Caffeine and its ergogenic effect in sport (second part)

Antonio García Moreno
Universidad Pablo de Olavide. Sevilla

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Summary

The effects of caffeine on the human body have been studied for some time and much is now known about its characteristics. In the sports world, caffeine is one of the most popular ergogenic aids and is widely used by coaches and athletes. Given its importance, in this paper we analyze the ergogenic effects of caffeine on athletic performance and related actions, through a review of the latest scientific literature. We selected studies that included well-trained subjects performing a physical activity that reflects current practices in sport. Close attention was given to the methodology used, including the dose, timing and administration method of the caffeine, with the aim of establishing an updated guide to caffeine as an ergogenic aid in sport. The results show there are a variety of studies that have investigated the effects of caffeine on exercise using different methodologies, making it impossible to reach a general assumption. Nevertheless, we are able to draw valuable conclusions including the clear trend towards the effectiveness of caffeine as an ergogenic aid in certain situations, new findings that deal with the use of caffeine on consecutive days of physical activity, the best time of day to take the substance, the strategic management of caffeine to counteract sleep deprivation, and in what direction the latest research trends in this field are moving.

Key words:
Caffeine. Ergogenic effects. Sports. Aerobic exercise.

La cafeína y su efecto ergogénico en el deporte (segunda parte)

Resumen

Los efectos de la cafeína sobre el organismo humano han sido estudiados desde hace tiempo y, a día de hoy, ya conocemos gran parte de sus características. En el mundo del deporte, la cafeína es una de las ayudas ergogénicas más populares y empleadas por entrenadores y atletas. Debido a su importancia, en este trabajo nos hemos propuesto el objetivo de analizar los efectos ergogénicos de la cafeína sobre el rendimiento deportivo y todo lo que rodea a esta acción, a través de una revisión de la literatura científica más actual. Hemos seleccionado aquellos estudios que incluyeran sujetos bien entrenados realizando una actividad física que reflejara las actuales prácticas en el deporte, prestando mucha atención a la metodología empleada, esto es la dosis, el momento y la forma de administración de la cafeína, para conseguir alcanzar nuestra meta de constituir una guía actualizada sobre todo lo que rodea a la cafeína como ayuda ergogénica en el deporte. Los resultados obtenidos nos han mostrado una gran variedad de estudios que han investigado acerca de la cafeína y el ejercicio físico siguiendo diferentes metodologías, lo que provoca una imposibilidad de generalizar sobre el asunto. Sin embargo, hemos podido extraer valiosas conclusiones como la clara tendencia hacia la efectividad de la cafeína como ayuda ergogénica en situaciones determinadas, nuevos hallazgos que tienen que ver con el uso de la cafeína en días consecutivos de actividad física, el mejor momento del día para el consumo de la sustancia o la administración estratégica de cafeína para contrarrestar la falta de sueño, y hacia dónde se dirigen las últimas tendencias en investigación dentro de la materia.

Palabras clave:
Cafeína. Efectos ergogénicos. Deportes. Ejercicio aeróbico.

Correspondence: Antonio García Moreno
E-mail: antoniogm91@hotmail.com

The ergogenic effect of caffeine on anaerobic exercise

High-intensity, short-duration exercise

Research[41] assessed the performance of racing cyclists completing a 1-km time trial on cycloergometers. The subjects took a tablet with 5 mg/kg of caffeine or placebo dissolved in an aqueous solution 75 minutes beforehand. The results showed that taking the caffeine cut the time it took to finish the trial and led to a higher average speed, higher average power and greater peak power compared to the placebo. Caffeine in tablet form administered to trained subjects accustomed to the protocol of the activity improves performance in high-intensity, short-duration exercise.

