Caffeine and its ergogenic effect in sport (first part)

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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 (primera 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.

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Introduction

This review comes a decade after caffeine was struck off the World Anti-Doping Agency's (WADA) prohibited list. One of the reasons why WADA removed caffeine from the list of banned substances was that many experts considered it pervasive in a wide variety of drinks and food, meaning that athletes could be sanctioned for social consumption or dietary caffeine. Caffeine is also metabolised to varying degrees in different individuals and, therefore, the concentrations found in urine may vary considerably and not always correlate with the dose ingested[1].

The ergogenic effect of caffeine on human performance is fairly widely accepted. The most current reviews of the subject[2,3] indicate that caffeine helps to improve performance in many sporting situations, depending on a number of variables, including exercise intensity, the number of doses administered, habituation and the level of training of the subjects.

Physiologically, the action of caffeine in the body is difficult to determine to any degree of precision due to its wide distribution throughout the tissues of the body. It is largely believed that caffeine acts as a stimulant of the central nervous system; however, the glycogen-saving effect, the ability to increase fatty acid mobilization and induce the release of catecholamines, as well as direct effects on muscles, have been verified as mechanisms which contribute to the ergogenic effect of the substance[1,3].

Enhanced performance in endurance exercises can be isolated as the thread common to most of the studies which have investigated the matter. Although conflicting results do exist to a certain extent, the general conclusion would seem to be that both small doses of caffeine and moderate-to-high doses have beneficial effects on aerobic activities[2,4,5].

However, there is less consensus when it comes to anaerobic activities and exercises based on strength and power. The evidence provided in some studies suggests that caffeine can directly enhance skeletal muscle force, work and power, which may well contribute to improved overall performance in exercises of this kind[3,6,7]. Other research, however, has obtained very different results which deny this hypothesis[8,9].

The same is true, albeit on a smaller scale, of studies of real training or competition situations focusing on different sports. Although the study of the ergogenic effects of caffeine *in situ* during real events comes closest to reality, the idiosyncratic nature of these events means that they take place in extremely open and variable environments, exposing them to a wide range of outcomes which depend on whether we are dealing with a team sport or an individual sport, or on the techniques and tactics employed by the players, among other factors. Nevertheless, a large proportion of the studies conducted in the field conclude that caffeine is ergogenically effective in sport[2,10,11].

In order to understand why such disparate results are obtained, it is necessary to appreciate both the variety of methodological approaches used for studies of this kind and the difficulty involved in conducting research in this field, the sum of these two factors lying at the root of very different sets of results.

The experiments conducted have employed a very wide range of methodologies: everything from low doses of caffeine (less than 3 mg/kg) to high doses (over 9 mg/kg), with the consequent bearing on the mental and physiological response of the subject; administration of the substance by means of coffee, other drinks or capsules, and even other methods, leading to different rates of caffeine absorption in the body; and ingestion of caffeine at different times with respect to the physical exercise performed, ranging from minutes to hours before the start of the activity, or even during exertion itself, meaning that the physical activity is carried out with differing levels of caffeine in the body. Attention should also be paid to the type of protocol designed (whether it coincides with the reality of the sport or exercise, the level of training of the subjects or how familiar they are with the protocol of the activity), since this will affect the subjects' ultimate performance.

The complexity involved in conducting studies of this kind is reflected in the wide range of factors which can affect and/or compromise research results. The most important factors to bear in mind are: the degree of habituation of the participants to the substance, the side effects of caffeine, the effects of withdrawal from the substance, the intensity of the exercise performed and the different degree to which each individual metabolises caffeine[3].

So, although the effectiveness of caffeine as a performance enhancer has been widely proven, the discrepancies that have emerged make it very difficult to evaluate the specific action of caffeine precisely.

This study aims to solve this problem by reviewing the latest studies on the ergogenic effects of caffeine on sport in order to provide the members of the world of sport with a useful tool through which they can consult the characteristics of caffeine and its ergogenic effects on different sporting situations, how and when it can be administered, the factors which must be controlled and, ultimately, an updated, scientifically thorough guide on everything about caffeine as an ergogenic aid in sport.

