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RESEARCH ARTICLE

Acute Low and Moderate Doses of Caffeine Improve Aerobic Endurance but Not Throwing Velocity in Trained Female Handball Players

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Abstract
Handball is a high-intensity team sport requiring muscle power and high aerobic capacity. Caffeine is a commonly used ergogenic aid known to enhance sports performance. However, its effects on female handball players remain unclear. This study aims to investigate the effects of acute low (LCAF) and moderate (MCAF) doses of caffeine intake on aerobic endurance and throwing velocity in trained female handball players. Fifteen trained female handball players participated in this randomized, double-blind, crossover study. Participants completed four sessions, including a familiarization session and three test sessions. The test sessions involved ingesting either 3 mg/kg (LCAF) or 6 mg/kg (MCAF) of caffeine or a placebo (PLA). Throwing velocity and aerobic endurance were measured using a hand radar gun and the Yo-Yo Intermittent Recovery Test Level 1, respectively. The results showed a significant improvement in aerobic endurance with both LCAF and MCAF doses of caffeine compared to the PLA condition (f= 5,993; p= ,014; $\eta2$= ,480). However, there was no significant difference in throwing velocity between the caffeine and placebo conditions (f= ,040; p= ,961; $\eta2$= ,006). Acute LCAF and MCAF doses of caffeine supplementation can enhance aerobic endurance but do not affect throwing velocity in trained female handball players. These findings contribute to the limited literature on the effects of caffeine in trained female handball players and suggest that caffeine may be a useful nutritional strategy for improving performance in this sport.

Keywords
Handball, Caffeine, Aerobic Endurance, Throwing Velocity, Female Athletes

INTRODUCTION

Handball is an intermittent high-intensity team sport (Ortega-Becerra et al., 2020) that includes combined defensive and offensive actions as well as technical and tactical skills (Rocha et al., 2021). During a handball match, multiple interval running, jumping and ball throwing actions occur. Increasing the muscle power and aerobic capacity of handball players is an important component in improving the incompetition performance of their athletes (Ortega-Becerra et al., 2020). In order to increase muscle power and aerobic capacity, support can be obtained from some ergogenic aids as well as specific exercise training modalities.

Given the large body of research that supports its effects on athletic performance, caffeine (1,3,7-trimethylxanthine) is one of the most widely used ergogenic aids (Muñoz et al., 2020). Improvements in perceived exertion and neuromuscular performance due to its antagonist effect on adenosine receptors probably constitute the main mechanism of action of caffeine, unlike many other mechanisms (Grgic, 2021). Many studies have extensively demonstrated that caffeine ingestion at doses ranging from 3 mg/kg (LCAF) to 6 mg/kg (MCAF) 15-60 minutes before exercise can improve athletic performance in many sports (Berjisian et al., 2022; Pickering & Kiely, 2018; Venier et al., 2019; Wang et al., 2022). The

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recommendation for the duration of caffeine intake may vary depending on the form of caffeine consumed (capsule, anhydrous, chewing gum and other intake modalities). In last studies related with caffeine has been administered in either tablet or anhydrous forms ~60 minutes before an exercise protocol to allow for full absorption and reaching peak plasma caffeine concentrations (Pickering & Kiely, 2018; Wickham & Spriet, 2018). Also, dose recommendation may not be applicable to all athletes due to individual differences such as daily caffeine consumption level and side effects (Pickering & Kiely, 2018). Therefore, it is important for researchers to test different doses and observe metabolic responses in order to achieve optimal efficiency.

Although there are limited studies in the literature claiming the opposite (Pettersen et al., 2014), the general opinion is that low and moderate doses of caffeine increase aerobic endurance by 2%-7% between in many sports (Abian-Vicen et al., 2014; Anderson et al., 2000; Clarke et al., 2018; Hanson et al., 2019; Jenkins et al., 2008). For example, Abian et al. reported that 3 mg/kg caffeine increased aerobic endurance by 3.9% after the Yo-Yo IRT1 test they applied to 16 basketball players(Abian-Vicen et al., 2014). However, the effect of caffeine on aerobic capacity in female handball players has not been clearly determined yet. All of this evidence consists of sample groups consisting of sportsmen other than handball players. In a review conducted by Tan and his colleagues in 2022, examining the impact of caffeine on basketball performance outcomes, it was reported that LCAF and MCAF did not exert any significant effect on basketballspecific parameters such as shot accuracy. However, it was found that caffeine intake might contribute to the enhancement of physical parameters crucial for the game, such as intermittent long-term, low, or high intensity running performance(Tan et al., 2021). Basketball is similar to handball due to its which the upper extremity is important, requiring high-intensity intermittent movements such as sprinting and jumping for a long time (Abian-Vicen et al., 2014), and high level of power, speed, strength and aerobic-anaerobic capacity requirements (Chia et al., 2017). Therefore, the study results of Tan et al. can guide our research.

