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ORIGNAL ARTICLE

The effects of low-dose caffeinated coffee ingestion on strength and muscular endurance performance in male athletes

Raci Karayigit[1], *Mehmet Akif Sahin*[2], *Cengizhan Sari*[1], *Aysegul Sisman*[3], *Haktan Yildiz*[1], *Hakan Buyukcelebi*[1], *Gülfem Ersöz*[1]

[1]Ankara University, Faculty of Sport Sciences, Ankara, Turkey; [2]University of Chichester, Institute of Sport, Chichester, United Kingdom; [3]Muğla Sıtkı Koçman University, Faculty of Sport Sciences, Muğla, Turkey

Summary. *Aim:* Caffeine, especially in the form of coffee, are widely consumed among athletes to increase performance. Its effects on aerobic exercise is well-established, yet reports in strength and muscular endurance performance is equivocal. The aim of this study is to investigate the effects of acute low dose (3 mg/kg) of caffeinated coffee ingestion on upper-lower body strength and muscular endurance performance in moderately strength trained men aged between 18-26 years. *Methods:* 14 moderately resistance-trained men (mean ± SD: weight- 82.64 ± 9.92, height-181.00 ± 7.68, body fat percentage- 15.25 ± 5.43) performed lower-upper body 1RM and %60 1RM to failure test protocol on 2 occasions ingesting 0.09 gr/kg caffeinated coffee (COF) or 0.09 gr/kg decaffeinated coffee (PLA). Heart rate (HR), blood pressure (BP) and rating of perceived exertion (RPE) were measured at different time points during test protocol. *Results:* There were no statistical differences in upper body strength (p=0.281), muscular endurance (p=0.727) and lower body strength (p=0.414) performance between COF and PLA trials. COF trial showed a trend for increased lower body muscular endurance performance by 8.8% compared to the PLA (p = 0.057). No significant differences were observed in HR, BP and RPE between trials (p>0.05). *Conclusion:* Ingestion of acute low dose of caffeinated coffee may increase lower body muscular endurance performance on moderately strength trained athletes. The lack of statistical significance in lower body muscular endurance performance may be related to the ingesting low dose of caffeine, training status and high level of habitual caffeine consumption of the participants'

Key words: Caffeine, supplement, ergogenic aid, tolerance, habituated

Introduction

Caffeine (1,3,7 trimethylxanthine), which is the most consumed pharmacological and psychoactive substance after water by humans, is widely used by athletes to increase physical and mental performance (1). With the World Anti-Doping Agency (WADA) removing it from the doping list in 2004, there has been a large increase in the number of studies investigating the effect of caffeine on sports performance (2). It is widely accepted that caffeine intake enhances performance by acting as an adenosine receptor (A_1, A_{2A} and A_{2b}) antagonist stimulating the central nervous system (CNS), especially during long-term (> 1 hour) endurance exercises, and increasing Na^+/K^+ pump activation in skeletal muscle tissue (3).

Many studies in the literature have examined the effects of caffeine intake on aerobic endurance performance. However, its effects on short-term high-intensity exercise performance is not well-known (3). The effects of caffeine intake on maximal strength (1-repetition maximum (1RM)) and muscular endurance performance vary in the literature. Beck et al. (4) reported that caffeine intake significantly increased bench press 1RM performance in strength-trained men, but not bilateral knee extension 1RM and muscular endurance performance. In other studies, while lower body 1RM performance increased significantly with caffeine intake, upper body 1RM performance have not changed (5). Timmins et al. reported that 6 mg/kg anhydrous caffeine significantly increases the performance of 1RM in men with strength training regardless of muscle group location and the effects on muscle group size should be examined (6). Astorino et al. found that caffeine consumptions between 120-150 mg/day is not effective on upper body endurance performance (7). In addition, high daily caffeine consumption may affect the adenosine receptor upregulation in neural and vascular tissues and decrease the magnitude of the ergogenic effect caused by acute caffeine intake (8). Based on these results, it can be speculated that inhomogeneous daily caffeine consumption level of participants may have changed caffeine's ergogenic effect on lower and upper body strength/endurance performance. Many studies have been conducted on athletes of low caffeine consumption (9), but daily caffeine consumption of elite athletes' can be high due to their daily/weekly caffeine ingestion to improve training and competition performances (3). Therefore, more research is needed in athletes with high caffeine consumption (10). In recent years, it has been suggested that the caffeine form (i.e. caffeinated coffee, caffeinated gum, gel, powder) determines the magnitude of the ergogenic effect (11). Further, there is no significant difference between the most preferred, caffeinated coffee, (3) and anhydrous form of caffeine intake in terms of ergogenic effect, and there are many studies suggesting that it increases high-intensity exercise and strength performances in 2 forms (12,13). Even Richardson et al. (14) demonstrated that 5 mg/kg caffeinated coffee increased lower body muscular endurance performance more effectively compared to anhydrous form. However, they suggested that 5 mg/kg caffeine intake from coffee is not practical for most athletes in terms of volume-temperature of coffee, and the effects of lower dose (3 mg/kg) caffeinated coffee on performance should be examined (14). Considering that all nutrients are taken orally throughout evolutionary history, it can be suggested that caffeine in the capsule is metabolised directly by reaching the stomach and decreases the size of the ergogenic effect by not stimulating caffeine-sensitive receptors in the oral cavity and esophagus (15).

