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Review

Caffeine and its ergogenic effect in sport (second part)

Antonio García Moreno

Universidad Pablo de Olavide. Sevilla

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.

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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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The influence of fatigue in hamstrings:quadriceps ratio. A systematic review

Juan P. Martín Martínez, Jorge Pérez Gómez, Jorge Carlos Vivas

Universidad de Extremadura.

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Summary

Sport injuries are considered the main cause of cessation of training process, either completely or partially. Among the different types of injuries that may be produced in any sport disciplines, muscular injuries, and more specifically hamstring injuries, are the most common. For that matter the best indicator for evaluating the muscular risk of this kind of injury produced by a muscular imbalance is the hamstrings:quadriceps ratio, of which two types can be distinguished: functional ratio and conventional ratio. The aim of this study was to search in scientific literature how the fatigue presents an influence in the values of both conventional and functional hamstrings:quadriceps ratio as an injury risk indicator. An electronic search of different databases was carried out and a total of thirteen studies publicated until 19th May 2015 were included in this review. The following keywords were employed: "Hamstrings", "quadriceps", "Isokinetic", "Peak torque" and "Fatigue".

Analysed studies showed a significant decrease of both ratios values, but especially functional ratio, after the fatigue protocols application. Besides, a greater decrease of both ratios were noticed when protocols were more specific. This fact means a greatest risk of muscular injury. In addition, the fall in both ratios levels were produced by a decrease in hamstings strength values, in particular during the eccentric phase of movement.

Hence, our results suggest that it would be important to develop an injury prevention strategy focused on delay fatigue, specially in hamstrings, as much as possible and improve hamstrings strength during the eccentric phase of movement.

Key words:
Peak torque. Prevention. Risk. Injury muscular. Strength.

Efecto de la fatiga en el ratio isquiotibiales:cuádriceps. Revisión sistemática

Resumen

Las lesiones deportivas conforman la principal causa por la que el proceso de entrenamiento se ve interrumpido total o parcialmente. Entre los diferentes tipos de lesión que pueden darse en cualquier disciplina deportiva, las lesiones musculares, y más especialmente las que se producen en la musculatura isquiotibial, son las más recurrentes. En este sentido, uno de los indicadores más fiables para cuantificar la descompensación muscular que produce esta lesión es el ratio isquiotibiales: cuádriceps, del cual se diferencian dos tipos: ratio convencional y ratio funcional. El objetivo de esta revisión fue buscar en la literatura científica cómo afecta la fatiga a los valores de ambos ratios que indican el riesgo de sufrir una lesión muscular. Se realizó una búsqueda electrónica en diferentes bases de datos, y un total de trece artículos publicados hasta el 19 de Mayo de 2015 fueron incluidos en el análisis bajo las palabras clave "Hamstrings", "Quadriceps", "Isokinetic", "Peak torque" y "Fatigue".

Los estudios analizados revelaron un importante descenso en los valores de ambos ratios, en especial del funcional, tras la realización de diferentes protocolos de fatiga, sobretodo en aquellos que eran más específicos. Este descenso de los valores del ratio se traduce en un mayor riesgo de sufrir una lesión muscular. Además, el descenso en ambos ratios se producía por una disminución en los valores de fuerza de los isquiotibiales, especialmente durante su fase excéntrica.

Por tanto, los resultados obtenidos sugieren la implantación de estrategias de prevención enfocadas al retraso de la aparición de la fatiga, especialmente en la musculatura isquiotibial, y en el fortalecimiento de la misma durante la fase excéntrica del movimiento.

Palabras clave:
Pico torque. Prevención. Riesgo. Lesión muscular. Fuerza.

Correspondence: Juan Pedro Martín Martínez
E-mail: jpmartinm19@hotmail.com

Introduction

Sporting injuries are the main cause of interruptions to training, and around 30% are related to muscular injuries[1].

Over the years, different strategies have been developed to prevent these types of injuries[2], from theoretical models such as that by Van Machelen *et al*.[3], to more current models[4] that classify the factors that may influence the risk of suffering from a sporting injury into extrinsic and intrinsic factors. Extrinsic factors include the type of competition, the footwear used, the playing surface, or environmental conditions. Intrinsic factors are made up of anatomical, hormonal and neuro-muscular factors. Other authors have also indicated other factors such as deficient flexibility[5], insufficient warm-up[6], the existence of previous injuries[7] and fatigue[8,9] as risk factors in suffering from an injury.

Among the most common with the sporting population, are injuries to the hamstring muscles[10], a muscle-tendon complex formed of different muscles (semitendinosus, semimembrasosus and biceps femoris), that act together[11] and that present a high injury rate in sports that require maximum sprints, blows or ball throws, accelerations and direction changes[12-14]. The most common injury in this muscle group often occurs during the quick extension of the knee, which requires an eccentric action of the hamstrings followed by a deceleration of the leg at the end of the swinging phase in the running technique cycle[15]. Various studies affirm that the risk of injury on a weakened muscle may increase during these eccentric contractions[16,17].

The ratio of the peak torque of the hamstrings and quadriceps has been shown to be one of the most reliable indicators in quantifying the neuro-muscular de-compensation caused by this injury[18]. It has been revealed that a de-compensation in this ratio is correlated to a greater rate of muscular injuries in the lower body[19]. There are two types: The conventional ratio (H:Q) has traditionally been determined by the peak isometric or concentric torque measured using an isokinetic dynamometer (H_{con}:Q_{con})[18]. However, due to the function of these muscles during movement, a new ratio called *"Dynamic Control Ratio"* (DCR) has been proposed by different authors[20-24]. It is calculated as the ratio between the peak torque in eccentric contraction of the hamstring muscles and the peak torque in concentric contraction of the quadriceps (H_{ecc}:Q_{con}). This ratio has also been called "Functional"[21] or "Mixed"[25]. The H:Q ratio values of a healthy knee oscillate between 50% and 80%[26]. It is commonly accepted that an H:Q ratio measured at 60 degrees split by seconds (°/s) (1.05 radians per second raised to minus one [rad*s^{-1}]) of 60% or less, should be treated and rehabilitated to avoid injuries[27]. For its part, the DCR values are generally higher than those of the H:Q Ratio[28], and recent studies suggest that it is more effective when establishing the risk of suffering a hamstring injury[25]. The optimum range of the DCR fluctuates between 0.7 and 1.0[20,29].

