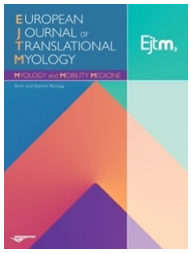
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Ergogenic effects of beetroot juice supplementation on neuromuscular function and simulated combat demands in elite female taekwondo athletes

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Abstract

Beetroot juice supplementation has been widely examined across various sport disciplines due to its potential ergogenic effects. However, evidence regarding its impact on combat sports particularly in female athletes remains limited. The aim of this study was to evaluate the acute effects of beetroot juice supplementation on simulated taekwondo combat performance and neuromuscular function in elite female taekwondo athletes. Seven elite female Olympic taekwondo athletes (age: 20.3 ± 3.7 years), participated in a randomized, double-blind, placebo-controlled study consisting of two experimental trials). Each trial involved the consumption of either 140 mL of beetroot juice (which contains 12.8 mmol NO_3^-) or 140 mL of a placebo (with 0.08 mmol NO_3^-) followed by a simulated taekwondo combat session and assessments of neuro-muscular function (*i.e.*, vertical jump and visual cognitive performance). In addition, metabolic (*i.e.*, blood lactate), and perceptual responses (*i.e.*, rate of perceived exertion) were measured before, after, and 3 minutes post-combat. No significant differences during the simulated taekwondo combat (e.g., attack time; $p = 0.531–0.989$; $\eta p^2 = 0.01–0.05$), neuromuscular function battery ($p = 0.302$-0.700; $\eta p^2 = 0.02$-0.04), blood lactate concentrations ($p = 0.705$; $\eta p^2 = 0.13$), or rate of perceived exertion values (RPE) ($p = 0.717$; $\eta p^2 = 0.12$) were obtained between beetroot juice and placebo conditions. Acute ingestion of beetroot juice (140 mL) did not enhance simulated combat performance or neuromuscular function in female Olympic taekwondo athletes.

Key words: nitrate, nitrite, combat sports, female athletes.

Taekwondo is a combat sport practiced around the world, officially recognized as an Olympic sport in 210 countries.[1] It is characterized by alternating high-intensity efforts with moderate to low-intensity periods, which serve as rest intervals.[2] Taekwondo competitions are composed by three 2-minute rounds separated by 1-minute rest intervals. During these rounds, athletes perform striking sequences lasting approximately 1 to 5 seconds, followed by active pauses (e.g. bouncing movements) lasting 10 to 35 seconds. Overall, the work-to-rest ratio typically ranges from 1:2 to 1:7.[3,4] with the aim to defeat the opponent by scoring more points through effective kicking and punching techniques aimed at designated scoring areas, or by achieving a technical knockout.[5] Taekwondo performance is determined by several factors, including technical, tactical, physical, and psychological aspects.[5] From a physical perspective, the high-intensity intermittent efforts required in taekwondo place a substantial demand on non-oxidative metabolic pathways. These metabolic demands are primarily supported by the rapid degradation of Phosphocreatine (PCr) and, to a lesser extent, by glycolysis, highlighting the high metabolic needs and dependence on non-oxidative energy systems in this sport (≈ 8 $mmol \cdot L^{-1}$ of blood lactate concentration).[4,6] Taekwondo athletes need to develop their oxidative metabolism to re-plenish phosphocreatine and enhance recovery between consecutive matches during a tournament.[3] Thus, all energy sources are utilized to varying degrees during taekwondo matches, suggesting that improved efficiency in metabolic pathways could enhance performance.[3-5]

Due to the minimal differences in performance that may determine success in high-level taekwondo athletes, dietary supplements have been suggested to enhance the physiological and physical performance of these athletes.[7,8] In this regard, previous research shows that 47.4% of men and 41.7% of women practicing taekwondo use dietary supplements to enhance performance.[9] However, only a limited number of dietary supplements have demonstrated moderate to strong evidence for enhancing exercise performance such as caffeine, creatine, sodium bicarbonate, β-alanine, and beetroot juice.[8,10] Beetroot juice is a rich source of nitrates (NO_3^-), which are converted into Nitrite (NO_2^-) in the oral cavity by the action of oral bacteria that express the enzyme nitrate reductase.[11] In the stomach, nitrite is further converted to nitric oxide (NO).[12] This process leads to improvements in blood flow,[12] energy efficiency,[13] muscle contractility,[14] neurotransmitter release[15] and enhancing PCr resynthesis.[14] All these physiological effects may potentially enhance taekwondo performance. However, to our knowledge, only two previous studies have specifically investigated the effects of beetroot juice in male taekwondo athletes. Miraftabi *et al.* (2021) conducted a study on male taekwondo athletes from the Iranian National Taekwondo League to analyze the effects of acute doses of NO_3^- at 400 mg and 800 mg on taekwondo-specific performance and cognitive function tests, compared to a placebo conditions. This study found an improvement in cognitive function with a 400 mg dose of $NO_3^-$when compared to the other treatments. However, no statistically significant differences were observed in taekwondo-specific performance.[16] In another study, Khosravia *et al.* (2021) investigated the impact of six days of beetroot juice supplementation on muscle performance during isokinetic contractions of the knee in semi-professional male taekwondo athletes. Their findings indicated that short-term beetroot juice supplementation improved bilateral muscle strength at the highest velocities of isokinetic contractions and decreased fatigue during contractions of the knee extensors.[17] However, to the best

of our knowledge, no previous studies have examined elite female taekwondo athletes during a simulated competition being essential to determine the potential ergogenic effects of beetroot juice on female taekwondo performance.

