The Effects of Caffeine on Vertical Jump Height and Execution in Collegiate Athletes

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Abstract

Bloms, LP, Fitzgerald, JS, Short, MW, and Whitehead, JR. The effects of caffeine on vertical jump height and execution in collegiate athletes. *J Strength Cond Res* 30(7): 1855–1861, 2016–Caffeine ingestion elicits a variety of physiological effects that may be beneficial to maximal-intensity exercise performance, although its effectiveness and physical mechanism of action enhancing ballistic task performance are unclear. The purpose of this study was to examine the effects of caffeine ingestion on vertical jump height and jump execution in Division I collegiate athletes. The study used a single-blind, randomized, crossover design. Athletes ($n = 25$) consumed either caffeine (5 $mg \cdot kg^{-1}$) or placebo. After a 60-minute waiting period, athletes performed 3 squat jumps (SJ) and 3 countermovement jumps (CMJ) while standing on a force platform. Jump height and execution variables were calculated from mechanography data. In comparison with placebo, caffeine increased SJ height (32.8 ± 6.2 vs. 34.5 ± 6.7 cm; $p = 0.001$) and CMJ height (36.4 ± 6.9 vs. 37.9 ± 7.4 cm; $p = 0.001$). Peak force ($p = 0.032$) and average rate of force development ($p = 0.037$) were increased during the CMJ in the caffeine trail compared with the control. Time to half peak force was the only execution variable improved with caffeine ($p = 0.019$) during the SJ. It seems that caffeine affects both height and execution of jumping. Our data indicate that the physical mechanism of jump enhancement is increased peak force production or rate of force development during jumping depending on technique. The physical mechanism of jump enhancement suggests that the ergogenic effects of caffeine may transfer to other ballistic tasks involving the lower-body musculature in collegiate athletes.

Key Words ergogenic aid, explosive strength, ballistic exercise

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Introduction

Caffeine (1,3,7-trimethylxanthine) ingestion elicits a variety of physiological effects that may be beneficial to maximal-intensity exercise performance. One of the most widely accepted mechanisms of action is caffeine acting as an adenosine antagonist competing at receptor sites (8). This may lead to increased arousal by reducing the impact of adenosine on the central nervous system (4,8). The supraspinal excitatory effect of caffeine may enhance motor unit recruitment and rate coding (6). Because of caffeine's lipophilic nature, in addition to crossing the blood-brain barrier, it also has the ability to permeate the membranes of both nerve and muscles cells and thus affect both central and peripheral factors of force development (21).

Caffeine is widely accepted as an ergogenic aid at moderate doses for most modes of exercise, although much of the existing evidence for its effectiveness is conflicting (12). Most studies have focused on the effects of caffeine on endurance performance and fewer studies have evaluated maximal-intensity exercise performance outcomes (4,8). The results from these investigations are varied (4–6,9,17,22,23). Among other factors, it seems that an ergogenic effect of caffeine tends to be observed in trained athletes, (4) and the effect may be more pronounced when testing tasks requiring larger muscle groups (22). Emerging evidence suggests an ergogenic effect of caffeinated containing energy drinks on jumping performance in athletes (1,2,13,20). These data indicate that caffeine may have a positive effect on the performance of a single maximal-intensity ballistic task. However, it is not clear if increases in jumping performance are due to caffeine alone or a synergistic effect of the combined ingredients contained in energy drinks. To date, we are not aware of any study evaluating how caffeine effects the execution of the ballistic task leading to increased performance. During the performance of a ballistic task such as jumping, it is not known which execution characteristics change after caffeine ingestion contributing to an enhanced impulse and an increased jump height. Determining caffeine's physical mechanism of action during jumping may be useful for practitioners to evaluate the potential for caffeine to augment performance in related ballistic tasks. Therefore, the purpose of this study was to examine the effects of caffeine ingestion on vertical jump height and

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jump execution in National Collegiate Athletic Association (NCAA) Division I athletes. We hypothesized that caffeine ingestion would increase vertical jump height, peak force production, and rate of force development.

