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ORIGINAL ARTICLE

The Impact of Caffeine Supplementation on Muscular Strength and Endurance in Male Bodybuilders

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K E Y W O R D S

Caffeine;
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A B S T R A C T

The aim of this study was to investigate the effect of caffeine supplementation on the strength and muscular endurance of female bodybuilders. The statistical population of this study consisted of active men in bodybuilding clubs in Tehran, of whom 15 were selected voluntarily, purposefully and conveniently as a sample and were randomly assigned to a control group, placebo group and supplement group at an interval of 3 days from each other in a crossover manner. They participated in one-repetition (1RM) maximum leg press tests to measure muscular strength and repetitions to exhaustion of leg press movements to measure muscular endurance. One-way analysis of variance test was used to analyze the data and examine the mean difference between the groups, and if significant, Bonferroni test was used. The results of the study showed that consuming 5 mg of caffeine supplementation per kilogram of body weight increased muscular strength and endurance in bodybuilders. As a result, it appears that caffeine consumption (5 mg per kilogram of body weight), which is approximately equivalent to 2 or 3 cups of coffee per day, can lead to increased maximal strength and muscular endurance in strength athletes.

Introduction

Strength is a component of physical fitness and a fundamental factor in success in many sports. Resistance training programs have been used for many years as an integral part of fitness programs to enhance athletic performance. Research shows that regular participation in a strength training program may increase strength and endurance and also reduce the risk of injury in sports and recreational activities (Feigenbaum, 2003).

Today, bodybuilders are often under pressure from sponsors, politicians, coaches, parents, organizations, and sports clubs to achieve athletic success. All of these pressures cause them to seek physiological, biomechanical, nutritional, and psychological advantages in any way possible. Therefore, these factors often lead athletes to consume supplements and energy-boosting substances; given the increasing commercialization of food products in sports performance, many people involved in physical activities, especially bodybuilders, use energy-boosting supplements to improve muscle size, strength, and endurance. In the meantime, caffeine supplementation has become more prevalent among these athletes (Kashi, 2006), and much attention has been drawn to this supplement, and studies have examined the effects of its consumption on sports activities (Davis, 2009).

Given that many profit-seeking and uninformed individuals have opened so-called shops in the field of stimulants, supplements, and pharmaceuticals, and by

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making false and incorrect statements, they cause irreparable physical and mental harm to a large group of young people, it seems that informing and making athletes and coaches aware of the latest information available in the field of stimulants and pharmaceuticals is a task that weighs heavily on the shoulders of those in charge of sports affairs (Dehkhoda *et al*., 2008).

Caffeine is a trimethylxanthine composed of carbon, hydrogen, nitrogen, and oxygen ($C_8H_{10}N_4O_2$) and is classified as an alkaloid. Caffeine is a natural stimulant found in more than 60 plant species, but is mainly obtained from a plant called Coffea arabica and is found in coffee, tea, cocoa, cola, etc. A 150-ml cup of tea, coffee, and cocoa contains 75 mg, 85 to 100 mg, and 5 to 40 mg of caffeine, respectively (James, 1987). It is rapidly absorbed from the intestine and metabolized in the liver to three metabolites: paraxanthine, theophylline, and theoromine. Paraxanthine, the main metabolite of caffeine in humans, increases lipolysis of glycerol and plasma free fatty acids. Theobromine is a vasodilator and increases urine volume. Theophylline is a bronchial smooth muscle relaxant (Graham and Sprint, 1995). Therefore, caffeine affects various organs and tissues such as the nervous system, cardiovascular system, smooth and skeletal muscles, and adipose tissue; many studies have investigated the effect of caffeine consumption in sports, especially endurance activities, and the ergogenic effects of low to moderate doses on endurance performance, especially time trial and intense interval activities such as football, rugby, etc. have been well demonstrated (Goldstein *et al*., 2010). The effects of caffeine on aerobic exercise such as skiing (Berglung *et al*., 1982), cycling (Jenkins *et al*., 2008), rowing (Bruce *et al*., 2000), and running (Schneicker *et al*., 2006) have been proven. Perhaps caffeine's reputation for having a greater effect on endurance activities is due to researchers' greater understanding of the mechanisms involved in improving these activities.

Due to the attractiveness of resistance training among young people and adolescents to achieve a muscular and desirable and acceptable appearance in society, the number of athletes in this type of training and bodybuilding is increasing day by day. Unfortunately, the prevalence of using illegal supplements and drugs among athletes in this field is also high, so if the ergogenic effects of caffeine on strength and endurance performance are confirmed, this legal and available supplement can be used without worry. Even if the effects of caffeine are small and minor compared to other illegal supplements and drugs such as steroids, hormones, etc., because it is legal, it is a valuable supplement and can be used by athletes in many disciplines such as weightlifting, bodybuilding, powerlifting and other strength disciplines; therefore, this study attempts to investigate the effects of caffeine consumption on muscle strength and endurance in bodybuilding athletes.