Various factors influence the values of both ratios: the angle of the knee in the test, angular speed, the sport chosen, gender[30] and fatigue in the lower limbs, especially at advanced stages of the game[9,31]. Fatigue during play provokes a reduction in the athletes ability to continue to maximum performance[9]. This means that if fatigue is detrimental to the athlete's capacity to produce adequate muscle power, the running cycle mechanism may be altered and, as a result, the risk of injury to the muscles involved increases[32]. Therefore it is necessary to thoroughly understand the effect of fatigue, both on the H:Q ratio and on the DCR, to help establish more effective strategies in preventing and rehabilitating this type of injury[33].

In our bibliographic search we were only able to find two reviews that dealt with some of the influencing factors in the H:Q ratio or DCR[21,29], but none included fatigue. Consequentially, the aim of this review was to gather and exhaustively analyse all the articles that included information about the effects of fatigue on the conventional and functional H:Q ratio.

Material and method

Search strategies in electronic databases and in article selection

To collect the articles we analysed in this review, the scientific information line "Web of Science" was used, from which three important data bases were selected: *Web of Science Core Collection, Medline and Scielo Citation Index*. Two researchers independently examined each of these databases using the following key words: *"Hamstrings", "Quadriceps", "Isokinetic", "Peak torque"* and *"Fatigue"*, and included all studies published until 19th May 2015.

45 articles were identified (Figure 1) and both authors proceeded to read the abstract or the complete article to establish whether or not they complied with the inclusion and exclusion criteria. The inclusion criteria were: (a) Protocols were applied to induce the subjects to fatigue; (b) Adult population (18+ years); (c) Use of Isokinetic Dynamometer to determine the isokinetic strength in the quadriceps and the hamstrings; (d) Article written completely in English. The articles were excluded if they met any of the following exclusion criteria: (a) Population with any pathology or illness; (b) Repeated article; (c) Does not include any of the ratios or does not provide data with which they can be calculated. Conflicts between the two researchers in terms of this analysis were debated to unify the criteria; and a third researcher resolved any issues for which consensus was not reached.

The level of evidence was established following the guidelines of the "Dutch Institute for Healthcare Improvement" (CBO)[34]. The results are displayed in Table 1.

The data that was extracted for each study was as follows: characteristics of the sample and of the intervention protocols (Table 1), procedures in the isokinetic tests (Table 2) and results in the tests applied in each investigation (Tables 3 and 4).

Table 1. Features of the sample, intervention protocols and level of evidence.

Study	Year	Features of the sample				Protocol	Level of
		Size sample (n)	Age (years) and gender	Height (cm)	Weight (kg)	of Intervention	Evidence
Castelo-Oliveira *et al.*[45]	2009	16 (M)	22 ± 2.6	173.8 ± 27.9	79.6 ± 10.3	Treadmill run	C
Cohen *et al.*[35]	2015	9 (M)	25.3 ± 0.8	178.8 ± 2.9	77.0 ± 3.7	LIST	C
Coratella *et al.*[11]	2014	22(M)	20.1 ± 2.4			LIST	C
Delextrat *et al*[36]	2013	14 (F)	26.1 ± 4.6	168 ± 12	62.7 ± 5.5	LIST (modified)	C
Delextrat *et al.*[46]	2012	9 (F)	24.3 ± 4.1	173 ± 7.9	65.1 ± 10.9	Standard week	C
Greco *et al.*[41]	2013	22 (M)	23.1 ± 3.4	178.0 ± 8.0	73.4 ± 7.4	PEIEF	C
Jones *et al.*[38]	2015	20 (M)	21.8 ± 2.3	172.1 ± 6.2	68.4 ± 9.1	SAFT[90]	C
Koller *et al.*[44]	2006	16 (14M-2F)	41		79	Marathon	C
McIntyre, *et al.*[39]	2012	10 (M)	28 ± 7		79 ± 5	Sub-maximum test exercise bike	C
Olyaei *et al.*[43]	2006	32 (M)	24.89 ± 4.5		67 ± 8	IP	C
Rahnama *et al.*[9]	2010	13 (M)	23.3 ± 3.9	178 ± 0.05	74.8 ± 3.6	PEIEF	C
Small *et al.*[47]	2010	16 (M)	21.3 ± 2.9	185 ± 8.7	81.6 ± 6.7	SAFT[90]	C
Wrigth *et al.*[33]	2009	8 (M)	22 ± 2.3		85 ± 3.3	IP	C

Note. Average Values ± Standard deviation; LIST; *Loughborough Intermittent Shuttle Test;* PEIEF: Soccer-Specific Intermittent Exercise Protocol; IP; Isokinetic Protocol; M: Male; F: Female; C: Non Comparative Studies (Evidence levels based on the indications of the CBO)

Table 2. Isokinetic Test Characteristics.

Study	Warm-up	Range of Movement	Leg	Con_Q	Con_H	Ecc_H	Rec.(min)	A.S.(rad*s^{-1})
Castelo-Oliveira, *et al*[45]	5’ on exercise bike at 70W	70º		5	5	5	5	1.05 3.14
Cohen *et al.*[35]	10’ exercise bike at 70W 2 x 30” static stretch H and Q	10º-90º	Dominant	2x5	2x5	2x5	2	2.09
Coratella *et al.*[11]			Both	3	3	3	2	1.05 3.14 5.24
Delextrat *et al.*[36]	10’ exercise bike, with 5 sprints at the last 2’	0-90º	Both	5	-	5	2	2.09
Delextrat *et al.*[46]	30’ jogging, basketball-specific movements, accelerations and active stretches		Dominant	3	3	-		1.05
Greco *et al.*[41]		70º	Dominant	5	5	5	5	1.05 3.14
Jones *et al.*[38]	5’ on exercise bike at 60 W		Both	3	-	3	0.3	1.05
Koller *et al.*[44]	10’ exercise bike	0º-110º	Both	4	4	4		1.05
McIntyre *et al.*[39]		90º	Dominant	3	3		1	3.14
Olyaei *et al.*[43]	5’ (undefined)	10º-90º	Both					2.09
Rahnama *et al.*[9]	5’ exercise bike at 60 revolutions*min-1, 10’ static stretches and 2 sub-maximum repetitions	0º-90º	Both	3	3	3	1	1.05 2.09 5.24
Small *et al.*[47]	5’ exercise bike at 60 W, 5’ stretches static and dynamic, 5’ jogging getting used to the SAFT	0º-90º	Dominant	3	3	3	1	2.09
Wrigth *et al.*[33]	5’ treadmill, stretches and 5 repetitions sub-maximums	10º-90º	Dominant	5	5	5	0.1	2.09

H: Hamstrings; Q: quadriceps; Con_Q: number of maximum repetitions in concentric contraction of the quadriceps; Con_H: number of maximum repetitions in concentric contraction of the hamstrings; Ecc_H: number of maximum repetitions in eccentric contraction of the hamstrings; Rec.(min): recovery between series in minute; A.S: Angular Speed.