Methods

Experimental Approach to the Problem

The study used a single-blind, randomized, crossover design to investigate the effects of caffeine ingestion on jump height and jump execution using mechanography. Caffeine anhydrous was selected for the treatment rather than a combined ingredient preparation to allow for the evaluation of caffeine alone. Mechanography was used to measure jump height because it is accurate, reliable (3), and allows for the simultaneous evaluation of the execution of the task. A crossover study design was used to enhance statistical power to detect effects of caffeine in anticipation of a limited number of collegiate athlete volunteers. The study was conducted in the Biomechanics Laboratory at the University of North Dakota. Athletes attended 2 testing sessions approximately 1 week apart. Testing sessions took place before sport training sessions between the hours of 6:30AM and 12:30PM. Testing took place at the same time of day for each athlete. Athletes were encouraged to continue with their normal eating habits during the study except for special instructions on the day of their testing. Athletes were instructed not to eat 3 hours before testing or consume caffeine on the day of testing.

Subjects

National Collegiate Athletic Association Division I collegiate athletes ranging from 18–23 years from the University of North Dakota were recruited for this study. Collegiate athletes were recruited because ergogenic effects of caffeine are usually only seen in trained athletes due to factors, such as more consistent performances and differences in physiology due to training (11). Athletes were recruited from sports in which maximal-intensity ballistic tasks were incorporated in training and competition. An initial meeting was scheduled with all the athletes to inform them about the procedures and risks associated with study participation. Participation was voluntary, and all athletes provided written and verbal consent before the start of the study. Approval to conduct the study was granted by the University of North Dakota Institutional Review Board. Athletes were excluded if they had a lower-body injury in the past 6 months that removed them from competition or under 18 years of age.

Sixteen men (mean ± *SD*: age = 21 ± 1.5 years, height = 183 ± 5.6 cm, body mass = 95.2 ± 18.7 kg, 3 track throwers, 2 jumpers, 2 sprinters, 5 baseball, 4 football) and 9 women (mean ± *SD*: age = 20 ± 1.3 years, height = 171 ± 5 cm, body mass = 70.4 ± 17.3 kg, 3 track throwers, 2 jumpers, and 4 sprinters) Division I collegiate athletes participated in the study. Of the 25 athletes, 16 were not regular consumers of caffeine. Nine of the participants consumed caffeine on a regular basis in the form of coffee, energy drinks, or preworkout supplements. Teams were training 8–20 hours per week depending on sport season. Training consisted of a combination of sport practice and weight lifting.

Procedures

Treatment order was randomly assigned. Athletes either consumed caffeine (5 $mg \cdot kg^{-1}$) or a placebo in the form of a pill 60 minutes before testing. Caffeine anhydrous in pill form was used because it seems to be the most efficient form for absorption (11). The dose was selected to stay within the NCAA regulations for urinary caffeine excretion of 15 $\mu g \cdot ml^{-1}$ (24). Height and weight were recorded using a stadiometer (Model 213; Seca Corp., Hamburg, Germany) and force platform (Bertec Corp., Columbus, OH, USA), respectively. Participants performed a 10-minute dynamic warm-up specific to jumping before testing. All participants performed 3 squat jumps (SJ) and 3 countermovement jumps (CMJ) on the force platform separated by 30 seconds of rest in-between jumps and 2 minutes between different jump techniques. Hands were placed on the hips during all jumps. For the SJ, participants were told to slowly lower to a self-selected depth,

Table 1. Paired samples *t*-test to evaluate the effect of caffeine compared with placebo on SJ height and jump execution variables ($n = 25$).*

	Placebo, mean (*SD*)	Caffeine, mean (*SD*)	*p*
Jump height (cm)	32.8 (6.2)	34.5 (6.7)	0.001
Peak force (N)	1,253 (388)	1,246 (431)	0.760
Time to half peak force (s)	0.084 (0.041)	0.074 (0.038)	0.019
Time to peak force (s)	0.228 (0.072)	0.225 (0.074)	0.652
Peak rate of force development ($N \cdot s^{-1}$)	13,329 (7,540)	14,452 (7,784)	0.197
Average rate of force development ($N \cdot s^{-1}$)	6,267 (3,601)	6,644 (4,163)	0.312
Starting gradient ($N \cdot s^{-1}$)	9,793 (6,304)	10,904 (6,507)	0.077
Acceleration gradient ($N \cdot s^{-1}$)	5,333 (3,166)	5,431 (3,501)	0.791
Takeoff time (s)	0.342 (0.061)	0.344 (0.057)	0.798

*SJ = squat jump.

