ten seconds frequency speed of kick test, FSKT-mult: multiple frequency speed of kick test, RPE: rating of perceived exertion, FAS: felt arousal scale, FS: feeling scale, PACES: physical activity enjoyment scale.



2.3. Testing procedures

(a) Physical performances

- *Taekwondo specific agility test:* From a guard position with both feet behind the start/finish line, each athlete moved as quickly as possible towards the center point at their discretion. Then, following her own choice, she moved in sideways towards partner 1 and performed a roundhouse kick with the lead leg. Afterward, they turned and shifted to partner 2 and performed a right roundhouse kick with the other lead leg. Subsequently, they returned to the center, and moved forward to partner 3 in a guard position and performed a double roundhouse kick. Lastly, each athlete returned to the start/finish line (Chaabene et al., 2018). The completion time was measured using photocells (Brower Timing Systems, Salt Lake City, UT, USA). Each athlete performed three trials and the best one was used for analysis. The intra-class correlation coefficient (ICC) for test-retest in the present study was 0.87.
- *Ten seconds frequency speed of kick test:* Throughout the task, the athlete performed the maximum number of bandal-chagui possible against a punching bag by alternating the right and left leg (da Silva Santos et al., 2015). The performance index was determined by the total number of techniques performed during the 10s (da Silva Santos et al., 2015). The ICC for the test-retest in the present study was 0.79.
- *Multiple frequency speed of kick test:* The FSKT-mult presented the multiple version of the FSKT-10s. In fact, each athlete performed the FSKT-10s five times with a 10 s rest interval between repetitions (Da Silva Santos et al., 2016). The total number of kicks performed during the 5 sets represented the performance index of the task. The ICC for the test-retest in the present study was 0.60.

(b) Perceived exertion and psychological measures

- *Rating of perceived exertion:* Athletes rated their perceived exertion after each test using the CR-10 Borg scale (Borg, 1985). This comprised a scale ranging from "0" to "10", with corresponding verbal expressions, which gradually increased with the intensity of perceived sensation (0 = nothing at all; 1 = very week; 2 = week; 3-4 = moderate; 5-6 = strong; 7-9 = very strong; and 10 = extremely strong).
- *The physical activity enjoyment scale:* PACES was used to identify the pleasure and enjoyment level of each participants (Kendzierski & DeCarlo, 1991). The original 18-item version of this scale was used. Items involved 11 negative and 7 positive items measured through a 7-point score ranging from 1 to 7 (Kendzierski & DeCarlo, 1991). Based on the sum of total responses for each athlete, the score could range from 18 to 126.
- *Feeling scale:* The affective responses were assessed using the feeling scale (Hardy & Rejeski, 1989). The FS utilized a single-item 11-point bipolar rating scale ranging from-5 to +5, with the stem ''How do you currently feel?''. Anchors were given at0 (Neutral) and all odd integers, ranging from ''Very Bad'' at -5 to ''Very Good'' at +5. Each athlete reported her FS after each test for each of the conditions.
- *Felt arousal scale:* Along a 6 point scale ranging from low arousal (1 point) to high arousal (6 points), the felt arousal scale was used to measure the level of activation (Svebak & Murgatroyd, 1985). The participants were instructed to mark the scale based on their perceived activation after each test.
- *Gastro-intestinal discomfort questionnaire:* This questionnaire was used to check the presence of any gastro-intestinal problems pre- and post- supplementation. The questionnaire included gastrointestinal symptoms that could be associated with CAF intake (i.e., nausea, vomiting, headache, heartburn, abdominal pain, diarrhea, breathlessness and constipation) (de Souza et al., 2022). Each symptom was considered: 1) absent, 2) mild, 3) moderate, or 4) severe. As a tool for the screening of side effects, this questionnaire does not require a large simple size to be effective (Pereira et al., 2014).

2.4. Statistical analyses

The statistical analysis was performed using SPSS 20.0 statistical software (IBM corps. Armonk, NY, USA). Data were presented as mean and standard deviation and Median and Interquartile range values were reported for non-normal distribution data. The Shapiro-Wilk test was used to check and confirm the normality of data sets, and the Levene test was used to verify the homogeneity of variances. Sphericity was tested using the Mauchly test. For PACES post FSKT-mult, a one-way analysis of variance (ANOVA) (condition) with repeated measurements was used, with Bonferroni was used as post hoc test. Standardized effect size analysis (Cohen's d) was used to interpret the magnitude of differences between variables and considered as: trivial (≤ 0.20); small (≤ 0.60); moderate (≤ 1.20); large (≤ 2.0); very large (≤ 4.0) (very large); and extremely large (> 4.0) (Hopkins, 2002). For the remaining variables (i.e., TSAT, FSKT-10 s, FSKT-mult, RPE, FAS, FS, PACES post-TSAT, PACES post-FSKT-10s), the non-parametric Friedman test was used with the Wilcoxon signed rank test used as post hoc. The correlation coefficient (*r*) was calculated using the Wilcoxon Z-scores and the total number of observations (N) (i.e., $r = Z/\sqrt{N}$) and considered as 0.1 to < 0.3 (small), 0.3 to < 0.5 (moderate) and ≥ 0.5 (large) (Tomczak & Tomczak, 2014). The level of statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Agility performance (TSAT)