The new trends in research on the subject[2] are also reviewed. These include:

- The administration of caffeine in alternative forms.
- The effect of caffeine on performance in adverse environmental conditions.
- The effect of caffeine on performance in sports people who are habitual consumers as opposed to those not habituated to the substance.
- The effect of caffeine on reaction time.
- The effect of caffeine on athletes' cognitive and perceptual dimensions.
- The side effects of caffeine consumption.

Finally, some of the more original results of the latest research, yet to be covered in any other review of caffeine in sport, are showcased, such as:

- The effect of caffeine on performance depending on the time of day.
- The effect of caffeine on performance in exercise carried out on consecutive days.
- The effect of caffeine on the recovery period and delayed onset muscle soreness (DOMS).
- The effect of caffeine on performance in a state of sleep deprivation.

Methodology

The databases *Medline, Scopus* and *Sport Discus* were used to search for the articles to cover in this systematic review. The search was conducted using the keywords *cafeina y deporte* in Spanish, and caffeine and sports in English, adding some other keywords like caffeine and sports performance in order to find as much information on caffeine in sport as possible. The search was also defined to the period between 2005 and 2015, the intention of the study being to compile the most recent work on the subject.

In this way, we found 361 documents on caffeine in sport, including both articles and reviews. We then screened all the articles to arrive at a list of all those addressing our chosen subject. In order to do this, and basing ourselves on our objectives, we defined a set of criteria for inclusion which the articles had to meet in order to enter the study. These criteria were:

- Articles investigating the ergogenic effects of caffeine on performance in aerobic or anaerobic sports activities.
- Articles using protocols involving well trained subjects familiar with the activity, reflecting current practices in the sport and/or simulating real events.
- Articles using methodologies specifying the dose, form and moment of administration of caffeine.

Articles which did not meet the criteria were excluded from the study. After this screening, the number of research articles for study dropped to 87.

The latest reviews were studied and compared to look into the background and current situation in our field of inquiry and, thereby, establish a starting point for our study.

Having done this, the data from all the studies were collected for their subsequent classification according to the following categories:

- The ergogenic effect of caffeine on aerobic exercise
- The ergogenic effect of caffeine on sport
- The ergogenic effect of caffeine on anaerobic exercise
- The methodology of research on caffeine and sport
- The latest trends in research on caffeine and sport
- Developments in research on caffeine and sport

Results and discussion of the studies

The ergogenic effect of caffeine on aerobic exercise

The relationship between aerobic exercise and caffeine is one of the most studied subjects within the scientific field of ergogenic aids in sport. Two studies employed a similar protocol but different methodologies to investigate the effect of caffeine on endurance in well-trained cyclists[4,5]. The trial consisted of an initial warm-up stage on a cycloergometer at 60% of maximum oxygen consumption (VO_2max) in which the subjects in the first study pedalled for 60 minutes and those in the second study pedalled for 105 minutes, followed by a second stage consisting of a 40-kilometre (km) time trial to be carried out in the shortest possible time. In the first study[4], the cyclists ingested 3 mg/kg of caffeine in capsule form 1 hour before the start of the trial, while the cyclists in the second study[5] took a solution of glucose and carbohydrates with 5.3 mg/kg of caffeine at the beginning of the trial and at 15-minute intervals during the first stage. In both studies, the cyclists improved their performance in the time trial after the intake of caffeine. Another study conducted with cyclists[12] showed that the intake of 6 mg/kg of caffeine 1 hour before exercise improved performance in a 1-hour trial, the participants covering greater distances with the administration of caffeine than they did with the placebo. In the same vein of research, Norwegian researchers[13] designed a trial for first-class cross-country skiers which consisted of covering 8 km in the shortest time possible on a ski simulator. The participants were given a concentrate sports drink containing 6 mg/kg of caffeine or placebo 75 minutes before performing the test. Caffeine significantly decreased the time it took the participants to complete the test compared to the placebo.

