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Effect of Low-Dose Caffeine on Performance in Elite Sitting Volleyball Players	3
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Materials and Methods

Participants

Thirteen elite male sitting volleyball players (29.84 ± 11.50 years) from the 2024 Paravolley European Champion Turkish Sitting Volleyball Men's National Team participated in this study. as the inclusion criteria were: (1) having a minimum level of disability according to the World ParaVolley classification, (2) not having any neuromuscular or musculoskeletal disorders that would prevent participation in the measurements, (3) not smoking or consuming alcohol, and (4) not using any ergogenic support to increase performance in the last 3 months. Exclusion criteria were: (1) failure to complete all test sessions, (2) occurrence of injury or illness during the study period that could affect performance and (3) changes in habitual caffeine consumption during the study.

All athletes were given detailed information about the study, their voluntary participation was ensured, and an informed consent form was obtained before any measurement. The study was approved by the Sinop University Human Research Ethics Committee (approval no: 2025/91) and was conducted in accordance with the ethical standards of the Declaration of Helsinki [19]. This study adheres to the Consolidated Standards of Reporting Trials (CONSORT) guidelines to ensure transparency and comprehensive reporting of the randomized controlled trial design and methodology (Figure 1).

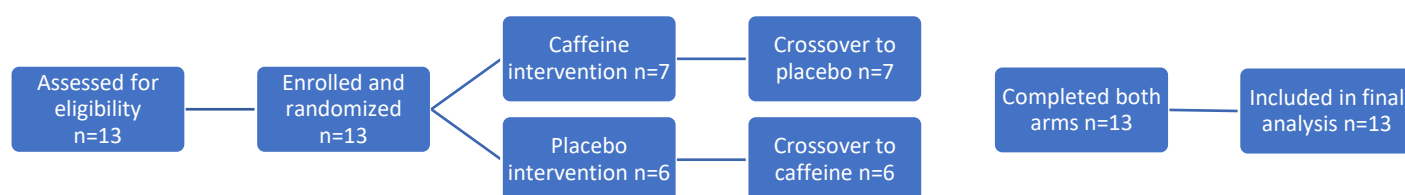


Figure 1. CONSORT flowchart of the study

Study Design

This study had a randomized, double-blind, counterbalanced, and cross-over design. Athletes participated in a total of three sessions (one familiarization session and two test sessions) (Figure 2). Participants were randomly divided into two groups (n=7 and n=6) using a computer-based random number generator (simple randomization, 1:1 ratio), one group receiving low-dose caffeine (L-CAF) and the other group receiving placebo (PLA). As required by the design, each participant received both supplements, but the order of supplementation was randomized. A 48-hour washout period was given between each test session. All measurements were performed at the same time interval (e.g., 09:00 - 10:00) to minimize the possible effects of circadian rhythm differences. Participants were asked not to change their eating habits, to avoid intense exercise, and to consume alcohol during the study. They were also advised to maintain their individual daily caffeine consumption habits. Moreover, it was taken all participants' daily caffeine consumption survey before sessions.

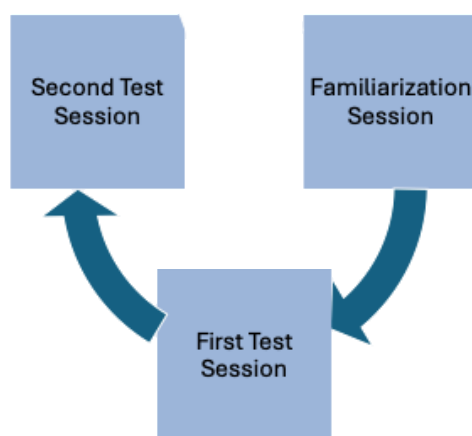


Figure 2. Test Protocol

In each test session, participants consumed a randomly assigned supplement containing caffeine (LCAF) or placebo (PLA) with 250 ml of water 45 minutes before the tests. All participants completed a standard warm-up protocol which consisted of a 5-minute low-intensity general warm-up, followed by 10 minutes of dynamic stretching and technical work, 15 minutes before the test. After the warm-up period, athletes performed the serve speed, spike speed, and speed-endurance performance tests, respectively. In the serve and spike speed tests, each athlete performed three trials, and the highest value was recorded. Participants were given a 30-second rest period between trials and a 2-minute rest period between tests (Figure 3.). Rating of Perceived Exertion (RPE) during the speed-endurance course were recorded using the Borg 6-20 scale immediately at the end of the test. Caffeine and placebo doses were prepared using an analytical laboratory balance (Shimadzu, Tokyo, Japan) capable of measuring to within precision of 1 mg, and Oxford brand pure caffeine powder (ISO 14001; The Oxford Vitality Health Company Ltd; London, UK) and polydextrose was used throughout the study.