There was a significant effect of conditions ($Chi^2 = 56.02$; N=16; df = 5; p < 0.001) with CAF+M eliciting better performance than control (z=-3.52; r = 0.88; p <0.001), NS+M (z=-3.52; r = 0.88; p < 0.001), PL+NM (z=-3.00; r = 0.75; p = 0.003) and PL+M (z=-3.52; r = 0.88; p < 0.001) conditions. Moreover, CAF+NM elicited better performance than control (z=-3.52; r = 0.88; p < 0.001), NS+M (z=-3.00; r = 0.75; p = 0.003), PL+NM (z=-3.05; r = 0.76; p = 0.002) and PL+M (z=-3.52; r = 0.88; p < 0.001). In addition, better performance was recorded under the NS+M (z=-3.52; r = 0.88; p < 0.001), PL+NM (z=-3.18; r=0.80; p=0.001), and PL+M (z=-2.61; r=0.65; p=0.009) conditions as compared to control (Table 1).

3.2. Ten second frequency speed of kicks (FSKT-10s)

There was a significant effect of conditions (Chi^2 = 51.17; N=16; df = 5; p < 0.001). CAF+M induced better performance than control (z=-3.53; r = 0.88; p < 0.001), NS+M (z=-3.53; r = 0.88; p < 0.001), CAF+NM (z=-3.45; r= 0.86; p= 0.001), PL+NM (z=-3.55; r = 0.89; p < 0.001), and PL+M (z=-3.56; r = 0.89; p < 0.001) conditions. Moreover, CAF+NM elicited better performance than control (z= -3.19; r= 0.80; p =0.001), NS+M (z=-2.82; r = 0.71; p = 0.005), PL+NM (z= -3.23; r= 0.81; p=0.001), and PL+M (z= -2.30; r=0.58; p=0.02). In addition, PL+M elicited better performance than control (z= -2.85; r= 0.71; p= 0.004), and PL+NM (z= -2.10; r= 0.53; p=0.04). Furthermore, NS+M condition elicited better performance than control (z=-2.13; r = 0.53; p = 0.03) (Table 1).

3.3. Multiple frequency speed of kicks (FSKT-mult)

There was a significant effect of conditions (Chi^2 = 65.07; N=16; df = 5; p < 0.001). CAF+M resulted in better performance than control (z=-3.54; r = 0.89; p < 0.001), NS+M (z=-3.53; r = 0.88; p < 0.001), CAF+NM (z=-3.52; r= 0.88; p< 0.001), PL+NM (z=-3.53; r = 0.88; p < 0.001), and PL+M (z=-3.52; r = 0.88; p < 0.001) conditions. Moreover, CAF+NM elicited better performance than control (z= -3.55; r= 0.89; p < 0.001), NS+M (z=-3.30; r = 0.83; p = 0.001), and PL+NM (z= -3.35; r= 0.84; p=0.001). Furthermore, PL+M elicited better performance than control (z= -3.43; r= 0.86; p=0.001), NS+M (z= -2.06; r= 0.52; p = 0.04), and PL+NM (z= -2.69; r= 0.67; p= 0.007). In addition, greater performance was recorded under NS+M (z= -3.55; r= 0.89; p < 0.001), and PL+NM (z= -3.44; r= 0.86; p= 0.001) as compared to control (Table 1).

3.4. Perceived Exertion

- RPE_TSAT

  There was a significant effect of conditions (Chi^2 = 43.37; N = 16; df = 5; p < 0.001), with CAF+M eliciting lower values than control (z=-3.56; r = 0.89; p < 0.001), NS+M (z=-3.34; r = 0.84; p = 0.001), CAF+NM (z=-3.34; r = 0.84; p = 0.001), PL+NM (z=-2.98; r = 0.75; p = 0.003) and PL+M (z=-2.50; r = 0.63; p = 0.013) conditions. In addition, lower values were recorded under PL+NM than control (z= -2.68; r= 0.67; p =0.007) and NS+M (z=-2.38; r= 0.60; p= 0.017). Moreover, PL+M elicited lower values than control (z= -3.26; r= 0.82; p=0.001), CAF+NM (z= -2.25; r= 0.56; p= 0.025), and NS+M (z= -2.60; r= 0.65; p=0.009) (Table 2).