These studies demonstrate that low and moderate doses of caffeine administered at different times improve performance in endurance tests, thereby supporting the effectiveness of caffeine as an ergogenic supplement. This is possibly due, as suggested by the Norwegian study[13], to a drop in the exertion perceived as a result of caffeine, allowing the subject to exercise with greater intensity and a higher heart rate.

However, a 2005 study[14] with top male long-distance runners concluded that a dose of 5 mg/kg of caffeine 60 minutes before activity did not effectively improve performance in the multi-stage fitness test. The researchers did not control the level of habituation of the subjects to the substance or whether caffeine intake had produced any side effects detrimental to the athletes during the trial, so the reason for the results is unknown. Another study conducted with trained athletes[15], however, concluded that the administration of 6 mg/kg of caffeine 60 minutes before exercise led to a significant improvement in the performance of the participants in a test consisting of intermittent, high intensity, prolonged exercise which combined flat-out sprints with active recovery periods in two 36-minutes phases with 10 minutes of passive rest in between. So, contradictory results

can be observed in similar subjects carrying out aerobic exercise after receiving very similar doses at the same time before starting.

Therefore, although the effectiveness of caffeine as an ergogenic aid in endurance tests can be considered fairly well proven and its use would appear to improve the performance of trained subjects, it is necessary to control the factors surrounding the administration of the substance in order to achieve the desired effect.

The ergogenic effect of caffeine on sports performance

Much of the research into the effects of caffeine on performance is carried out in laboratory conditions and although many studies try to reproduce the parameters of actually doing the sport in question, it is not possible to capture the true mood of performing the activity in real conditions. The researchers are aware of the complexity of controlling studies in the actual field, where the atmosphere and the way in which the sport is performed can vary widely, and even factors such as tactics or strategy, level of motivation, etc. can affect performance in individual and team sports alike. Even so, the number of studies *in situ* investigating athletic performance during training and competitions under the effects of caffeine has increased over recent years.

Individual sports

Athletics

One study[16] looked into the effect of ingesting 3 mg/kg of caffeine 1 hour before running 8 km on a track on well-trained competitive runners. The results showed a faster time for the 8 km after the ingestion of caffeine compared to the placebo. The same effects were observed in another study[17] on trained runners who consumed 5 mg/kg of caffeine 1 hour before running 5 km. In both studies, the athletes improved their performance when they took the caffeine supplement (of 3 and 5 mg/kg) 1 hour before testing commenced.

Shot put

A study by Bellar *et al*[18] used university shot putters to observe the effect of chewing gum with 100 mg of caffeine on 6 standard throws. 20 minutes before the round of throws, the subjects chewed the gum for 5 minutes and then removed it. The caffeine significantly increased the distances of the throws, thereby demonstrating that a low dose of 100 mg of the substance is sufficient to improve the performance of shot putters.

Swimming

Vandenbogaerde and Hopkins[19] conducted a study with 9 top swimmers which measured their performance in their specific specialities in training and competitions both in the morning and in the evening. The swimmers took 100 mg of caffeine 75 minutes before beginning and the results showed that their performance was better in the afternoon than in the morning, better in competitions than in training and better with the use of caffeine than in controls. A low dose of caffeine, such as 100 mg, can improve performance in swimmers in both competitions and training, which can prove useful when it comes to scheduling use of the substance when desired.

Cycling

A study by Bortolotti *et al*[20] selected 13 well-trained racing cyclists to do a time trial on a 20-km circuit designed for the occasion. Cyclists took capsules containing 6 mg/kg of caffeine or placebo 1 hour before the start of the test, but the results with caffeine and with the placebo were similar. The 6 mg/kg dose did not improve the performance of the cyclists, but the freedom of participants to choose their cadence and gears, together with the design of the circuit, which included areas with steep slopes which made the test harder, led the athletes to choose different strategies to confront the course. This may explain the results of this study[20], since two other studies[21,22] looked into the ergogenic effect of caffeine on trained cyclists but this time using cycloergometers. In a study by Kilding *et al*[21], cyclists did a 3-km time trial after taking 3 mg/kg of caffeine 1 hour before starting. In another study conducted by McNaughton *et al*[22], the participants pedalled to cover the greatest possible distance in 1 hour with the aid of 6 mg/kg of caffeine administered 1 hour before the test. In both studies, the caffeine improved the cyclists' performance: in the first study[21], the participants who took caffeine completed the 3 km in less time compared to those who took the placebo, whereas in the second study[22], the cyclists who took caffeine covered greater distances in one hour compared to those only taking the placebo. So it would seem that caffeine improves performance in cyclists when trials are conducted in laboratory environments, but when trials are conducted on open circuits, other variables which can affect the result come into play.