Materials and Methods

The present research method is a semi-experimental type that aimed to investigate the effect of caffeine supplement consumption on some physical fitness indicators of male bodybuilders. The statistical population of the research consisted of male bodybuilders with at least one year of experience in this field; for this purpose, people active in bodybuilding in bodybuilding clubs in Tehran were asked to voluntarily participate in this research. After explaining the method and purpose of the research, the subjects completed a written consent form to participate in the research and a medical history questionnaire. From among the volunteers (about 53 people), 15 qualified people (no cardio-respiratory disease, no use of drugs or tobacco, no history of supplement use) were selected as a sample. In all training sessions, the subjects first warmed up and stretched for 5 minutes, then participated in one-repetition maximum leg press tests to measure muscle strength, and repetitions to failure of the leg press movement to measure muscle endurance, and at the end of the sessions, a 5-minute cool-down was performed. Of course, in the later sessions, including caffeine (5 mg per kilogram) and placebo, the subjects arrived at the training site 45 minutes earlier and, after consuming caffeine or placebo (starch powder) in capsule form, sat on a chair without activity for 45 minutes in order to maximize the concentration of caffeine in the blood (Honri, 2007). The research design was cross-sectional and in three conditions: control (n = 15), placebo (n = 15), and experimental group with caffeine consumption (n = 15). The subjects visited the hall three times with an interval of 3 days, and according to a crossover design, 15 subjects were placed in one of the three groups: control, placebo, and caffeine consumption. Descriptive statistics were used to calculate central and dispersion indices. The Kolmogorov-Smirnov test was used to determine the normality of the distribution of the variables in the study. A repeated-measures analysis of variance was used to evaluate the differences between the control, placebo, and caffeine conditions of the subjects, and if significant, the Bonferroni post hoc test was used. All statistical operations were performed using SPSS version 22 software.

Results

The subjects' characteristics, including age, height, weight, training history, and Body Mass Index (BMI), are reported in Table 1. All values are expressed as mean ± standard deviation.

The mean and standard deviation of the measured variables across the experimental groups are presented in Table 2.

Table 1. Characteristics of the Research Subjects

Variable	Mean ± Standard deviation
Age (years)	24.32 ± 3.41
Height (cm)	175.24 ± 7.25
Weight (kg)	75.22 ± 9.18
BMI (kg m^{2-1})	24.53 ± 1.84
Training History (months)	26.04 ± 14.12

Table 2. Mean and Standard Deviation of Research Variables

Variable	Control	Placebo	Caffeine supplement
Strength (kg)	217.24 ± 19.82	236.61 ± 22.78	270.86 ± 25.27
Endurance (reps)	17.02 ± 4.32	19.31 ± 4.23	23.19 ± 6.05

To examine the data distribution, the Kolmogorov-Smirnov test was used, and the results are reported in Table 3. As the results show, given that the significance level is greater than the critical value of 0.05, the data distribution is normal.

Table 3. Results of the Kolmogorov-Smirnov Test for Research Variables

Variable	Control		Placebo		Caffeine	
	z	Sig.	z	Sig.	z	Sig.
Strength	0.925	0.468	0.823	0.052	0.929	0.471
Endurance	0.837	0.070	0.937	0.583	0.922	0.406

The results of the repeated measures analysis of variance (ANOVA) for muscle strength are reported in Table 4. The statistical analysis showed a significant difference in muscle strength after caffeine consumption between the groups ($P < 0.05$).

Table 4. Results of Analysis of Variance for Muscle Strength in the Study Groups

Index Muscle Strength (kg)	Sum of squares	Degrees of Freedom	Mean Square	F Value	Significance level
Between Groups	118.750	2	39.583	16.063	0.002*
Within Groups	594.850	12	19.189		
Total Variation	713.6	14			

After observing a significant difference in muscle strength between the groups, a Bonferroni post-hoc test was used to determine the differences between the groups. Results indicated no significant difference between the placebo and control groups, but there was a significant difference between the supplement group and the placebo group, and between the supplement group and the control group ($P < 0.05$). Therefore, caffeine consumption increases strength. This information is summarized in Table 5.

Table 5. Results of the Bonferroni Post-Hoc Test for Muscle Strength Changes in the Study Groups

Measurement stages	Control	Placebo	Caffeine supplement
Control	-	0.083	0.005*
Placebo	0.083	-	0.022*
Caffeine Supplement	0.005*	0.022*	-
***Significant difference (P < 0.05)**			

The results of the repeated measures analysis of variance (ANOVA) for muscle endurance are reported in Table 6. The statistical analysis showed a significant difference in muscle endurance after caffeine consumption between the groups ($P < 0.05$).

Table 6. Results of Analysis of Variance for Muscle Endurance in the Study Groups

Index	Sum of squares	Degrees of Freedom	Mean square	F Value	Significance level
Muscle Endurance (reps)					
Between Groups	19.293	2	6.431	8.535	0.022*
Within Groups	43.960	12	1.418		
Total Variation	63.253	14			

After observing a significant difference in muscle endurance between the groups, a Bonferroni post-hoc test was used to determine the differences between the groups. The results indicated that a significant difference existed only between the supplement group and the control group ($P < 0.05$), and no significant differences were found in muscle endurance changes between the other groups. This information is summarized in Table 7.

