Caffeine, Energy Drinks, and Strength-Power Performance

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SUMMARY

CAFFEINE AND ENERGY DRINKS ARE POPULAR SUPPLEMENTS THAT HAVE VARIABLE USES IN BOTH ATHLETIC AND NONATHLETIC POPULATIONS. EVIDENCE HAS BEEN RELATIVELY CONSISTENT IN SHOWING THE EFFICACY OF THESE "HIGH-ENERGY" COMPOUNDS IN ENHANCING ENDURANCE PERFORMANCE, BUT LESS IS UNDERSTOOD REGARDING ITS ERGOGENIC POTENTIAL IN STRENGTH/POWER ACTIVITIES. THIS REVIEW FOCUSES ON THE EFFICACY ON THESE PRODUCTS (CAFFEINE BY ITSELF OR IN COMBINATION WITH OTHER INGREDIENTS) ON STRENGTH/POWER PERFORMANCE AND REACTION TIME. IN ADDITION, DISCUSSION ON THE EFFICACY OF CAFFEINE DURING PROLONGED ACTIVITY AND ITS ROLE DURING TACTICAL PERFORMANCE IS ADDRESSED.

INTRODUCTION

The popularity of high-energy drinks seems to be increasing on an annual basis. Recent evidence suggests that energy drinks are available in more than 140 countries, and sales in 2011 were expected to be in excess of $9 billion (61). Marketing strategies are aimed at young, athletic populations. Supplement companies are frequently serving as event sponsors, and their products are endorsed by competitive athletes. The success of these strategies is evidenced by reports indicating that half of the energy drinks are sold to individuals of 25 years and younger (61). Hoffman et al. (40) reported that 31.5% of adolescents self-admit using high-energy drinks, whereas others have suggested that 30%–50% of adolescents and young adults (61) and nearly half of intercollegiate athletes consume energy drinks (70).

The primary ingredient in energy drinks is caffeine. However, to enhance the effect of caffeine, many of these drinks contain several additional ingredients to provide a synergistic or additive effect. The efficacy of caffeine, and various combinations of caffeine and other ingredients has been well-established regarding endurance performance (10,14,16–18,31,44,45). Studies have shown that caffeine enhances performance in running and cycling trials to exhaustion (18,34,35,42,53,56), rowing (9), and swimming (15). However, research has been equivocal when examining the effect of caffeine on strength-power performance. The focus of this review is to provide a clearer understanding of the ergogenic role that caffeine and energy drinks have on strength, power, and anaerobic exercise performance.

MECHANISM OF ACTION

Caffeine is a central nervous system (CNS) stimulant, and its effects are similar yet weaker than those associated with amphetamines. Caffeine is used as an ergogenic aid by both aerobic and anaerobic athletes. However, the mechanism of action for these athletes may be quite different. For the aerobic athlete, caffeine is thought to prolong endurance exercise. The mechanisms that have been proposed to cause this effect involve an increase in fat oxidation by mobilizing free fatty acids from adipose tissue or intramuscular fat stores (1,14,16,17,20,44,45,62). The greater use of fat as a primary energy source will slow glycogen depletion and delay fatigue. However, there have been a number of researchers who have questioned this mechanism (32,33,36,46).

During short-duration high-intensity exercise, the primary ergogenic effect attributed to caffeine supplementation is enhanced power production. There are a number of possible mechanisms that have been reported to explain the effect of caffeine on strength-power performance. These mechanisms include action on both the CNS and neuromuscular systems. One of the most significant effects of caffeine on the CNS is its action as an adenosine antagonist, possibly delaying fatigue by binding to adenosine receptors, reducing the inhibitory effects of adenosine (4,29). In a meta-analysis by Warren et al. (69), it was suggested that the effect of caffeine on the CNS is the most likely source of improvement in strength-power performance by enhancing muscle activation (motor unit recruitment). In addition, there is evidence that supports caffeine as an analgesic, lowering pain and

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ratings of perceived exertion (18,27,54). There is also evidence suggesting that caffeine produces an enhanced excitation-contraction coupling, affecting neuromuscular transmission and mobilization of intracellular calcium ions from the sarcoplasmic reticulum (64). Caffeine is also thought to enhance the kinetics of glycolytic regulatory enzymes, such as phosphorylase (62). The exact mechanism to explain the effect of caffeine on strength-power performance is not clearly defined at this time. However, there is evidence to support both central and peripheral factors that contribute to this effect (4,29).

