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Caffeine and sports performance

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Abstract: Athletes are among the groups of people who are interested in the effects of caffeine on endurance and exercise capacity. Although many studies have investigated the effect of caffeine ingestion on exercise, not all are suited to draw conclusions regarding caffeine and sports performance. Characteristics of studies that can better explore the issues of athletes include the use of well-trained subjects, conditions that reflect actual practices in sport, and exercise protocols that simulate real-life events. There is a scarcity of field-based studies and investigations involving elite performers. Researchers are encouraged to use statistical analyses that consider the magnitude of changes, and to establish whether these are meaningful to the outcome of sport. The available literature that follows such guidelines suggests that performance benefits can be seen with moderate amounts (~3 mg·kg^{-1} body mass) of caffeine. Furthermore, these benefits are likely to occur across a range of sports, including endurance events, stop-and-go events (e.g., team and racquet sports), and sports involving sustained high-intensity activity lasting from 1–60 min (e.g., swimming, rowing, and middle and distance running races). The direct effects on single events involving strength and power, such as lifts, throws, and sprints, are unclear. Further studies are needed to better elucidate the range of protocols (timing and amount of doses) that produce benefits and the range of sports to which these may apply. Individual responses, the politics of sport, and the effects of caffeine on other goals, such as sleep, hydration, and refuelling, also need to be considered.

Key words: ergogenic aid, sports performance, doping.

Résumé : Les athlètes font partie des gens concernés par les effets de la caféine sur l'endurance et la capacité physique. Même si de nombreuses études ont porté sur les effets de la consommation de la caféine sur l'exercice physique, elles ne permettent pas toutes de tirer des conclusions au sujet des effets de la caféine sur la performance sportive. Pour analyser de tels effets, il faut des études incluant des sujets bien entraînés, des conditions reflétant les pratiques sportives en cours et des protocoles expérimentaux simulant des conditions réelles. Il y a très peu d'études réalisées sur le terrain qui incluent des athlètes d'élite. On invite les chercheurs à utiliser des outils statistiques mesurant l'importance des variations notamment sur le plan de la pertinence dans la pratique sportive. Les études scientifiques qui prennent en compte ces directives rapportent qu'une quantité modérée de café (~3 mg·kg^{-1} de masse corporelle) suscite des gains sur le plan de la performance. De plus, ces gains devraient se manifester dans un large spectre d'activités sportives dont les activités d'endurance, les activités constituées d'arrêts et de départs tels les sports d'équipe et de raquette et les activités demandant une forte intensité soutenue de 1 min à 60 min comme la natation, l'aviron, la course de demi-fond et de fond. Les effets directs de la consommation de caféine dans les activités de force et de puissance tels les levers, les lancers et les sprints ne sont pas bien établis. Il faut faire d'autres études pour bien déterminer les variétés de protocoles admissibles (moment de l'année, quantité consommée) qui suscitent des gains et qui identifient les sports pouvant en bénéficier. Il faut aussi faire d'autres études sur les réponses individuelles, les politiques du sport et sur les effets de la caféine sur d'autres facteurs tels le sommeil, l'hydratation et la recharge d'énergie.

Mots-clés : facteur ergogène, performance sportive, dopage.

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Introduction

Caffeine is a drug that enjoys social acceptance and widespread use around the world, with about 90% of adults consuming it in their everyday eating patterns. The effects of caffeine in reducing fatigue and increasing wakefulness and alertness have been recognised for many centuries. These properties have been targeted by shiftworkers, long-haul truck drivers, members of the military forces, athletes, and other populations who need to fight fatigue or prolong their capacity to undertake their occupational activities. Indeed, the availability, in many countries, of nonprescription medications, energy drinks, confectionary and sports foods, and (or) supplements that contain caffeine or guarana (Table 1) has increased the opportunities for people to specifically consume caffeine as an ergogenic (work-enhancing) aid.

The past 30 years has seen the publication of a substantial

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Table 1. Caffeine content of common foods, drinks, and nonprescription preparations.

Food or drink	Serving	Caffeine, mg*
Instant coffee	250 mL (8 oz) cup	60 (12–169)†
Brewed coffee	250 mL (8 oz) cup	80 (40–110)†
Short black coffee or espresso	1 standard serving	107 (25–214)‡
Starbucks Breakfast Blend brewed coffee (Venti size)	600 mL (20 oz)	415 (300–564)§
Iced coffee (commercial brands)	500 mL bottle (16 oz)	30–200
Frappuccino	375 mL (12 oz) cup	90
Tea	250 mL (8 oz) cup	27 (9–51)†
Iced tea	600 mL (20 oz) bottle	20–40
Hot chocolate	250 mL (8 oz) cup	5–10
Chocolate milk	60 g	5–15
Dark chocolate	60 g	10–50
Viking chocolate bar	60 g	58
Coca-Cola	375 mL (12 oz) can	49
Pepsi cola	1375 mL (12 oz) can	40
Jolt soft drink	1375 mL (12 oz) can	75
Red Bull energy drink	250 mL (8 oz) can	80
Red Eye Power energy drink	250 mL (8 oz) can	50
V Energy drink	250 mL (8 oz) can	50
Smart Drink - Brain fuel	250 mL (8 oz) can	80
Lift Plus energy drink	250 mL (8 oz) can	36
Lipovitan energy drink	250 mL (8 oz) can	50
Black Stallion energy drink	250 mL (8 oz) can	80
AMP Energy tallboy	500 mL (16 oz) can	143
Spike Shotgun energy drink	500 mL (16 oz) can	350
Fixx energy drink	600 mL (20 oz) can	500
Ammo energy shot	30 g (1 oz)	170
Jolt endurance shot	60 g (2 oz)	150
PowerBar caffeinated sports gel	40 g sachet	25
PowerBar double caffeinated sports gel	40 g sachet	50
GU caffeinated sport gel	32 g sachet	20
Carboshotz caffeinated sports gel	50 g sachet	80
PB Speed sports gel	35 g sachet	40
PowerBar Acticaf Performance bar	65 g bar	50
Jolt caffeinated gum	1 stick	33
No-Doz (Australia)	1 tablet	100
No-Doz (U.S.)	1 tablet	200
Extra Etrength Excedrin	1 tablet	65

*These values were gathered from a variety of sources, including manufacturers' information and nutrition databases (Centre for Science in the Public Interest (available at http://www.cspinet.org/new/cafchart.htm), and USDA National Nutrient Database (available at http://www.nal.usda.gov/fnic/foodcomp/search/). Note that commercial brands may vary slightly from country to country.