Although throwing velocity, which is one of the fundamental ability and performance variables in handball, is frequently examined in the literature, there is only one study (Munoz et al., 2020) on the effect to throwing velocity of caffeine. The fact that caffeine causes neuromuscular excitability through central mechanisms acting on adenosine receptors will enable high-intensity actions such as jumping and throwing during a match. Munoz et al. reported in a randomized, double-blind study that pre-exercise caffeine intake of 3 mg per kg improved ball throwing speed in elite female handball players. These result show us that caffeine supplementation can be a useful nutritional strategy for handball players (Munoz et al., 2020). A greater stature, mass and upper body power have been associated with higher throwing speed (Vila & Ferragut, 2019). Although the results are controversial (Rocha et al., 2021), there are studies reporting that anhydrous caffeine intake (3 mg/kg) increases muscle power (Gomez-Bruton et al., 2021; Munoz et al., 2020). Although there are limited studies directly related to the effect of caffeine on throwing velocity, examining the effect of caffeine on parameters that affect throwing velocity, such as muscle power, can give us an idea. However, the limited literature suggests that further studies are needed in the future.

Although the ergogenic effects of caffeine are clear, the literature on female handball players is limited. Also, recent evidence suggests that low or moderate dose of caffeine may provide a similar ergogenic benefit on exercise performance as higher doses, but with fewer side effects for athletes. However, it has been argued that a high daily frequency of caffeine consumption may create a tolerance and thus inhibit the ergogenic benefit of caffeine. The aim of this study is to examine the effects of acute LCAF and MCAF caffeine supplementation on aerobic endurance and throwing velocity in trained female handball players.

MATERIALS AND METHODS

Participants

15 trained female handball players (mean ± SD, age = 21 ± 3 years; BMI = 21.73 ± 36 kg/m2; height = 172.06 ± 7.24 centimetres; weight = 64.40 ± 10.68 kilogram) were included in the study. The sample size was calculated using the G Power statistical programme (version 3.1.9.4; Dusseldorf, Germany) using the following variables: ANOVA, repeatedmeasures, within-factors, effect size f (ES)

for 0.24, alpha = 0.05, power (1-error probability) = 0.90, statistical power = 90%, r = 0.85, one set of participants, and three test sessions were used in the statistical test. According to the power analysis, a sample size of at least 13 people was required to detect statistically significant differences in ball throwing speed and aerobic endurance levels in female handball players, between 3 mg/kg (LCAF) or 6 mg/kg (MCAF) of caffeine and placebo (PLA) conditions. Handball players were competing in the Handball Turkish 1st League and had at least five days training sessions and one match in a week. Participants did not have any musculoskeletal injuries in the last 3 months before the tests and did not use any ergogenic aids. Each participant signed an informed consent form after receiving full information about the study. The study was given the go-ahead by Sinop University's ethical committee (2023/170), in accordance with the most recent Helsinki Declaration.

Experimental Design

The study was design in a randomized, double-blind, counterbalanced, and cross-over. Participants were attended four sessions in total (one familiarization and three test session). The test sessions were including 3 mg/kg caffeine (LCAF) or 6 mg/kg caffeine (MCAF) or placebo (PLA). Participants were given adequate period between all sessions. All measurements were made at the same time of day to eliminate any circadian effect (09:00 – 10:00 a.m.). Additionally, participants were asked to watch on their diet also avoid hard exercise and consuming alcohol throughout the measurements. All players advised to maintain their standard daily caffeine consumption routines throughout the study since to avoid “abstinence” effect (Pickering & Kiely, 2019). In each session, each participant ingested LCAF or MCAF pure caffeine (ISO 14001; The Oxford Vitality Health Company ltd; London, UK) or cellulose as PLA in a glass with water 60 min before starting the tests. Doses were adjusted with a closed chamber precision laboratory scale (Shimadzu Company; Tokyo, Japan). Protocol was started 40 minutes after caffeine ingestion after a standard warm-up including 5 minutes of jogging, 10 minutes of stretching and 5 minutes of special warm-up. Pasman et al. (Pasman et al., 1995) also followed a similar protocol in their published study. Then, ball throwing speed test and Yo-Yo Intermittent Recovery Test Level 1 (IRT) were performed, respectively. Two attempts were made for ball throwing speed, with a halfminute recovery period between them. Two-minute rest was given between tests. Immediately after the completion of the experimental trials, participants were asked to have if any side effects.