EFFECT OF CAFFEINE AND ENERGY DRINKS ON STRENGTH AND POWER PERFORMANCE

The evidence supporting caffeine alone as an ergogenic aid in strength, power, and anaerobic activities seems to be inconclusive. When caffeine is ingested in relative dosages of 5 to 6 mg/kg body weight, significant increases in acute strength and power performance, as well as increases in training volume, have been reported (3,5,6,21,28). A significant increase in maximal bench press strength has been observed in resistance-trained women after caffeine ingestion (28). Others have shown that acute caffeine ingestion can improve peak torque and power in the first of 2 bouts of isokinetic knee extension/flexion exercise (5) and increase contraction velocity during elbow flexion (6). Increases in training volume (repetitions performed) have also been demonstrated after acute caffeine ingestion in the first 2 sets of performing the leg press to exhaustion (3), knee extension/flexion (5), and bench press to exhaustion at 60% of 1 repetition maximum (1RM) (21). In contrast, no changes in 1RM in the bench press and leg extension exercises were seen in untrained male subjects after an ingestion of 400 mg of caffeine (37). Similarly, a 6 g/kg ingestion of caffeine was unable to enhance strength performance during maximal effort isometric plantar flexion exercise (23).

Several studies examining the effect of preexercise energy drink consumption have shown significant increases in training volume (number of repetitions performed) and power performance (24,26,30,43). These preexercise energy drinks often contain an "energy matrix" that may contain caffeine, taurine, and glucuronolactone. However, they also contain additional ingredients such as amino acids, creatine, and beta-alanine. These other ingredients are not designed to provide an energy boost for acute exercise performance but to enhance recovery and provide the daily intake of these compounds to increase strength and power performance. The latter reasons are more of a marketing tool that minimizes the number of supplements that athletes need to consume on a daily basis. In regards to the effect of these propriety energy blends on enhancement of training volume, the results of these studies have consistently supported the marketing claims of greater training volume. Typically, the ingestion of these propriety blends 10 minutes before a workout have been demonstrated to significantly increase the total number of repetitions performed during resistance exercise varying between 4 and 6 sets (30,43). In addition, the average peak and mean power for repetitions performed have also been shown to be significantly higher in subjects consuming these high-energy blends (30) (see Figure 1). Others have shown that an energy matrix using the same ingredients discussed above, but with an additional carbohydrate load (21.5 g of sucrose, 5.25 g of glucose, and 50 mg of inositol) (marketed as Red Bull) was shown to significantly improve the total number of repetitions performed during 3 sets of bench press exercise (24).

The use of energy drinks may also have efficacy in maintaining strength performance after exhaustive exercise. Ganio et al. (26) showed that subjects ingesting an energy drink (containing 195 mg/L caffeine, 1.92 g/L taurine, 46 mg/L carnitine, and electrolytes in a 7% carbohydrate solution) after 120 minutes of cycling exercise (intensity alternated between 61 and 75% of $\dot{V}O_2max$) were able to maintain maximal strength performance in a leg extension exercise compared with subjects consuming a placebo (26).