Rowing

We did not find any tests centring on rowing conducted in real conditions. However, three studies[11,23,24] did conduct research using the same protocol: well-trained rowers completed a 2,000-metre test in the shortest possible time on ergometers. In the study by Scott *et al*[11], the athletes took 100 mg of caffeine in an isotonic carbohydrate gel 10 minutes before the test and the results showed a significant improvement in their times. Carr *et al*[23] made rowers take 6 mg/kg of caffeine in capsule form 30 minutes before the test and the performance of the athletes also improved significantly over the 2,000 metres. Skinner *et al's* test[24] combined 3 different doses of caffeine: 2, 4 and 6 mg/kg of the substance were administered to the rowers 60 minutes before the test. However, no significant differences were observed in the performances of the rowers taking the different doses. This test differed from the other two in that the subjects ate a standard light meal containing 2 g/kg of carbohydrates beforehand. The concentration of caffeine in blood plasma at the start of the test was significantly lower in the subjects of Skinner et al's study[24] than they were in the other studies using the same dose[15,22], which may explain the lack of improvement in performance. Attention should, therefore, be paid to food intake when administering caffeine

supplements as it may alter the levels of the substance in plasma and affect the performance of athletes. In view of these studies, we can say that both low doses (100 mg) and moderate doses (6 mg/kg) of caffeine administered before a 2,000-metre test on ergometer can improve a rower's performance.

Badminton

Two studies proved the effectiveness of caffeine on performance in competitive badminton players. In the first study[25], the players ingested 3 mg/kg of caffeine in an energy drink 60 minutes before doing the trial; this consisted of a series of tests to measure jumping power, followed by a 45-minute badminton match. After the intake of caffeine, the players jumped higher and with greater maximum power when performing counter-movement jumps and squat jumps, and the total number of impacts during the match increased. Similar results were obtained in Clarke and Duncan's study[26], in which the participants faced 3 tests simulating specific features of badminton: coincidence-anticipation timing, serve accuracy and choice reaction-time. The players took a concentrated aqueous solution containing carbohydrates and 4 mg/kg of caffeine 60 minutes before and also during the tests which substantially improved their performance in the 3 tests in comparison with the placebo. So caffeine supplements containing between 3 and 4 mg/kg taken in an energy or carbohydrate drink 1 hour before and during sessions would seem to improve competitive badminton players' patterns of activity during games.

Tennis

A study similar to that of Abian *et al*[25] was conducted with top junior tennis players. In this case[27], a set of tests consisting of measuring maximum grip strength with both hands, the speed of 3 tennis serves and speed in 8 series of 15-metre sprints one hour after ingesting an energy drink with 3 mg/kg of caffeine were designed. Following completion of the tests, the players rested for 15 minutes and then played a best-of-three-sets singles match against a similar opponent. The caffeine increased the players' maximum grip strength, their sprint speed in the test and the intensity and number of sprints they did during the match compared to the placebo. They also tended to win a higher percentage of points from serves with the intake of caffeine in comparison with the placebo. Horney *et al*[28] administered the same dose of caffeine, 3 mg/kg, in capsule form to trained tennis players 30 minutes before a simulated tennis match against a ball machine lasting 2 hours and 40 minutes. The length of the match induced significant decreases in playing capabilities due to the great physiological demands made of the players, but the caffeine supplement partially attenuated the effects of fatigue and increased serve speed towards the end of the game compared to the placebo. A small dose of caffeine, 3 mg/kg, therefore, is enough to improve aspects of performance in trained tennis players, be it administered in energy-drink form 60 minutes before exercise or in gelatine-capsule form 30 minutes beforehand.