Although there are studies in the literature showing that caffeine intake of 2-9 mg/kg increases intermittent sprint, muscular endurance and time-trial performance, caffeine intake of 6 mg/kg or more has side effects such as dizziness, nausea, tension, and decreased sleep quality. (16). The effects of low-dose caffeine (≤ 3mg / kg) intake on strength and muscular endurance performances differ between studies. Mora-Rodriguez et al. (17) reported that 3 mg/kg caffeine intake in elite-strength-trained men directly stimulates muscle tissue and increases neuromuscular performance in lower and upper body muscle groups. Astorino et al. (18). suggested that 5 mg/kg caffeine increase significantly peak knee flexion torque, knee extension/flexion total work output but 2 mg/kg caffeine did not produce the same effect. Although anhydrous caffeine increases muscular performance, there is a potential for involuntary high-dose usage. It would be safer to use caffeine in coffee to avoid side effects of high-dose intake (3). In addition, it has been stated that more research is needed regarding the effects of caffeine in coffee form on strength and muscular endurance (19). Therefore, the aim of this study is to investigate the effects of low dose (3 mg/kg) caffeine in coffee form on upper and lower body muscular strength and muscular endurance performance in trained men with homogeneous habitual caffeine consumption. To the best our knowledge, the effect of low-dose caffeinated coffee on lower and upper body muscular performance will be examined for the first time.

Materials and Methods

14 healthy males aged 18-26 years who had been training at least 3 days a week for the last 1 year participated in this study. Habitual caffeine consumption was measured by an expert dietitian using an adapted version of the valid-reliable caffeine consumption frequency questionnaire, which was used by other studies (20, 21, 22). Ankara University Faculty of Medicine Clinical Research Ethics Committee approval (decision no. 15-764-16) was obtained. Each participant signed an informed consent declaring the purpose and risk of the research protocol. The research was conducted according to the Declaration of Helsinki.

Research Design

With a single-blind, counter-balanced, randomized and cross-over research design, participants attended in a total of 3 test days: 1-) familiarization 2-) caffeinated coffee (COF) 3-) placebo (decaffeinated coffee) PLA) tests. Tests were separated by at least 72 hours to complete recovery. Participants were asked to avoid strenuous physical activities 48 hours before the tests and to avoid foods and beverages containing alcohol and caffeine for the last 24 hours and not to consume food and beverages for the last 12 hours. They were asked to record their diets 24 hours before the tests and repeat this diet before the next test. Adherence to these procedures was verbally confirmed at the beginning of each test. Tests were performed in the morning (07.00-09.00 am) after a overnight fasting. Caffeine content of the caffeinated-decaffeinated coffees (Nescafe Gold) calculated according to the measurements made by Ankara Food Control Laboratory Directorate; 100 gr. caffeinated coffee contains 36 mg of caffeine meaning that each participant ingest 0.09 gr/kg coffee to intake 3 mg/kg of caffeine and same dose of decaffeinated coffee (0.09 gr/kg) provides just 0.12 mg/kg of caffeine. Coffees were consumed with 300 ml. hot water in 10 minutes. COF and PLA were administered 60 minutes before each test protocol. During the familiarization day, body composition (Jawon Segmental Avis 333 Plus, Korea), height and weight of the participants was taken. Further, according to Baechle and Earle (23) protocol, bench press and full squat exercise techniques were reminded to the participants and 1RM and %60 of 1RM muscular endurance tests were performed.