Thus, the first aim of the present study was to assess the effectiveness of acute supplementation with 140 mL of beetroot juice (*i.e.*, containing 12.8 mmol NO_3^-) or a 140 mL placebo (*i.e.*, containing 0.08 mmol NO_3^-) on performance during a simulated combat in elite female taekwondo athletes. The second aim was to evaluate the effect of beetroot juice enriched supplementation on neuromuscular function (e.g., countermovement jump and cognitive velocity reaction test), metabolic (blood lactate concentration), and perceptual (*i.e.*, Rating of Perceived Exertion (RPE) responses.

Material and Methods

Participants

Nine elite female Olympic taekwondo athletes from different countries, who were participating in an international training camp, were assessed for eligibility. The inclusion criteria were: i) female taekwondo athletes; ii) aged between 16 and 40 years; iii) active participation in international competitions representing their national teams; and iv) a minimum of 10 years of taekwondo training experience with at least six training sessions per week. Exclusion criteria included i) intolerance to beetroot juice or NO_3^-derivatives; ii) any chronic pathology or injury occurring within three months prior to the study; iii) the use of medications or dietary supplements (e.g., caffeine) during the study; and iv) failure to attend all experimental sessions. After the initial screening, eight participants were recruited for this study. One athlete was excluded due to not attending one of the experimental sessions, resulting in a final study sample of seven elite female Olympic taekwondo (*i.e.*, one Olympic gold medallist, one Olympic silver medallist, and five medallists at the World or European Championships), being all athletes classified as Tier 5[18] (Figure 1). The participants' characteristics were age: 21.7 ± 3.8 years; weight: 57.5 ± 6.8 kg; height: 167.7 ± 5.5 cm; body mass index: 20.66 ± 1.47 $kg \cdot m^{-2}$. During the current season, participants trained an average of 6.71 ± 0.45 sessions per week, totaling 13.43 ± 0.9 hours weekly (including 9.57 ± 0.79 hours for technique-tactical training and 5.43 ± 0.98 hours for strength and conditioning). Two participants competed in the category under 49 kg, four in the range between 53 kg and 57 kg, and one in the category between 62 kg and 67 kg. The classification was done according to the participant classification framework. Prior to the start of the study, the research team held an informative session to explain the experimental protocols, and all participants provided their in-formed written consent to participate. The study complied with the Declaration of Helsinki and received ethics approval from the Bioethics Commission of the CEIm at Hospital Clínico San Carlos (code: 22/172-E_TFM). The study was also retrospectively registered at ClinicalTrials.gov under the identifier NCT06675305.

Experimental design

This study employed a randomized, double-blind, placebo-controlled crossover design. Each athlete completed two identical experimental trials separated by a one-week interval, consistent with previous studies using similar crossover protocols.[16] The order of the trials was randomized for each athlete using an online randomization tool (https://www.randomizer.org/). An independent researcher assigned alphanumeric codes to each trial to maintain blinding for both athletes and researchers throughout the study. These codes were revealed to the researchers only after the statistical analysis was completed. Five days before the first testing session, athletes took part in a familiarization session that included detailed explanations, demonstrations, and the completion of the testing battery to reduce learning effects. To maintain consistency across sessions, all tests were conducted in the same order, at the taekwondo facilities where the athletes regularly trained, and at the same time of day (9:30 AM). This approach was taken to minimize the impact of circadian variations on sports performance.[19]

Experimental protocol

Participants were randomly assigned to receive either 140 mL of beetroot juice, which contains 12.8 mmol of NO_3^- (two shots of 70 mL) made from 98% BRJ concentrate and 2% lemon juice, or a taste-matched placebo drink that contains only 0.08 mmol of nitrate (also two shots of 70 mL each)(nutritional information (per 100 mL), energy: 373 kJ; fat: 0 g; carbohydrates: 18 g [sugars: 17 g]; protein: 3.7 g; salt: 0.48 g) or 140 mL (*i.e.*, two shots of 70 mL) of a taste-matched placebo drink (0.08 mmol of NO3-, Beet-It-Pro Elite Shot, James White Drinks Ltd., Ipswich, UK). Beetroot juice and placebo were administered once, at the same time (7:00 AM) in identical bottles to prevent identification of the substances consumed, and 150 minutes before performance measurements began, following established protocols.[20] This timing was chosen to align with previous studies indicating that peak nitrate/nitrite ($NO_3^-$and NO_2^-) responses occur 2–3 hours post-ingestion.[21] A standardized diet was prescribed by a dietitian 48 hours before the beginning of the experimental sessions. The diet provided 44.8 kcal per kilogram of fat-free mass, with the following macronutrient distribution: 6.5 g of carbohydrate per kilogram of fat-free mass, accounting for 58.0% of total energy intake; 2.0 g of protein per kilogram of fat-free mass, accounting for 17.9% of total energy intake; and 1.2 g of fat per kilogram of fat-free mass, accounting for 24.1% of total energy intake. In addition, to avoid any possible interaction with the NO_3^-content of the diet, foods high or moderate in NO_3^-were restricted, such as beetroot, spinach, cabbage, celery, lettuce, escarole, and carrot. Also, to minimize the potential ergogenic effects of caffeine in the diet, foods high in caffeine, such as coffee, tea, mate, chocolate, cocoa, gels, and energy bars, were avoided. Additionally, 24-hours prior to each experimental session, participants were advised to avoid using any oral antiseptic rinses, as well as refraining from brushing their teeth, chewing gum, or consuming sweets, due to could potentially alter the oral microbiota and interfere with the reduction of nitrate $NO_3^-$to nitrite NO_2^-.[22, 23] During the experimental sessions, female taekwondo participants first completed a standardized warm-up specific to taekwondo (see Table 1). Following the warm-up, they performed a neuromuscular battery consisting on countermovement jump and a cognitive test before engaging in simulated taekwondo combat. After a 3-minute recovery period, participants took part in the simulated combat, which consisted of three bouts, each lasting 2 minutes, with a 1-minute recovery interval between bouts. To ensure consistency between experimental conditions, each athlete faced the same opponent during both the beetroot juice and placebo trials. Opponents