†The caffeine content of tea and coffee varies widely, depending on the brand, the way the beverage is made, and the size of the mug or cup.

‡Commercial samples bought from a variety of outlets (Desbrow et al. 2007).

§Commercial samples bought from the same Starbucks outlet (McCusker et al. 2003).

number of studies of caffeine supplementation and exercise or physical activity. Table 2 provides a summary of our current knowledge about the effects of caffeine on exercise capacity or performance from this robust literature. It is beyond the scope of this paper to examine the mechanisms by which caffeine exerts its ergogenic effects related to exercise on the body; readers are referred to several extensive reviews for this information (Graham 2001*a*, 2001*b*, 2008; Jones 2008; Keisler and Armsey 2006; Tarnopolsky 2008). Instead, the aim of this paper is to discuss the available information on caffeine and exercise from the perspective of sports performance. It should be noted that the views expressed in this paper only apply to adult athletes who already consume caffeine within their normal dietary practices. This author believes it is inappropriate and unnecessary for children and young adults to consume caffeine as an ergogenic aid, and notes that younger populations have the potential for greater performance enhancement through maturation and experience in their sport. Caffeine use in all populations should be seen against the background of its effects on human health, where it has been suggested that, in healthy adult populations, moderate daily caffeine intakes of up to 400 $mg \cdot d^{-1}$ or ~6 $mg \cdot kg^{-1}$ are not associated with adverse effects, whereas children aged 12 or under should

Table 2. A summary of our current understanding of the effect of caffeine supplementation on exercise capacity or performance.

Issue	Supporting evidence
There is sound evidence that caffeine enhances endurance and provides a small but worthwhile enhancement of performance over a range of exercise protocols, with the traditional protocol involving a caffeine dose of ~6 mg·kg^{-1} body mass taken 1 h pre-exercise.	Jones (2008); Keisler and Armsey (2006); Doherty and Smith (2004); Graham (2001*a*, 2001*b*)
Recent studies show that beneficial effects from caffeine occur at very modest levels of intake (1–3 mg·kg^{-1} body mass, or 70–150 mg caffeine).	Bridge and Jones (2006); Cox et al. (2002); Kovacs et al. (1998); Graham and Spriet (1995)
Several studies suggest there is no dose–response relationship between caffeine intake and benefits to endurance exercise or, if a dose–response exists, there is a plateau at ~3 mg·kg^{-1}.	Anderson et al. (2000); Bruce et al. (2000); Cox et al. (2002); Kovacs et al. (1998); Pasman et al. (1995); Graham and Spriet (1995)
A variety of protocols of caffeine intake, including doses before or during exercise, or after the onset of fatigue, may be beneficial for exercise capacity.	Cox et al. (2002); Kovacs et al. (1998)
Some tissues become tolerant to repeated caffeine use, while others do not. Since the mechanisms by which caffeine exerts effects on performance are not fully known, it is unclear whether an athlete should withdraw from caffeine prior to competition. Some studies show that there is no difference in the performance response between nonusers and users of caffeine. Withdrawal can be achieved by 24–48 h of cessation of caffeine use. However, athletes should be aware of the side effects of withdrawal, such as headaches, and the greater potential for negative side effects from subsequent caffeine exposure.	Graham (2001*b*)
The effects of caffeine can be long lasting. Although there is some evidence that the benefits do not persist up to 6 h, people who ingest caffeine to enhance a morning exercise task may still receive benefits during a session undertaken later in the day.	Bell and McLellan (2002, 2003)
Coffee may not be a good source of caffeine for exercise enhancement; it is difficult to know the dose of caffeine in any serving of coffee. Some studies have found that while caffeine alone was ergogenic for a given exercise task, caffeine consumed in a caffeine medium did not enhance performance of the same protocol. Coffee may contain other ingredients that counteract the benefits of caffeine. Nevertheless it appears that caffeine is ergogenic when coffee is consumed with a prerace meal.	Graham et al. (1998); Graham (2001*a*, 2001*b*)
There is individual variability in the changes in exercise capacity in response to caffeine. Some people are nonresponders to caffeine.	Graham and Spriet (1995)
Higher doses of caffeine (>6–9 mg·kg^{-1}) may be associated with side effects, such as jitters, increased heart rate, and performance impairment.	Graham and Spriet (1995)

limit their caffeine intake to <2.5 mg·kg^{-1}·d^{-1} because of their increased risk of behavioural side effects (Nawrot et al. 2003).

Special issues related to study design for examining caffeine and sports performance

Research design reflects a number of scientific and practical concerns, including the primary question (hypothesis) of interest, level of funding, the availability and limitations of equipment and subjects, interest in examining the mechanisms underpinning outcomes, approval from ethics panels, and the requirements or expectations of participants in the peer-review process. Given the range of potential uses for any beneficial effects of caffeine on physical and occupational activities, and the diverse interests of scientists who have undertaken studies of caffeine and exercise, we might expect that a variety of research protocols have been undertaken. While many studies may have been able to address issues related to caffeine and exercise per se, not all were well suited to address special issues of sports performance. Table 3 summarizes some of the characteristics of the methodologies used in many studies of caffeine supplementation and exercise, and contrasts these with the features of real-life sport.