Judo

In 2014 an experiment on six trained male judokas with competition experience was published[29]. The sportsmen had to complete a 5-day rapid weight loss course. After this period, the participants spent 4 hours recovering, eating and rehydrating, and took a 6-mg/kg caffeine capsule in the third hour. At the end of the recovery time, the judokas fought 3 Senior Judo Fitness Test matches to simulate the characteristics of a competition. There was no difference in the number of throws in the fights between athletes taking caffeine and the placebo, but a higher blood lactate level and lower rated perceived exertion were observed with caffeine compared to the placebo. So caffeine is able to reduce the sensation of fatigue and speed up lactic anaerobic metabolism without altering the performance of judokas in competition conditions after a rapid weight loss course. Analysing the results, the important role of technique and one's opponent in judo should be taken into account, because even when a judoka's physiological dimensions are improved, if the opponent is technically or physically superior, then he/she is more likely to win. However, this study has laid the foundations for cognitive and physiological improvements in competitive judokas, which can serve as a guide for future research into the relationship between caffeine and judo.

Fencing

Bottoms *et al*[30] conducted a study with 11 competition-level fencers in which the participants completed 2 rounds of tests consisting of a reaction-time test and a test of skills specific to fencing; the first tests 30 minutes before a fencing competition simulation consisting of 6 fights and lasting 60 minutes, and the second set of tests at the end of the simulation. The subjects ingested 3 mg/kg of caffeine or placebo in fruit juice after the first round of tests. There were no significant differences in reaction time between the fencers taking the caffeine and those taking the placebo, but the former tended to make fewer mistakes than the latter in the skills test. The caffeine also produced significantly lower perceived fatigue, so the findings suggest that the low dose of 3 mg/kg of caffeine maintains fencing skills while decreasing the degree of tiredness fencers perceive. This supplement does not help to improve athletes' reaction time, but can be helpful to those seeking to optimise their performance when fencing.

Team sports

In order to win in team sports, factors such as understanding between team members, the design of a good strategy and conditions favourable to the team, as well as physical and specific abilities, all play a part. The relationship between caffeine and team sports has been studied using different methodologies, but always with the same objective: to determine how to achieve better performance in these sports. To cite one example, one research group[31] designed a protocol to simulate a rugby match of 2 halves lasting 40 minutes each, in which the participants had to complete a series of circuits which included straight and sideways sprints, and combining agility tests, tackles,

passes and periods of rest standing and walking. The subjects, 9 rugby players from First Division teams, took a capsule with 6 mg/kg of caffeine 70 minutes before the trial and after taking it registered improvements in sprint speed, tackling power and accuracy, as well as perceiving less fatigue. It would appear, therefore, that caffeine produces substantial improvements in several aspects of performance in team sports. We will now see what else scientific literature has published on the subject.

Volleyball

Two studies proposed a protocol which consisted of a series of volleyball-specific tests followed by a simulated match[32,33]. In both, 3 mg/kg of caffeine was administered by means of an energy drink 1 hour prior to the trial. Both Del Coso *et al's* study[32] on 15 well-trained male volleyball players and Perez-Lopez *et al's* study[33], involving 13 top female volleyball players, observed improvements in their subjects in terms of ball speed on serving, jumping height and agility in the tests, coupled with a higher percentage of successful actions during the match following the ingestion of caffeine compared to the placebo. This shows that the caffeine supplement used (3 mg/kg in energy drink) is an effective ergogenic aid for male and female volleyball players because it improves their physical performance and accuracy.