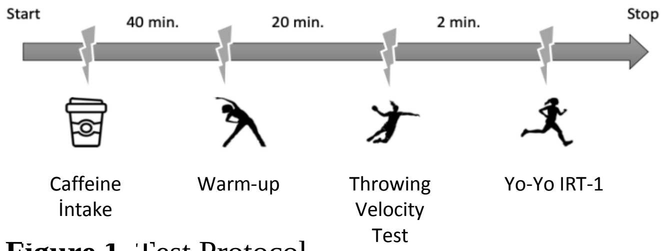


Figure 1. Test Protocol

Throwing Velocity

On a handball court, the generation of specific explosive strength during a throw with the dominant hand was assessed. After the warm-up, the handball players were given a handball ball (size 3) in accordance with international standards and were asked to throw the ball from the 7-meter line to the goal at maximum effort. It was forbidden to take steps and fall to the ground before throw. Throw speed were measured with a hand radar gun (Bushnell Velocity Speed Gun, USA) from behind the goal and results recorded as mile. The players were allowed using wax to hand. Research group members supervised all throws to make sure the athletes were using the correct handball technique. Each handball player was performed two times with rest of halfminutes and best score recorded.

Aerobic Endurance

In the Yo-Yo Intermittent Recovery Level 1 (IRT-1) test, 20 meters of shuttle runs at increasing speeds were interspersed with 5 meters (10 seconds) of active recovery until exhaustion. The beeper used in the test was downloaded to a phone and connected via Bluetooth to a portable speaker (JBL; Los Angeles, United States). The players were ready for the test at the beginning that prepared side by side parallel to each other and started running towards the finish funnel from the funnel that indicated the starting point with the signal sound. With the second signal tone, they stepped on the line where the finish funnel was located and started running towards the funnel where they started again. After the participants came to the starting line simultaneously with the third signal, they jogged towards the resting funnel behind the starting funnel. After ten seconds rest, again was started with the beep and continued the same protocol. The situation was noted as 'error 1' on the scale of the participant who returned to the relevant track after the beep. After the second fault or the players request, the test was terminated for the respective player and score in the last fault was the recorded as the final test result (Yildirim, 2022). All test sessions were held on the handball field that the players were familiar with. The procedure was similar to applied of Souhail et al. procedure (Souhail et al., 2010).

Statistical Analysis

Data's are reported as mean ± standard deviation (m ± SD) for all participants. The distribution of the data was confirmed by the Shapiro-Wilk normality test. Differences in performance variables following LCAF, MCAF and PLA groups was performed a one-way ANOVA with repeated measures. Partial eta square (η2) with Cohen's effect sizes ''trivial (< 0.2), small (0.2 – 0.5), moderate (0.5 – 0.8) and large (> 0.8)'' was used to evaluate the effect size (Cohen, 1988). The violations of the sphericity assumption were evaluated using the Geisser-Greenhouse epsilon correction. Post hoc analysis using the Bonferroni multiple comparison test was performed where any significant interactions and main effects werefound. A p value of < 0.05 was used to determine statistical significance. The all data was analysed using IBM SPSS Inc. 25.0 software (IBM Armonk, Chicago, USA).

RESULTS

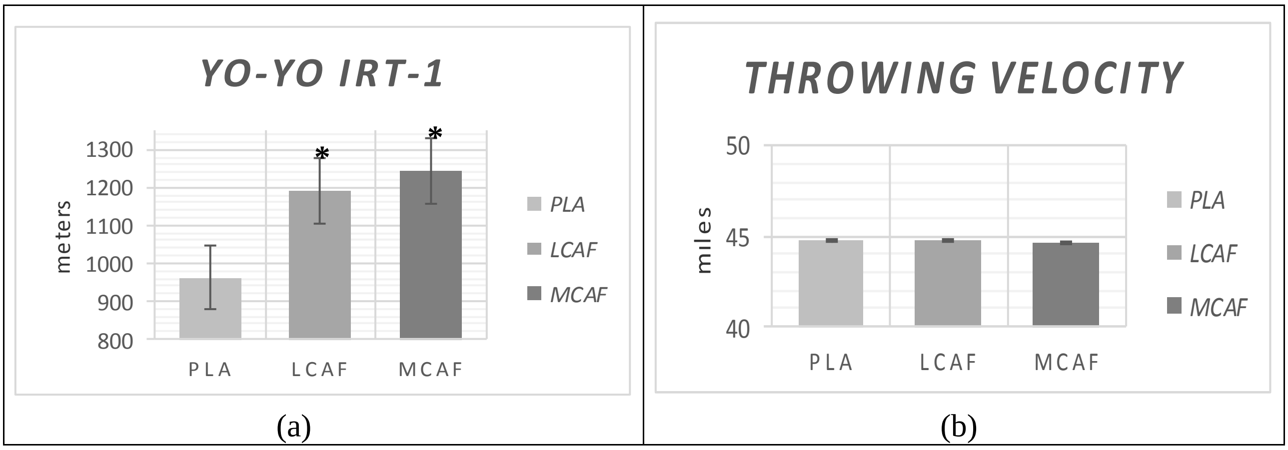
Table 1. and Figure 2. show descriptive analyses (mean, standard deviation) and one-way repeated ANOVA (frequency, significant and partial eta square) results of female handball players who intake LCAF, MCAF and PLA. When examined Table 1., there was a significant difference in Yo-Yo IRT performance between conditions (f= 5,993; p= ,014; η2=,480). Bonferroni post-hoc analysis showed Yo-Yo IRT performance better in LCAF (1190,66 ± 441,09 m) and MCAF (1242,66 ± 456,68 m) than PLA (962,66 ± 315,22 m) (Figure 2.).