One of the key tenets of research is that the results really only apply to the population and the situation that was investigated. Therefore, Table 3 provides a list of the characteristics that should be included in studies specifically designed to investigate the effect of caffeine on sports performance. It is likely that there is a spectrum of athletes who are interested in the outcomes of such research. The rewards for achieving success in elite-level sports are highly visible and offer a clear incentive to search for strategies that can enhance performance by even a small margin. Theoretically, the potential for detecting small but worthwhile changes in performance should be greater among elite athletes. After all, elite athletes are usually highly reliable at performing the tasks for which they have trained; a small coefficient of variation in performance increases the precision of the separation of the true effects of an intervention (the signal) from everyday differences in performance (the noise).

Ironically, few studies on caffeine and elite athletes are available. This is understandable because, by definition, they are few and special. It is usually difficult to achieve a large sample size of elite athletes for statistical rigour or to impose the conditions or invasive techniques of research on their training and competition schedules. Therefore, most studies of caffeine and sports performance have been undertaken on athletes at recreational to highly trained but subelite levels (Tables 4–7). It is unclear whether the results of

Table 3. The characteristics of traditional laboratory-based research vs. research focussed on elite sports performance.

Characteristics of traditional studies	Characteristics of elite and serious sport	Comments on the ideal characteristics of studies on sports performance
Subjects are often drawn from available populations, such as college students or recreationally and moderately trained subjects.	Competitors are highly trained in their sport and event. Characteristics include reliability in repeating a given performance task, and specific adaptations achieved though natural selection of sport and the conditioning effects of training.	Subjects should reflect the population to which the results of the study are intended to apply; subjects should be familiar with and reliable in undertaking the performance protocol; and studies that involve elite or highly trained athletes are underrepresented and should be encouraged.
Exercise protocols typically measure endurance or exercise capacity (the ability to sustain a given exercise task for as long as possible). The task is terminated when the subject is fatigued and unable to continue at the prescribed output.	Sports performance typically includes completing a task in the fastest possible time (pace judgement is important), executing skills and making complex decisions while undertaking exercise, and executing a single task as well as possible. Training situations may better represent the execution of an exercise task to fatigue.	Protocols should involve a close-looped task (i.e., completing a task in the fastest time possible), which involves pacing rather than simply exercising to fatigue; protocols should simulate, as much as possible, a real-life event; and field studies are underrepresented and should be encouraged.
Protocols are often undertaken with baseline metabolic conditions (subjects fast overnight and consume only water during exercise) and without the confounding effects of other nutritional strategies.	Athletes undertake other nutrition strategies that provide additional support for performance, including eating a carbohydrate-rich pre-event meal consuming carbohydrates during prolonged events, and using other scientifically supported ergogenic aids (e.g., bicarbonate, creatine).	Protocols should allow subjects to follow nutrition strategies that optimize performance and reflect the real-life practices of athletes; and studies should investigate the interaction between caffeine intake and other nutrition strategies or supplements, and their combined effect on performance.
Differences (which must reach a level of >5% probability to be considered significant) in performance between the control treatment and the active treatments(s) are assessed using probability statistics.	The margins between winning and losing, or between the "podium" athletes (first-, second-, and third-place winners) and the rest of the field, can often be measured in hundredths of seconds and meters.	Differences in performance should be assessed using magnitude-based statistics: the likely range of the true difference in performance should be compared with the coefficient of variation of performance for individuals undertaking that protocol.
Protocols are conducted with consideration to the concerns of the ethics committee overseeing the project.	Sports are conducted within the regulations of their governing body, and many athletes compete within an anti-doping code that may not permit the use of otherwise legal products or strategies.	Projects that are focussed on high-level sports should be conducted within the logistical and anti-doping rules that govern athletes in that sport.

current research apply to the true elite, since top competitors may have unusual characteristics, as a result of genetics or conditioning, that have made them the best. However, we can be sure that the population base to which the results of currently available studies of caffeine and exercise and (or) sport best apply is far larger than the elite athlete population. It should also be remembered that athletes at lower levels of competition can also be highly motivated, even if the rewards are simply the satisfaction of achieving personal bests. As such, they will be highly interested in utilizing the results of caffeine studies. Although it would be good to see more studies of elite athletes, the practicalities that prevent this will mean that top class athletes will need to extrapolate the information on protocols for caffeine in sport from studies of well-trained athletes, and to test what works for their individual situation.

Sports scientists who work with athletes are understandably interested in investigations that have been carried out in a field setting or in a situation of sport (Berglund and Hemmingsson 1982; Cohen et al. 1996; Van Nieuwenhoven et al. 2005). The advantages of such studies relate to the validity of performance measures, since they can include features such as real airflow and ground resistance, real-life pacing strategies (which are often stochastic), changes in the environment and course over the event, and the effect of competition and other extrinsic motivating factors. The negatives of field and real-life settings typically include a reduction in the control that is possible over the environment and the athlete. This is likely to reduce the precision of the results and, therefore, the likelihood of detecting small changes that could be important.

Therefore, it is important to recognise that our interest in caffeine exists because of the laboratory-based studies in which tight control has allowed the effects on metabolism and exercise capacity or performance to be detected. As well as selecting an appropriate subject pool, there are features that can be built into laboratory (or field) studies to enhance the reliability and validity of the results in relation to sporting activities. Table 3 lists many such factors, including the choice of performance tasks that are related to sport, the control or standardization of training and diet leading into performance trials, and the choice of conditions that mimic what happens in the world of sport. For example, some recent studies of caffeine and endurance sports that have required subjects to be well fuelled from the days and the meal leading into a performance trial, and have provided carbohydrate intake during prolonged events are helpful (Cox et al. 2002). Similarly, studies examining the interaction of caffeine with other proven ergogenic aids, such as creatine (Doherty and Smith 2004) and bicarbonate (Pruscino et al. 2008), are important, since this is a likely scenario in real life.