Although energy drink ingestion has been shown to be efficacious in regards to enhancing training volume and power performance during resistance training, the ability of energy drinks to enhance anaerobic power during high-intensity exercise seems limited. No improvements have been noted in a 30-second Wingate anaerobic power test (WAnT) after ingestion of an energy drink containing anhydrous caffeine and several herbal and botanical compounds, including yohimbine, evodiamine, hordenine, tyramine, and tyrosine (41). These compounds are suggested to provide a stimulatory effect. Similarly, consumption of coffee enriched with 450 mg of caffeine, 1.2 g of garcinia cambogia, 360 mg of citrus aurantium, and 225 mg of chromium polynicotinate had no ergogenic benefit on peak power, mean power, time to peak power, fatigue index, and total work in the WAnT (42). The use of the Red Bull energy drink also had no ergogenic benefit during multiple WAnT trials (24).

EFFECT OF CAFFEINE AND ENERGY DRINKS ON SPRINT, AGILITY, AND REACTION TIME

Caffeine ingestion has been demonstrated to provide an ergogenic effect on repeated sprint performance during both running and cycling modes of exercise (25,47,57,58,60,63). Acute caffeine intake before exercise has been reported to improve repeated sprint performance for subjects performing 5 sets of 6 × 20 m sprints (58) and repeated 30-second sprints on a cycle ergometer (57). Schneiker et al. (60) reported significant improvements in sprint performance during two 36-minute simulated game halves, with each half containing 18 × 2-minute blocks of 4-second sprints with 120 seconds of recovery (both active and passive) after caffeine ingestion. This study simulated the physiologic demands of a team sport and suggests that caffeine may be able to maintain sprint performance during a competitive contest. In a similar study, Stuart et al. (63) also observed greater repeated sprint performance during a simulated rugby contest after caffeine ingestion.

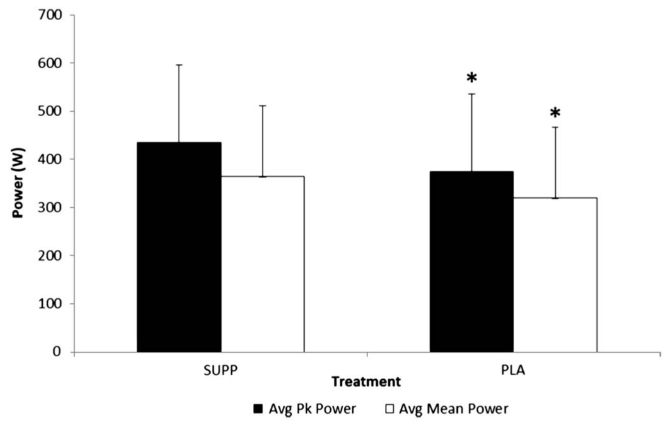


Figure 1. Average peak and mean power during resistance exercise. Supp = supplement; PLA = placebo.*Significant difference ($p < 0.05$) between the groups. Data from Gonzalez et al. (30).

Others have shown that acute ingestion of a proprietary blend of caffeine, creatine, and amino acids ingested 30 minutes before treadmill sprint drills will result in an improvement in anaerobic running capacity at 110%, 105%, and 100% of peak velocity (25) (see Figure 2). Caffeine also appears to augment performance above that seen from other supplements. Lee et al. (47), after a 5-day loading dose of creatine that increased repeated sprint performance, showed that the addition of an acute intake of caffeine (6 mg/kg) is able to stimulate further improvements in power outputs during intermittent high-intensity sprints on a cycle ergometer.

Acute ingestion of caffeine or energy drinks also appears to have some potential beneficial effects on agility performance and reaction time (2,22, 41). Caffeine ingestion appears to be beneficial in competitive athletes for improving reactive agility in both fresh and fatigue situations (22), including a rugby game (63). However, this may be limited to trained individuals as no ergogenic effect was observed in untrained individuals performing the proagility test after caffeine supplementation (49). Several studies have demonstrated that energy drinks may have a significant effect on reactive ability and increase concentration, focus, and memory (2,41). This may have important implications for tactical personnel (e.g., military, police, and fire/rescue).