were instructed to compete at maximal intensity in all bouts to standardize the physiological and technical demands of the simulated combat. The opponents were also participants in the study, with the exception of one athlete who served only as an opponent and did not participate in the experimental protocol. After each bout, RPE was recorded. Immediately after the third bout, blood lactate concentration was measured, and a second measurement was taken 3 minutes post-combat (Figure 2). Additionally, a counter-movement jump was performed at 0.5 minutes (0.5 min post) and 3 minutes (3 min post) after combat, and a cognitive test was administered immediately before and immediately after combat (0.5 min post).

Simulated taekwondo combat session demands

Simulated taekwondo combat was conducted according to the World Taekwondo guidelines, with participants divided into Olympic weight categories. All the matches took place in an officially sanctioned octagonal competition area, supervised by an international referee who was unaware of the experimental treatments being used. Currently, the rules of the World Taekwondo Federation (WTF) require the use of electronic protectors for athlete safety and to accurately record scoring. Nevertheless, the use of complete protective equipment, without activating the electronic punctuation system, did not distract the participants and ensured their safety. Additionally, there was no form of encouragement provided during the combats. Each combat was divided into three rounds, lasting 2 minutes each, with a 1-minute recovery period between rounds. All the combats were recorded using two Canon 700D cameras, which provided high-quality footage. The cameras were positioned in front of the mat, capturing each competitor from the left and right at the start of the recording. After-ward, a frame-by-frame analysis of each bout was conducted using computer software (Filmora, Wondershare Technology, China) to determine various sports performance variables. In this way, two experienced researchers independently analyzed each combat, focusing on potential discrepancies in their findings. Through this analysis, they established a time/movement relationship to estimate the work/recovery dynamics of each combat, using the criteria set forth Santos *et al.* (2011). The variables examined included Attack Time (AT), Step Time (ST), Pause Time (PT), and the Period Without Attack (PWA = ST + PT), as well as the Number of Attacks (AN). Additionally, they calculated two ratios: the ratio of attack time to step time (R1 = AT/ST) and the ratio of the total action time to pause time (R2 = (AT + ST) / PT).[6] In contrast to the approach taken by Santos *et al.* (2011), which analyzed the timing of actions independently, this study focuses on assessing the total duration of each action across all rounds.[6] This method offers a more comprehensive understanding of how the supplement affects the athletes' physical capacity.

Neuromuscular function test battery

Vertical jump capacity was measured using a countermovement jump started from a stationary standing position, with weight evenly distributed over both feet. Participants descended to approximately 90 knee flexion before performing an ex-plosive jump to reach maximum height.[20] Participants were instructed to keep their hands on their hips throughout the entire CMJ and were

required to maintain their knees fully extended during the flight phase until landing. The test consisted of two jumps, with a 30-second recovery period in between. The best result was selected, as previously reported in the literature. Participants were encouraged to achieve a maximum vertical jump height via countermovement jump was assessed with athletes keeping their legs extended and their hands placed on their hips.[20] Additional attempts were permitted until the heights of two consecutive jumps differed by less than 10% for each jump type. The test was repeated 30 seconds and 3 minutes after the simulated combat. For both pre- and post-combat assessments, maximum jump height was recorded using an infrared jump system (Optojump, Microgate, Italy). The instrument's Intraclass Correlation Coefficient (ICC) has been previously reported as 0.982. Visual response time was measured using BlazePod™ (Play Coyotta Ltd., Tel Aviv, Israel). Prior to the first experimental sessions, participants completed a familiarization session with the device. Female taekwondo players were positioned one meter away from a wall where five pods were arranged in a cross shape, each pod separated by 30 cm. For 60 seconds, participants reached out to touch the pod that was emitting a light signal each time they received a visual stimulus and then returned to the starting position. They were instructed to stand in the initial position and try to tap as many lights as possible with their dominant foot within the 60-second time frame. The pods lit up in a random order that was unknown to both the participants and the researchers. The distance between the pods was consistently maintained at 30 cm (Figure 3). The average reaction time for the entire trial was recorded. This test was conducted before simulated combat, right after simulated combat, and each participant completed two attempts with a one-minute rest interval in between. The best reaction time from the two attempts was selected for further statistical analysis. ICC for this procedure was previously reported at 0.820.[24]

Blood lactate concentrations and Rating of Perceived Exertion (RPE)

Before the warm-up, researchers collected a blood sample to determine baseline blood lactate concentrations (Pre). Subsequent blood samples were obtained immediately after the simulated combat (Post) and again 3 min after its completion (Post-3). Blood samples were collected from the fingertip of the index finger of the participants' left hand using a Lactate Pro 2 LT-1710 analyzer (Arkray Factory Inc., KDK Corporation, Shiga, Japan). Immediately after each of the three combat rounds, participants reported their Rating of Perceived Exertion (RPE) using a modified 1–10 scale.