Table 3. Result of the H:Q Ratio and DCR for the dominant leg.

Study	A.V.	H:Q Ratio		DCR		Effect	Variation (%)	
	(rad*s^{-1})	Pre	Post	Pre	Post		H:Q Ratio	DCR
Castelo-Oliveira *et al.*[45]	1.05	0.51	0.52	0.78	0.77	X		
	3.14	0.67	0.68	1.14	1.05	⇓+		-8
Cohen *et al.*[35]	2.09			1.11	0.98	⇓+		-12
Coratella *et al.*[11]	1.05	0.61 ± 0.07	0.60 ± 0.10	0.68 ± 0.07	0.66 ± 0.12	X		
	3.14	0.67 ± 0.07	0.68 ± 0.12	0.98 ± 0.14	0.88 ± 0.17	⇓+		-10
	5.24	0.69 ± 0.07	0.71 ± 0.15	1.29 ± 0.13	1.20 ± 0.20	⇓+		-7
Delextrat *et al.*[36]	2.09			0.85 ± 0.15	0.73 ± 0.13	⇓+		-14
Delextrat *et al.*[46]	1.05	0.75 ± 0.08§	0.69 ± 0.08			⇓*	-8	
		0.73 ± 0.06§	0.68 ± 0.06			⇓*	-7	
Greco *et al.*[41]	1.05	0.60 ± 0.06	0.58 ± 0.06			⇓*	-3.3	
	3.14			1.29 ± 0.2	1.16 ± 0.2	⇓+		-10
Jones *et al.*[38]	1.05			0.77 ± 13	0.77 ± 15	X		
	3.14			1.09 ± 20	0.98 ± 21	⇓+		-10
Koller *et al.*[44]	1.05	0.71	0.74	0.85	0.85	X		
McIntyre, *et al.*[39]	3.14	0.62 ± 0.09	0.77 ± 0.03			⇑*	24	
Olyaei *et al.*[43]	2.09			1.11	1.07	X		
Rahnama *et al.*[9]	1.05	0.54	0.53			X		
	2.09	0.62 ± 0.11	0.56 ± 0.09	0.77 ± 0.13	0.67 ± 0.12	⇓**	-10	-13
	5.24	0.80 ± 0.09	0.75 ± 0.07			⇓*	-6.3	
Small *et al.*[47]	2.09	0.60	0.58	1.16	1.00	⇓+		-15
Wrigth *et al.*[33]	2.09	0.62-0.90¶	0.85-1.23¶	0.78-1.00¶	0.95-1.23¶	X		

Note. A.S: Angular speed; DCR *Dynamic Control Ratio* (H_{ecc}/Q_{con}); H:Q ratio: H_{con}/Q_{con} ; X: with no significant effect on DCR and H:Q ratio; ⇓+ : significant decrease only of the DCR (p<0.05); ⇓*: significant decrease only of the H:Q ratio (p<0.05) ; ⇑*: significant increase only of the H:Q ratio (p<0.05); ⇓** : Significant decrease of the DCR and the H:Q ratio (p<0.05);§: data corresponding to the 5th and 6th day of applying the fatigue inducing protocol in this study, both measured at the same angular speed: 1.05 rad*s^{-1}; ¶: results expressed in oscillations of the values according to the authors.

Table 4. Result of the H:Q Ratio and DCR for the non-dominant leg.

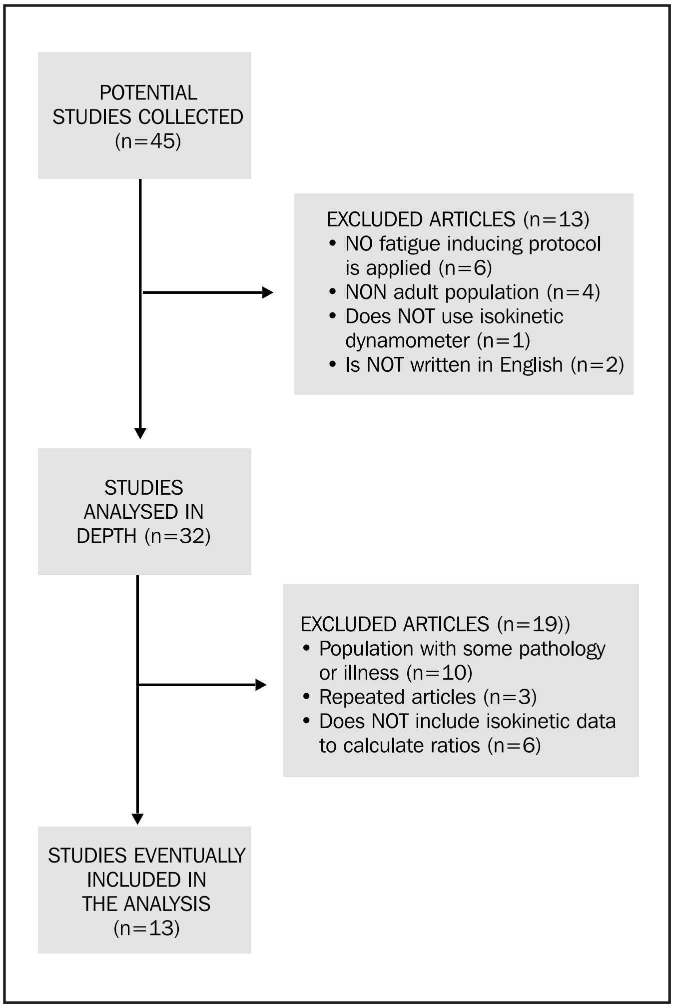
Study	A.S.	H:Q Ratio		DCR		Effect	Variation (%)	
	(rad*s^{-1})	Pre	Post	Pre	Post		H:Q Ratio	DCR
Coratella *et al.*[11]	1.05	0.59 ± 0.06	0.58 ± 0.08	0.68 ± 0.09	0.64 ± 0.10	X		
	3.14	0.64 ± 0.09	0.66 ± 0.11	0.93 ± 0.11	0.87 ± 0.17	X		
	5.24	0.69 ± 0.11	0.71 ± 0.14	1.29 ± 0.16	1.23 ± 0.26	X		
Delextrat *et al.*[36]	2.09			0.88 ± 0.17	0.81 ± 0.15	⇓+		-8
Koller *et al.*[44]	1.05	0.73	0.78	0.89	0.91	X		
Olyaei *et al.*[43]	2.09			1.02	1.03	X		
Rahnama *et al.*[9]	1.05	0.58 ± 0.07	0.56 ± 0.06			⇓*	-3	
	2.09	0.62	0.59	0.75	0.68	X		
	5.24	0.79	0.75			X		

Note. A.S: Angular speed; DCR *Dynamic Control Ratio* (Hecc/Qcon); H:Q ratio: Hcon/Qcon; X: with no significant effect on the DCR and H:Q ratio; ⇓+ : significant decrease of the DCR (p<0.05); ⇓* : significant decrease of the H:Q ratio (p<0.05).