Upon arrival at the testing site following to overnight fasting, in the morning hours, before consuming coffee, participants' resting heart rate (HR) (Polar Team 2 telemetric system, Finland) and blood pressure (BP) with aneroid sphygmomanometer (Erka, Germany). After ingesting of COF and PLA, participants were allowed 1 hour period to rest followed by HR and BP measurements. Participants completed warm-up consisted of 5 min. light intensity running on treadmill and 5 min standardized static-dynamic stretching. 1RM was established to strength performance in full squat (Esjim smith machine, Eskişehir, Turkey) and immediately after %60 of 1RM to failure squat protocol started to measure muscular endurance performance (23). Following to 5 min. passive rest period, participants began the bench press protocol with Olympic free bars and plates (Eleiko, Sweden) in a same way to measure 1RM strength and %60 of 1RM muscular endurance performance. Repetitions were fixed to a cadence of seconds for both the eccentric and concentric phases of the movements with a metronome (30 beat/min). Immediately after the bench press protocol, HR, BP and ratings of perceived exertion (RPE) with 6-20 borg scale (24) were measured. Strong encouragement was given for all strength and muscular endurance test. The test protocol is shown in Figure 1.

Lower and Upper Body Strength and Muscular Endurance Tests

Lower and upper body 1RM strength was determined in 4-5 steps as describe by past studies (23). Participants warm up with light load (%40 1RM) followed by 1 min rest. Weight was increased by %10-20 for lower, %5-10 for upper body test and the participant performed 3 repetitions. After 2 min. passive rest, participant chose a near maximum weight and performed

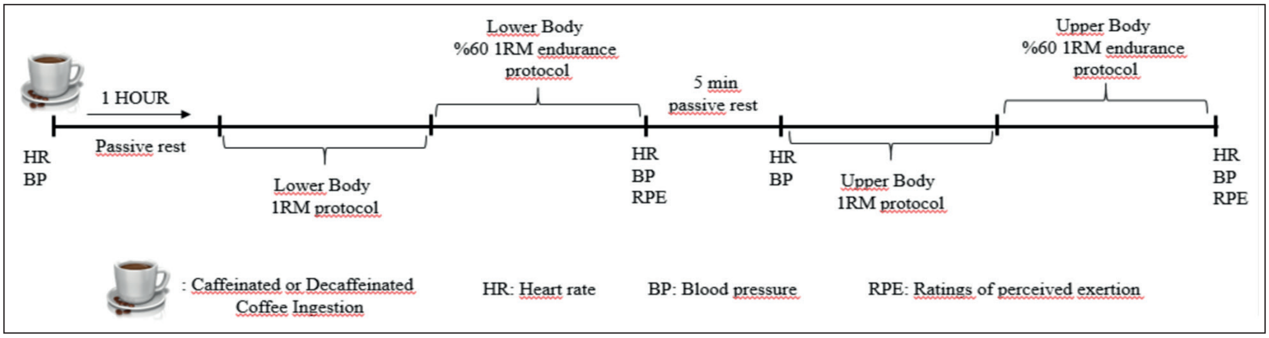

Figure 1: Test Protocol

2 repetitions. Load was increased by %10-20 for lower, %5-10 for upper body and the participant performed first 1RM attempt. If **successful**, the weight increased by %10-20 for lower, %5-10 for upper body, if unsuccessful, the weight was decreased by %5-10 for lower, %2.5-5 for upper body and attempted again followed by 3 min. rest. This cycle was performed for a maximum of 5 attempts until a 1RM was measured. Immediately after 1RM test, participants performed repetitions to failure (maximum number of repetition as much as possible with correct technique) at %60 of 1RM load to determine muscular endurance performance. Muscular endurance performance was determined as multiply %60 of 1RM load with the number of repetitions completed (23).

Statistical analysis

SPSS 22.0 software was used for data analysis. Normality distribution was tested with Shapiro Wilk. Lower and upper body muscular strength and muscular endurance values were analyzed with dependent sample T-test. HR, RPE, and BP values taken at different time points were tested by two-way analysis of variance in repeated measurements. The sphericity assumption was determined by the Mauchly test. In cases where the sphericity assumption was not met, Greenhouse-Geisser correction was applied for epsilon <0.75 and Huynh-Feldt correction was applied for> 0.75. Alpha value was accepted as 0.05 in all analyzes.