As for sprint capability, Graham-Paulson *et al*[42] conducted research on 12 trained wheelchair athletes who completed a trial consisting of four 4-minute pushes and three sets of three 20-m sprints, each separated by 4 minutes of rest. In another study by Kopec *et al*[43], 11 athletes did six 20-metre sprints at the beginning, in the middle and at the end of a 60-minute simulated team-sport circuit. The wheelchair athletes who took 4 mg/kg of caffeine 70 minutes before the trial registered better times in the 20-metre sprints and improved their maximal-push performance compared to those who took the placebo. In the other study, the athletes who took capsules with 6mg/kg of caffeine 60 minutes before the trial improved their sprint capability both when fresh and when tired.

Another study[44] measured the sprint capability of trained cyclists by means of a trial on cycloergometers consisting of four 5-minute sets of five maximal sprints lasting 30 seconds with five 30-second active recovery periods. The cyclists chewed gum with 240 mg of caffeine for 5 minutes at the end of the second set of tests. The caffeine reduced the subjects' fatigue during the sprints, which may imply improvements in high-intensity performance in cyclists. So, the most recent studies show that caffeine has an ergogenic effect on performance in high-intensity, short-duration exercise.

Exercises based on strength and power

Most of the studies investigating the ergogenic effect of caffeine on exercises based on strength and power included in this review employed similar methodologies. One example is provided by 3 studies on resistance-trained athletes who were administered 6 mg/kg of caffeine in capsule form 60 minutes prior to sessions in test conditions. In the first study[45], the subjects performed a maximal leg-press test, while the participants in the second[46] completed leg-press and arm-curl tests with a 12-repetition maximum (RM) load to achieve the greatest number of reps to failure. In both studies, caffeine improved the maximum isometric voluntary contraction of knee extensors[45] and increased the total number of leg-press and arm-curl reps[46], providing foundations for improvement in the performance of exercises involving resistance. However, in the third study[8], in which the athletes performed 4 sets of as many bench-press and shoulder-press reps as they could at 70% of 1RM, and as many leg-press and bar-row reps as they could at 80% of 1RM, the caffeine had no ergogenic effect on performance. The study suggests that all the participants were regular caffeine consumers, which may have altered their response to caffeine. Nevertheless, the number of leg-press repetitions was greater after caffeine intake, although the scale of this improvement was small and no significant differences were observed in the exercises for the upper part of the body. Consequently, two studies point towards improvements in strength and power performance after taking 6 mg/kg of caffeine 1 hour before exercise, while another study shows no ergogenic effect under the same conditions. The habituation of the subjects to caffeine in the study by Astorino *et al*[8] may go some way towards explaining the lack of beneficial effects, but the subjects in the study by Hudson *et al*[46] were also regular caffeine users (daily consumption of 100-400 mg) and their performance improved. In Chen *et al's* trial[45], the subjects were not regular consumers of caffeine (weekly consumption of less than 200 mg) and they benefited from the effect of the substance in their anaerobic tests. With the data available, it is difficult to pinpoint why the studies gave the results that they did because the tests were conducted in very similar conditions and threw up very different results. Perhaps the answer lies in individual physiological and metabolic responses to caffeine. Be that as it may, it is necessary to place greater emphasis on and study the physiological and metabolic parameters that these studies ignored and which may explain the results obtained.

In 3 other studies conducted along similar lines to the ones just described, well trained athletes with experience in strength training took 5 mg/kg of caffeine diluted in an aqueous solution 1 hour before exercise[6,7,47]. The studies measured the number of bench-press, leg-press, deadlift and horizontal-row repetitions to failure. In all three studies, the subjects increased the number of repetitions completed in each exercise after caffeine intake and experienced a significant reduction in the perceived exertion and muscle soreness rating. In Da Silva *et al's* study[6], the participants also showed a greater readiness to invest in mental effort. In view of these results, we can conclude that the intake of 5 mg/kg of caffeine 1 hour before exercise can improve the strength performance of trained athletes, possibly due to a greater readiness to make mental effort and a reduction in perceived muscle soreness and exertion.