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Table 2. Paired samples *t*-test to evaluate the effect of caffeine compared with placebo on CMJ height and jump execution variables ($n = 25$).*

	Placebo, mean (*SD*)	Caffeine, mean (*SD*)	*p*
Jump height (cm)	36.4 (6.9)	37.9 (7.4)	0.001
Peak force (N)	1,225 (379)	1,282 (391)	0.032
Time to half peak force (s)	0.088 (0.027)	0.087 (0.039)	0.721
Time to peak force (s)	0.219 (0.087)	0.209 (0.086)	0.258
Peak rate of force development ($N \cdot s^{-1}$)	10,979 (5,029)	12,453 (6,716)	0.069
Average rate of force development ($N \cdot s^{-1}$)	6,371 (3,435)	7,229 (4,049)	0.037
Starting gradient ($N \cdot s^{-1}$)	7,995 (4,337)	9,487 (6,342)	0.040
Acceleration gradient ($N \cdot s^{-1}$)	5,813 (3,147)	6,558 (3,253)	0.040
Takeoff time (s)	0.460 (0.057)	0.456 (0.061)	0.502

*CMJ = countermovement jump.

pause for approximately 3 seconds, and then jump as high as possible. For the CMJ, participants were told to simply jump as high as possible without a pause at the bottom position. Testing occurred on 2 occasions separated by at least 5 days. Each testing session took approximately 70 minutes to complete (60-minute waiting period and approximately 10 minutes of testing).

Jump height and jump execution variables were evaluated using the mechanography data. The procedure used has been described in detail elsewhere (10). Jump start and takeoff were identified as the vertical net force trace exceeding 5% of the athlete's body mass and when the force platform was unloaded, respectively. The force platform was deemed unloaded when the vertical net force trace was equal to a block moving average taken from a 0.2-second data sample during flight plus an error term (peak residual + 2 N). Jump height (m) was measured by vertical velocity of center of mass at takeoff squared divided by 2 times gravity (16). Jump execution time (s) was measured by time from jump start to takeoff. Peak force (N) was the highest vertical force trace before takeoff. Time to peak force (s) was determined by time from jump start to peak force. Time to half peak force was measured by time from jump start to half peak force. Peak rate of force development ($N \cdot s^{-1}$) was the peak time derivative of the vertical force trace. Average rate of force development ($N \cdot s^{-1}$) was the peak force divided by time to peak force. Force gradient and acceleration gradient were calculated to investigate the uniformity of the average rate of force development. Force gradient ($N \cdot s^{-1}$) was measured by half peak force divided by time to half peak force (27). Acceleration gradient ($N \cdot s^{-1}$) was measured by half peak force divided by time to peak force minus time to half peak force (27). Stretch-shortening cycle efficiency was estimated as the percent difference in jump height between the CMJ and SJ (1). All variables were reported as the average of 3 jumps for each technique. Determining jump height from mechanography data is a valid and reliable technique (3). Jump execution variables tend to exhibit more variability. Peak force displays high reliability (ICC = 0.97; CV range: 2.8–3.5%) during both the SJ and CMJ, while time to peak force, peak rate of force development, and average rate of force development demonstrate low but acceptable reliability (ICC range: 0.72–0.90; CV range: 11.8–17.9%) (15). The reliability of time to half peak force, starting gradient, and acceleration gradient has not been determined.

Table 3. Correlations between jump height and jump execution variables during the SJ with placebo and caffeine ($n = 25$).*

	Jump height placebo *r*	Jump height caffeine *r*
Peak force (N)	0.251	0.236
Time to half peak force (s)	−0.162	−0.178
Time to peak force (s)	−0.131	−0.207
Peak rate of force development ($N \cdot s^{-1}$)	0.296	0.388
Average rate of force development ($N \cdot s^{-1}$)	0.206	0.230
Starting gradient ($N \cdot s^{-1}$)	0.314	0.421†
Acceleration gradient ($N \cdot s^{-1}$)	0.157	0.142
Takeoff time (s)	−0.164	−0.202

*SJ = squat jump.
†Statistical significance at $p \leq 0.05$.