Statistical analysis

All data are presented as means ± standard deviations. A Shapiro-Wilk test was used to confirm the normality of the variables, while homogeneity was assessed using Levene's test. To evaluate differences across time and between the two experimental conditions for each variable, a repeated measures analysis of variance (ANOVA-RM) was conducted, incorporating the factors of time (*i.e.*, different measurement points) and supplementation (beetroot juice versus placebo), as well as their interaction. Effect sizes for the ANOVAs were measured using partial eta squared (ηp^2), which was interpreted as follows: trivial ($\eta p^2 \leq 0.01$), small ($0.01 < \eta p^2 < 0.06$), medium ($0.06 \leq \eta p^2 < 0.14$), or large ($\eta p^2 \geq 0.14$). If statistical differences were found for any variable, a Bonferroni post-hoc

analysis was performed. Statistical significance was set at $p < 0.05$. All statistical analyses were conducted using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA)

Results

Specific demands analysis during simulated taekwondo combats

No statistical differences were reported in the different variables were reported in Attack Time (AT), Step Time (ST), Pause Time (PT), Period Without Attack (PWA), Numbers of Attacks (AN), the ratio for attack time and step time (AN / ST) (see Table 2).

Countermovement jump and visual cognitive performance

The multivariate analysis indicated that there were no significant effects of time ($F(2, 12) = 2.412$, $p = 0.132$, $\eta p^2 = 0.03$; small), supplementation ($F(1, 6) = 0.004$, $p = 0.954$, $\eta p^2 = 0.00$; trivial), or the interaction between time and supplementation ($F(2, 12) = 1.327$, $p = 0.302$, $\eta p^2 = 0.04$; small) on countermovement jump values (see Figure 3a). In contrast, cognitive performance showed a significant main effect of time ($F(1, 6) = 16.01$, $p = 0.007$, $\eta p^2 = 0.16$; large). There were no significant effects for supplementation ($F(1, 6) = 0.003$, $p = 0.960$, $\eta p^2 = 0.00$; trivial) or for the interaction between time and supplementation ($F(1, 6) = 0.16$, $p = 0.700$, $\eta p^2 = 0.02$; small) (see Figure 3b).

Metabolic and perceptual demands

Blood lactate levels showed an effect of time ($F(2, 5) = 104.010$, $p < 0.001$, $\eta p^2 = 0.97$; large), while no effects were observed for supplementation ($F(1, 6) = 0.012$, $p = 0.916$, $\eta p^2 = 0.00$; trivial) or the interaction between time and supplementation ($F(2, 5) = 0.375$, $p = 0.705$, $\eta p^2 = 0.13$; medium). Blood lactate levels increased significantly ($p < 0.001$) at both post-exercise and three minutes post-exercise under beetroot juice and placebo conditions (see Figure 3c). For RPE, there was a significant main effect of time ($F(2, 5) = 18.43$, $p = 0.005$, $\eta p^2 = 0.88$; large), but no significant effects of supplementation ($F(1, 6) = 0.28$, $p = 0.617$, $\eta p^2 = 0.04$; small) or the interaction between time and supplementation ($F(2, 5) = 0.36$, $p = 0.717$, $\eta p^2 = 0.02$; moderate). RPE perception values were significantly increased ($p < 0.001$) at both post-exercise and three minutes post-exercise under both beetroot juice and placebo conditions (see Figure 3d).

Discussion

The present study investigated the acute effects of beetroot juice supplementation (140 mL containing 12.8 mmol of NO_3^-) on simulated taekwondo combat performance, neuromuscular function (*i.e.*, vertical jump performance and visual cognitive performance), metabolic responses (*i.e.*, blood lactate concentration), and RPE. To the best of our knowledge, this is the first study to examine the effects of acute beetroot juice supplementation on simulated combat performance and the associated neuromuscular, cognitive, and physiological responses in elite female Olympic taekwondo athletes. The main findings showed that acute beetroot juice ingestion did not improve