Two other studies investigating strength and power performance showed beneficial results after the intake of caffeine. In the study by Woolf *et al*[9], 18 highly trained men ingested a multi-ingredient shake with 5 mg/kg of caffeine 1 hour before exercise. In the trial, the subjects performed a leg-press test and a bench-press test in which the repetitions and total weight were measured, followed by a 30-second Wingate anaerobic test on cycloergometer in which power output was measured. The intake of caffeine significantly increased the total weight lifted in the bench-press test and the maximum power produced in the Wingate test compared to the placebo, while no differences were registered in the leg-press test. Glaister *et al's* study[48] used a protocol consisting of sets of 6-second maximal sprints one hour after taking

a capsule with 5 mg/kg of caffeine. The caffeine supplement led to greater maximum anaerobic power output in comparison with the placebo. These studies demonstrate that doses of 5 mg/kg of caffeine can increase muscle power and strength in the upper body of trained athletes.

After this look at the studies of recent years, we can say that the use of caffeine supplements by trained athletes accustomed to anaerobic exercise may be effective when it comes to achieving improvements in performance. We have also found, however, that, when certain parameters, such as habituation to caffeine and individual responses to the substance, are not controlled, then the desired effect may not be achieved. Nevertheless, these studies reveal very important findings within the field, because from now on, research can develop protocols taking into account the necessary indications in order to cater for caffeine as an important factor in anaerobic performance.

The methodology of research on caffeine and sport

Doses of caffeine

We have seen a wide range of doses administered; from small to more moderate amounts of between 1.5 and 6 mg/kg, to absolute doses, classified as those between 80 mg and 300 mg. Small doses have proven sufficient to produce significant improvements in performance, as in the case of the study by Lane *et al*[49], in which a dose of 3 mg/kg improved power in competitive cyclists and triathletes during high-intensity interval training. Absolute doses are less commonly used because each individual has a different body weight, which means that the caffeine-subject relationship varies. However, when doses involving more or less standard quantities are used, similar effects may be achieved among different participants, as the study by Beck *et al*[50], in which 37 trained athletes improved their upper-body strength with a supplement of 200 mg caffeine, goes to show.

The most significant study was conducted with trained athletes[51] using 3 different doses of 3, 6 and 9 mg/kg to evaluate the effects of caffeine on neuromuscular tests consisting of bench-press and full-squat exercises against incremental loads (25%, 50%, 75% and 90%1RM), followed by an inertial load test on cycloergometer. The results revealed that mean propulsive velocity at light loads (25% and 50% 1RM) increased significantly for all caffeine doses compared to the placebo. At the medium load (75%), the 3-mg/kg dose did not improve muscle velocity or power in the bench-press and full-squat exercises. The 9-mg/kg dose improved velocity in the bench press and power in the full squat with the heaviest load (90%). There were no significant differences between the placebo and the 3- and 6-mg/kg doses in the cycloergometer test, while the 9-mg/kg dose improved maximum power output. The 9-mg/kg dose increased the frequency of adverse side effects dramatically. So we can conclude that the caffeine dose required for an improvement in neuromuscular performance depends on the magnitude of the load employed. A dose of 3 mg/kg of caffeine is enough to improve high-velocity muscle actions against low loads, whereas a higher caffeine dose (9 mg/kg) is necessary against greater loads, despite the appearance of adverse side effects.

The timing of caffeine administration

According to Ryan *et al*[52], the organism completely absorbs caffeine within approximately one hour following ingestion, although this may vary depending on the dose and the method of consumption. After the oral intake of caffeine, the concentration of the substance in plasma increases in proportion to the dose and peak levels in plasma can be seen between 15 and 120 minutes later. Researchers, therefore, normally administer caffeine doses (in capsule or drink form) 1 hour before exercise in their studies to ensure maximum concentrations in plasma during the activity[52].