Football

The most recent study conducted on professional football players[34] indicates that the administration of 6 mg/kg of caffeine by means of capsules 65 minutes before playing does not seem to have any ergogenic effect on players' activity profile during a football match. 22 junior-team players were evaluated during a football match after ingesting caffeine or placebo; the results showed no significant differences in the total distance covered, in the number of accelerations or in sprint intensity or distance between players taking caffeine and players taking the placebo. However, as we know, the patterns of activity in football are extremely variable and depend on numerous factors, such as possession of the ball; teams with the best technique tend to play a game based on greater possession without making great physical effort. Technical parameters were not evaluated in the study and so these may explain the lack of performance in the match. A study conducted on semi-professional football players by Del Coso *et al*[10] revealed improvements in jumping ability and sprint speed measured before a football match after caffeine intake; during the match, the total distance covered was greater and run at greater speed by players who had consumed caffeine. The participants were given an energy drink with 3 mg/kg of caffeine 60 minutes before performing a trial consisting of a maximal jump test and a test of repeated 30-metre sprints, followed by a standard football match. So the results of this study contradict those of Pettersen *et al* [34], suggesting that a dose of 3 mg/kg of caffeine is sufficient to increase sprint capability and both the distance covered and the speed at which it is covered in a football match. The increase in jumping ability may also favour how well footballers play in the air.

Two other studies[35,36] evaluated trained football players during simulations of 90-minute matches in which the participants completed intermittent running trials interspersed with jumping and passing accuracy tests. In Gant *et al's* study[35], 3.7 mg/kg of caffeine was administered to the players in a concentrated carbohydrate drink 60 minutes before the simulation and every 15 minutes during the activity, while in Foskett *et al's* study[36], the players consumed capsules containing 6 mg/kg of caffeine 60 minutes beforehand. In both studies, the participants significantly improved their jumping ability with caffeine intake compared to the placebo, while their passing accuracy only improved with caffeine intake in Foskett *et al's* study[36] and average running speed increased with caffeine in Gant *et al's*[35]. In general, we can say that caffeine is an effective ergogenic supplement in football; you simply have to take into account the dose of caffeine and how and when it is administered in order to achieve the desired improvements in the different parameters of performance, as seen in the studies conducted in the field.

Rugby football

Several studies have researched the ergogenic effects of caffeine on rugby-playing performance. One of these[37] evaluated the responses of the players belonging to the women's national rugby sevens team to an energy drink with 3 mg/kg of caffeine. The players took the drink 1 hour before the start of a competition consisting of three 14-minute long rugby sevens matches with 15 minutes of rest between each game. At the end of the matches, the players performed a 15-second jumping test on a force platform. The caffeinated energy drink increased both the power produced in the leg muscles during the jumping test and running pace and speed during the games. Two other studies[38,39] designed rugby simulation protocols with trained university rugby players in which rugby-specific skills such as passing, coordination and sprinting were measured. In both studies, a solution with caffeine was administered 60 minutes before the tests, the dose in one study being 6 mg/kg[38] and the dose in the other being 4 mg/kg[39]. The results with the two doses were similar: the caffeine increased the athletes' sprint speed at the beginning of the protocol and maintained their speed at the end of the trial, improved their coordination and showed a tendency to improve their passing accuracy compared to the placebo. These findings are a valuable example of the ergogenic effects of caffeine on performance in rugby.

Hockey

Duncan *et al's* research[40] conducted on 13 competitive field hockey players concluded that the administration of 5 mg/kg of caffeine 60 minutes before playing hockey may be effective in offsetting decrements in skilled performance associated with fatigue. The study designed a protocol to fatigue the participants before performing a series of tests to measure hockey-specific skills (dribbling and ball handling). The results showed a significant increase in test scores after the intake of caffeine compared to the placebo. So the use of a caffeine supplement in hockey may be useful to enhance performance in players when fatigue sets in.

As we have seen, caffeine has proven to be an effective ergogenic aid in most sports situations. From small to moderate doses administered in different forms (gum, capsules, energy drinks and isotonic gels), it has helped improve technical, physical and cognitive performance abilities in sports people. However, studies which conclude that caffeine has no ergogenic effect on sports performance should not be overlooked: in these cases, we should draw conclusions to help us understand the behaviour of the substance better, i.e. to understand that caffeine intake does not entail an automatic improvement in the performance of the person taking it and that a number of factors determine whether its effects may prove optimal or null as far as performance is concerned.

Bibliography

The entire bibliography is provided at the end of the second part of the Review.