

UCLA
Nutrition Bytes

Title

Caffeine: Can it Improve My Performance in Endurance Exercise?

Permalink

<https://escholarship.org/uc/item/6qb2s73p>

Journal

Nutrition Bytes, 4(1)

ISSN

1548-4327

Author

Stone, Jason

Publication Date

1998

Peer reviewed

Introduction

There is no stimulant consumed by more people in the world than caffeine (1). It can make us feel perkier, less tired, and more energetic. Knowing this, we may wonder if caffeine can aid us in increasing our exercise performance in long, fatiguing endurance activities. This paper examines the results seen in studies that look at the effect of caffeine on exercise ability for activities requiring over 20 minutes to complete. Additionally, we look at the possible sources of caffeine for exercise enhancement, the potential dehydration and diuretic effects of caffeine, and, the possible biochemical methods by which caffeine can influence exercise ability in an endurance event.

General Information on Caffeine

The following general information on caffeine is helpful in understanding the topics we discuss in this paper. The level of caffeine present on average in a few common substances is as follows (2,3):

Soda (12 ounces)

Coca-Cola 45 mg

Pepsi Cola 40 mg

Mountain Dew 55 mg

Coffee (10 ounces)

Drip Method 230 mg

Instant 130 mg

Tea (10 ounces) 100 mg

No Doz (1 tablet) 100 mg

Vivarin (1 tablet) 200 mg

Caffeine is completely absorbed in the gastrointestinal tract and it reaches its maximal level in the blood approximately 30 to 60 minutes after being consumed (1). In healthy adults, the half-life of caffeine ranges from 2 to 12 hours, and, on average, is 4 to 6 hours (1).

The Correlation between Caffeine and Endurance Performance

Caffeine was considered an illegal doping substance by the International Olympic Committee (IOC) until 1972, at which time the committee decided to take caffeine off the list of banned agents. In 1984, however, the IOC reconsidered its view on caffeine and today a limit of 12 mg/l stands as the maximum amount of caffeine that can be present in an athlete's urine. (It would take approximately 800 mg of caffeine, 40 ounces of coffee, or 16 cans of cola consumed in 2-3 hours for one to reach this level (2,3). A historic article printed in 1978 from the laboratory of Costill sparked the athletic and scientific interest on the ergogenic effect, or exercise enhancing ability, of caffeine. Costill's lab reported that when trained cyclists consumed 330 mg of caffeine one hour prior to cycling to exhaustion at 80 percent of maximal oxygen consumption (VO₂max), their time to exhaustion increased from the 75 min, observed with placebo, to 96 min(4). A second study shortly followed showing that 250 mg of caffeine increased the amount of work athletes could perform in 2 hours by 20% (5).

In the 1980's, most studies concerning caffeine and exercise focused on how the drug affected metabolism, while few looked at the potential ergogenic effect of caffeine. However, those studies that did examine caffeine's ergogenic ability were highly contradictory. Some papers reported that caffeine had no effect on endurance exercise performance, while others concluded that caffeine gave athletes an edge in endurance activities. Much of the inconsistency is thought to have arisen due to the lack of control among factors in the studies (6,7). In the 1990's, many variables that relate to experimental method and the qualities of the subjects studied have been controlled more precisely (6). The methodical factors that have been scrutinized include exercise modality, caffeine dosage, and percent power exertion (6,7). Concern with the experimental participants' nutritional and training status, previous caffeine use, and individual variability are being monitored more closely in studies during this decade (6,7). Lastly, the ability to obtain accurate results about exercise performance is better understood now (6). For example, we now have more accurate equipment, and we know that well-trained subjects provide more consistent and reliable data than poorly trained subjects in the studies (6).

Since 1990, numerous investigations have shown an ergogenic effect of caffeine in relation to prolonged exercise (6,8-13). Graham and Spriet performed one of the first important studies of this decade when they looked at seven trained competitive runners perform each of four double blind, randomly ordered tests (8). With each athlete, there were two trials where they ran at 85% VO₂max to exhaustion and two trials where they biked at 85% VO₂max to exhaustion. One hour before beginning exercise, the test subjects consumed a placebo or 9 mg/kg body weight caffeine. (A 9 mg/kg body weight dose is equivalent to 614 mg caffeine in a 150 pound person.) In both running and biking, caffeine significantly ($p < 0.05$) improved endurance. The mean results in running were 49 +/- 7.2 min with placebo and 71.0 +/- 11.0 min with caffeine, and, in biking, 39.2 +/- 6.5 min with placebo and 59.3 +/- 9.9 min with caffeine.