Results

The mean age of 14 male participants was 20.85 ± 2.07 years, height was 181.00 ± 7.68 cm, body weight was 82.64 ± 9.92 kg, body fat percentage was 15.25 ± 5.43, and habitual caffeine consumption was 347 ± 56 mg/day (4.19 mg/kg/day). Lower body muscular strength and muscular endurance values were not significantly different between trials shown in Figure 2 ($p > 0.05$). Although no statistically significant difference was detected, the lower body muscular endurance value was observed to increase by 8.8% in the COF trial compared to the PLA and was very close to the significance level ($p = 0.057$). Upper body muscular strength and muscular endurance values did not differ significantly between trials shown in Figure 3 ($p > 0.05$). HR values measured at different time points are shown in figure 4A and 4B respectively. HR and RPE values did not differ significantly between trials ($p > 0.05$). Diastolic and systolic BP measurements are shown in Figure 5 and no significant difference was found between trials ($p > 0.05$). Similarly, the RPE levels shown in figure 4B did not differ significantly between COF and PLA trials ($p > 0.05$).

Discussion

To the best our knowledge, the effect of low-dose caffeinated coffee on lower and upper body muscular performance examined for the first time in this study. The main finding of this study was that although not statistically significant, low-dose (3 mg/kg) caffeinated coffee increased lower body muscle endurance performance by 8.8% compared placebo (Figure 2B). In parallel with this finding, Astorino et al. (25) reported that caffeine increased 1RM %60 bench and leg press endurance performance by %11-12 but not statistically significant. In the current study, COF ingestion showed a trend for increased lower body muscle endurance performance by 8.8% with 10 out of 14 participants had higher performance compared to PLA. Although the effect of anhydrous caffeine on strength and muscular endurance has been studied by several studies (13, 14), the effects of caffeine in low-dose and coffee form on muscular performance are not well known (26, 27). It has been shown for the first time that low-dose caffeinated coffee can improve lower body muscular endurance performance. However, lower body strength, upper body strength and endurance did not increase. In addition, heart rate, rpe and blood pressure values did not differ significantly between the trials.

Evidence to date, although no study has demonstrated that there is no difference between lower and upper body muscular strength/endurance responses to acute caffeine intake (4, 17), most studies, parallel to current study, report that lower body responses are higher (14, 23, 28, 29). Strength and muscular endurance performance with caffeine intake may be directly enhanced via mechanisms with muscle tissue (Na^+/K^+ ATPase enzyme activation and Ca^{2+} release from

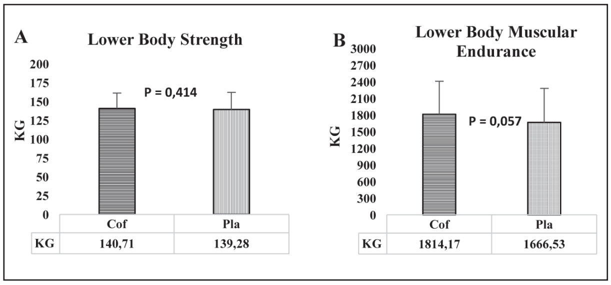

Figure 2: Lower body strength (figure A) and muscular endurance (Figure B) performance in COF and PLA trials.

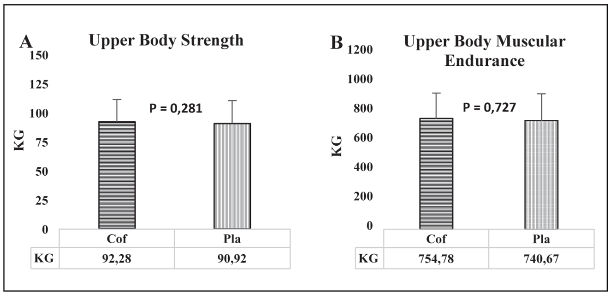

Figure 3. Upper body strength (Figure A) and muscular endurance (Figure B) performance in COF and PLA trials.