- RPE_FSKT-10s

  A significant effect of conditions was recorded (Chi^2 = 46.09; N = 16; df = 5; p < 0.001). CAF+M resulted in lower values than control (z=-3.55; r = 0.89; p < 0.001), NS+M (z=-3.20; r = 0.80; p = 0.001), CAF+NM (z=-3.33; r = 0.83; p = 0.001), PL+NM (z=-3.43; r = 0.86; p = 0.001), and PL+M (z= -3.08; r = 0.77; p = 0.002) conditions. Moreover, NS+M elicited lower values than control (z= -3.12; r= 0.78; p= 0.002), and PL+NM (z= -2.20; r= 0.55; p= 0.027). Furthermore, CAF+NM elicited lower values than control (z= -3.26; r= 0.82; p= 0.001), PL+NM (z= -2.39; r= 0.60; p= 0.017). In addition, PL+M elicited lower values than control (z= -2.81; r= 0.70; p= 0.005) (Table 2).

- RPE_FSKT-mult

  There was a significant conditions' effect (Chi^2 = 45.60; N = 16; df = 5; p < 0.001). CAF+M elicited lower values than control (z= -3.58; r = 0.90; p < 0.001), NS+M (z=-3.10; r = 0.78; p = 0.002), PL+NM (z=-2.74; r = 0.69; p = 0.006), and PL+M (z=-2.72; r = 0.68; p = 0.007) conditions. Moreover, CAF+NM elicited lower values than control (z= -3.46; r= 0.87; p= 0.001), NS+M (z=-2.15; r= 0.54; p= 0.03), PL+NM (z= -2.44; r= 0.61; p= 0.015), and PL+M (z= -197; r= 0.49; p= 0.049). In addition, lower values were recorded under NS+M (z= -2.94; r= 0.74; p= 0.003) and PL+M (z= -2.35; r= 0.59; p =0.019) as compared to control (Table 2).

3.5. Physical enjoyment (PACES)

- PACES_TSAT

There was a significant conditions' effect ($Chi^2 = 62.95$; N = 16; df = 5; $p < 0.001$). CAF+M elicited higher values than control (z= -3.53; r = 0.88; $p < 0.001$), NS+M (z=-3.41; r = 0.85; p = 0.001), PL+NM (z=-3.52; r = 0.88; $p < 0.001$), and PL+M (z=-3.52; r = 0.88; $p < 0.001$) conditions. Moreover, CAF+NM elicited higher values than control (z= -3.42; r = 0.86; p = 0.001), NS+M (z=-3.52; r = 0.88; $p < 0.001$), PL+NM (z=-3.52; r = 0.88; $p < 0.001$), and PL+M (z=-3.52; r = 0.88; $p < 0.001$). In addition, higher values were recorded in the NS+M (z= -2.82; r= 0.71; p=0.005), PL+NM (z= -3.52; r= 0.88; p<0.001), and PL+M (z= -3.16; r= 0.79; p=0.002) as compared to control condition (Table 2).

- PACES_FSKT-10s

There was a significant conditions' effect ($Chi^2 = 40.16$; N = 16; df = 5; $p < 0.001$). CAF+M resulted in higher values than control (z= -3.14; r = 0.79; p = 0.002), NS+M (z=-3.52; r = 0.88; $p < 0.001$), CAF+NM (z=-3.24; r= 0.81; p= 0.001), PL+NM (z=-2.75; r = 0.69; p = 0.006), and PL+M (z=-3.52; r = 0.88; $p < 0.001$) conditions. Moreover, CAF+NM elicited higher values than PL+NM (z=-2.30; r = 0.88; p =0.022), and PL+M (z=-2.46; r = 0.62; p = 0.014). In addition, higher values were recorded under NS+M (z= -2.76; r=0.69; p=0.006), PL+NM (z= -2.05; r=0.51; p=0.041), and PL+M (z=-2.56; r= 0.64; p=0.01) as compared to control (Table 2).

- PACES_FSKT-mult

There was a significant conditions' effect ($F_{5,11} = 52.08$; $\eta_p^2 = 0.96$; p<0.001). CAF+M elicited higher scores than NS+M ($95\%CI_{diff}$: 0.02 to 13.22; p = 0.049; d =1.47), CAF+NM ($95\%CI_{diff}$: 1.07 to 13.43; p = 0.015; d =1.48), PL+NM (95%CIdiff: 15.03 to 23.60; p < 0.001; d = 5.23), and PL+M (95%CIdiff: 7.09 to 19.78; p < 0.001; d = 2.83) conditions. In addition, higher values were recorded under control ($95\%CI_{diff}$: 12.01 to 20.49; p<0.001; d= 4.27), CAF+NM ($95\%CI_{diff}$: 6.98 to 17.15; p < 0.001; d = 2.60), and NS+M ($95\%CI_{diff}$: 7.33 to 18.04; p<0.001; d= 3.02) as compared to PL+NM. Moreover, higher values were recorded under control ($95\%CI_{diff}$: 4.20 to 16.55; p<0.001; d= 2.15), CAF+NM ($95\%CI_{diff}$: 0.37 to 12.01; p = 0.032; d = 1.12), and NS+M ($95\%CI_{diff}$: 1.28 to 12.01; p =0.01; d= 1.32) as compared to PL+M. Furthermore, PL+M elicited higher values than PL+NM ($95\%CI_{diff}$: 0.01 to 11.74; p= 0.049; d= 1.30) (Table 2)