Another study, in 1995, again conducted by Graham and Spriet, looked to see if there existed a dose dependent relationship between caffeine and exercise performance (9). Eight well-trained endurance athletes, who had not consumed any caffeine 48 hours prior

to beginning each of the investigative tests, were given a placebo, or a capsule that contained 3, 6, or 9 mg/kg body weight caffeine. One hour later they were asked to run at 85% VO₂max until they reached voluntary exhaustion. There were significant increases in exercise performance by 22 +/- 9% and 22 +/- 7% over the placebo time of 49.4 +/- 4.2 min with the 3 and 6 mg/kg body weight dosages, respectively. There was no significant difference between the 9 mg/kg dose and the placebo. This contradicted the result seen in their 1991 paper.

A somewhat similar report was released only two months after the previous paper by Graham and Spriet (9) and Pasman, et al. (10). This study looked at nine well-trained cyclists and asked the athletes to cycle at 80% of maximum workload (W_{max}) to exhaustion one hour after being given, in a double-blind and randomized manner, caffeine capsules of 0, 5, 9, or 13 mg/kg body weight. The resulting times were 47 +/- 13, 58 +/- 11, 59 +/- 12, and 58 +/- 12 min for the 0, 5, 9, 13 mg/kg body weight dosages, respectfully. Each caffeine dosage gave a significant increase in endurance performance relative to the placebo. However, the improvements are extremely similar in all three caffeine doses, and, thus, Pasman, et al. did not find a dosage dependent relationship with exercise performance in the caffeine range of 5 to 13 mg/kg body weight. After exercise, mean urinary concentrations of caffeine were 4.8 +/- 1.8, 8.9 +/- 5.2, and 14.9 +/- 6.9 mg/l urine for 5, 9, and 13 mg caffeine/kg body weight dosages, respectively. Only the dose of 5 mg/kg body weight would have allowed all participating subjects to pass the IOC limit of 12 mg/l urine.

In the same year, Trice and Haymes reported on the relationship they had observed in a double blind study between caffeine and intermittent exercise (13). After ingesting placebo or 5 mg/kg caffeine and waiting one hour, subjects exercised at 85 to 90% W_{max}. The participants were asked to try to complete three 30 min cycling periods with a 5 min break between each period. They were considered to have failed if they did not finish a 30 min period, or when their cycling fell below 70 rpm. Once again, the time until failure was significantly longer in the caffeine test than in the placebo test.

In addition to running and biking, caffeine has also been shown by Macintosh and Wright to have an ergogenic effect in swimming (12). In a double-blind crossover study, trained swimmers were given either a placebo or a dosage of caffeine at 6 mg/kg body weight, two and one-half hours before swimming a 1500m freestyle time trial. (The swimmers were allowed a 100m warm up before the race). The time required to finish was significantly shorter with caffeine 20:58.8 +/- 0:36.4 as compared to placebo 21:21.8 +/- 0:38.

Together, these recent experiments strongly support the idea that caffeine is an ergogenic aid in endurance exercises requiring, on average, over 20 minutes to complete. As stated earlier, Graham and Spriet (9) reported no significant improvement in exercise performance during a running trial that compared placebo to caffeine consumed at 9 mg/kg body weight. This likely occurred because at this dosage some athletes begin to notice side effects, such as headache, gastrointestinal distress, and dizziness, that decrease exercise performance. However, side effects are rare at dosages of 6 mg/kg

body weight and lower. Considering this point and the fact that no significant improvement has been demonstrated by a dose greater than 6 mg/kg body weight compared to a dose at 6 mg/kg body weight, it seems that the optimal exercise enhancing dosage could lie near or below this area for most athletes. It is ironic that this dosage keeps an athlete's urine caffeine level well below the IOC illegal limit of 12 mg/l urine, and even further below the illegal limit of caffeine in the NCAA of 15 mg/l urine (1).

While caffeine appears to provide a substantial ergogenic effect in prolonged exercise, results remain ambiguous in short term exercise requiring less than 20 minutes to complete and in sprints (6,14). More research is necessary in these areas before results become conclusive.

Sources of Caffeine to Improve Endurance

While studies have shown that caffeine administered in a pill can have an ergogenic effect in prolonged exercise, caffeine from other sources may not provide the same ergogenic effect (15). Graham, et al. compared the exercise performance of 4.5 mg caffeine/kg body weight given via a "pure" caffeine tablet and the same amount of caffeine given in two mugs of strong coffee consumed in approximately 10 min by the subjects. The tablet form of caffeine gave the usual performance advantage, while caffeine consumption in coffee showed little of no effect on exercise performance. When plasma concentrations of caffeine were tested, the caffeine levels were identical between the two methods of caffeine consumption. It was hypothesized that coffee contains several compounds that may negate the ergogenic effect of caffeine.