simulated taekwondo performance, neuromuscular function, metabolic responses, or perceived exertion compared with placebo. Therefore, despite the proposed ergogenic potential of acute beetroot juice supplementation for short-duration, high-intensity exercise, the present findings do not support its effectiveness under the conditions examined in this study. Different physiological mechanisms has been associated with beetroot juice ingestion such as increased vasodilation,[25] enhanced intramuscular nitrate stores,[26] and greater force production in type II muscle fibers.[14] However, this study did not find any significant differences in the measured variables, (e.g. attack time or the number of attacks). These results are consistent with a previous study that also reported no benefits from beetroot ingestion in a specific taekwondo test (*i.e.*, multiple frequency speed of kick test) compared to a placebo condition.[16] A possible explanation for these findings could be linked to the high cardiovascular fitness levels of the elite athletes involved in this study. As noted earlier, athletes with high cardiovascular fitness may experience diminished ergogenic benefits from beetroot juice supplementation, due to these athletes generally have higher baseline levels of $NO_3^-$and NO_2^-.[27] Enhancing performance in elite athletes may require different mechanisms than those observed in moderately trained or untrained combat sports athletes, warranting further investigation. Vertical jump height, measured using a CMJ, is commonly utilized in sports science to evaluate lower limb muscle strength and power[28] and to monitor muscular fatigue.[29] According to our data, acute beetroot juice, compared to placebo, did not improve jump height in any of the measurements (pre-, post-, and post-3) following a simulated taekwondo combat. This indicates no significant differences between protocols in the recovery kinetics of the lower limbs after an exhaustive protocol (*i.e.*, simulated taekwondo combat) in female elite taekwondo athletes. These findings align with a previous study involving male taekwondo athletes,[16] but differ from research on team sports like soccer, which indicated that beetroot juice supplementation reduced post-exercise perceived muscle soreness and improved recovery of vertical jump capacity (as measured by countermovement analysis) in soccer players.[30] The discrepancies may be due to different beetroot juice supplementation strategies (*i.e.*, acute versus chronic) and the varying physical demands of soccer compared to taekwondo. Future research should investigate the potential ergogenic effects of multi-day or chronic beetroot juice supplementation. Regarding cognitive function, it has been observed that Olympic and elite athletes possess superior anticipation skills in both real and simulated scenarios, along with improved attentional processes, compared to moderately trained or untrained athletes.[31] The results of this study revealed no benefits of beetroot juice supplementation compared to placebo on cognitive responses measured before and after a simulated taekwondo demands. These findings contrast with previous studies conducted on male taekwondo athletes and male football players.[16,31] However, these discrepancies could be attributed to several factors, including sex differences (male *vs*. female), variations in performance levels (Olympic athletes vs. national or recreational athletes), and differences in the cognitive demands measured. This study focused on visual cognitive reaction times, whereas other studies assessed cognitive flexibility (via the Stroop Test)[16, 31] or information processing speed (via a decision-reaction test) 31. Thus, future studies should investigate the effects of beetroot juice on various cognitive demands, particularly in female athletes.

Regarding metabolic responses, blood lactate levels increased immediately and three minutes after the simulated taekwondo combat in all conditions (beetroot juice and placebo conditions). However, no significant differences in lactate concentrations were observed between the two conditions (beetroot juice versus placebo). These findings are consistent with previous research that indicates

beetroot juice supplementation has no effect on lactate levels following high-intensity efforts.[16, 32] Similarly, RPE increased significantly over time during the simulated combat, reflecting the progressive physiological demands of the exercise, however, no differences were observed between beetroot juice and placebo conditions. These findings are consistent with previous studies in taekwondo athletes reporting no effect of acute beetroot juice supplementation on perceived exertion.[16,17]

The current study has several limitations that should be discussed to enhance its relevance to real-world sports contexts. First, we only investigated the effects of an acute supplementation protocol using 140 mL beetroot juice containing 12.8 mmol of nitrate (NO_3^-) ingested 150 min before the onset of performance testing. This same dosage and timing protocol has been employed in other investigations that found an ergogenic benefit of beetroot juice ingestion in some neuromuscular parameters in female team-sports athletes.[20] Thus, further research is required to determine if an optimal supplementation regime exists for Olympic taekwondo female athletes, per-haps with the inclusion of higher doses or using chronic supplementation protocols for beetroot juice.[33] Second, while this study focused on Olympic female taekwondo athletes, more studies with broader samples that include males and taekwondo athletes at different competition levels are recommended to strengthen the evidence base on this topic, given that factors such as sex and training status may influence the response to beetroot juice supplementation. Third, our testing included a simulated taekwondo combat in a non-competitive environment. Fourth, we did not obtain blood or saliva samples, thus, we were unable to assess the levels of circulating NO3- and NO2- after beetroot juice administration.

Conclusions

Acute ingestion of 140 mL of beetroot juice containing 12.8 mmol of NO_3^- did not significantly improve simulated combat demands or neuromuscular and cognitive responses in female Olympic taekwondo athletes. These findings suggest that acute beetroot juice supplementation may not provide ergogenic benefits in this population under the conditions tested. Further studies with larger samples and alternative supplementation protocols are warranted.

List of Abbreviations

AN, Number of Attacks
AT, Attack Time
BRJ, Beetroot Juice
CMJ, Countermovement Jump
NO, Nitric oxide
NO_2^-, Nitrite
NO_3^-, Nitrate(nitrato)
PCr, Phosphocreatine
PT, Pause Time
PWA, Period Without Attack (ST + PT)
R1, Ratio of attack time to step time (AT/ST)
R2, Ratio of total action time to pause time [(AT + ST)/PT]

ST, Step Time (tiempo de desplazamiento/pasos)
WTF, World Taekwondo Federation

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Samanes; investigation, Román Illescas-Quiroga, Álvaro López-Samanes, Lucía Sánchez-Llanos, Jesús Ramal, Raúl Domínguez, Juan José Ramos-Álvarez and Juan José Montoya-Miñano; resources, Álvaro López-Samanes, Raúl Domínguez and Juan José Ramos-Álvarez; data curation, Román Illescas-Quiroga, Álvaro López-Samanes, Raul Domínguez and Juan José Montoya-Miñano; writing – original draft preparation, Román Illescas-Quiroga, Álvaro López-Samanes and Raul Domínguez; writing – review & editing, Román Illescas-Quiroga, Álvaro López-Samanes, Lucía Sánchez-Llanos, Jesús Ramal, Alireza Naderi, Raúl Domínguez, Juan José Ramos-Álvarez and Juan José Montoya-Miñano; supervision, Álvaro López-Samanes, Raúl Domínguez and Juan José Ramos-Álvarez; project administration, Román Illescas-Quiroga, Alvaro López-Samanes and Raúl Domínguez. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; and no other relationships or activities that could appear to have influenced the submitted work.