3.6. Feeling scale

- FS_TSAT

There was a significant conditions' effect ($Chi^2 = 46.55$; N = 16; df = 5; $p < 0.001$). CAF+M elicited higher values than control (z= -3.42; r = 0.86; p = 0.001), NS+M (z=-3.24; r = 0.81; p = 0.001), CAF+NM (z=-3.33; r= 0.83; p= 0.001), PL+NM (z=-3.54; r = 0.89; $p < 0.001$), and PL+M (z=-3.42; r = 0.86; p = 0.001) conditions. Moreover, higher values were recorded under NS+M (z= -3.27; r= 0.82; p=0.001), CAF+NM (z= -2.93; r=0.73; p=0.003), and PL+M (z= -2.68; r= 0.67; p= 0.007) conditions as compared to control. In addition, higher values were recorded under NS+M (z= -2.96; r= 0.74; p= 0.003), CAF+NM (z= -2.82; r= 0.71; p= 0.005) and PL+M (z= -2.36; r= 0.59; p= 0.018) as compared to PL+NM (Table 2).

- FS_FSKT_10s

There was a significant conditions' effect ($Chi^2 = 45.14$; N = 16; df = 5; $p < 0.001$). CAF+M elicited higher values than control (z= -3.44; r = 0.86; p = 0.001), NS+M (z=-3.55; r = 0.89; $p < 0.001$), CAF+NM (z=-3.44; r= 0.86; p= 0.001), PL+NM (z=-3.33; r = 0.83; p = 0.001), and PL+M (z=-3.57; r = 0.89; $p < 0.001$) conditions. Moreover, NS+M elicited higher values than control (z= -2.50, r= 0.63; p= 0.012), PL+NM (z= -2.10; r= 0.53; p= 0.036), and PL+M (z= -2.27; r= 0.57; p= 0.023). In addition, CAF+NM elicited higher values than control (z= -2.46; r= 0.62; p= 0.014), PL+NM (z= -1.99; r= 0.50; p= 0.046), and PL+M (z= -2.15; r= 0.54; p= 0.032) (Table 2).

- FS_FSKT-mult

There was a main significant conditions effect ($Chi^2 = 61.75$; N = 16; df = 5; $p < 0.001$). CAF+M elicited higher values than control (z= -3.54; r = 0.89; $p < 0.001$), NS+M (z=-3.54; r = 0.89; $p < 0.001$), CAF+NM (z=-3.54; r= 0.89; p< 0.001), PL+NM (z=-3.53; r = 0.88; $p < 0.001$), and PL+M (z=-3.54; r = 0.89; $p < 0.001$) conditions. Moreover, NS+M elicited higher values than control (z= -3.34, r= 0.84; p= 0.001), and PL+NM (z= -2.58; r= 0.65; p= 0.01). In addition, CAF+NM elicited higher values than control (z= -3.42; r= 0.86; p= 0.001), NS+M (z=-2.08; r= 0.52; p= 0.038), PL+NM (z= -3.22; r= 0.81; p= 0.001), and PL+M (z= -2.03; r= 0.51; p= 0.042). Furthermore, PL+M elicited higher values than control (z=-3.53; r= 0.88; p<0.001), and PL+NM (z= -2.77; r= 0.69; p=0.006). Finally, PL+NM elicited higher values than control (z=-3.11; r= 0.78; p=0.002) (Table 2).

3.7. Felt arousal scale

- FAS_warm-up

  There was a significant conditions effect (Chi^2 = 43.59; N = 16; df = 5; p < 0.001). CAF+M elicited higher values than control (z= -3.44; r = 0.86; p = 0.001), NS+M (z=-3.33; r = 0.83; p = 0.001), CAF+NM (z=-3.44; r= 0.86; p=0.001), PL+NM (z=-3.55; r = 0.89; p < 0.001), and PL+M (z=-2.97; r= 0.74; p =0.003). In addition, PL+M elicited higher values than control (z= -2.51; r= 0.63; p= 0.012), PL+NM (z= -3.08; r= 0.77; p= 0.002), and CAF+NM (z= -1.99; r= 0.50; p= 0.047). Moreover, NS+M elicited higher values than control (z= -2.44; r= 0.61; p= 0.015), and PL+NM (z= -2.11; r= 0.53; p= 0.034). Furthermore, PL+M elicited higher values than control (z= -2.51; r= 0.63; p= 0.012), PL+NM (z= -3.08; r= 0.77; p= 0.002), and CAF+NM (z= -1.99; r= 0.50; p= 0.047) (Table 2).