Table 1. Yo-Yo Intermittent Recovery Test (Level) and throwing velocity parameters One-way repeated ANOVA outcomes.

Parameters	*f*	*p*	*η2*
YO-YO IRT-1 (m)	5,993	**,014**	,480
THROWING VELOCITY (mi)	,040	,961	,006

Yo-Yo IRT-1= Yo-Yo Intermittent Recovery Test Level 1; m= meters; mi= miles; f= frequency; p= significant; η2= partial eta square

According to Figure 2., mean and standard deviation throwing velocity values of female handball players are PLA (44.73 ± 4.19 mi) LCAF (44.80 ± 4.63 mi) MCAF (44.60 ± 4.54 mi), respectively. Also, there is no significant difference in throwing velocity between conditions (f= ,040; p= ,961; η2= ,006) (Table 1).



* = Significant difference

Figure 2. Yo-Yo IRT **(a)** and throwing velocity **(b)** performance outcomes during PLA, LCAF and MCAF.

DISCUSSION

The purpose of this study was to examine how trained female handball players' aerobic endurance and throwing velocity were affected by acute caffeine supplementation at two different doses (3 mg/kg or 6 mg/kg). The study concluded that LCAF (3 mg/kg) and MCAF (6 mg/kg) caffeine improved Yo-Yo IRT-1 performance compared to PLA. There was no significant difference between PLA, LCAF and MCAF trials in terms of throwing velocity.

Caffeine supplementation is recommended as an ergogenic aid for aerobic endurance performance (Maughan, 2018). In the current study, it was concluded that LCAF and MCAF caffeine doses increased aerobic endurance performance in trained female handball players with a moderate effect size (η2=.480). Previous studies have shown that caffeine intake of 3-9 mg per kg body weight is effective in various endurance activities (Abian-Vicen et al., 2014; MacIntosh & Wright, 1995; Wang et al., 2022; Wiles et al., 1992). In a study, it was reported that 6 mg/kg caffeine increased running distance by 16% in male and female team athletes during the Yo-Yo IRT-2 test (Mohr et al., 2011). In a recent meta analysis, it was reported that caffeine intake at doses ranging from 3-9 mg/kg increased the time to exhaustion in running performance by 16.97% with a moderate effect (Wang et al., 2022). There are studies reporting that different doses of caffeine also increase aerobic endurance performance (Dittrich et al., 2021; Ping et al., 2010). In their study, Ping et al gave 5mg/kg caffeine and placebo capsules to male runners 1 hour before an exercise trial performed on a treadmill until exhaustion at 70% of VO2max(Ping et al., 2010). As a result, caffeine was found to significantly increase aerobic endurance. Similarly, Dittrich et al. administered 300 mg of caffeinated gum to male runners in 2 separate trials until exhaustion at an intensity corresponding to 50% between the initial lactate threshold and maximal aerobic rate. At the end of the study, it was reported that exercise tolerance increased by 18% and longer distances were run in the caffeine condition (Dittrich et al., 2021). These findings are consistent with the results of our current study. However, it is seen that the subjects were mostly men. Especially the number of studies on female handball players is quite limited. Handball is a sport that involves repetitive high-intensity activities played in 2*30-minute halves. Aerobic endurance is therefore an important performance determinant to recover quickly between high-intensity activities and to maintain maximum performance throughout the entire game. In our study, 3 mg/kg and 6 mg/kg caffeine intake increased aerobic endurance in female handball players, indicating that caffeine is an effective ergogenic supplement. Blockade of adenosine receptors with caffeine affects the release of norepinephrine, dopamine, acetylcholine and serotonin, among other neurotransmitters. This may delay fatigue by reducing pain sensation and perceived difficulty during exercise. This mechanism of caffeine may explain its ergogenic effect on aerobic endurance (Southward et al., 2018; Souza et al., 2017) and intermittent sports (Gomez-Bruton et al., 2021; Souza et al., 2017). Current findings and previous research suggest that caffeine doses between 3-6 mg/kg have a similar ergogenic effect on endurance performance. Therefore, individuals who may feel more sensitive to caffeine or wish to minimize potential negative side effects can use a low dose of caffeine (3 mg/kg) and maintain similar ergogenic effects with a moderate dose (6 mg/kg) (Southward et al., 2018).