Characteristics of the sample and of the intervention protocol

Seven studies performed three protocol types based on the simulation of the activity performed in a football match. Three[11,35,36] applied the *Loughborough Intermittent Shuttle Test* (LIST)[37], two[38,39] used the SAFT9040, and a further two[9,41] carried out a soccer-specific intermittent exercise protocol (PEIEF)[42]. Furthermore, two of them[33,43] carried out isokinetic protocols; and a further four performed a marathon[44], a

Figure 1. Flow chart of the selection procedure for review studies.



continuous running protocol on a treadmill[45], a sub-maximum test on an exercise bike[39], and a quantification of the training load of a week of normal basketball training[46].

Isokinetic Test Characteristics

Table 2 displays the characteristics and conditions of the isokinetic tests. Four different angular speeds were used in the different joints that were included in this review. Six studies[9,11,38,41,45,46] performed their measurements at 1.05 rad*s^{-1} (60º/s); seven[9,33,35,36,43,44,47] at 2.09 rad*s^{-1} (120º/s), five[11,38,39,41,45] at 3.14 rad*s^{-1} (180º/s) and two[9,11] at 5.24 rad*s^{-1}.

In addition, seven only assessed the dominant leg[33,35,39,41,45-47], defined as the one used to kick a ball, and five assessed both legs[9,11,36,43,44].

Results

The results obtained following the analysis of the studies collected in the review are displayed in Tables 3 and 4.

Figure 2. Overview of significant differences.

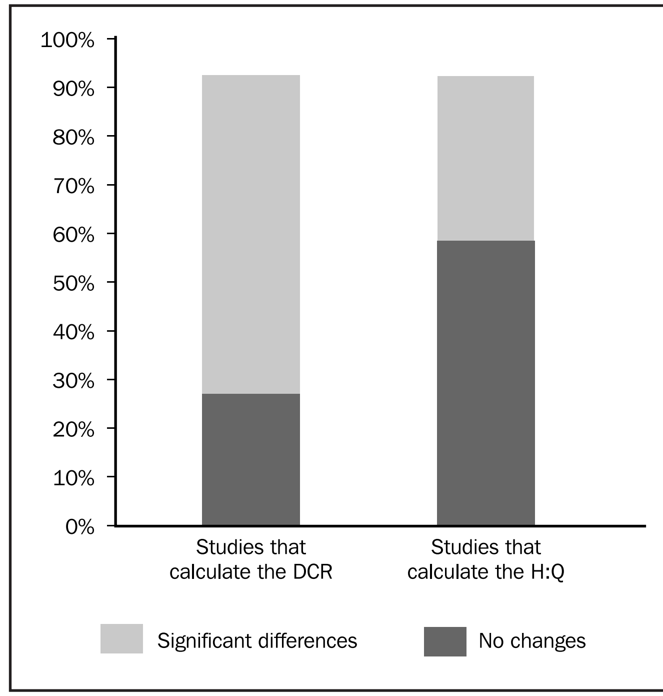
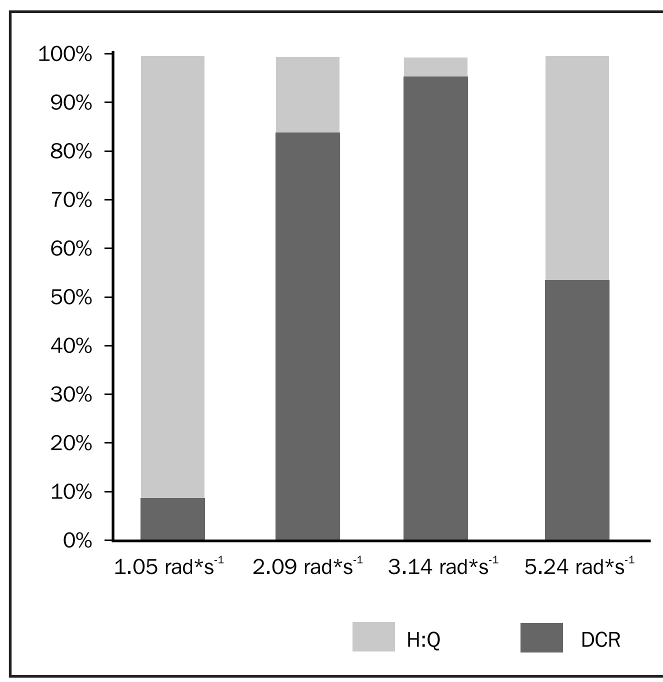


Figure 3. Decreases in the values in both ratios by speeds.



Dominant leg

This analysis reveals that more studies were found that discovered significant reductions in the DCR values than in the H:Q ratio upon applying different fatigue protocols (Figure 2).

Furthermore, these decreases in the DCR were produced at higher angular speeds in comparison to the H:Q ratio, in which the majority of the decreases occurred at 1.05 rad*s^{-1} (Figure 3).

LIST, SAFT and PEIEF

The studies that applied soccer-specific fatigue protocols[9,11,35,36,38,41,47] were those in which the greatest decreases were registered, especially regarding the DCR (Table 3), in which all but the Coratella *et al*.[11] studies revealed significant decreases at different angular speeds. On the other hand, only three of the studies that calculated the H:Q ratio[9,41,47] suffered significant decreases after performing these protocols.

Isokinetic Protocols

With regards to the isokinetic protocols, none of the two studies found significant differences in the DCR or the H:Q ratio in demographics made up of amateur footballers[33,43].

Others

The Castelo-Oliveira *et al.*[45] study assessed both ratios at different angular speeds before and after performing a fatigue protocol on a treadmill on subjects that were physically active but that did not practise any particular sport. However, only one significant decrease in the DCR was discovered, assessed at 3.14 rad*s^{-1}.