- FAS_TSAT

  There was a significant conditions' effect (Chi^2 = 50.46; N = 16; df = 5; p < 0.001). CAF+M elicited higher values than control (z= -3.43; r = 0.86; p = 0.001), NS+M (z=-2.33; r = 0.58; p = 0.02), CAF+NM (z=-2.28; r= 0.57; p=0.02), and PL+NM (z=-3.43; r = 0.86; p = 0.001). Moreover, higher values were recorded under NS+M (z= -3.50, r= 0.88; p< 0.001) and CAF+NM (z= -3.12; r= 0.78; p= 0.002) as compared to control. In addition, higher values were recorded under and NS+M (z= -3.48; r= 0.87; p< 0.01) and CAF+NM (z= -3.31; r= 0.83; p= 0.001) as compared to PL+NM. Furthermore, PL+M elicited higher values than control (z=-3.21; r= 0.80; p=0.001), and PL+NM (z= -3.24; r= 0.81; p=0.001) (Table 2).

- FAS_FSKT_10s

  There was a significant conditions effect (Chi^2 = 46.13; N = 16; df = 5; p < 0.001). CAF+M induced higher values than control (z= -3.56; r = 0.89; p < 0.001), NS+M (z=-3.55; r = 0.89; p < 0.001), CAF+NM (z=-3.21; r= 0.80; p=0.001), PL+NM (z=-3.57; r = 0.89; p < 0.001) and PL+M (z= -3.60; r= 0.90; p<0.001). In addition, CAF+NM elicited higher values than control (z= -2.86; r= 0.72; p= 0.004), and NS+M (z=-1.97; r= 0.49; p= 0.049). Moreover, higher values were recorded under NS+M (z= -2.31, r= 0.58; p= 0.02) and PL+M (z=-2.95; r= 0.74; p=0.003) as compared to control (Table 2).

- FAS_FSKT-mult

  There was a significant conditions' effect (Chi^2 = 48.95; N = 16; df = 5; p < 0.001). CAF+M elicited higher values than control (z= -3.55; r = 0.89; p < 0.001), NS+M (z=-3.55; r = 0.89; p < 0.001), CAF+NM (z=-3.55; r= 0.89; p<0.001), PL+NM (z=-3.56; r = 0.89; p < 0.001) and PL+M (z= -3.56; r= 0.89; p<0.001). Moreover, higher values were recorded under NS+M (z= 3.21; r= 0.80; p= 0.001), CAF+NM (z= -2.44; r= 0.61; p= 0.015), and PL+M (z=-2.12; r= 0.53; p= 0.034) as compared to control. Furthermore, higher values were recorded under NS+M (z= -2.07; r= 0.52; p= 0.039) and CAF+NM (z= -2.07; r= 0.52; p= 0.039) as compared to PL+NM (Table 2).

3.8. Gastro-intestinal discomforts

Before supplementation, under the CAF+NM condition, three athletes reported moderate headache symptoms and four others reported moderate diarrhea symptoms. Moreover, one athlete reported moderate headache symptoms and three others reported moderate diarrhea symptoms, under the CAF+M condition. After supplementation, five athletes (one of them from before supplementation) reported moderate headache symptoms and four (two of them from before supplementation) reported moderate headache symptoms under the CAF+NM condition. Under the CAF+M condition, the same three athletes reported moderate diarrhea symptoms as before supplementation and another one athlete reported moderate headache symptoms.

Table 1. Physical performance of female taekwondo athletes (*n*=16).

	Control		NS+M		CAF+NM		PL+NM		PL+M		CAF+M	
	***M* (*SD*)**	**Mdn/ IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**
TSAT (s)	6.15 (0.27)	6.14/0.33	5.82 (0.31) [*]	5.95/0.58	5.53 (0.11) [*,b,ϕ,d]	5.51/0.16	5.81 (0.33)[a]	5.76/0.62	5.87 (0.20)[a]	5.86/0.33	5.50 (0.26) [*,$, ϕ,d]	5.43/0.43
FSKT-10s (*n*)	24.19 (1.33)	25/2	24.94 (1.34) [a]	25/ 2	26.56 (1.55) [a,b,ϕ,¥]	26/2	24.50 (1.10)	24/1	25.38 (1.15) [a,ϕ]	25/1	29.5 (0.89) [*,$,§,c,d]	29.5/1
FSKT-mult (*n*)	122 (1.37)	122/2	124.81 (1.60) [*]	125/2.75	126.94 (1.57) [*,b,ϕ]	127/3	123.94 (1.53) [a]	124/ 2	125.75 (1.84) [a,b,ϕ]	125.5/3.5	131.69 (1.70) [*,$,e,c,d]	131.5/3