However, a lot of studies have investigated the effect of caffeine by applying it more than one hour before, less than one hour before and even during exercise. A study conducted by Marriott *et al*[53] administered a capsule with 6 mg/kg of caffeine 70 minutes before high-intensity intermittent exercise, leading to improvements in the performance of the participants. In another study carried out with racing cyclists, caffeine was consumed 20 minutes before a 40-km time trial on cycloergometer and beneficial effects on performance after taking the supplement were observed[54]. In a recent study[55], caffeine gum was given to cyclists at kilometre 10 of a 30-km trial which included a 200-metre maximal sprint every 10 km. The participants had to chew the gum for 5 minutes and then remove it. The results showed an improvement in the power of the sprint in the last 10 km, leading to the conclusion that the ergogenic effect of caffeine gum appears 20 minutes after consumption.

Meanwhile, Cooper *et al*[56] designed an experiment with trained athletes who completed a four-block intermittent sprint test. The subjects took a carbohydrate gel with caffeine 60 minutes before exercise, just before starting and at the end of the second block, and the results showed that the gel was effective at reducing fatigue and perceived exertion, and contributed to maintaining high levels of glucose in the final stage of the exercise. Skinner *et al*[57] conducted very interesting research in which performance was measured in a 40-km time trial on cycloergometer following consumption of a caffeine capsule 1 hour before exercise compared to starting exercise with the level of caffeine in blood serum at its peak, which turned out to be between 120 and 150 minutes after intake. The caffeine consumed one hour before the trial significantly enhanced the athletes' performance in the 40-km time trial compared to the caffeine at its maximum concentration in serum on starting the activity, the maximum concentration in blood showing no ergogenic effect.

One of the most significant studies in this field was that conducted by Ryan *et al*[52], in which the subjects were given chewing gum with 3 mg/kg of caffeine 120, 60 or 5 minutes before a cycling trial lasting approximately one hour. The caffeine chewing-gum supplement improved the performance of the cyclists when given immediately before exercise (5 minutes earlier), but no beneficial

effects on performance were appreciated when it was consumed 1 or 2 hours beforehand.

Therefore, we can see that, depending on the dose and form of delivery, the ergogenic effect of caffeine can affect performance regardless of when it is applied.

Methods of caffeine administration

Caffeine can be administered in many different ways, but the most common way to take caffeine is through coffee. One study[58] compared the effects of caffeine administered through coffee with caffeine anhydrous diluted in water at a dose of 5 mg/kg. The results showed that both caffeine anhydrous and coffee consumed one hour before exercise could improve the performance of trained cyclists in aerobic cycling activities.

Due to the growing popularity of energy drinks, laboratory tests have started to use energy drinks on an increasing basis to evaluate the effects of caffeine on sports performance. A very recent study59 compared the ergogenic effect of caffeine on trained cyclists by means of both an energy drink (Red Bull) and capsules containing 3 mg/kg of caffeine. The results showed that caffeine consumed both through an energy drink and through capsules improves performance in cycling endurance tests.

The results seen in this review would seem to indicate that the way in which caffeine is taken can influence the speed at which the organism absorbs the substance, but that, regardless of the way it is taken, the effect on performance is the same when the dose is the same.

The latest trends in research on caffeine and sport

The administration of caffeine in alternative forms

More and more research is focusing on the ergogenic effect of caffeine taken in alternative ways. Paton *et al*[55] and Scott *et al*[11] used caffeine chewing gum and caffeinated isotonic carbohydrate gel, respectively, to demonstrate the effectiveness of caffeine at improving performance. Another study[60] used a carbohydrate and electrolyte solution with 5.3 mg/kg of caffeine to measure the ergogenic effect of the substance on endurance in trained cyclists; the results revealed that the caffeinated solution was effective at providing energy during prolonged exercise, improving performance and reducing muscle fatigue in the cyclists.