McIntyre *et al.*[39] checked the effects of a fatigue protocol on an exercise bike on the H:Q ratio, assessing an angular speed of 3.14 rad*s^{-1}. The results obtained in this study reveal a significant increase of 24% of the H:Q ratio, something that contrasts with the results of the other articles analysed in this review.

Finally, two articles by Delextrat *et al.*[46] and Koller *et al.*[44] studied the variation of the H:Q ratio and DCR before and after each normal training session of a basketball team, and after a marathon respectively. The data revealed that for the first study, significant differences in the H:Q ratio before and after training were only registered on the 5th and 6th days. Koller *et al.*[44] assessed the H:Q ratio and the DCR at an angular speed of 2.09 rad*s^{-1}, but no significant differences were obtained in the post-test in comparison to the initial measurement.

Non-dominant leg

Of the 13 articles analysed in this review, only 5 included the assessment of the non-dominant leg in the assessment of lower body strength (Table 2); and only two of them revealed significant differences after applying the corresponding protocol. Specifically, Delextrat *et al.*[36] discovered a decrease of almost 8% in the DCR at 2.09 rad*s^{-1} after performing the LIST; whilst in the results provided by Rahnama *et al.*[9] there is a decrease of 3% in the H:Q ratio after performing the PEIEF.

Discussion

The aim of this review was to analyse and check how fatigue affects two of the most used indicators in estimating the risk of suffering from an injury: the conventional ratio (H_{con}/Q_{con}) and the functional ratio (H_{ecc}/Q_{con}).

The recent research explains the decrease in the values of both ratios as the consequence of the great effort made by the hamstrings when controlling movement in running, and in the stabilisation of the knee joint during contact of the foot with the ground[9], which provokes high levels of fatigue in this muscle complex and a reduced capacity of maximum elongation of the muscle[48,49]. Other studies have revealed that the hamstring muscle complex suffers from the most fatigue during quick changes that occur from the eccentric phase to the concentric phase of a contraction, such as those that occur when kicking a ball or sprinting[25,50,51]. Furthermore, it has been shown that the greatest level of fatigue is reached towards the end of the game[52], and it is estimated that around 26% of injuries through strain occur in the final 15 minutes of a match[31]. The study by Cohen *et al.*[35] reveals a deterioration in the production of strength and deceleration capacity in the hamstrings related to the production of strength of the quadriceps in joint angulation at which hamstrings are more likely to suffer an injury. This angulation corresponds to the moment near full extension[53]. The explanation behind the low vulnerability of the quadriceps in terms of suffering an injury compared to the hamstrings in sports such as football, is that the specific actions of this sport represent considerable strength training for this muscle group, and therefore normal training provides a series of neuro-muscular adaptations against fatigue that do not occur with the hamstrings[9]. Another reason why the hamstrings and quadriceps do not tire the same way is down to the composition of the fibre types in each, which has proven to be very different[52]. The hamstrings tend to have a greater number of quick contraction fibres (type II) compared to the quadriceps[54,55]. These fibres have a greater tendency to become fatigued in comparison to slow fibres, and they do so earlier, which is why the hamstrings present a greater risk of suffering this type of fatigue-induced injury[7].

On the other hand, muscles are more likely to suffer from injuries during their eccentric phase, especially the hamstrings[7,17]. In the H:Q ratio, both muscles are assessed in concentric contractions, which is why recent studies suggest that the DCR is more effective in estimating the risk of suffering from a muscular injury, as the eccentric phase is considered[25,36,56,57]. In our review, the majority of the studies analysed that found significant differences after applying any fatigue protocol, in great measure, were done so in the DCR compared to H:Q (Figure 2).

Three studies[11,35,36] assessed the effect of fatigue provoked by a Test that includes the physical and physiological demands of football: LIST. All of them found significant decreases in the values of the DCR. Based on these results, Delextrat *et al.*[36] suggest the need to implement prevention methods based on the measurement of the decompensation between the hamstrings and quadriceps and in the application of programmes targeted at working on the eccentric phase of the hamstrings.

The peak eccentric torque of the hamstrings, and consequently the DCR also experienced a significant reduction as a result of the application of two fatigue protocols based on football: the SAFT[38,47] and

PEIEF[41,9]. This indicates that the eccentric strength of the hamstrings is reduced to decelerate the lower limb, especially at the end of periods in which the tests were divided. For this reason, the authors suggest the establishment of injury prevention strategies to reduce the impact of fatigue on the functional capacity of the hamstrings.

In terms of protocols to induce more non-specific fatigue, Castelo-Oliveira *et al.*[45] obtained significant differences by applying an on-going treadmill run and assessing subjects at a speed of 3.14 rad*s^{-1}. These authors attribute the decrease of the DCR to muscular damages caused by exercise in the contractile system, as given that no significant differences were found between the activation of agonist and antagonist muscle groups, the possible effects of neural transmission were ruled out[45]. Two isokinetic protocols were also carried out in which no significant changes were observed to the DCR between the pre and post[33,43]. The authors attribute this result to the nature of the protocol in terms of the intensity of the exercise, environment and nature of the load in question, variables that have proven to be capable of influencing fatigue mechanisms[58]. Finally, no significant changes were found in the DCR in a study in which the isokinetic strength of the lower body was assessed before and after running a marathon[44].

With regards to the H:Q ratio, this has traditionally been used to determine the risk of injury[18] when assessed at a speed of 1.05 rad*s^{-1}[27]. However, in our review, just five of the nine articles that calculated the H:Q ratio did so at this speed. And among them, only two found significant differences after applying a fatigue protocol[41,46]. Furthermore, the decrease percentages of the H:Q ratio were less in comparison to those of the DCR (Tables 3 and 4). Delextrat *et al.*[46] assessed the strength of the lower body before and after each female basketball training session. The H:Q ratio values decreased significantly by 8% and 7% just in the last two days of the week in which the measurements were taken. These results align with a study that determined the reduction of working capacity in a female basketball team after finishing a game[59]. Greco *et al.*[41], for their part, obtained a decrease of 3% after applying a PEIEF. However, Rahnama *et al.*[9] applied this same protocol and the significant differences were obtained for higher angular speeds. The main difference between both studies is in the demography used. Greco *et al.* use a semi-professional demographic, whilst Rahnama *et al.* assessed amateur footballers, for which the contrary results may be due to the difference between one group and the other. The studies by Coratella *et al.*[11] and by Castelo Oliveria *et al.*[45] also failed to find significant differences in the H:Q ratio after performing the LIST and an on-going treadmill run as fatigue protocols, at any of the angular speeds assessed. Nor were any significant results found in the H:Q ratio in three studies that assessed the isokinetic strength of the lower limbs at a speed of 2.09 rad*s^{-1}[33,44,47]. The protocols used were the SAFT, an isokinetic protocol, and the running of a marathon. Finally, one last study calculated the H:Q ratio after applying a prolonged test on an exercise bike until exhaustion, where the ratio values revealed a 24% increase[39]. The authors justify this result with another study in which it is concluded that a specific pedal strength may increase the point of strength on the joint on the knee flex[60], which may be the cause of this increase.