TSAT: taekwondo specific agility test; FSKT-10s: 10s frequency speed of kick test; FSKT-mult: multiple version of FSKT; *: Different from control at p < 0.001; a: different from control at p < 0.05; $: different from NS+M at p < 0.001; b: different from NS+M at p < 0.05; c: different from PL+NM at p < 0.001; ϕ: different from PL+NM at p < 0.05; d: different from PL+M at p < 0.001; ¥: different from PL+M at p < 0.05; e: different from CAF+NM at p < 0.001; §: different from CAF+NM at p < 0.05; NS+M: No supplement with music: CAF+NM; caffeine with no music; PL+NM: placebo with no music; PL+M: placebo and music; CAF+M: caffeine and music; s: seconds; n: number of techniques; *Mdn*/IQR: median/interquartile range.

Table 2. Perceived exertion (RPE), physical enjoyment (PACES), feeling scale (FS), and felt arousal scale (FAS) of female taekwondo athletes under each condition (*n* = 16).

		Control		NS+M		CAF+NM		PL+NM		PL+M		CAF+M	
		***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**	***M* (*SD*)**	***Mdn*/IQR**
RPE	TSAT	4.94 (1.12)	5/1	4.44 (0.96)	4.5/1	4.31 (0.95)	4/1	3.56 (1.26) [a,b]	3.5/ 2.5	3.19 (1.28) [a,§,b]	3/2	2.31 (0.79) [*,b,§,ϕ,¥]	2/1
	FSKT-10s	7.25 (0.68)	7/1	5.88 (0.96) [a,ϕ]	6/2	5.88 (0.62) [a,ϕ]	6/0.75	6.81 (1.22)	7/1.75	6.06 (1.18) [a]	6/2	3.94 (1) [*,b,§,ϕ,¥]	4/1.75
	FSKT-mult	9.63 (0.50)	10/1	8.63 (0.96) [a]	9/1	7.75 (0.93) [a,b,ϕ,¥]	8/1.75	8.94 (2.17)	9/1	8.63 (2.16) [a]	9/1.75	7.31 (0.60) [*,b,ϕ,¥]	7/1
PACES	TSAT	62.56 (3.69) [b,c,¥]	62.5/ 5.75	55.81 (4.28)	56/ 7.5	70.56 (3.78) [a,$,c,d]	70.5/ 4.5	54.56 (3.42)	55/ 5.75	54.88 (5.60)	55/10	74.44 (1.77) [*,b,c,d]	72/ 7.5
	FSKT-10s	62.63 (5.25)[b,ϕ,¥]	62/ 7.5	59.38 (3.38)	59.50/ 6.5	61.69 (4.11)[ϕ,¥]	62/ 6.75	58.81 (8.70)	56.5/ 5.75	57.94 (4.17)	58.5/ 5.75	68.56 (3.54) [a,$,§,ϕ,d]	68.5/ 5.25
	FSKT-mult	66.94 (4.20) [ϕ,d]	–	63.38 (4.91) [c,¥]	–	62.75 (5.63) [c,¥]	–	50.69 (3.36)	–	56.56 (5.40) [ϕ]	–	70.00 (4.00) [b,§,c,d]	–
FS	TSAT	-0.75 (1.48)	-0.5/2	1.31 (0.95) [a,ϕ]	1/1	1.31 (1.20) [a,ϕ]	1/1	-0.38 (1.41)	0/2.75	0.88 (0.96) [a,ϕ]	1/1.75	3.25 (1.06) [a,b,§,c,¥]	3/2
	FSKT-10s	-0.75 (1.57)	-0.5/2	0.50 (0.63) [a,ϕ,¥]	0/1	0.56 (0.73) [a,ϕ,¥]	0/1	-0.31 (1.20)	0/1.75	-0.38 (1.41)	-1/2.75	2.69 (0.95) [a,$,§,ϕ,d]	2.5/ 1.75
	FSKT-mult	-3.50 (1.15)	-3.5/2.5	-0.75 (1.53) [a,ϕ]	-1/2.75	0.19 (1.17) [a,b,ϕ,¥]	0/2	-2.06 (1.18) [a]	-2/ 1.75	-0.63 (0.96) [*,ϕ]	-1/ 1	2.69 (1.25) [*,$,e,c,d]	2/1.75
FAS	Warm-up	2.44 (0.89)	2/1	3.25 (0.93) [a,ϕ]	3/1.75	2.81 (1.11)	2/1.75	2.38 (0.89)	2/1	3.5 (1.15) [a,ϕ,§]	3.5/2.5	5.13 (0.72) [a,b,§,c,d]	5/1
	TSAT	1.31 (0.48)	1/1	2.81 (0.83) [*,c]	3/1.75	2.56 (0.89) [a,ϕ]	2/1	1.31 (0.48)	1/1	3.25 (1.24) [a,ϕ]	3/2	3.88 (1.50) [a,b,§,ϕ]	4/2.75
	FSKT-10s	1.31 (0.60)	1/0.75	1.88 (0.72) [*,c]	2/1	2.63 (1.15) [a,ϕ]	2.5/2	1.94 (0.85)	2/2	2.19 (0.75) [a,ϕ]	2/0.75	4.69 (0.70) [a,b,§,ϕ,d]	5/1
	FSKT-mult	1.19 (0.40)	1/0	1.94 (0.57) [a]	2/0	1.94 (0.77) [a,b]	2/1.75	1.38 (0.50)	1/1	1.56 (0.51) [a]	2/1	4.56 (0.73) [*,$,§,c,d]	4/1