Two innovative pieces of research in the field were conducted by Doering *et al*[61], who exposed the subjects to mouthwash with 35 mg of caffeine 8 times during a 60-minute cycling activity, and by Schubert *et al*[62], who gave the participants a 59-millilitre "shot" of 2 different energy drinks with caffeine before a 5-km treadmill test. Neither of the studies, however, revealed any ergogenic effects of caffeine on performance in the tests or differences in physiological or perceptive variables compared with the placebo. This lack of benefits was associated with the low doses of caffeine employed. Nevertheless, there is a focus in current research on new ways of using caffeine, such as energy drinks, chewing gum, gels or carbohydrate and electrolyte solutions[11,55,59,60], which are different to the traditional ones, such as coffee or capsules, and good results are being obtained.

The effect of caffeine on performance in adverse environmental conditions

Exercise is tolerated less in hot environments than it is in cool ones, and several studies have investigated whether caffeine can counteract exercise fatigue induced by heat[63]. One study reports that a dose of 6 mg/kg of caffeine did not produce any ergogenic effect on aerobic performance in a hot environment[64], while 3 other studies suggest that doses of 3 and 6 mg/kg of caffeine are effective when it comes to providing benefits in endurance exercises carried out at high temperatures of between 33°C and 36°C[63,65,66].

Bearing in mind that the subjects in the study by Roelands *et al*[64] responded very differently to the caffeine and that their internal temperature increased significantly during the exercise after consuming caffeine compared to the placebo, which may have counteracted the ergogenic effects of the substance, we could say that caffeine, in doses of 3 to 6 mg/kg, proves an effective supplement to compensate performance diminished by high temperatures.

The effect of caffeine on performance in sports people who are habitual consumers as opposed to those not habituated to the substance

Several studies associate the level of habituation to caffeine of participants to an absence of beneficial effects on physical activity. In research conducted by Desbrow *et al*[67], low doses of caffeine did not improve the performance of trained subjects during prolonged exercise, possibly due to their habituation to the substance. Other studies attribute the participants' low level of caffeine consumption to a lack of improvement in their performance, the adverse reactions induced by caffeine in the subjects possibly counteracting its ergogenic effect[68,69].

However, one study conducted on cyclists and triathletes who were habitual caffeine consumers did note improvements in performance with low doses[70]. Meanwhile another study carried out on athletes with different levels of caffeine consumption only observed improvements in strength performance in those participants less accustomed to the substance, who also registered more intense emotional responses[71].

It can be concluded, therefore, that the subjects' level of caffeine consumption should be controlled and their response to the substance should be observed more strictly in future research. However, Gliottoni *et al*[72] did try to clarify the matter somewhat when they conducted research on 24 university athletes, split into two groups: small caffeine consumers, who took 100 mg or less a day, and major caffeine consumers who ingested 400 mg or more a day. The results showed similar work levels during exercise between the two groups after taking 5 mg/kg of caffeine, which caused a moderate hypoalgesic effect during

high-intensity activity in both groups. So, according to Gliottoni *et al*[72], the level of habituation to the substance does not affect the scale of the ergogenic effect of caffeine on physical performance.

The effect of caffeine on reaction time

Two studies used a reactive agility test to measure the reaction time of trained athletes after taking caffeine[73,74]. In both studies, 6 mg/kg of caffeine was administered to the subjects in capsule form 60 minutes before the trial, with the difference that Duvnjak-Zaknich et al's research[74] evaluated the subjects in conditions of fatigue, while Jordan *et al's*[73] did so when they were fresh. In the reactive agility test, the participants had to react as quickly as possible to a stimulus indicating one side (left or right) to which they had to make a 5-metre sprint. The results of both studies showed better reaction times after taking caffeine compared to the placebo, so caffeine intake can be understood to enhance reactive agility performance no matter whether athletes are fresh or tired.