Trial registration

The study was registered in ClinicalTrials.gov with the following ID: NCT06675305.

Ethics approval

The Ethics Committee of Bioethics Commission of the at Hospital Clínico San Carlos approved this study (22/172-E_TFM). The study is conformed with the Helsinki Declaration of 1964, as revised in 2013, concerning human and animal rights.

Informed consent

All patients participating in this study signed a written informed consent form for participating in this study.

Patient consent for publication

Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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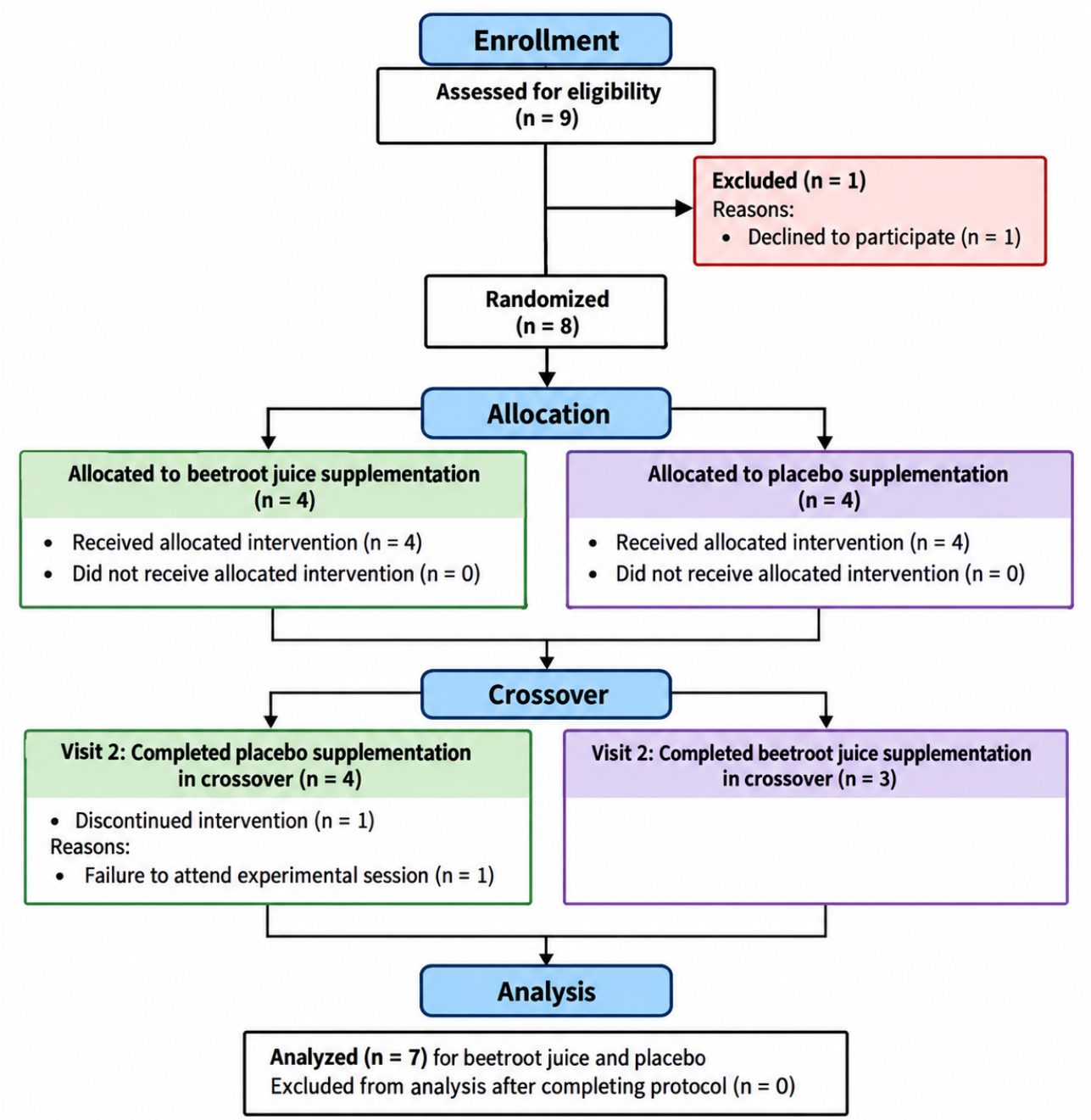


Figure 1. CONSORT flowchart of randomized, double-blind, crossover design.