*: Different from control at p < 0.001; a: different from control at p < 0.05; $: different from NS+M at p < 0.001; b: different from NS+M at p < 0.05; c: different from PL+NM at p < 0.001; ϕ: different from PL+NM at p < 0.05; d: different from PL+M at p < 0.001; ¥: different from PL+M at p < 0.05; e: different from CAF+NM at p < 0.001; §: different from CAF+NM at p < 0.05; NS+M: No supplement with music: CAF+NM; caffeine with no music; PL+NM: placebo with no music; PL+M: placebo and music; CAF+M: caffeine and music; *Mdn*/IQR: median/interquartile range; TSAT: taekwondo specific agility test; FSKT-10s: 10s frequency speed of kick test; FSKT-mult: multiple frequency speed of kick test.

4. Discussion

This study is the first to analyze the acute effects of combining supplementation of a low dose of CAF and listening to music during warm–up on female taekwondo athletes' performance. The findings demonstrate that the combined use of pre-task CAF intake followed by preferred warm-up music enhanced female athletes' subsequent taekwondo performance and psychophysiological responses when compared with using either strategy alone.

The acute effects of CAF and warm-up music have been rarely and independently investigated using female combat sports athletes; hence it is difficult to effectively compare our results with those obtained in previous studies. Nevertheless, it is pertinent to evaluate both the independent and synergist effects elicited by these strategies, and consider the prospective mechanisms of action. Regarding CAF intake, previous studies (Arazi et al., 2016; Pereira et al., 2010) on female combat sports athletes have reported no ergogenic effect of the supplement even with higher doses (5-6 mg/kg). However, it should be noted that the aforementioned studies have previously used generic testing procedures, which may limit athletes' responses to the supplement, and/or the tests sensitivity in detecting small, but meaningful, changes in performance (Delleli et al., 2022). Using specific taekwondo tasks, Ouergui et al. (2023) reported improvements in agility and the number of techniques executed by elite female athletes 60 min after the intake of 3 mg/kg of CAF. In addition to the confounding influences of test specificity, the severity of adverse effects associated with using high dosages of CAF might also account for some the disparity observed between the findings of the present study and previous research (Norum et al., 2020). In support of this notion, a recent meta-analysis conducted by Grgic (2022) indicated that relatively low doses of CAF elicit comparable performance improvements as moderate-high doses on tests of muscular strength, muscular endurance and mean velocity, albeit with markedly lower prevalence of side effects.

CAF benefits have been reported to be altered by steroid hormones (Temple & Ziegler, 2011). Recently, Grgic & Varovic (2023) revealed the ergogenic potential of CAF at the different menstrual cycle phases in female athletes, with greater benefits observed during the follicular phase. However, such findings have not been observed consistently within the literature. Muñoz et al. (2020) highlighted jumping, handgrip strength and sprinting performance's enhancement in elite female handball players with different menstrual cycle phase, 60 min after 3 mg/kg CAF intake. Similarly, Lara et al. (2020) reported that 3 mg/kg of CAF enhanced female triathletes' performances during the 15 s Wingate test throughout different menstrual cycle phases. The findings of our study suggest that ingestion of 3 mg/kg of CAF prior to the warm-up can improve taekwondo specific performance in female athletes through their menstrual cycle.

Regarding warm-up music, benefits from preferred music have been documented using mix-gender and adolescent samples of taekwondo athletes (Ibrahim Ouergui, Arwa Jebabli, et al., 2023; I. Ouergui et al., 2023). Previous research conducted on female handball players suggested that preferred warm-up music stimulus enhanced short-term maximal performance regardless of the menstrual cycle phases (Ghazel et al., 2022). Such results were explained by the fact that menstrual cycle phases do not influence muscle glycogen intake during a short period of intense exercise (Tsampoukos et al., 2010). Although no hormonal variation was measured in the present study, our current findings support the idea that female athletes might benefit from performance improvements by listening to preferred warm-up music throughout different phases of their menstrual cycle. It's pertinent to note, however, that the ergogenic benefits accrued from listening to preferred music during the warm-up could potentially dimmish over time (Aloui et al., 2015), perhaps more so than the ergogenic effects of caffeine, especially in relation to the typical half-life of CAF in plasma, and since CAF metabolism is often lower in females (Lara et al., 2020).