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Table 4. Correlations between jump height and jump execution variables during the CMJ with placebo and caffeine ($n = 25$).*

	Jump height placebo *r*	Jump height caffeine *r*
Peak force (N)	0.288	0.505†
Time to half peak force (s)	0.090	0.032
Time to peak force (s)	0.114	−0.042
Peak rate of force development ($N \cdot s^{-1}$)	0.250	0.535‡
Average rate of force development ($N \cdot s^{-1}$)	0.174	0.483†
Starting gradient ($N \cdot s^{-1}$)	0.201	0.422†
Acceleration gradient ($N \cdot s^{-1}$)	0.159	0.479†
Takeoff time (s)	−0.237	−0.422†

*CMJ = countermovement jump.
†Statistical significance at $p \leq 0.05$.
‡Statistical significance at $p < 0.01$.

Statistical Analyses

Data were analyzed using SPSS version 23.0 (IBM, Armonk, NY, USA). Descriptive statistics are expressed as mean values ± *SD*s. Data were inspected to determine whether criteria for normal distributions were met. Paired samples *t*-tests were used to compare the differences between Caffeine and placebo conditions. An eta-squared statistic was used to indicate effect size (19). At the individual level, athletes were classified as responders if jump height increased beyond the typical error of measurement of 1.0 cm (18) multiplied by 1.5 as per Moir, Garcia, and Dwyer (16). With 25 athletes, this investigation was powered to detect large effects. Statistical significance was set at $p \leq 0.05$ using 2-tailed *p*-values.

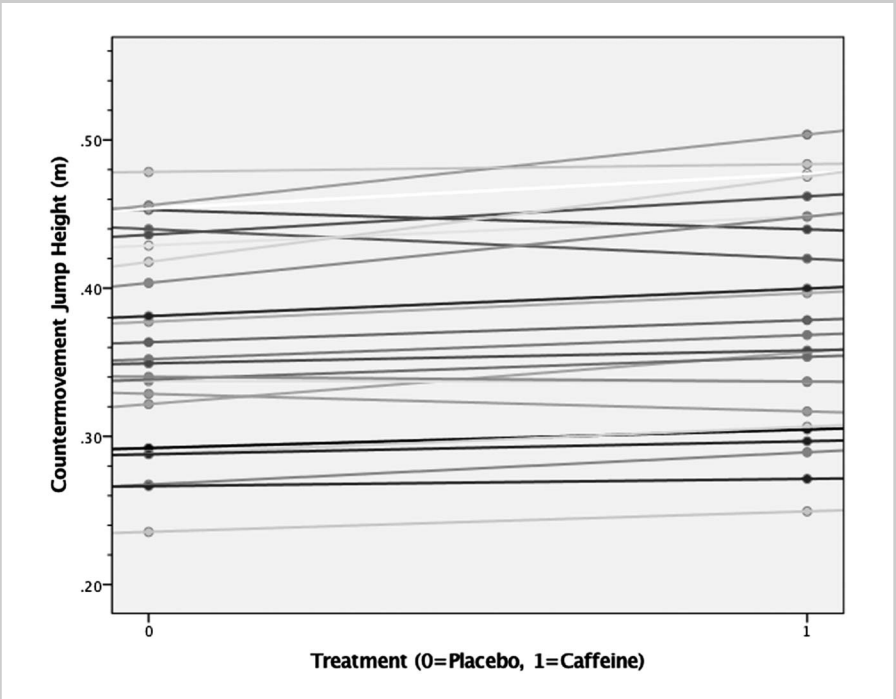

Figure 1. Individual differences in CMJ height between placebo and caffeine ($n = 25$). CMJ = countermovement jump.