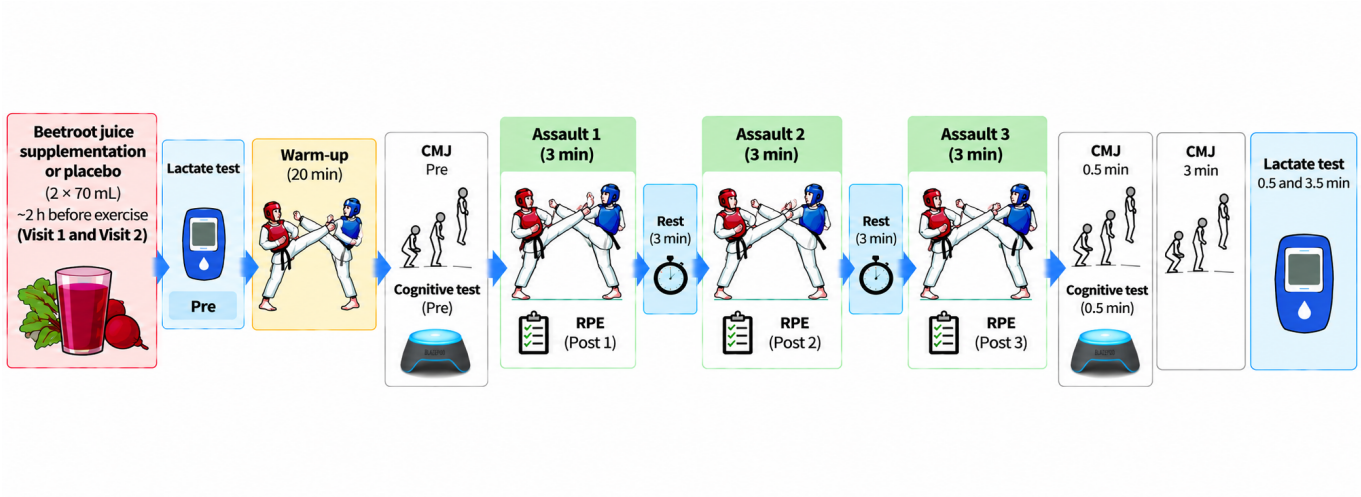


Figure 2. Experimental protocol

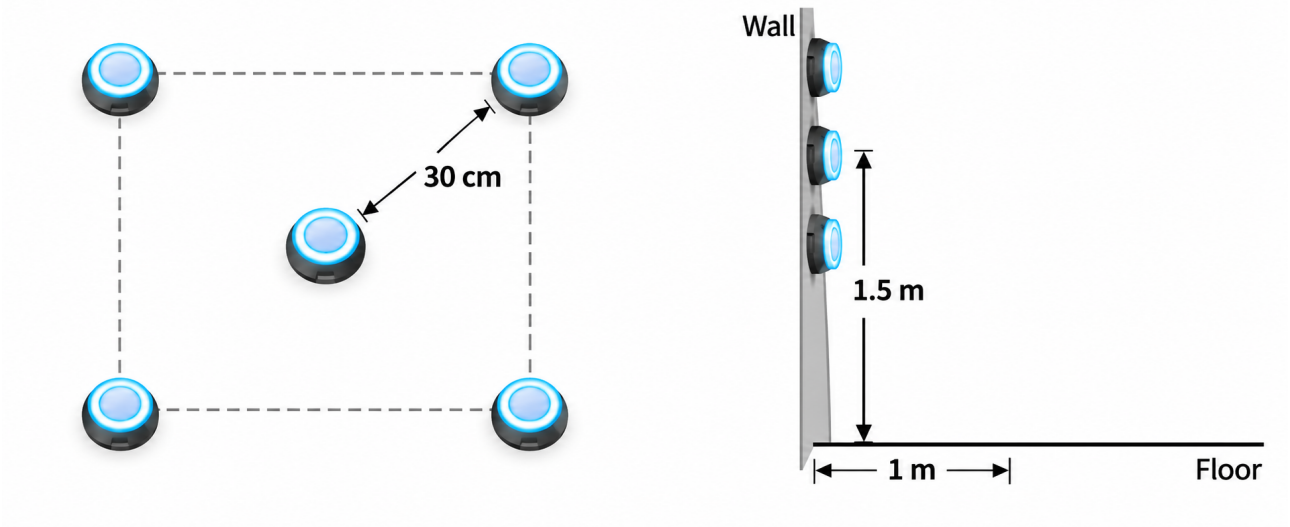


Figure 3. Visual response test.