The analysis and interpretation of the results of studies need to be undertaken with sympathy for effect sizes that would be worthwhile to an athlete. In many sports, the margins between winning and losing can be measured to several decimal points. An emerging area in sports science is the use of magnitude-based statistics, which look at the range of the likely true effect of an intervention in comparison to the differences in performance that might change the outcome of an event (Batterham and Hopkins 2006). In fact,

Table 4. Crossover-designed studies of caffeine supplementation related to an endurance sport (>60 min).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Cycling					
Jenkins et al. (2008)	Trained cyclists (13 males)	1 $mg \cdot kg^{-1}$, 2 $mg \cdot kg^{-1}$, or 3 $mg \cdot kg^{-1}$ (60 min pre-exercise)	15 min cycling (60% $VO_{2\ max}$) + 15 min TT	Yes for 2 and 3 $mg \cdot kg^{-1}$ doses; no for 1 $mg \cdot kg^{-1}$ dose	Work done during the 15 min TT was increased by 4% (1–6.8) with 2 $mg \cdot kg^{-1}$ of caffeine and by 3% (–0.4%–6.8%) with 3 $mg \cdot kg^{-1}$; improvement varied in magnitude between individual cyclists
Cureton et al. (2007)	Well-trained cyclists (16 males)	Total, 5.3 $mg \cdot kg^{-1}$; 1.2 $mg \cdot kg^{-1}$ pre-exercise + 0.6 $mg \cdot kg^{-1}$ every 15 min during exercise	120 min cycling (60% and 75% $VO_{2\ max}$) + 15 min TT; CHO-fed during cycling	Yes	Higher exercise intensity in 15 min TT with caffeine and CHO (90±11% $VO_{2\ max}$) vs. CHO alone (79±14 $VO_{2\ max}$)
Conway et al. (2003)	Trained cyclists and triathletes (9 males)	6 $mg \cdot kg^{-1}$ 60 min pre-exercise; 3 $mg \cdot kg^{-1}$ pre-exercise; and 3 $mg \cdot kg^{-1}$ at 45 min during exercise	90 min cycling at 68% $VO_{2\ max}$ + TT (~30 min)	Perhaps	Trend to better performance in TT with caffeine trials (~24.2 and 23.4 min) vs. placebo (28.3 min) ($p = 0.08$); urinary caffeine concentrations lower with split dose
Hunter et al. (2002)	Highly trained cyclists (8 males)	6 $mg \cdot kg^{-1}$ 60 min before exercise + 0.33 $mg \cdot kg^{-1}$ every 15 min	100 km cycling TT, including 5 × 1 km and 4 × 4 km high-intensity efforts; CHO-fed during cycling	No	No difference between trials with respect to total 100 km time or time to complete high-intensity efforts; no difference between trials in EMG characteristics, although differences within trial attributable to workload
Cox et al. (2002)	Well-trained cyclists and triathletes (12 males)	6 $mg \cdot kg^{-1}$ 60 min pre-exercise; 6 × 1 mg every 20 min during exercise; 10 $mL \cdot kg^{-1}$ Coca-Cola in last 50 min (~1–1.5 $mg \cdot kg^{-1}$ caffeine)	2 h cycling at 70% $VO_{2\ max}$ + 7 $kJ \cdot kg^{-1}$ TT (~30 min); CHO-fed during cycling	Yes at all doses	Compared with placebo, caffeine in large dose (6 $mg \cdot kg^{-1}$) provided 3% performance benefit in TT, regardless of timing of intake; commercial cola drink consumed late in exercise (~1 $mg \cdot kg^{-1}$ caffeine) produced effects of equal magnitude; urinary caffeine levels ~4–5 $\mu g \cdot mL^{-1}$ for large dose of caffeine and <1 $\mu g \cdot mL^{-1}$ for cola drink
Cox et al. (2002)	Well-trained cyclists and triathletes (8 males)	Sports drink replaced during last 70 min with 15 $mL \cdot kg^{-1}$ of a cola drink (caffeine dose ~1.5 $mg \cdot kg^{-1}$): 6% CHO; 11% CHO; 6% CHO + 130 $mg \cdot mL^{-1}$ caffeine; or 11% CHO + 130 $mg \cdot mL^{-1}$ caffeine*	2 h cycling at 70% $VO_{2\ max}$ + 7 $kJ \cdot kg^{-1}$ TT (~30 min); CHO-fed during cycling	Yes	Commercial cola drink consumed late in exercise produced 3% performance benefit in TT compared with cola-flavoured placebo drink. Benefits attributable to caffeine content (~2%) and increased CHO intake (~1%)
Jacobson et al. (2001)	Trained cyclists (8 males)	6 $mg \cdot kg^{-1}$ (60 min pre-exercise)	2 h cycling at 70% $VO_{2\ max}$ + 7 $kJ \cdot kg^{-1}$ TT (~30 min); CHO-fed during cycling	No	TT performance similar in caffeine + CHO trial (29.12 min) and CHO trial (30.12 min), with both trials better than placebo trial
Ivy et al. (1979)	Trained cyclists (9 males + females)	Total dose, 500 mg; 250 mg at 60 min pre-exercise + 7 doses during exercise	2 h isokinetic cycling at 80 $r \cdot min^{-1}$	Yes	7% increase in total work, compared with placebo trial; RPE same, despite increased work