Results

Caffeine ingestion had a positive effect on both SJ height and CMJ height ($p = 0.001$; $p = 0.001$). Squat jump height and CMJ height were significantly improved 5.4 ± 6.5% and 4.3 ± 4.6%, respectively, in the caffeine trial compared with placebo. The eta-squared statistic for SJ height (0.38) and CMJ height (0.42) indicated a large effect size. The results from the paired samples *t*-test for jump height and jump execution variables are presented in Tables 1 and 2.

Select jump execution variables for both jump techniques were also enhanced in the caffeine trail compared with the control. For the SJ, time to half peak force was reduced after caffeine ingestion compared with the placebo ($p = 0.019$; $\Delta = 9.5 \pm 20.2\%$; eta squared = 0.21). For the CMJ, peak force ($p = 0.032$; $\Delta = 4.9 \pm 9.6\%$; eta squared = 0.18), average rate of force development ($p = 0.037$; $\Delta = 14.1 \pm 29.4\%$; eta squared = 0.17), starting gradient ($p = 0.040$; $\Delta = 16.3 \pm 29.6\%$; eta squared = 0.17), and acceleration gradient ($p = 0.040$; $\Delta = 18.4 \pm 41.2\%$; eta squared = 0.17) were increased in the caffeine trial compared with the placebo. The eta-squared statistic for the jump execution variables indicated large effect sizes (>0.14). Stretch-shortening cycle efficiency in the caffeine trail (10.0 ± 5.7%) was not different than the control (11.2 ± 7%; $p = 0.364$). Correlations between jump height and jump execution

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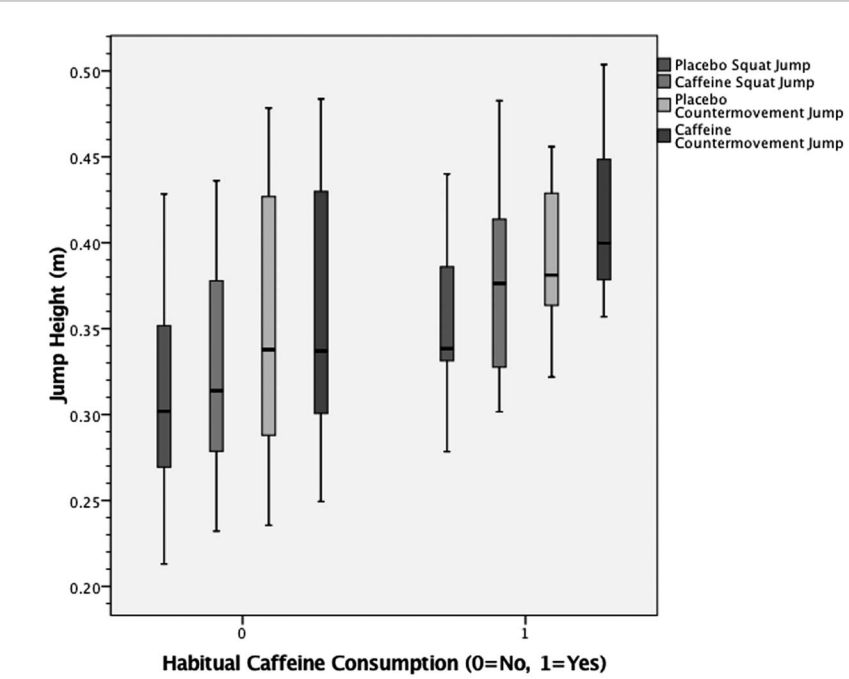

Figure 2. Box plots of SJ height and CMJ height for placebo and caffeine with respect to habitual caffeine consumption. Plot whiskers represent minimum to maximum values. Nine of 25 athletes reported habitual caffeine consumption. SJ = squat jump; CMJ = countermovement jump.

variables for both the caffeine and placebo trial are presented in Tables 3 and 4.