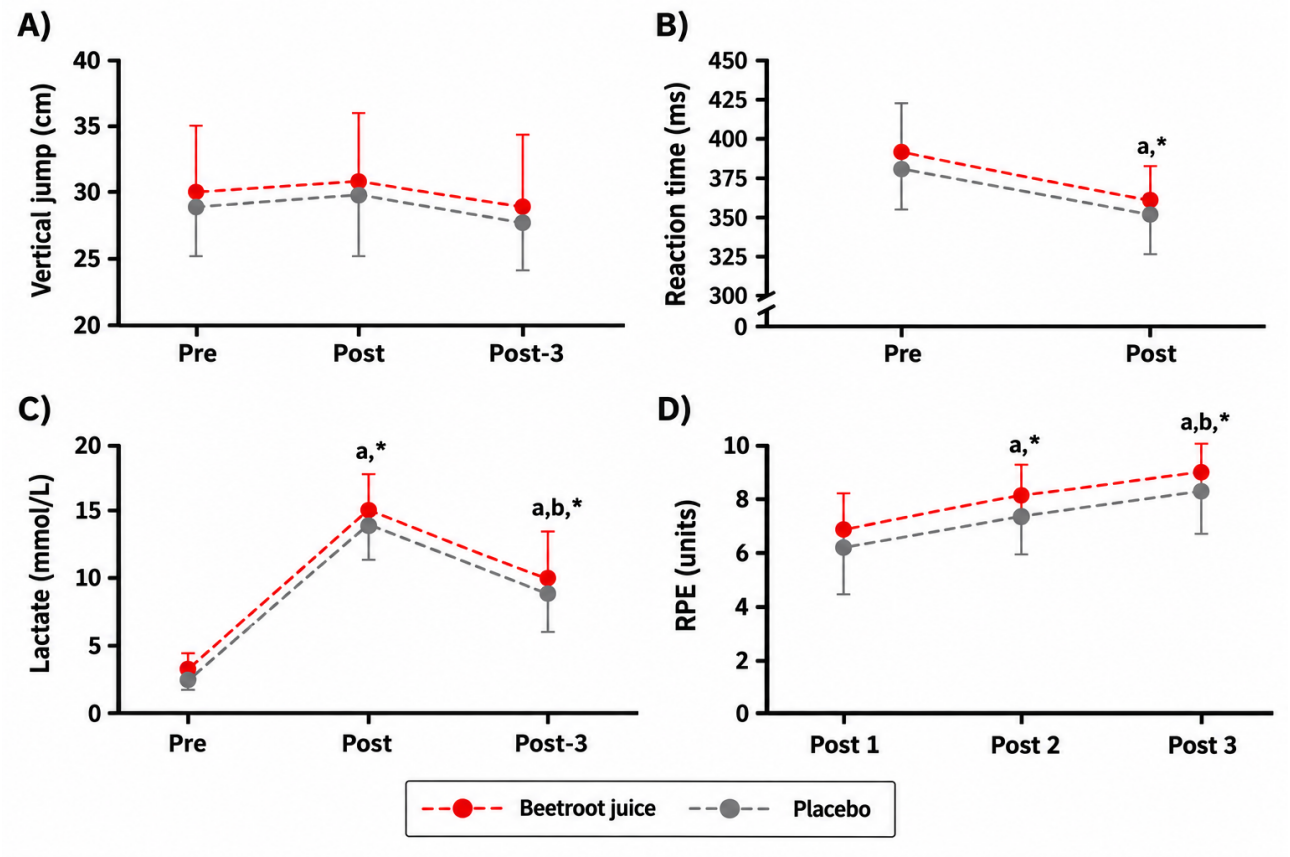


Figure 4. Neuromuscular function tests, metabolic and perception demands.

Table 1. Warm-up protocol

Tatami 8 m (back and forth way 16m)	
Sequence	Exercises
1	Running light 16 x 3
2	Knees up 16 x 1
3	Heels to glute 16 x 1
4	Lateral step + open arms left side 16m x 1
5	Lateral step + open arms right side 16m x 1
6	Step lateral crossing left side 16m x 1
7	Step lateral crossing right side 16m x 1
8	Jump one knee up, two sides 16m
9	Step knee up, two sides 16m
10	Step knee front up step knee lateral up, two sides 16m
11	Jump one leg, hold position, two legs 16 m
12	Jump one leg, hold position + jump one leg, two legs 16 m

13	10 nerio chagui, 2 sides
14	10 naco chagui, 2 legs
15	10 scorpion kick 2 legs
16	10 dolyo chagui 2 legs
17	10 dolyo andari chagui 2 legs
18	10 lateral up 2 legs
19	mobility 3 '
20	2' combination techniques

Table 2. Specific demands analysis during simulated taekwondo combats

	Placebo	**Beetroot juice**	Time	Supplementation	Time x supplementation
AT					
Round 1	49.17 ± 15.38	50.30 ± 12.13			
Round 2	42.91 ± 12.53	43.08 ± 16.58	0.007	0.695	0.849
Round 3	39.51 ± 13.74	42.64 ± 19.71			
ST					
Round 1	66.53 ± 15.71	62.26 ± 25.11			
Round 2	71.30 ± 13.76	67.15 ± 17.31	0.099	0.284	0.570
Round 3	76.96 ± 15.79	67.29 ± 24.79			
PT					
Round 1	25.29 ± 17.47	30.79 ± 16.87			
Round 2	29.64 ± 15.85	33.70 ± 16.76	0.668	0.542	0.770
Round 3	26.42 ± 20.13	36.11 ± 27.15			
PWA					
Round 1	91.89 ± 19.02	93.05 ± 24.30			
Round 2	100.94 ± 17.11	102.19 ± 15.15	**0.048***	0.913	0.988
Round 3	103.39 ± 18.16	103.40 ± 17.23			
AN					
Round 1	43.28 ± 10.25	44.12 ± 9.26			
Round 2	40.28 ± 10.40	40.00 ± 12.47	**0.025***	0.950	0.944
Round 3	38.42 ± 12.47	38.57 ± 15.06			
AN/ ST					

Round 1	0.81 ± 0.40	0.89 ± 0.45			
Round 2	0.65 ± 0.29	0.72 ± 0.42	0.085	0.349	0.531
Round 3	0.57 ± 0.30	0.81 ± 0.59			
AS+ ST)/ PT					
Round 1	8.58 ± 7.57	5.95 ± 6.09			
Round 2	6.54 ± 7.50	4.86 ± 3.94	0.626	0.625	0.996
Round 3	6.67 ± 4.45	5.97 ± 5.41			