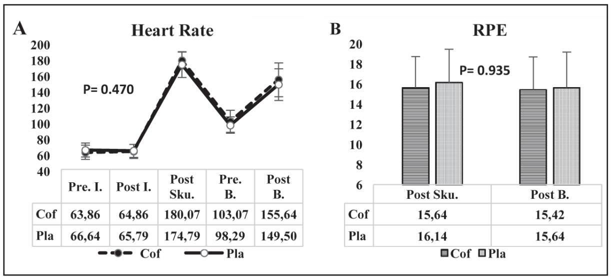

Figure 4. Heart Rate and RPE values measured at different time points for COF and PLA trials. Pre.I.: Pre-Ingestion Post I.: Post-Ingestion Post Sku.: Post Skuat Pre. B.: Pre-Bench Press Post B.: Post Bench Press

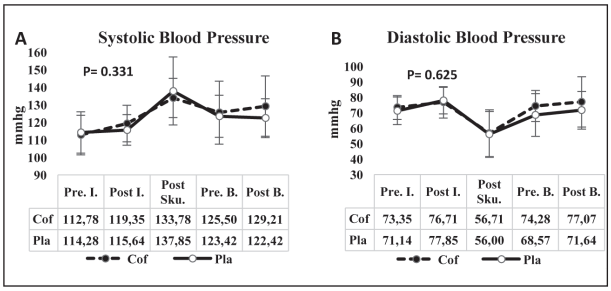

Figure 5. Systolic (Figure A) and Diastolic (Figure B) Blood Pressure values measured at different time points for COF and PLA trials. Pre.I.: Pre-Ingestion Post I.: Post-Ingestion Post Sku.: Post Skuat Pre. B.: Pre-Bench Press Post B.: Post Bench Press

sarcoplasmic reticulum) or CNS (adenosine A2A, A2B receptor antagonism that reduce muscle pain and rpe and increase motor unit activation) (3). In their meta-analysis, Warren et al. reported that the effect size of caffeine was related to muscle group size-location (parallel to increase in adenosine receptor number) and responses in lower and large muscle groups (especially knee extensors) are 4-6 times greater compared to upper and small muscle groups (30). The fact that caffeine increases the activation of knee extensors more easily may be due to the different activation levels of the upper and lower body muscle groups during maximal voluntary contraction (30). This is explained by the fact that activation levels of knee extensors and other muscle groups (respectively 85-95% and 90-99% (no/minimal room for improvements)) during MVC were different (31). In addition, 1 repetition maximum strength measurement method used in the literature and in our study may not have been sufficiently sensitive to measure the ergogenic effect of caffeine. Timmins et al., stated that lower and upper body strength performance in the isokinetic dynamometer (more sensitive measurement method) was significantly increased in the caffeine trial (6). Further research is needed to investigate the effects of low doses (≤3 mg / kg) of caffeine on muscular performance by measuring ergometers with different sensitivity (isokinetic vs. isotonic). In the current study, participants were moderately strength-trained, and as highly strength trained athletes may produce greater responses to caffeine in the 1RM test method, the impact of training status may be examined in future research.

In this study, low-dose caffeinated coffee did not affect RPE, heart rate and blood pressure values. According to the meta-analysis of the physiological responses of caffeine during sub-maximal exercise a few years ago, it was reported that caffeine intake did not significantly increase heart rate but significantly decreased rpe values (32). In addition, there are studies showing that anhydrous caffeine significantly increases systolic blood pressure (33, 34). In another study, it was reported that 3 and 5 mg / kg caffeine did not affect rpe values (18). Blood pressure can be affected by temperature, mood, arm support and position, cuff, posture, etc. Because most of these studies do not state these parameters, it is difficult to make comparisons. In parallel with our study, Green et al. (5) reported that while anhydrous caffeine increased lower body muscular endurance, upper body endurance did not significantly increase and rpe values were not affected. Caffeine's rpe lowering effect was generally reported during long-term endurance exercises, but the same effect could not be detected when measured at the end of exercise (35). In our study, rpe measured after resistance exercises, during which measurement is not very practical, weren't affected.