The number of responders to caffeine was similar when comparing jump techniques and sex, but markedly different for habitual caffeine consumption. After caffeine ingestion, 52% and 56% of athletes increased jump height 1.5 cm, our threshold to consider the change real, during the SJ and CMJ, respectively. Individual responses to caffeine for the CMJ are presented in Figure 1. Forty-four percent (4/9) of women and 56% (9/16) of men were identified as responders during the SJ. Proportionally, more men (68%) were identified as responders when compared with women (33%) during the countermovement. Only 9 men reported habitual caffeine consumption. Seventy-eight percent (7/9) and 100% (9/9) of habitual caffeine consumers were responders during the SJ and CMJ, respectively. The percentage of athletes classified as responders dropped to 38% (6/16) for the SJ and 31% (5/16) for the CMJ for those who did not consume caffeine on a regular basis. Group responses for jump height with respect to habitual caffeine consumption are presented in Figure 2.

Discussion

The primary purpose of this study was to evaluate the effects of caffeine on vertical jump height and jump execution in NCAA Division I athletes competing in sports involving maximal-intensity ballistic tasks during training and competition. Squat jump ($p = 0.001$) and CMJ ($p = 0.001$) heights were significantly improved with caffeine ingestion. Also, it seems that caffeine affects both height and execution of jumping, although the extent of change in the execution seems to be dependent on jumping technique. Our results are consistent with other studies evaluating the effects of caffeine containing energy drinks on jump height (1,2,13,20). It seems that caffeine ingestion alone in our athletes (4.3–5.4%) results in a similar improvement in jump height when compared with athletes after energy drink consumption (2.1–6%) (1,2,13,20). Abian et al. (1) noted that this effect size is roughly equivalent to 5–8 weeks of combined resistance and plyometric training. To our knowledge, this is the first study to find that caffeine enhances peak force and rate of force development during the CMJ and time to half peak force during the SJ.

Although several jump execution variables were not changed with caffeine supplementation for both jump techniques, jump execution was altered to a greater extent during the CMJ compared with the SJ. A possible reason for the greater change in CMJ execution may be the technique. The rapid transition from an eccentric contraction to a concentric contraction is believed to use the stretch-shortening cycle (14). Because of the countermovement, this technique also has an increased execution time compared with SJ. This is evident in our data, as takeoff time is approximately 0.1 second longer during the CMJ. The increased execution time allows for greater time to produce force. It may be that caffeine positively influences stretch-shortening activity and associated force production. Our data seem to support this as average rate of force development, starting gradient, A-gradient, and peak force were enhanced with caffeine. However, our investigation and others (1,20) evaluating stretch-shortening cycle efficiency have failed to find improvements with caffeine ingestion. This suggests that the effect of caffeine on jumping performance may be independent of the slow stretch-shortening activity during the CMJ. Increased rate of torque development (5,6) and peak torque (6,9,22) with caffeine has been found during isokinetic evaluation. We speculate that the greater change in jump

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execution detected was likely a product of the increased time to develop force during the countermovement. Interestingly, changes in jump execution were not mirrored in the SJ although the effect sizes for jump height were comparable, eta squared 0.38 and 0.42.

The statistically significant change in jump execution for the SJ was time to half peak force ($p = 0.019$), which is an indicator of rate of force development. During the SJ, it seems that caffeine effects force production only during the initial portion of the jump. This is also supported by the trend for increased starting gradient ($p = 0.077$), which reflects the average rate of force development during roughly the first half of concentric force production in the SJ. Improvements in rate of force development with no change in peak force after caffeine have been reported during isokinetic plantar flexion (5). The lack of peak force change during the SJ may be due to the increased velocity obtained during the initial portion of the jump, mitigating a peak force gain during the most advantageous position. This may be overcome during the CMJ as force production begins during the eccentric contraction and peak force may be obtained at a lower velocity. Albeit, it seems that increases in peak force during a ballistic task with caffeine ingestion are not necessary for performance enhancement.

The relationships between jump height and jump execution variables for both the caffeine and placebo trials were also examined. In the placebo trial, jump execution variables were not associated with jump height for both jump techniques. In contrast, each jump execution variable that was altered in the caffeine trial during the CMJ was correlated with jump height in that trial ($p \leq 0.05$). Starting gradient during the SJ, which trended ($p = 0.077$) toward improvement in the caffeine trail compared with the control was the only variable correlated ($p \leq 0.05$) to jump height during the SJ in the caffeine trial. Starting gradient during the SJ is directly influenced by time to half peak force, which was improved ($p \leq 0.05$) in the caffeine trial. These data provide evidence that the observed changes in jump execution in the caffeine trail have a meaningful relationship to jump height.