In a military environment, caffeine ingestion has been shown to improve vigilance, psychomotor performance, shooting accuracy, learning, memory, and mood state in ground and aviation operations (11,48,50–52,65).

CAFFEINE USE IN OPERATIONAL/ TACTICAL SETTINGS

In a unique environment where strength, power, and anaerobic fitness are essential for success, U.S. Air Force centrifuge riders showed a significant increase in their relaxed G-tolerance after ingestion of an energy drink containing 5 mg/kg body weight of caffeine along with a number of other ingredients including proprietary amounts of taurine, L-theanine, fructose, among others. Relaxed G-tolerance is measured while the centrifuge accelerates at 0.1 *g*/second with the rider sitting relaxed in the centrifuge gondola, looking straight ahead at a light bar. Relaxed G-tolerance is that point when the riders loses 100% of their peripheral vision and 50% of their central vision. Even though there was a significant increase in relaxed G-tolerance, there was no benefit shown during simulated air combat maneuvering, where the centrifuge was alternated every 15 seconds between +4.5 Gz and +7.0 Gz in these same riders for up to 15 repetitions. There was also no effect seen during a rapid Gz onset ride to +6 Gz (68). However, in the same study, hip adductor strength was 37% lower in the placebo session than in the caffeine session.

Strength and power are important during the high-*g* environment encountered in fighter and attack aircraft operations because of the deleterious effect the G-forces have on the ability of the heart to deliver blood to the brain. Each additional "G" above the 1G experienced on earth reduces the cerebral blood pressure by approximately 20 mmHg. Strength and power are required to perform what is termed an anti-G straining maneuver (AGSM). During an AGSM, a maximal isometric contraction is performed in the peripheral musculature to try to reduce pooling of blood, while a maximal Valsalva maneuver is

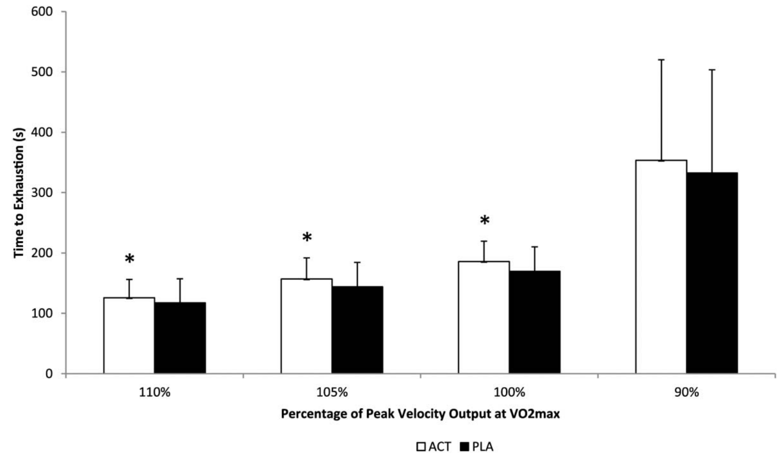


Figure 2. Time to exhaustion at each percentage of peak velocity for ACT and PL testing sessions. *Significant difference ($p < 0.05$) between the groups. ACT = supplement; Pl = placebo. Data from Fukuda et al. (25).

performed. The Valsalva maneuver is where maximal pressure is generated against a closed glottis to increase driving pressure in the chest (71). A similar maneuver is seen during maximal efforts in the weight room. This AGSM can enhance G-tolerance by as much as 3–4 *g*s in trained personnel (55).

In military aviation, alertness and reaction time are critical to successful completion of missions. Several approaches have been used to maximize the potential for success. These methods have included both nonpharmacological and pharmacological interventions. On the nonpharmacological side, the services have policies in effect that state required rest for aircrew. During combat operations, there are many times when operational needs override the policies for aircrew rest. The pharmacologic interventions have included the use of caffeine in Operation Southern Watch in the 1990s (7) to the use of dextroamphetamines and modafinil during prolonged flight operations during the wars in Iraq and Afghanistan. As stated previously, the use of these pharmacologic interventions is secondary to adequate rest and is under the supervision of the military medical community (66).