Table 4 (*concluded*).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Kovacs et al. (1998)	Well-trained cyclists (15 males)	2.1 mg·kg^{-1}, 3.2 mg·kg^{-1}, and 4.5 mg·kg^{-1} doses; 75 min pre-exercise and at 20 and 40 min during TT	Cycling TT of about ~1 h; CHO-fed during cycling	Yes at all doses	Addition of caffeine to CHO–electrolyte drinks improved 60 min TT performance; improvement with 3.2 and 4.5 mg·kg^{-1} caffeine doses equal to and greater than improvement with 2.1 mg·kg^{-1}; urinary caffeine levels related to total dose, but all below 12 µg·mL^{-1}
Cross-country Skiing					
Berglund and Hemmingsson (1982)	Well-trained cross-country skiers (14 males)	6 mg·kg^{-1} (prerace)	21 km cross-country ski race (field study) at low and high altitudes	Perhaps at low altitude; yes at high altitude	Race times were normalized to account for differences in weather (individual times expressed as % of mean race time); at low altitudes, at half way, the race time with caffeine was decreased by 0.9% of the mean time (~33 s), compared with placebo ($p < 0.05$); at full distance, decrease was 1.7% of the mean time (~59 s) ($p < 0.1$); at high altitudes, the race time was significantly faster with caffeine than with placebo ($p < 0.001$) both after 1 lap (2.2% or ~101 s) and 2 laps (3.2% or ~152 s)
Distance running					
Cohen et al. (1996)	Trained runners (5 males + 2 females)	5 mg·kg^{-1}, 9 mg·kg^{-1} (prerace)	21 km half-marathon (field study)	No	No effects on RPE or performance at either dose, compared with placebo
Van Nieuwenhoven et al. (2005)	Trained to well-trained runners (90 males + 8 females)	~1.3 mg·kg^{-1} in 7% CHO sport drink vs. CHO sport drink alone + water (pre-exercise and at 4.5, 9, and 13.5 km during race)	18 km road running race (field study); CHO-fed during some trials	No	No differences in performance of whole group between caffeinated sport drink (78:03±8:42 min:s), sport drink (78:23±8:47 min:s), or water (78:03±8:30 min:s), or for 10 fastest runners (63:41, 63:54, and 63:50 min:s for caffeine sport drink, sport drink, and water, respectively)

Note: CHO, carbohydrate; EMG, electromyographical; RPE, rate of perceived exertion; TT, time trials; $VO_{2\ max}$, maximal oxygen consumption.
*Caffeine content equivalent to Coca-Cola.

Table 5. Crossover-designed studies of caffeine supplementation and performance of sustained high-intensity sports (1–60 min).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Middle distance and distance running					
Bridge and Jones (2006)	Distance runners (8 males)	3 mg·kg^{-1} (60 min pre-exercise)	8 km race on track	Yes	Relative to the mean time of the control and placebo trials, caffeine supplementation resulted in a 23.8 s or 1.2% improvement in run time ($p < 0.05$), with individual improvements ranging from 10 to 61 s; heart rate was significantly higher in caffeine trial, with trend toward lower RPE, despite faster running speed
Wiles et al. (1992)	Well-trained runners (18 males)	3 g of coffee (150–200 mg of caffeine) 60 min pre-exercise	1500 m race on treadmill	Yes	Mean time improved by ~4.2 s ($p < 0.05$) with caffeine, compared with placebo
Wiles et al. (1992)	Well-trained runners (10 males)	3 g of coffee (150–200 mg caffeine) 60 min pre-exercise	1500 m race: 1100 m at constant speed and 1 min final burst at self-selected speed	Yes	Caffeine enhanced speed of 1 min final burst by ~0.6 km·h^{-1}, equivalent to 10 m ($p < 0.05$)
Rowing					
Bruce et al. (2000)	Well-trained rowers (8 males)	6 mg·kg^{-1} or 9 g·kg^{-1} 60 min prerace	2000 m ergometer row	Yes for both doses	Caffeine enhanced performance by a mean of 1.3% and 1% for 6 mg·kg^{-1} and 9 g·kg^{-1} doses, respectively, compared with placebo ($p < 0.05$); some participants had urinary caffeine concentrations >12 ng·mL^{-1} with higher caffeine dose, but participants were unable to identify caffeine trials, suggesting that effect is subtle
Anderson et al. (2000)	Well-trained rowers (8 females)	6 mg·kg^{-1} or 9 g·kg^{-1} 60 min pre-exercise	2000 m ergometer row	Yes for both doses	Caffeine enhanced performance by a mean of 0.7% and 1.3% for 6 mg·kg^{-1} and 9 g·kg^{-1} doses, respectively, compared with placebo ($p < 0.05$); performance improvement achieve primarily by enhancing the first 500 m
Swimming					
Burke et al. (unpublished observations)	Elite and highly trained swimmers (15 males + females)	2 mg·kg^{-1} 60 min prerace	100 m race (best stroke)	No, but lower RPE	No difference in reaction time, 50 m split, or 100 m race time between trials, but ratings of perceived exertion was lower in the caffeine trial (16.6 vs. 17.1; $p = 0.01$); self-reports of sleeping patterns following the trial found that caffeine supplementation was associated with an increase in time taken to fall asleep and a reduction in quality of sleep
MacIntosh and Wright (1995)	Well-trained swimmers (11 males + females)	6 mg·kg^{-1} 60 min prerace	1500 m freestyle race	Yes	23 s improvement in swimming time with caffeine ($p < 0.05$); caffeine affected substrate and electrolyte balance

Table 5 (*concluded*).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Collomp et al. (1992)	Trained swimmers (14 males + females)	250 mg (~4 $mg \cdot kg^{-1}$) 60 min pre-exercise	2 × 100 m swimming races, separated by 20 min	Yes	Caffeine enhanced mean swimming velocity in both 100 m races ($p < 0.01$), and prevented the decrease in velocity otherwise seen in the second swim with the placebo treatment
Track cycling					
Wiles et al. (2006)	8 trained cyclists	5 $mg \cdot kg^{-1}$ 75 min pre-exercise	1 km cycling TT	Yes	Performance improved by a mean of 2.4 s or 3.1% (95% CI, 0.7% to 5.6%; $p < 0.05$), which also achieved practical significance in context of real-life 1 km track cycling event

these performance differences are not the hundredths of seconds or millimetres that often separate competitors or a winning shot from a miss in the memorable moments of sport. Rather, the modelling of athletic performances has shown that they are related to the coefficient of variation of performers in the event (Hopkins et al. 1999). Readers are directed to the work of Will Hopkins and colleagues, which describes this new approach (Batterham and Hopkins 2006; Hopkins et al. 1999) and provides resources with which to undertake it (www.sportsci.org).