Of all the studies included in the review, only five included the assessment of the non-dominant leg. One of them found a decrease of 8% in the DCR after performing the modified LIST[36], and the other, a slight decrease of 3% in the H:Q ratio[9]. They are the only two studies analysed that reveal a significant decrease in the non-dominant leg. Coratella *et al.* found no significant decrease in any of the three speeds assessed, or in the H:Q ratio or in the DCR[11]. Neither did Koller *et al.*[44], Olyaei *et al.*[43] and Rahnama *et al.*[9]. Koller assessed both the H:Q ratio and the DCR, whilst Olyeaei *et al.* only assessed the DCR. Rahnama *et al*. only found a decrease in the H:Q ratio at 1.05 rad*s^{-1}, but for the other speeds assessed (2.04 and 5.24 rad*s^{-1}) and for the DCR, no significant changes were found. These results are explained as the dominant leg is frequently used in stopping and direction changes, as well as for dribbling and kicking the ball in matches. It has been shown that these actions have a greater energy expenditure when compared to just running, which is what the non-dominant leg would do[61] and therefore this may justify the results found in this review for the non-dominant leg.

Conclusions

Fatigue produces a reduction of the H:Q ratio and DCR values, which translates as a lessened capacity to produce strength in the lower limbs, especially in the hamstrings, and the consequential increased risk of suffering from an injury.

The DCR seems to be a more reliable indicator than the H:Q ratio as it considers the eccentric phase of the hamstrings, where there is a greater risk of suffering from an injury if the muscle is fatigued or weakened.

The most specific protocols provoked greater fatigue in the hamstring muscle group and the quadriceps, and consequentially a greater decrease in the values of both ratios compared to laboratory tests. Therefore, future research should consider a match or real test as an element that induces fatigue.

The dominant leg suffered greater decreases in terms of recovering strength, and as a result, greater decreases of the H:Q ratio and especially the DCR. This could mean that greater fatigue is produced in this limb in comparison to the non-dominant leg through the actions performed more by one than by the other: kicking a ball, starting the direction change or starting the sprint. This is why comparative work should be carried out to try and correct these imbalances and fatigue rate in the dominant leg.

Based on the results obtained from the different studies included in this review, the injury prevention strategies should focus attention on the one hand on strengthening the hamstrings, mainly during the eccentric phase, which is when the greatest risk of suffering from an injury is concentrated. And on the other hand, in slowing the appearance of fatigue to avoid imbalances in recruiting strength from both muscle groups of the lower limbs, but especially in the hamstrings.

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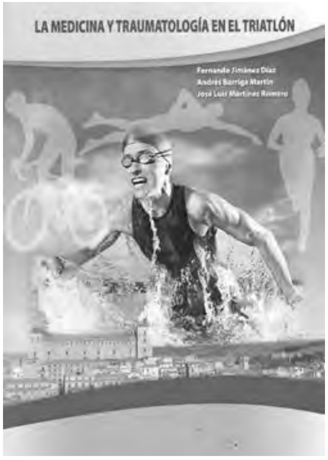


LA MEDICINA Y LA TRAUMATOLOGÍA EN EL TRIATLÓN

Por: Fernando Jiménez Díaz, Andrés Barriga Martín, y José Luis Martínez Romero
Edita: F. Jiménez
E-mail: femede@femede.es
Murcia 2016. 184 páginas. P.V.P: gratuito

El triatlón es un deporte individual y de gran resistencia que reúne tres disciplinas deportivas a la cual más importantes: natación, ciclismo y carrera a pie. Es un deporte muy duro y competitivo y los deportistas que lo practican se someten a un intensivo entrenamiento a lo largo de la temporada para poder hacer frente a las exigencias de las pruebas que van a acometer y que supondrán un reto, tanto físico como psicológico.

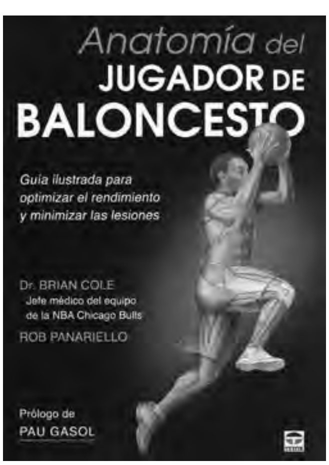
Este deporte fue el elegido para el IV Curso de Medicina y Traumatología del Deporte, celebrado en 2015 en Toledo. Y de dicha actividad emana la presente monografía. Dividida en cuatro secciones (Entrenamiento y Medicina del Deporte; Medicina del Deporte y Lesiones en el Triatlón; Traumatología del Deporte y Triatlón; Ejercicio físico, Salud y Discapacidad) se tratan –por parte de algunos de los mejores especialistas nacionales en Medicina y Traumatología del Deporte- todos los temas relacionados con la fisiología del deportista, la salud, el entrenamiento, las características técnicas, las lesiones típicas y, sobre todo, los mecanismos y programas de prevención.

EL MÉTODO MEB PARA CORREDORES

Por: Meb Keflezighi y Scott Douglas
Edita: Ediciones Tutor-Editorial El Drac
Impresores 20. P.E. Prado del Espino. 28660 Boadilla del Monte. Madrid. Tel. 915 599 832 – Fax: 915 410 235
E-mail: info@edicionestutor.com Web: www.edicionestutor.com
Madrid 2016. 224 páginas. P.V.P: 19,95 euros

El Método Meb para corredores describe con una minuciosidad sin precedentes cómo este participante en tres Juegos Olímpicos se prepara para enfrentarse a los mejores corredores del mundo. Y aún más importante, el libro enseña a los corredores normales y corrientes cómo poner en práctica los principios del entrenamiento, nutricionales y mentales que han orientado al autor a lo largo de toda su larga carrera deportiva (además de la victoria en la maratón Boston en 2014 dos semanas antes de cumplir 39 años, al inscribirse en la carrera tenía solamente la 15ª mejor marca de maratón del año, incluye una medalla de plata olímpica y el Maratón de Nueva York de 2009).