It is important to note that although we reported increases in vertical jump height with caffeine at the group level, an evaluation of individual performances indicates roughly equal numbers of responders and nonresponders. Our data suggest that men and women have a similar proportion of responders, whereas a greater proportion of habitual caffeine consumers were identified as responders compared with those who do not regularly consume caffeine. It is possible that these athletes have self-selected to habitually use caffeine over time based on performance feedback. It has been proposed that single-nucleotide polymorphisms for genes related to caffeine metabolism may account for some of the variability in the degree of response to caffeine (4) and have been linked to habitual caffeine consumption (26).

The exact mechanism responsible for the effect of caffeine ingestion on vertical jump performance is not known. Caffeine seems to influence both central (6) and peripheral (21) factors of force development. One of caffeine's primary sites of action is at the central nervous system, and it is believed to enhance cognitive functions, such as concentration and arousal (11). Most of the testing sessions were conducted in the morning, so caffeine's ability to increase arousal may have been augmented. The supraspinal excitatory effect of caffeine may enhance motor unit recruitment and rate coding (6). Improved recruitment and rate coding of the large lower-body muscle groups involved in jumping may partially explain our results. Large muscle groups are more difficult to recruit and achieve optimal rate coding (22). It seems that the effect of caffeine on force production may be greater in tasks that involve larger muscle mass (22,25). This is consistent with the evidence from studies using electromyography demonstrating that caffeine may produce a supraspinal excitatory effect (5,6). Peripheral factors such as sarcoplasmic calcium kinetics may also be involved (21). It is likely a combination of several factors contributing to the increased performance observed in our athletes (8,21).

This study has several limitations. This investigation was not a double-blind design. The blinding of caffeine may have been insufficient. A 5 $mg \cdot kg^{-1}$ of body weight dose of caffeine seemed to be detectable in our study. Some of the participants were able to correctly guess which treatment was caffeine after testing, however these data were not collected. The study was limited to Division I collegiate athletes, and the results may not transfer to lower-level athletes and the general population. Our results may not be generalizable to ballistic tasks involving smaller muscle mass (22,25) or performed during a different time of day (17). Only 25 athletes with a diverse sporting background (sprinters, jumpers, throwers, baseball, and football) completed the study. Discrepancies in anthropometric characteristics and jumping familiarity may have introduced more variability in the jump execution variables reducing our ability to detect meaningful change. Reliability of jump execution variables may be different between jumping techniques. The athletes were in different stages of their seasons. It is difficult to account for a collegiate athlete's total physical activity in a given week. Sport participation may have exposed the athletes to activities very similar to jumping which can lead to fatigue. However, this is not a likely explanation for our observed results because of the randomized, crossover design.

Practical Applications

Our data indicate that caffeine (5 $mg \cdot kg^{-1}$) enhances vertical jump performance in Division I collegiate athletes competing in sports involving maximal-intensity ballistic tasks. It seems that the physical mechanism of enhancement is increased rate of force development or peak force production during jumping. The importance of rate of force development and peak force production during the performance of maximal-intensity ballistics tasks is well known (27). Thus, our data suggest that the ergogenic effects of caffeine may transfer to

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other ballistic tasks involving the lower-body musculature in collegiate athletes. It is not known if the degree of skill involved in the task modifies the effect of caffeine on physical performance. However, investigations have reported an ergogenic effect of caffeine on maximal ball velocity during spiking in volleyball (20) and standing shot-put performance in throwers (7) suggesting that the effect may also transfer to ballistic tasks requiring a higher degree of skill. Caffeine ingestion of 3–5 $mg \cdot kg^{-1}$ of body weight seems effective for improving jumping performance in athletes (1,2,13,20), although an evaluation of individual responses indicates that many may not exhibit a performance gain. Caffeine may be effective to enhance the quality of maximal-intent ballistic tasks during training and competition. Future investigations should evaluate the effectiveness of caffeine to enhance maximal-intensity ballistic tasks requiring greater skill, repeated performances, and performed during different times of the day.

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