It is sometimes difficult to convince the reviewers of journals to accept this new approach, and some researchers try to combine traditional probability-based statistics with a more athlete-friendly interpretation. For example, Wiles and colleagues (2006) undertook a laboratory-based study simulating the 1 km cycling time trial in track cycling. They found that caffeine supplementation enhanced the performance of trained cyclists by a mean of 2.4 s, or 3.1%, which achieved statistical significance. However, in highlighting the relevance of these results, they noted that the 95% confidence limits of this effect (the range of likely true effects in a similar cycling population) showed a decrease in 1 km time, ranging from 0.7% to 5.6%. To put this into context, at the mens 1 km event at the 2004 Summer Olympic Games in Athens, the difference between the gold and silver medal performances was 0.0185 s, or 0.3%, while the difference between first and tenth place was 2.39 s (Wiles et al. 2006).

Finally, the issue of the blinding of caffeine supplementation is important to consider. A double-blinded application of an intervention, in which neither the subject nor the researcher know which treatment has been received, is considered a benchmark of study design. However, because caffeine has effects on various body functions, subjects are sometimes able to detect whether or not they have received an active treatment from clues such as changes in heart rate or arousal. The placebo effect has been well documented in sport. In fact, studies in which trained subjects were told that they were receiving caffeine showed a dose-dependent improvement in cycling time-trial performance (small improvement when they thought they were receiving a small caffeine dose, and larger improvement when they thought they were receiving a large caffeine dose), even when they actually received an inert substance on all occasions (Beedie et al. 2006). Since the perceived benefit of a treatment may actually allow subjects to perform better, researchers should consider strategies to minimize or at least recognise the possibility that the placebo effect occurs in response to the unmasking of a blinded treatment. Asking subjects to rank the order of their treatments and their performance results may uncover whether the placebo effect could be, at least in part, responsible for performance outcomes.

Studies of caffeine and sports performance

So what does the current scientific literature say about the effect of caffeine on sports performance? A summary has been prepared that includes studies that meet as many of the criteria outlined in Table 3 as possible, but with particular focus on the use of trained subjects, and an exercise protocol involving a close-looped outcome rather than time to

Table 6. Crossover-designed studies of caffeine supplementation and stop-and-go sports (team and racquet sports).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Team sports					
Stuart et al. (2005)	Rugby union players (9 males)	6 mg·kg^{-1} (70 min pre-exercise)	2 × 40 min circuits (simulated rugby union protocol), involving repetitions of:		Study involved probability statistics rather than testing of null hypothesis. Interpretation included change in fatigue with caffeine, compared with placebo. Mean improvements of 0.5%–3% in performance of sprint tasks, with greater improvement in second half. Suggests caffeine effect achieved by reduction in fatigue. Improvement (10%) in ability to pass ball accurately because of enhancement of arousal or attention.
			• 20 m sprint speed	Possible	
			• 30 m sprint speed	Very likely	
			• Offensive sprint	Likely	
			• Defensive sprint	Likely	
			• Drive 1 power	Likely	
			• Drive 2 power	No, harm possible	
			• Tackle speed	Likely	
			• Passing ability	Likely	
Schneiker et al. (2006)	Team athletes (10 males)	6 mg·kg^{-1} (60 min pre-exercise)	2 × 36 min cycle protocol, each involving: 18 × 4 s sprint with 2 min recovery	Yes	Total work during sprints in first half was 8.5% greater in caffeine trial than placebo, and work in second half was 7.6% greater in caffeine trial ($p < 0.05$ for both). Mean peak power score achieved during sprints in first and second halves were 7% and 6.6% greater, respectively, in caffeine trial than in placebo trial ($p < 0.05$ for both).
Paton et al. (2001)	Team athletes (16 males)	6 mg·kg^{-1} (60 min pre-exercise)	10 × 20 m sprints on interval of 10 s	No	Negligible difference between caffeine and placebo trials for time to complete 10 sprints and decay in performance over 10 sprints.
Racquet sports					
Strecker et al. (2007)	Collegiate tennis players (10 males)	3 mg·kg^{-1} (90 min pre-exercise)	Skill test performed pre-exercise, 30 min, 60 min, and 90 min during simulated tennis play against a ball machine (15 ground strokes in all 4 directions; 60 shots total):		Caffeine trial showed better performance of both forehand shots across the 90 min of simulated tennis play. There was no difference in skill in backhand shots between trials.
			• Forehand cross-court	Yes	
			• Forehand up the line	Yes	
			• Backhand cross-court	No	
			• Backhand up the line	No	

Table 6 (*concluded*).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Vergauwen et al. (1998)	Well-trained tennis players (13 males)	5 mg·kg^{-1} 1 h pre-exercise + 0.75 mg·kg^{-1}·h^{-1} over 2 h; separate trials for caffeine + CHO, CHO only, and placebo	Tests undertaken pre and post 2 h match play:		CHO trial resulted in maintenance of stroke quality and shuttle run speed, whereas placebo trial resulted in deterioration of these aspects of performance. Caffeine added to CHO did not further enhance post-trial performance. Authors suggest that caffeine dose was too high. However, it is also possible that effect could only be expected if protocol had caused fatigue, and this did not occur because of CHO intake.
			• Skills test (Leuven Tennis Performance Test) measuring stroke quality	No	
			• 70 m shuttle run (CHO consumed in some trials)	No	
Ferrauti et al. (1997)	Competitive tennis players (8 males + 8 females)	364 mg for males, 260 mg for females (~4–4.5 mg·kg^{-1})	4 h singles tennis (with 30 min break after 150 min); tests of skill and speed undertaken at end of 4 h:		No effect of caffeine supplementation on tennis-specific running speed; caffeine trial not different than placebo trial. No effect on hitting accuracy or success of games played during 4 h with male participants. However, female players had greater success during tennis play on caffeine than on placebo.
			• 6 × 15 min sprint with 30 min rest	No	
			• Hitting accuracy and success during games	Females, yes; males, no	

fatigue. There are relatively few investigations that meet these criteria in the larger literature on caffeine and exercise (Doherty and Smith 2004); these have been grouped according to the characteristics of endurance (Table 4), sustained high-intensity (Table 5), stop-and-go (Table 6), and strength and (or) power (Table 7) sports.