El Método Meb para corredores es el libro perfecto para cualquier atleta —tanto si es un recién llegado como un maratoniano curtido— con ansias de mejorar su rendimiento y disfrutar más corriendo.



ANATOMÍA DEL JUGADOR DE BALONCESTO

Por: Brian Cole y Rob Panariello
Edita: Ediciones Tutor-Editorial El Drac
Impresores 20. P.E. Prado del Espino. 28660 Boadilla del Monte. Madrid. Tel. 915 599 832 – Fax: 915 410 235
E-mail: info@edicionestutor.com Web: www.edicionestutor.com
Madrid 2016. 208 páginas. P.V.P: 25 euros

Esta interesante publicación tanto para jugadores, preparadores, entrenadores o espectadores, contempla lo que exige maximizar la potencia, la fuerza, la agilidad y la velocidad en la cancha. Intenta enseñar a mejorar el rendimiento aumentando la fuerza muscular y optimizando la eficiencia de cada movimiento.

Incluye 88 de los ejercicios específicos más efectivos para el baloncesto, cada uno de ellos con descripciones paso a paso e ilustraciones anatómicas en color para mostrar los músculos en acción. Incluso va más allá de los ejercicios, situando al lector en la cancha y en plena competición. Las ilustraciones de los músculos implicados al pivotar, rebotear y tirar muestran la estrecha vinculación entre estos ejercicios y el rendimiento en baloncesto; entrando también en la sala de entrenamiento y explorando la anatomía de las lesiones más habituales de tobillo, rodilla y hombro, así como ejercicios para minimizarlas y recuperarse de ellas.

Efectos beneficiosos de las aguas carbonatadas sobre el perfil lipídico. Vichy Catalán y colesterol

José M. Balibrea del Castillo
Cirugía General y Digestiva. Unidad de Cirugía Endocrino-Metabólica. Hospital Vall d'Hebron.
Profesor Asociado de Cirugía. Universidad Autónoma de Barcelona

El colesterol es un elemento fundamental en la estructura de los seres vivos. Como tal, sus niveles están sujetos a una estricta regulación interna que, a menudo, sólo se puede desestabilizar debido a graves enfermedades o bien factores relacionados con la dieta. Los niveles elevados de colesterol son así un importante factor de riesgo para enfermedades, principalmente cardiovasculares. Así, el control dietético constituye uno de los pilares en la prevención (primaria y secundaria) e incluso la prevención de este grupo de enfermedades. A menudo se hace referencia a la regulación de los alimentos sólidos, pero con frecuencia nos olvidamos de las posibilidades que tenemos de encontrar en los líquidos importantes aliados. Así, dentro de los mismos destacan las aguas minerales, especialmente aquellas llamadas "carbónicas". Se trata de aguas con una composición electrolítica constante y adecuada de modo que pueden constituir una fuente primordial y prácticamente suficiente. Las aguas minerales carbónicas poseen un efecto beneficioso a nivel de aparato digestivo que se extiende al aparato cardiovascular y, en general, a toda la homeostasia debido a sus efectos sobre el colesterol. De hecho, su consumo se comienza a considerar como un complemento de gran importancia en la estrategia preventivo-terapéutica de las enfermedades cardiovasculares.

La hipercolesterolemia es perjudicial fundamentalmente debido a su acúmulo en la pared de las arterias, aumentando su calibre y disminuyendo su elasticidad. En ocasiones, pueden llegar a bloquear completamente el paso de sangre a través de los vasos (embolias), generando lesiones agudas potencialmente vitales y de consecuencias, en ocasiones, catastróficas.

Así, dentro de las diferentes medidas que se pueden tomar, la modificación de los hábitos dietéticos debe ser la primera a implementar. Dentro de las mismas, se recomienda el consumo habitual de agua mineral. Curiosamente, si ésta es carbónica, la efectividad es mayor ya que se ha comprobado que mejora el perfil colesterolémico mediante el aumento de su fracción beneficiosa (HDL) con un descenso de la fracción perjudicial (LDL). De este modo, el consumo habitual de agua mineral carbónica (100-1500cc/día) podría ayudar a disminuir el riesgo cardiovascular individuos de riesgo, especialmente en casos de hipercolesterolemia o, como señala la literatura científica, mujeres post-menopáusicas. Debido a su cuidada elaboración, su equilibrada composición, especialmente en cuanto al contenido en oligoelementos, el agua mineral carbónica Vichy Catalán constituye una gran opción a la hora de considerar el consumo de este tipo de aguas como medida preventiva complementaria.

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XVI CONGRESO NACIONAL DE LA SOCIEDAD ESPAÑOLA DE MEDICINA DEL DEPORTE

GRANADA - HOTEL M.A. NAZARIES
23 AL 26 DE NOVIEMBRE DE 2016

Sociedad Española de Medicina del Deporte

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ÍNDICE PREVIO DEL PROGRAMA CIENTÍFICO

SESIONES PLENARIAS

- Lesiones de partes blandas.
- Reconocimientos: controversia EEUU-Europa.
- Fisiología del ejercicio en ambientes extremos.

PONENCIAS

- Síndrome compartimental de esfuerzo en el deporte.
- La Actividad Física Beneficiosa para la Salud (AFBS-HEPA) en España y la UE, mitos y realidades.
- Actualizaciones en entrenamiento
- La salud en las redes sociales.
- Lesiones de hombro en el deportista.

CONTROVERSIAS

- Electroestimulación corporal total.
- Entrenamiento en altitud.

REMISIÓN DE COMUNICACIONES CIENTÍFICAS

El Comité Científico invita a todos los participantes a remitir comunicaciones científicas (comunicaciones orales y póster-presentación interactiva) al XVI Congreso Nacional de la Sociedad Española de Medicina del Deporte.

Temas para presentación de Comunicaciones Científicas en el Congreso:

- Medicina del deporte.
- Entrenamiento y mejora del rendimiento.
- Biomecánica.
- Cardiología del deporte.
- Fisiología del esfuerzo.
- Nutrición y ayudas ergogénicas.
- Cineantropometría.
- Lesiones deportivas: diagnóstico, prevención y tratamiento.
- Actividad física y salud.

Las Comunicaciones Orales se distribuirán en sesiones de los temas del Congreso. Por favor, escoja uno de los temas del listado como propuesta para realizar su presentación. El Comité Científico podrá reasignar el abstract en otro tema del Congreso.

Los trabajos deberán ser originales y no se habrán presentado en congresos anteriores o reuniones similares.

Las comunicaciones científicas admitidas, comunicaciones orales y pósters (presentación interactiva), serán publicadas en la revista Archivos de Medicina del Deporte.