The effect of caffeine on athletes' cognitive and perceptual dimensions

Many studies have investigated the effectiveness of caffeine on cognitive function and perception during sports activity, pointing towards the potential of caffeine in this field. Hogervorst *et al*[75] suggest that a low dose of caffeine improves cognitive performance during and after vigorous exercise. The subjects, trained cyclists, ingested a carbohydrate energy bar with 100 mg of caffeine just before starting and at minutes 55 and 115 of a 3-hour cycloergometer exercise at 60% VO_2max, followed by a test to exhaustion at 75% VO_2max. Cognitive function measures (Stroop and Rapid Visual Information Processing tests) were taken before exercise and while cycling after 70 and 140 minutes of exercise, and again 5 minutes after completing the time to exhaustion ride. In the results obtained, the participants completed the complex information processing tests significantly faster and took longer to finish the time to exhaustion test after taking caffeine compared to the placebo. So caffeine in a performance bar can significantly improve endurance performance and cognitive ability during and after prolonged exercise. These effects may be salient for performance in sports and activities in which concentration and decision making play a major role.

In the same line of research, Stevenson *et al*[76] showed how caffeine not only improved the performance of experienced golfers during an 18-hole round, but also managed to increase their alertness and positively affect their mood compared to the placebo. These results support the effects observed after a moderate intake of caffeine of between 5 and 6 mg/kg in two studies which measured performance and mood in athletes[77,78]. In both studies, the participants enjoyed a more positive subjective experience and were in a more favourable mood during exercise after taking caffeine than after taking the placebo. The beneficial effects of caffeine on the affective dimensions of athletes during exercise may prove to be of great interest both to research and to sports people themselves, since these dimensions play an important role in tasks involving persistence and effort, and, therefore, directly influence performance in training and competitions.

The side effects of caffeine consumption

The effects of caffeine intake have been widely reported, their being understood as inherent to consumption of the substance. An irregular heartbeat, increased alertness, trembling hands, hyperactivity and nervousness are among the most common adverse effects experienced by athletes when they consume caffeine. On occasions, when these effects appear, they do not prevent the athlete from improving his/her performance, as was the case with the rowers in Carr *et al's* study[23], who improved their times in an 2,000-metre ergometer test, or the participants in the study of Pallares *et al*[51], who significantly improved their neuromuscular performance with 9 mg/kg despite the appearance of adverse side effects. On other occasions, however, the side effects do influence the athlete, hindering improved performance, as occurred in the study conducted by Share *et al*[79] with elite clay-pigeon shooters, who experienced symptoms such as headaches, anxiety and tremors after taking caffeine, which particularly affected their accuracy, the primary indicator of performance in the discipline.

Another study evaluated the effect of caffeine on sleep quality in athletes who consumed the substance as an ergogenic aid in an aerobic activity carried out in the afternoon[80]. Caffeine improved the physical performance of the participants in the afternoon, but significantly disrupted their sleep indices at night: reduction in sleep efficiency, difficulty falling asleep and overall decrease in sleep itself. So although caffeine may work as an effective supplement to improve endurance performance, athletes who consume it in training and/or competitions late in the afternoon or in the evening should take into account its detrimental effect on sleep.

Developments in research on caffeine and sport

The effect of caffeine on performance depending on the time of day

Three studies have investigated the effect of caffeine taken in the morning and in the afternoon to find out when caffeine should be taken to benefit athletic performance the most, while minimising adverse effects. Working on the basis that the body's circadian rhythm produces neuromuscular declines in the morning, Mora-Rodriguez *et al*[81] designed a series of muscle strength and power tests for trained athletes, who completed them in the morning (10 am) after taking either 3 mg/kg of caffeine or placebo and in the afternoon (6 pm) after taking placebo alone. Muscle strength and power output in the tests proved significantly higher in the afternoon than in the morning with the placebo, while caffeine improved performance in the morning compared to the placebo. Caffeine consumption, therefore, would appear to counter the neuromuscular declines caused by the body's circadian rhythm, improving muscle strength and power in trained athletes in the morning, raising their level of performance to that of the afternoon.

Mora-Rodriguez *et al*[82] and Souissi *et al*[83] administered caffeine (5 and 6 mg/kg) and placebo in morning and afternoon exercise sessions. The results showed that the level of caffeine in blood plasma increased in the participants in a similar fashion in the morning and in the afternoon, leading to a substantial improvement in performance. The negative effects were more prevalent after caffeine intake in the afternoon. So caffeine consumption can be recommended in the morning to favour performance and minimise any resulting adverse effects.