DOSE RESPONSE

There appears to be a dose response with caffeine supplementation in strength-power performance. The normal dose in most studies showing a positive effect of caffeine supplementation is 5–6 mg/kg body weight. This would mean that the average dose for a person weighing 175 pounds (80 kg) would be approximately 400 mg of caffeine. For comparison, a generic cup of drip coffee contains between 110 and 150 mg of caffeine per 8 oz. (38). A 12 oz Coca Cola or Pepsi contains between 30 and 40 mg of caffeine. Energy drinks typically contain between 75 and 80 mg of caffeine per 8 oz; however, there are some energy drinks that contain as much as 174 mg per serving (39,59). No significant effects have been seen from low caffeine doses (up to 2.1 mg/kg body weight) in studies examining multiple sprints, grip strength, and repetitions in the bench press exercise (8,12,19).

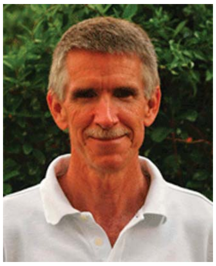
DOES CAFFEINE INGESTION POSE A RISK OF CAUSING A POSITIVE DRUG TEST?

Currently the World Anti-Doping Agency (WADA) lists caffeine as part of its monitoring program, meaning caffeine levels are still tested for and reported after urine testing, but it is not banned from use. Caffeine was removed from the WADA banned list in 2004. However, the National Collegiate Athletic Association (NCAA) still lists caffeine as a "drug subject to restrictions" if concentrations in urine exceed 15 μg/mL. The NCAA does not list an equivalent dosage required to test positive because there are a number of confounding factors, but it states that the cutoff is set so that moderate caffeine consumption will not cause a positive test. In a study by Van der Merwe et al. (67), they found that a dose of approximately 17.53 mg/kg of caffeine, which would be equivalent to 8 to 10 cups of coffee, produced a urinary caffeine level of 14 μg/mL still below the NCAA cutoff level to 15 μg/mL. In addition to caffeine, guarana seed extract is listed as part of the stimulant group banned by NCAA. Tuarine, L-theanine, green tea extract are listed as "Impermissible" by the NCAA, which means institutions may not supply these to their student athletes. Intercollegiate athletes should check with their coaches and medical staff before consuming energy drinks. Athletes competing under the rules of the United States Anti-Doping Agency should also check this organization's rules before consuming energy drinks.

PRACTICAL APPLICATIONS

Caffeine and energy drinks do appear to have an ergogenic effect on strength-power performance. Specifically, evidence is quite consistent in that supplementing with caffeine or an energy drink containing caffeine and other ingredients can increase the quality of a workout by increasing the number of repetitions performed and the power output per repetition. This may have important implications for long-term strength and power development because the stimulus to the muscle is greater from these training sessions. Evidence is also clear that the use of a "high-energy" supplement can impact athletic performance by delaying fatigue and improving reaction time. Thus, the ergogenicity of caffeine by itself and in combination with other synergistic ingredients can provide a competitive advantage to athletes. The ergogenicity of caffeine does appear to be dose related. It appears that a minimal dose of 5–6 mg/kg body weight is needed to enhance performance. The mechanism for an increase in performance is unclear at this point, but there is compelling evidence that suggests that both the CNS and neuromuscular system play a role. More research is needed in this area to clearly define the mechanisms at work.

As in all supplements, energy drinks and caffeine supplementation need to be taken with care. The Food and Drug Administration does not regulate the ingredients found in energy drinks. The adverse effects reported after energy drink consumption include insomnia, nervousness, headache, and tachycardia (13). If a person has a cardiovascular problem, supplementation with energy drinks or caffeine should be discussed with a doctor.



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