Normas de remisión de abstracts

Por favor, preste atención a las siguientes normas de preparación del abstract de su comunicación científica (comunicación oral o póster: presentación interactiva), porque son de obligado cumplimiento:

- La fecha límite para la remisión de los trabajos científicos será el día **10 de septiembre de 2016.**
- Se remitirá la Comunicación Científica a la atención del Presidente del Comité Científico, con el formulario debidamente cumplimentado, a la siguiente dirección de correo electrónico: congresos@femede.es.
- El abstract tiene que tener una clara relación con los contenidos del XVI Congreso Nacional de la Sociedad Española de Medicina del Deporte y, en definitiva, con la Medicina y Ciencias del Deporte.
- El Comité Científico podrá destinar el trabajo presentado a la forma de presentación (comunicación oral o póster: presentación interactiva) que considere más adecuada al tipo y contenido del mismo.
- El Comité Científico se reserva el derecho de rechazar los trabajos que no cumplan los requisitos indicados anteriormente por la calidad y temática que el evento científico requiere.

Forma de preparación del abstract

- Sólo se aceptarán las comunicaciones científicas presentadas en el formato electrónico que se encuentra en la página web del Congreso: www.femede.es/congresodegranada2016 "Formato de comunicación científica".
- **Título:** El título deberá ser breve (máximo de 15 palabras) y específico. Debe reflejar el contenido de la presentación. No use abreviaturas en el título. Se escribirá en letras mayúsculas, usando el tamaño 12 del tipo de letra Arial.
- **Autores:** Se escribirá, en minúsculas, el apellido seguido, sin coma, de la inicial del nombre de cada autor, separados por comas.
- **Centro:** Indicar el centro de trabajo de los autores. Si son varios, indicar con un número superíndice.
- **Preferencia de presentación:** Seleccionar con un asterisco el tipo de presentación a la que presenta la comunicación científica.
- **Texto:** La extensión máxima del texto es de 300 palabras o 3.000 caracteres. Se escribirá en minúsculas, usando el tamaño 10 de la letra Arial. Se evitarán abreviaturas no explicadas. Se escri-

birá el contenido del resumen científico sin repetir el título de la Comunicación y ajustándose al siguiente esquema: introducción, material y métodos, resultados y conclusiones.

- Respetando la extensión máxima del texto se pueden incluir tablas, gráficos o imágenes.
- Es obligatorio indicar un máximo de **tres palabras clave**.
- Los abstracts deben incluir **información específica** sobre los resultados y las conclusiones de la investigación. No se aceptarán abstracts que establezcan que "se discutirán los resultados".

Notificación de la recepción de la comunicación científica

En el plazo de 15 días, Vd. recibirá la confirmación de recepción de la comunicación por parte de la Secretaría del Congreso. Si no la recibiera, no vuelva a remitir la comunicación y envíe un mensaje electrónico: congresos@femede.es.

Inscripción del responsable de la comunicación científica

- Cada persona puede presentar dos comunicaciones científicas como máximo (comunicación oral o póster: presentación interactiva). En caso de ser aceptadas ambas, sólo una de ellas podrá ser presentada como comunicación oral.
- Los autores (CADA UNO PUEDE PRESENTAR DOS TRABAJOS) que presenten una comunicación científica (comunicación oral o póster- presentación interactiva) y ésta haya sido aceptada, deben haberse registrado y **haber pagado los derechos de inscripción del Congreso antes del 20 de octubre de 2016**. En caso contrario su comunicación científica (comunicación oral o póster-presentación interactiva) será eliminada del programa y del libro de abstracts.
- Cada autor puede FIRMAR todos los trabajos que quiera.
- No hay limitación en el número de comunicaciones que puede aparecer una misma persona.

Presentación de la comunicación oral

- Las Comunicaciones Orales tendrán un **tiempo de presentación de 8 minutos**. Al final de cada sesión habrá un turno de preguntas.
- Todas las exposiciones orales se harán en **formato Powerpoint**, debiendo estar en posesión del responsable de las Comunicaciones de la organización el día anterior a la presentación de la misma.
- Se limita a un **máximo de 12 el número de diapositivas** de la presentación de powerpoint.

Póster (presentación interactiva)

Si su abstract se acepta pero no se puede ajustar a una presentación en forma de Comunicación Oral, se le propondrá presentarlo en forma de póster-presentación interactiva, dándole un tiempo para su preparación.

Presentación del póster (presentación interactiva)

Para la elaboración del póster (presentación interactiva) debe seguir las siguientes instrucciones que son de obligado cumplimiento:

- Formato Microsoft Powerpoint.
- Hasta 12 diapositivas, de las cuales:
  - La primera: debe contener **título, autores, centro de trabajo**.
  - La última: debe contener **título** y la palabra **FIN** o expresión similar que indique que la presentación ha concluido.
  - La penúltima o las dos penúltimas deben contener las **conclusiones**.
- Fondo de diapositivas: color neutro y uniforme.
- Texto de diapositivas: color que **contraste** con el fondo.
- En lo posible evitar incluir vídeos en las diapositivas, si se hiciera debería ser en formato **.wmv** y se deberá incluir en un subdirectorio/carpeta que enlace automáticamente con la presentación remitida. Si el video no enlazara con la presenta-

ción, no se editará por parte de la organización para corregir el error.

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- El abstract debe remitirse preparado tal como se indica anteriormente **(Forma de preparación del abstract).**
- Una vez que se le confirme que su comunicación científica ha sido aceptada para ser presentada en forma de póster (presentación interactiva) debe enviar el documento electrónico **(.Ppt)**:
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Certificaciones

Tras la presentación de la comunicación oral o la defensa del póster en el modo en que se indique se entregará **un único certificado** al responsable de la comunicación científica.

Publicación de los trabajos científicos

Los abstracts de los trabajos científicos (comunicaciones orales y póster) **aceptados y presentados** en el XVI Congreso Nacional de la Sociedad Española de Medicina del Deporte serán publicados en la revista **Archivos de Medicina del Deporte**, publicación científica de esta especialidad y revista oficial de la Sociedad Española de Medicina del Deporte, que tiene una periodicidad de publicación bi-mensual.

ARCHIVOS DE MEDICINA DEL DEPORTE

Presentaciones

- Documento de consenso de la Sociedad Española de Medicina del Deporte (SEMED-FEMEDE) sobre deporte recreacional saludable.

- Pruebas de Esfuerzo en Medicina del Deporte. Documento de Consenso de la Sociedad Española de Medicina del Deporte (SEMED-FEMEDE).