In the present study, LCAF and MCAF caffeine intake did not increase throwing velocity in female handball players. Ball throwing velocity is one of the basic skill and performance parameters in handball. However, studies examining the effect of caffeine on ball throwing velocity are quite limited in the literature. In a study, it was reported that 3 mg/kg caffeine intake increased ball throwing velocity in elite female handball players (Munoz et al., 2020). In a similar study, it was reported that pre-exercise caffeine supplementation at a dose of 3 mg/kg increased ball throwing velocity from the 9 m line in professional handball players (16 men and 15 women) (Muñoz et al., 2020). In these studies, 3 mg/kg caffeine dose increased throwing velocity in handball, which contradicts the result of our current study. In our study, the ball throwing test was performed in a stationary standing position, whereas in other studies (Muñoz et al., 2020; Munoz et al., 2020), the throws were performed by vertical jumping after a three-step preparatory run. This may have made it easier for the subjects to better demonstrate the potential of caffeine to improve muscle power. Caffeine intake is also affected by individual differences. These differences seem to be due to genetic variations. Determining the genetic profile of athletes may help to optimize the effect of caffeine on physical performance and determine individual-specific doses (Pickering & Kiely, 2018). In the literature, there are also studies examining the effect of caffeine on upper extremity muscle strength with medicine ball throwing tests. In a study consistent with the results of our current study, Rocha et al, who examined the effect of caffeine on upper extremity strength in handball players, gave 5 mg/kg caffeine and placebo to 10 handball players and found no difference between the conditions in the medicine ball throwing test (Rocha et al., 2021). In another study, it was reported that only the highest dose of caffeine (6 mg/kg) increased medicine ball throwing performance, but lower doses (2 and 4 mg/kg) did not change medicine ball throwing performance (Sabol et al., 2019). In this study, 6 mg/kg caffeine dose increased medicine ball throwing performance, which is in contrast to our 6 mg/kg caffeine dose result, but the results showing that lower doses do not change performance seem to be compatible. The reason for these differences may be the individual differences of the subject groups and the different tests applied. In the current study, a handball was shot from the 7-meter line to the goal. However, other studies (Rocha et al., 2021; Sabol et al., 2019) applied a medicine ball throwing test. It should be emphasized that there are differences in these two tests in terms of both the weight of the balls and the application technique.

Some limitations should be considered when evaluating the results of the current study. In the study, only aerobic endurance and ball throwing velocity were examined with different doses of caffeine. However, vertical jump, anaerobic capacity, sprint and change of direction speed parameters are also critical in determining performance. Investigating these parameters in future studies may better explain how caffeine affects physical performance in female handball players. In addition, the fact that the daily caffeine consumption frequency of the participants was not determined in the current study can be considered as another limitation. Because participants with high caffeine consumption may have adapted to caffeine, which may reduce the ergogenic effect of caffeine.

Conclusions

LCAF and MCAF dose caffeine ingested 60 min prior to exercise improved Yo-Yo IRT-1 performance, but not ball throwing speed in trained female handball players. These findings suggest that caffeine intake may be an ergogenic aid to increase aerobic endurance before handball trainings or competitions. After determining the appropriate doses for handball players, coaches can use caffeine to contribute to the aerobic endurance level before handball matches. In the future, more studies examining different caffeine doses and different motoric and technical skills are needed to better understand handball specific performance parameters.

Acknowledment

We thank participants for contributing to the study.

Conflict of interest

No conflict of interest is declared by the authors. In addition, no financial support was received.

Ethics Committee

This study is approved by the Sinop Unıversıty The Human Research Ethıcs Commıttee (Approvel Nummer: 2023/170).

Author Contribution

Planned by the authors: Study Design, Data Collection, Statistical Analysis, Data Interpretation, Manuscript Preparation, Literature Search. Author have read and agreed to the published version of the manuscript.

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