The majority of the studies of caffeine and athletic performance concern endurance sports, including running, cycling, and cross-country skiing events. These provide reasonable but not unanimous support that caffeine use can be beneficial for these activities. A variety of protocols appear to be useful, including intake before and during the event, and investigations using relatively low doses of caffeine (2–3 mg·kg^{-1}) have been more prevalent in these sports. There is also evidence that caffeine can enhance performance of sustained high-intensity events (lasting 1–20 min) in running, cycling, swimming, and rowing. It is more difficult to find clear support for benefits to the performance of work patterns and skills activities within team and racquet sports. Whether the effect of caffeine is smaller or absent in these sports, or whether the current studies are confounded by problems in the reliability or validity of protocols, requires further examination. Finally, there is a dearth of studies involving strength or power, such as true sprints, lifts, and throws; therefore, there is currently a lack of information on the effect of caffeine on such events.

Other effects of caffeine related to sports nutrition goals

The previous section examined the effects of specific supplementation with caffeine on the performance of a single bout of exercise, with the most immediate application being the outcome of a competitive event. However, any summary of the effects of caffeine for an athlete should be widened to consider issues of training and recovery. It is beyond the scope of this paper, and indeed the scientific literature, to consider the effect of caffeine on repeated bouts of exercise within a single session or from day to day (i.e., the training scenario). Nevertheless, it is reasonable to speculate that the habitual social intake of caffeine, or its specific use in relation to a training session, may have some benefits in promoting endurance — that is, prolonging the athlete's capacity to undertake the physical and mental components of their workout. Therefore, caffeine use may indirectly enhance competition performance by allowing the athlete to train hard.

There are several other effects of caffeine that may make an indirect contribution to or may impair sports performance. First, the effect of caffeine on promoting wakefulness or interfering with sleep must be considered in the practical context of sport. In many sports, the outcome of a competition is decided through a series of races or games spread over days — for example, heats and semi-finals before the final event, or the schedule of matches in a tournament. In studies of exercise in the military context, caffeine has been shown to combat the effects of sleep deprivation on the performance of mentally and physically challenging tasks. However, there are no studies that satisfactorily consider that caffeine use by athletes in competition could potentially contribute to sleep deprivation after the first event and im-

Table 7. Studies of caffeine supplementation and performance of power events (throws, lifts, sprints <20 s).

Publication	Subjects	Caffeine intake	Sports performance	Enhanced performance	Comments
Astorino et al. (2008)	22 resistance-trained males	6 mg·kg^{-1} (60 min pre-exercise)	1 RM bench press	No	No changes in strength of lower or upper body with caffeine
			1 RM leg press	No	
Beck et al. (2006)	37 resistance-trained males; parallel-group design (trials 48 h apart)	6 mg·kg^{-1} (60 min pre-exercise)	1 RM bench press	Yes	Caffeine supplement group showed a 2% (2 kg) increase in upper body strength (1 RM bench press) following treatment, but no change in placebo group; there were no differences in lower body strength in either group
			1 RM leg extension	No	

Note: RM, repetition maximum.

pair the performance of subsequent events. It would be valuable if future studies of caffeine and performance of an exercise task examined whether caffeine doses that are found to be ergogenic also affect the quality and duration of sleep during the night following the exercise task. More sophisticated studies are needed to measure the carryover effect of caffeine-related impairment of sleep on subsequent performance. This would be an important issue to study because there is at least anecdotal evidence that some athletes resort to a cycle of caffeine supplementation followed by use of sleeping agents during a multiday competition. Until such studies can be undertaken, it would seem prudent for scientists and athletes to look for the smallest dose of caffeine that is ergogenic for sports performance.

Another indirect way in which caffeine supplementation can affect sports performance is through its impact on hydration status during exercise or in the recovery between exercise bouts. Acute intake of caffeine is known to have a diuretic effect — that is, to increase urine excretion. Indeed, common education messages regarding caffeine include advice to limit caffeine intake in situations in which hydration is challenged (e.g., air travel) or to consume extra fluid in combination with the intake of caffeine. There are a few studies involving exercise and hydration that show that caffeine can have a numeric effect on fluid losses. For example, during recovery from exercise, the intake of caffeine from cola beverages has been shown to cause a small but statistically significant increase in urine production, compared with hydration with caffeine-free fluids (Gonzalez-Alonso et al. 1992). However, a recent review of caffeine and hydration status found that there is little scientific evidence that caffeine intake impairs overall fluid status (Armstrong 2002). That report concluded that the effect of caffeine on diuresis is overstated and may be minimal in people who are habitual caffeine users. In fact, many studies that have examined caffeine supplementation and fluid balance have found that doses of caffeine that are within the range proven to be ergogenic do not alter sweat rates, urine losses, or indices of hydration status during exercise (Millard-Stafford et al. 2007; Wemple et al. 1997). Chronic daily intakes of caffeine, or a sudden increase in caffeine intake, have also been shown not to impair body fluid balance (Armstrong et al. 2005; Fiala et al. 2004). Therefore, it seems that athletes do not need to alter their fluid intake strategies to accommodate caffeine use or to avoid otherwise successful caffeine supplementation strategies in hot weather or other dehydrating environments.