The combined use of pre-task CAF intake followed by preferred warm-up music were 'additive' in our female athletic population, eliciting greater subsequent taekwondo performance and more desirable psycho-physiological responses when compared with using either strategy alone. Such findings are similar to those previously reported within male taekwondo athletes (Delleli et al., 2023). Plausibly, at the central level, CAF antagonist effects on adenosine serve to improve alertness and activate the central nervous system (Davis et al., 2003). From a music perspective, the use of a motivational music induces a brain state whereby an individual vigorously monitors his/her surroundings and quickly identify pertinent targets (Bishop et al., 2013). At the peripheral level, CAF may improve motor unit recruitment and synchronization, perhaps via improved intramuscular metabolic milieu (Davis & Green, 2009; Lima-Silva et al., 2021). CAF effects were, possibly, supported by music's actions on oxygen transmission to the active muscles and power production via stimulating hormonal release (i.e., adrenergic hormones) (Yamamoto et al., 2003).

Music is often used to boost performance, balance emotional and physical exhaustion, and serve as a motivator (Chtourou et al., 2012). The present study showed that, when used together, CAF and warm-up music induced greater effects on female athletes' psychophysiological responses (i.e., PACES post_FSKT-10s, FS, FAS post_warm-up, FAS post_FSKT-10s and FAS post_FSKT-mult). These results may make the synergetic effects of warm-up music and CAF somewhat generalizable when considering previous findings in male sample (Delleli et al., 2023). In fact, when motivational music is played, it stimulates the central nervous system in a way that mirrors increases in physiological arousal, which is linked to high-intensity exercise (Bishop et al., 2013). In fact, with preferred music, listeners present increased motivation and pleasure to exercise (Ballmann, 2021). In concert, CAF may serve to modulate dopamine secretion, through the adenosine receptors (Domaszewski, 2023). These processes that are proposed to regulate dopamine production or the rate at which dopaminergic neurons fire may be responsible for affecting behavioral activation, mood, and effort-related (Guest et al., 2021). However, when it was played during warm-up, previous studies reported deterioration of warm-up music effects by increased fatigue level (Aloui et al., 2015; Stork et al., 2015). In the present study preceding warm-up music by a low dose of CAF decreased perceived exertion despite the increased exercise intensity. This might be related to CAF analgesic effects and its efficacy to reduce fatigue rate through brain oxygenation via crossing the blood-brain barrier (Dominguez et al., 2021). Additionally, it may have an extended effect by potentiating neurotransmitter release and improving motor neuron transmission (Bishop, 2010). The intensity of the warm-up might also be an important factor in regulating the efficacy of this strategy.

The greater effects of low dose of CAF and warm-up music when compared to their separate effects (e.g., when compared to caffeine) were noted in most performance outcomes except for TSAT, PACES post-TSAT and RPE post-FSKT-mult. This could be of great importance in high level competition settings, where a small difference determines the winner (Dominguez et al., 2021). In fact, combining a low dose of CAF with warm-up music may help athletes to better manage the combat demands with negligible adverse effects. Moreover, this study presents novel information on female athletes involved in combat sports who have previously been underrepresented in the literature. Whilst this study is the first to investigate the synergetic effects of CAF and warm-up music on female athletes, some limitations should be highlighted. These include the omission of concomitant measures of plasma CAF and hormonal concentrations, which may provide further insight into the prospective mechanisms. Moreover, athletes' responses were analyzed for the whole menstrual cycle and not differentiate based on its phases. Finally, the study of different rest interval after supplementation and controlling for athletes' genotype could generate more individualized results and optimize the efficacy of this strategy in the field.

5. Conclusions

This study demonstrated that 3 mg/kg caffeine ingestion followed by listening to preferred music during warm-up enhanced specific fitness performance and affective valence in female taekwondo athletes, with negligible side effects. The combined warm-up music and CAF ingestion increased exercises' intensity with more desirable psychological responses while maintaining lower perceived exertion. The benefits from such combination persisted throughout single and repeated bouts of kicking exercise, which may implicate its effectiveness as pre-competition conditioning strategy. As well, athletes may perform harder with higher motivation to compete or train. This is may help both trainers and coaches to achieve their objectives with lower energy and time costs. Therefore, female taekwondo athletes may consider using this strategy pre-competition and training as an effective and safe ergogenic aid to enhance their performance.

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