Table 7. Results of the Bonferroni Post-Hoc Test for Muscle Endurance Changes in the Study Groups

Measurement stages	Control	Placebo	Caffeine supplement
Control	-	0.18	0.012*
Placebo	0.18	-	0.061
Caffeine Supplement	0.012*	0.061	-
***Significant difference (P < 0.05)**			

Discussion and Conclusion

In this research, the one-repetition maximum leg press test was used to measure strength, and a repetition-to-failure test at 60% of the one-repetition maximum leg press was used to measure muscle endurance in the subjects. After collecting and analyzing the data, the following results were obtained:

Caffeine supplementation resulted in a significant increase in muscle strength. This significant difference was observed between the supplement and control groups and between the supplement and placebo groups. Furthermore, the results showed that caffeine supplementation also has an impact on muscle endurance, with this significant difference observed between the supplement and control groups. The findings of this study indicate that caffeine consumption has a significant effect on muscle strength. These results are consistent with the findings of research by Samimi Yan (2016), Goldstein *et al*. (2010), and Beck *et al*. (2006), but inconsistent with the findings of studies by Jamshidi Hosseinabadi (2014), Beck *et al*. (2008), and Hendrix *et al*. (2010). The reasons for the inconsistencies with some studies could be the gender of the subjects, the type of test used, and the dosage of caffeine used.

Due to its structural similarity to certain body metabolites, caffeine is soluble in intracellular fluid and can cross the blood-brain barrier. These properties allow caffeine to affect various systems in the body, such as the central nervous system, skeletal muscles, and the cardiovascular system (Kessler, 2006). Caffeine likely affects the central nervous system by causing the release of serotonin in the cerebral cortex and increasing sympathetic activity, which results from the inhibition of adenosine receptors by caffeine. Inhibiting adenosine receptors leads to a greater recruitment of motor units and increased metabolism, resulting in greater contractile force (Beko, 2000). Caffeine also stimulates the release of epinephrine, which increases the activity of Na±K+ATPase, thereby causing a greater efflux of potassium from the muscle cell. This may indirectly increase the recruitment of motor units and, consequently, the force generated by each unit (Graham, 2001). Another mechanism that likely causes caffeine to affect strength activities is its effect on the release of calcium from the sarcoplasmic reticulum. The main function of calcium in muscle contraction is the binding of actin-myosin myofilaments. By affecting the sarcoplasmic reticulum and facilitating the release of calcium, caffeine helps to achieve these bindings, thereby increasing the speed and intensity of contraction (Mihic, 2000). The impact of caffeine on muscle strength can be influenced by various factors, including training status, dosage, type of muscle contraction, and muscle group. For example, in the studies by Beck *et al*. (2008) and Hendrix, the lack of impact of caffeine on strength may be due to the type of subjects and their lack of training. It is likely that the low muscle mass of untrained individuals, especially in the lower body, is the reason for the lack of effect of caffeine on muscle strength in these studies.

Furthermore, the results of this study indicate that caffeine consumption has a significant effect on the muscle endurance of male bodybuilders. These results are consistent with the findings of Duncan *et al*. (2011, 2008), Astorino *et al*. (2011), Jamshidi Hosseinabadi (2014), Yaghoubi *et al*. (2011), and Haghighi *et al*. (2011) and inconsistent with those of Ghorbani (2012), Beck *et al*. (2006), Williams *et al*. (2008), Goldstein *et al*. (2010), Green *et al*. (2007), and Astorino *et al*. (2008). The reasons for the inconsistencies with some studies could be the type of subjects, the timing and amount of supplementation, the types of tests used, and the differences in subject characteristics. For example, the consistency of the findings of the present study with those of Jamshidi Hosseinabadi and Yaghoubi *et al*. lies in the dosage and timing of caffeine consumption.

Caffeine may increase plasma epinephrine levels and glycogen storage in active muscles, at least in the first few minutes. On the other hand, cortisol secretion is associated with the stress of physical exertion. However, studies have shown that plasma cortisol can increase significantly under the influence of caffeine. Since cortisol can stimulate gluconeogenesis and increase the mobilization of free fatty acids, more energy can be available to active muscles in a limited time (Packer *et al*., 2008). Studies have shown that caffeine consumption reduces pain, which can improve the number of repetitions (Mattel, 2003). Another mechanism by which caffeine may enhance performance is through its impact on neural perception of fatigue by decreasing the ratio of tryptophan to branched-chain amino acids, reducing serotonin levels, and delaying central fatigue (Assig, 2003). Another potential mechanism through which caffeine may improve endurance performance is by increasing the release of beta-endorphins. Laurent *et al*. showed that, compared to a placebo group, caffeine consumption significantly increases plasma beta-endorphin concentrations following two hours of cycling and then a high-intensity sprint activity (Laurent, 2000).

Conflict of interests

NO conflict.

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