It has been suggested that caffeine in coffee can bind to adenosine receptors in the oral cavity and increase neurotransmitter release more than anhydrous caffeine in capsule taken without contacting the oral cavity because it is molecularly similar to adenosine (15). Richardson et al. demonstrated that caffeinated coffee increased the squat endurance performance more than anhydrous caffeine via synergistic effects of substances (antioxidants such as polyphenols, flavonoids, stilbenes etc.) and caffeine found in coffee (14). In another study, both the 5 mg/kg caffeinated coffee and anhydrous caffeine significantly increased endurance performance compared to placebo (12). Graham et al. suggested that anhydrous caffeine significantly increased running time to exhaustion compared to caffeinated coffee, and that chlorogenic acid in coffee neutralized the ergogenic effect of caffeine (36). However, other studies in the literature do not support this assumption (37-39). Methodological differences in researches (training and prandial status of participants, dose/form of caffeine, time and sexes, etc.) may lead to diversity of results. In the study using the test protocol with an average of 27% day to day performance variation, the ergogenic effect of caffeinated coffee was not shown, whereas when a more reproducible test with an average of 3% variance was used, the difference in ergogenic effect between caffeinated coffee and anhydrous caffeine was not reported (12, 36). The fact that it is a socioculturally accepted form, the risk of high dose intake and the possibility of gastrointestinal problems is less than that of anhydrous caffeine, makes caffeinated coffee a step forward (11, 26, 40). In order to give more precise caffeine ingestion recommendations, it is necessary to compared the effects of caffeinated coffee and anhydrous form at various doses and on female athletes.

Recently, habituation is one of the most frequently studied topic in the literature (41). High caffeine consumption chronicly may lead to an increase in the number of adenosine receptors and affect cytochrome P450 enzyme functions, leading to changes in caffeine metabolism rate, may reduce the size of the ergogenic effect of acute caffeine intake (42). Beaumont et al. It has been shown that 3 mg/kg anhydrous caffeine consumption for 4 weeks eliminates the effect of acute 3 mg/kg caffeine intake by developing tolerance (8). Describing the development of tolerance as a myth, Gonçalves et al. reported that 6 mg/kg caffeine intake significantly increased time trial performance in 40 trained cyclists regardless of daily caffeine consumption level (low, moderate and high) (21). In our study, participants also had a high caffeine consumption level and no significant increase in 1RM and upper body endurance performance was observed. In habituation studies, the difference between chronic caffeine consumption and acute caffeine intake doses leads to conflicting results in the literature. Thus, Beaumont et al. studied the effect of caffeine at the same dose after 3 mg/kg caffeine consumption for 4 weeks and reported tolerance development (8). In their study, Gonçalves et al. found that no tolerance development due to even in the highest caffeine consumption group (4.5 mg/kg/day) was still lower than the acute dose of 6 mg/kg (21). In this study, the daily caffeine intake of the participants was 4.19 mg/kg/day and higher than their acute dose (3 mg/kg), and although the lower body muscular endurance increased by 8.8%, the statistical significance level was not reached ($p = 0.057$). Pickering et al. have put forward the theory of "take the acute dose higher than consume chronically" to eliminate the tolerance effect (41). Although there are studies examining the effects of acute caffeine intake on muscular performance in athletes with high caffeine consumption (22, 28), it should be the subject of future studies whether different habitual caffeine consumption level causes tolerance to acute caffeine ingestion in strength and muscular endurance performance.

In the current study, participants were asked to record their diets 24 hours before the tests and to repeat this diet before the next test, but the diets were not analyzed with software. Participants' daily intake of macronutrients may have varied and affected the results. Plasma caffeine and neurotransmitter concentrations were also not measured. Although not statistically significant, lower body muscular endurance performance increased by 8.8% but no mechanism could be suggested. Genotype assessments of the participants' weren't conducted and recent studies have shown that CYP1A2 genetic polymorphism responsible for caffeine metabolism affects the size of caffeine's ergogenic effect (43, 44). Most studies in the literature, such as ours, have been conducted on male participants, but females may give lower ergogenic responses to caffeine than men due to body size-composition and hormonal differences (45). In future studies, the effects of caffeine on muscle performance of female athletes with different genotypes and habitual caffeine consumption level can be examined.

Conclusion

In summary, low dose (3 mg/kg) of caffeinated coffee ingestion, despite non significance, can increase lower body muscular endurance performance (8.8%) without any cardiovascular load accompanying to tending decrease in RPE compared to placebo. However, the increase in performance was observed only in lower body muscular endurance performance, and upper body strength and muscular endurance performance were not affected. Athletes can improve performance by consuming 3 mg/kg caffeinated coffee (0.09 gr/kg coffee) with 300 ml. hot water prior to running or lower body resistance training.

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Correspondence:
Raci Karayigit
Ankara University,
Faculty of Sport Sciences, Ankara, Turkey

E-mail: racikarayigit@hotmail.com