The effect of caffeine on performance in exercise carried out on consecutive days

A very recent study[84] assessed the performance of experienced golfers in a golf tournament played over two days in which the participants ingested a dose of 155 mg of caffeine before starting and halfway through each round. The results showed that the caffeine increased the golfers' capabilities and substantially reduced fatigue during the tournament. Two other studies measured the effect of caffeine intake on performance in demanding physical activities, skiing[85] and sprinting[86], over 2 consecutive days. Caffeine enhanced sprint capability and speed in the cross-country skiing trial (which consisted of 10 minutes on a laboratory simulator) on both days of exercise, and greater muscle damage was observed on the second day as a result of the heightened performance on the first. Caffeine, therefore, would seem to be a useful supplement for athletes competing on consecutive days because it can improve performance on both days of physical exercise, counteracting the muscle soreness produced after the first day and reducing fatigue.

The effect of caffeine on the recovery period and delayed onset muscle soreness (DOMS)

One study[87] measured the physiological parameters of wrestlers during the breaks between 4 fights simulating a competition after taking 5 mg/kg of caffeine. The elevated heart rates and blood lactate levels observed in the wrestlers who had consumed caffeine suggest that it may impair recovery between consecutive maximal efforts. In another study conducted by Hurley *et al*[88] with trained athletes who performed a set of muscle-strength exercises to failure after taking 5 mg/kg of caffeine 1 hour before exercise, soreness and soreness on palpation were recorded before exercise and 24, 48, 72, 96 and 120 hours afterwards. The results showed that caffeine intake prior to maximal strength training produces beneficial responses in terms of perception of soreness and performance, a significant decrease in soreness levels being observed 48 and 72 hours after exercise, and more total repetitions being performed with caffeine compared to placebo. A further beneficial effect of sustained caffeine ingestion in the days after the exercise bout was an attenuation of DOMS. This decreased perception of soreness in the days after a strenuous resistance training workout could prove useful as it may allow individuals to increase the number of training sessions in a given time period.

The effect of caffeine on performance in a state of sleep deprivation

We have seen that one of the adverse side effects of consuming caffeine in the afternoon or evening is the harm that it does to the quality of sleep. But can caffeine offset capabilities diminished by a lack of sleep?

Two studies evaluated the physical and cognitive performance of a group of athletes whose sleep was limited to between 2 and 4 hours[89,90]. The results were affected by sleeping fewer hours than normal. In one of the studies[89], 80 mg of caffeine was given to the subjects in a state of sleep deprivation without improving performance, but taking into account the extremely low dose used, one can only conclude that adequate sleep is essential for first-rate athletic performance and that a dose of 80 mg is no substitute for a lack of sleep. The latest study conducted in this field of research[90], however, did note improvements in the performance of participants taking 3 mg/kg of caffeine after little sleep, so it can be claimed that caffeine consumption is an effective strategy to maintain physical and cognitive performance after a night of limited sleep.

Conclusions

We can highlight the following conclusions from this review:

- Despite the wide variety of protocols and methodologies employed by the different studies investigating the subject, no generalisations can be made about the ergogenic effect of caffeine on athletic performance.
- Caffeine has a clear ergogenic effect on aerobic and anaerobic exercise, provided that those factors capable of limiting the response of individuals to the substance are controlled.
- The latest trends in research point towards caffeine consumption in alternative forms, such as gels, chewing gum and energy drinks, and have led to the discovery that caffeine is an effective supplement when it comes to compensating performance diminished by high temperatures.
- Recent findings show: that caffeine is effective when athletes compete or train on consecutive days; caffeine should be taken in the morning rather than in the afternoon in order to get the greatest benefit in terms of performance and minimise its adverse effects; and the use of caffeine is an effective strategy to maintain physical and cognitive performance after a night of limited sleep.

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