The Dehydration and Diuretic Effects of Caffeine

It has been well established that the consumption of caffeine during rest increases an individual's sweat rate and urine production. Thus, it is a concern that the consumption of caffeine during exercise might compromise an athlete's hydration status. However, when Falk, et al. performed a double-blind crossover study comparing men during exercise after placebo ingestion vs. after caffeine ingestion, they found no significant difference in sweat rate or fluid balance (16).

Additionally, in a recent paper by Wemple, et al. the diuretic effect of caffeine was examined during rest and during exercise (17). In six subjects, urinary volume (UV) was compared between a trial consisting of four hours of rest, and a trial consisting of one hour of rest followed by three hours of cycling at 60% VO₂max. Throughout the trials, subjects consumed 35 ml/kg body weight of a carbohydrate electrolyte drink without caffeine (placebo) or with 25 mg/dl caffeine. From 60 min to 240 min, in the four hours of rest trial, UV was greater ($p < 0.01$) when caffeine was present in the drink (UV caffeine trial: 1843 +/- 166 ml, UV placebo trial: 1411 +/- 181 ml) as would be expected. However, in the exercise containing trial, there was not a significant difference in UV during the cycling portion (from 60 min to 240 min) when caffeine was included in the drink (UV caffeine trial: 398 +/- 32 mL, UV placebo trial: 490 +/- 57 ml). It was

concluded that caffeine consumed in a carbohydrate electrolyte containing drink during exercise does not "compromise" the bodies hydration status.

Proposed Mechanism by Which Caffeine Provides an Ergogenic Effect in Prolonged Exercise

Although the mechanism by which caffeine enhances performance in endurance exercise is uncertain, it is believed that caffeine increases potassium transport into cells of inactive tissue by upregulating the Na-K pump (6,18). The increased K transport is thought to occur predominantly in inactive tissue since Na-K pump activity in working muscle is postulated to be close to maximal, giving little room for increase. Caffeine would thus attenuate the increased plasma K concentration generally seen during intense aerobic exercise. The relative decrease in the concentration of potassium in the plasma that has been observed is hypothesized to help maintain the membrane potential and the excitability of contracting muscle.

It is believed that caffeine increases Na-K pump activity by binding to adenosine receptors. This binding causes an increase in cytosolic cAMP, which activates the Na-K pump. While it has been proposed that caffeine and its metabolites may also increase cytosolic cAMP levels by inhibiting phosphodiesterase activity, as seen in vitro, this is likely an insignificant factor in the ergogenic effect of caffeine with endurance exercise. The trouble is that in vivo concentrations of caffeine and its metabolites are substantially smaller than the concentration needed to inhibit phosphodiesterase activity in vitro. Caffeine and its metabolites would provide only a weak inhibition of phosphodiesterase at physiological concentrations (19).

Additionally, caffeine is hypothesized to somehow reduce one's perception of exertion. Studies have shown that athletes perceive exercise as being easier after they have consumed caffeine vs. placebo (12). Furthermore, when asked to exercise to a specific rating on the Borg rating of perceived exertion scale, athletes performed significantly more work after receiving caffeine than placebo (20).

Conclusion

Studies during this decade have shown that caffeine acts as an ergogenic aid in exercise taking greater than 20 minutes to complete. Although we often equate caffeine with coffee, and while caffeine has proven to be an ergogenic aid, coffee with caffeine has not. Thus, it should be remembered that other chemicals, when taken in conjunction with caffeine, can alter the ergogenic effect of caffeine. We also saw that, contrary to popular belief, caffeine does not significantly increase dehydration in exercising athletes, as it does in resting individuals. This is a significant result for athletes, such as marathoners and triathletes, that consume caffeine during a long race. The mechanism by which caffeine acts as an ergogenic aid in endurance exercise is unknown, but it has been proposed to be related to the reduction of the concentration of plasma K observed in athletes after consuming caffeine vs. placebo. Additionally, a psychological effect caused by caffeine is hypothesized to decrease one's perception of exertion.