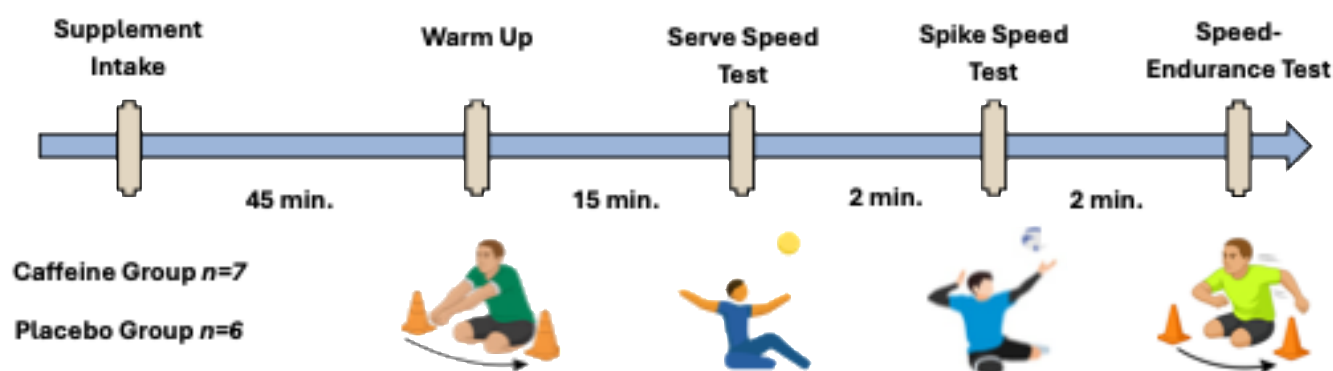


Figure 3. Timeline of Daily Experimental Procedures

Data Collection Tools

Serve Speed

The serve speed of sitting volleyball players was evaluated with a standardized measurement protocol within the framework of World ParaVolley game rules and court dimensions. Participants positioned themselves on the service line with their hips touching the court surface and used a serve. During the test, participants were instructed to hit the ball within the target area at the highest possible speed appropriate to their individual techniques. Each participant was given three attempts, and the best score was recorded. Serve speed measurements were performed with a high-precision handheld radar (Bushnell Velocity Speed Gun, USA).

Spike Speed

The spike performance was performed by positioning the participants in front of the net in accordance with the real conditions in the game. The participants were instructed to hit the ball at the highest speed possible into the 3×3 m target area. The spike speed measurements were performed with a high-precision handheld radar (Bushnell Velocity Speed Gun, USA). The data were recorded in miles.

Speed-Endurance Performance

The speed and endurance test developed by Marszalek et al. (Figure 4) was applied with a single-trial protocol to evaluate the anaerobic endurance capacity of the athletes [7]. The test begins with athletes in a seated position behind the starting point at cone A. The participants completed the specified route by moving back and forth between cones A, B, C, D, E and G respectively in the shortest time possible in accordance with the requirements of the test. All athletes were required to maintain physical contact with the base of each cone throughout the test. The results were measured precisely by the Optojump photocell system (Microgate, Bolzano, Italy) mounted on a tripod.

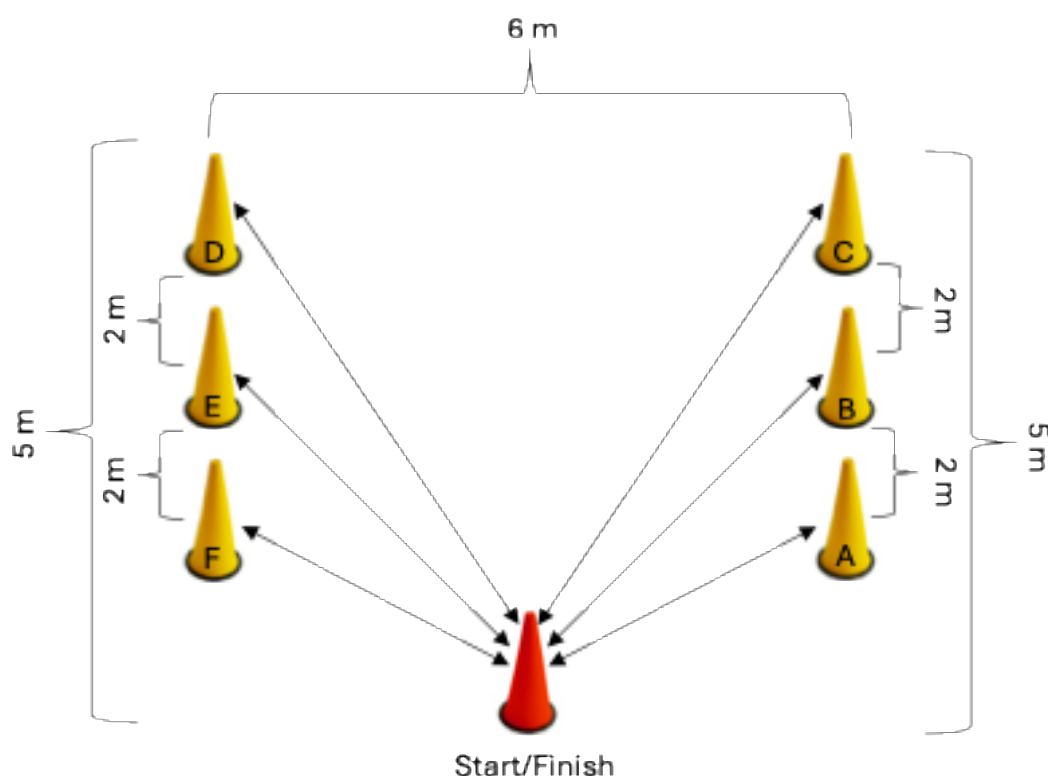


Figure 4. Speed-Endurance Test Parkour

Data Analysis

All data are reported as mean \pm standard deviation (Mean \pm SD). Normality of distribution of data was assessed by Shapiro-Wilk normality test. Paired t-test was applied to examine the differences between LCAF and PLA conditions in serve speed, spike speed and speed-endurance performance. Power analysis was conducted using G*Power for a paired-samples t-test (two-tailed, $\alpha = 0.05$, $n = 13$, power = 0.80). Cohen's d coefficient was calculated for effect sizes and interpreted according to the following classification: insignificant (<0.2), small (0.2-0.5), medium (0.5-0.8) and large (>0.8) [20]. Statistical significance was accepted as $p < 0.05$. All analyses were performed using IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA) software.