Although much has been done to show that caffeine can act as an ergogenic aid in prolonged exercise, it is important to remember that people do respond differently to caffeine and that the optimal dose for a specific individual can vary with what has been seen from those involved in the research studies. Many of the participants in the studies were male athletes who had been training. Additionally, caffeine before a race can bring about additional health risks to certain people, such as those with hypertension. Before certain types of prolonged exercise, such as soccer or basketball, caffeine may be unwanted by some individuals because it can cause them to feel too wired or off track. However, to many endurance athletes caffeine has become a major component of their race because they feel it gives them an important edge. Triathletes are often seen drinking defizzed Coke during a race or sipping from a bottle containing their own blend of ingredients, including powdered caffeine that they stirred in before the start. Ultimately, athletes must decide for themselves if caffeine is something they want to incorporate with their exercise. If one does decide to use caffeine with exercise, it is advised that this not be tried for the first time in a race considered important.

REFERENCES

1. Thein LA, Thei JM, Landry GL. Ergogenic aids. *Physical Therapy*. 1995;75:426-439.
2. International Food Information Council. *Caffeine and health; Clarifying the Controversies*. 1992.
3. Pennington J. *Bowes & Churches Food Values of Portions Commonly Used*, 16th ed. 1992.
4. Costill DL, Dalsky G, Fink W. Effects of caffeine ingestion on metabolism and exercise performance. *Med Sci Sports*. 1978;10:155-158.
5. Ivy JL, Costill DL, Fink WJ, Lower RW. Influence of caffeine and carbohydrate feedings on endurance performance. *Med Sci Sports*. 1979;11:6-11.
6. Graham TE, Spriet LL. Caffeine and exercise performance. *Sports Science Exchange*. 1996;9:SSE60.
7. Conlee RK. Amphetamine, caffeine, and cocaine. In: Lamb DR, Williams MH, eds. *Ergogenics: Enhancement of Performance in Exercise and Sport*. Indianapolis: Brown and Benchmark; 1991:285-330.
8. Graham TE, Spriet LL. Performance and metabolic responses to a high caffeine dose during prolonged exercise. *J Appl Physiol*. 1991;71:2292-2298.
9. Graham TE, Spriet LL. Metabolic, Catecholamine and Exercise Performance Responses to Varying Doses of Caffeine. *J Appl Physiol*. 1995;78:867-874.

10. Pasma WJ, VanBaak MA, Jeukendrup AE, DeHaan A. The effect of different dosages of caffeine on endurance performance time. *Int J Sports Med.* 1995;16:225-230.
11. Spriet LL, MacLean DA, Dyck DJ, Hultman E, Cedarblad G, Graham TE. Caffeine ingestion and muscle metabolism during prolonged exercise in humans. *Am J Physiol.* 1992;262: E891 - E898.
12. MacIntosh BR, Wright BM. Caffeine ingestion and performance of a 1,500-metre swim. *Canadian Journal of Applied Physiology.* 1995;20:168-177.
13. Trice I, Haymes EM. Effects of caffeine ingestion on exercise-induced changes during high-intensity, intermittent exercise. *Int J Sports Nutr.* 1995;5:37-34.
14. Dodd SL, Herb RA, Powers SK. Caffeine and endurance and performance: an update. *Sports Med.* 1993;15:14-23.
15. Graham, TE, Hibbert E, Sathasivam P. Caffeine vs. coffee: coffee isn't an effective ergogenic aid. *Med Sci Sports Exerc.* 1995;27:S224. (Abstract)
16. Falk B, Burnstein R, Rosenblum J, Shapiro Y, Zylber-Katz E, Bashan N. Effects of caffeine ingestion on body fluid balance and thermoregulation during exercise. *Canadian Journal of Physiology and Pharmacology.* 1990;68:889-892.
17. Wemple RD, Lamb DR, McKeever, KH. Caffeine vs.caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. *Int J Sports Med.* 1997;18:40-46.
18. Lindinger, MI, Graham TE, Spriet LL. Caffeine attenuates the exercise-induced increase in plasma [K+] in humans. *J Appl Physiol.* 1993;74:1149-1155.
19. Graham TE, Rush JWE, VanSoeren MH. Caffeine and exercise: metabolism and performance. *Can J Appl Physiol.* 1994;2:111-138.
20. Cole KJ, Costill DL, Starling RD, Goodpaster BH, Trappe SW, Fink WJ. Effect of caffeine ingestion on perception of effort and subsequent work production. *Int J Sport Nutr.* 1996;6:14-23.

Additional Readings

Clark, N. Nancy Clark's Sports Nutrition Guidebook. Human Kinetics, 1997.

Tinley S, McAlpine K. Scott Tinley's Winning Guide to Sports Endurance.

How to Maximize Speed, Strength, and Stamina. Rodale Press, 1994.