Finally, caffeine is known to have a range of apparently contradictory effects on carbohydrate metabolism, including short-term impairment of insulin-mediated glucose disposal in response to an acute dose at rest, along with an apparently protective effect (at least for coffee consumption) on the development of type II diabetes (for review, see van Dam and Hu 2005). One outcome of an effect of caffeine on glucose disposal would be to impair the synthesis of muscle glycogen, a key element of recovery after prolonged or high-intensity exercise. However, Battram and colleagues (2004) found that the intake of 6 mg·kg^{-1} of caffeine before and during glycogen-depleting exercise did not affect the rate of glycogen synthesis during the 5 h of recovery when adequate amounts of carbohydrate were consumed. There has been recent attention directed to the results of a study reporting enhanced muscle glycogen resynthesis following glycogen-depleting exercise in well-trained subjects. In that study, the intake of large amounts of caffeine after exercise (8 mg·kg^{-1}) were found to enhance the rates of muscle glycogen synthesis over 4 h of recovery, by 66%, when co-ingested with carbohydrate (Pedersen et al. 2008). In fact, the rates of sustained postexercise glycogen synthesis over this time period were among the highest reported in the literature. However, the intake of such high doses of caffeine may cause side effects in some subjects or may interfere with other aspects of recovery, such as the quality of sleep (see earlier). As such, they may be impractical for use in sport. Further studies are needed to examine whether this effect is seen at lower levels of caffeine intake.

The politics of caffeine in sport

The 1984 Summer Olympic Games in Los Angeles saw the introduction of an anti-doping program by the International Olympic Committee, involving the testing of a single urine sample collected after an event for the absence or presence of items described on a list of prohibited substances. Caffeine was included on that list, with the definition of a doping offence being a urinary caffeine exceeding a cutoff of 15 μg·mL^{-1}. This threshold was reduced in 1985 to 12 μg·mL^{-1}. The cutoff value was chosen to exclude normal or social coffee drinking (Delbeke and Debackere 1984) and to target the doses of caffeine that were being found to be ergogenic in the studies of the time. Indeed, with caffeine supplementation of up to 5–6 mg·kg^{-1}, positive urinary caffeine levels are unlikely (Conway et al. 2003; Cox et al. 2002; Kovacs et al. 1998; Pasman et al. 1995); a substantial risk of urinary caffeine values greater than 12 μg·mL^{-1} does not occur until intakes are greater than 9 mg·kg^{-1} (Pasman et al. 1995). It is unclear whether this ban was primarily related to safety concerns over intakes of very large doses of caffeine or the ethics of achieving performance advantages through caffeine use. In any case, there were relatively few cases of positive doping outcomes for caffeine use among elite athletes over the subsequent decade.

In the new millennium, the landscape of caffeine in sport has changed markedly. First, there is greater awareness of the frailty of urinary caffeine concentrations as a marker of caffeine use. Urinary concentration reflects the small amount (~1%) of plasma caffeine that escapes metabolism and is excreted unchanged. Metabolic clearance of caffeine varies widely among athletes and among different occasions of use by the same athlete (Birkett and Miners 1991). Urinary caffeine levels are determined by a variety of factors, including the size of caffeine dose, the metabolic clearance of caffeine, and the timing of the urine sample in relation to the caffeine dose. Since there is huge variation in urinary caffeine content for the same caffeine dose, and neither the standardization of the time between caffeine intake and urine collection nor the prevention of opportunities to urinate during or after an event, we now recognise that urinary caffeine levels have no practical utility as markers of a particular use of caffeine.

Second, the emerging evidence from studies over the past decade is that performance benefits can be found with very modest caffeine intakes (e.g., 2–3 mg·kg^{-1} body mass, or ~100–200 mg caffeine) when caffeine is taken before and (or) during exercise. Furthermore, there is no evidence of a dose–response relationship to caffeine beyond this level of intake — that is, performance benefits do not increase with increases in the caffeine dose. One of the practical outcomes of these newer findings is that athletes no longer need to practise controlled doping (i.e., finding the largest dose of caffeine that can be taken while keeping urinary caffeine levels below 12 μg·mL^{-1}). Instead, performance benefits can be found with caffeine intakes that are well within, or even below, normal social uses. Such intakes of caffeine are likely to be associated with very low urinary caffeine levels in most athletes. In essence, there is no longer a distinction between normal (social) caffeine intake and caffeine intake that enhances performance.

Finally, there have been changes in the methods and intentions of the major anti-doping programs. The World Anti-Doping Agency (WADA) was created in 1999 as an independent international organization that promotes, coordinates, and monitors the fight against doping in sport in all its forms (www.wada-ama.org/en/index.ch2). Following work to harmonise anti-doping policies and rules among sports and authorities, it took over the anti-doping work of the International Olympic Committee and instituted its first code and international standards on 1 January 2004. The WADA Code is still based on a List of Prohibited Substances and Methods (see http://www.wada-ama.org/en/dynamic.ch2?pageCategory.id=267). However, the code has evolved to include the possibility of "nonanalytical violations." Athletes (and their support staff) can be found guilty of a doping offence without a positive urine or blood test. Other offences include the possession or admitted use of these prohibited substances or methods.

The code that immediately preceded the institution of the first WADA Code, the 2003 Olympic Movement Anti-Doping Code, included caffeine within the category of stimulants banned in competition, with an explanatory comment that "for caffeine the definition of a positive is a concentration in urine greater than 12 μg/mL." (International Olympic Committee 2003) However, there are several interpretations of the wording of this code. It could mean that caffeine is a prohibited substance with the collary. Furthermore, it could mean that a urinary caffeine concentration > 12 μg·mL^{-1} could serve as a reporting limit, and that all observed or admitted uses of caffeine would constitute a doping offence. Alternatively, it could mean that caffeine is permitted at doses that produce urinary caffeine concentrations < 12 μg·mL^{-1}. These interpretations have widely different and far-reaching outcomes. Indeed, there are a range of different issues related to the different positions that caffeine could have in an anti-doping code, many of which would create considerable practical challenges if implemented (Table 8).

In fact, caffeine was removed from WADA's List of Prohibited Substances and Methods that came into effect on 1 January 2004, meaning that athletes could consume caffeine, either in their background diets or for the specific purposes of performance enhancement, without fear of sanctions. However, it is currently still on the list of banned drug classes of the National Collegiate Athletic Association, the body governing college sport in the United States (http://www1.ncaa.org/membership/ed_outreach/health-safety/drug_testing/banned_drug_classes.pdf). Furthermore, caffeine is part of the WADA monitoring program, meaning that caffeine concentrations are still measured in urine samples as a means of detecting patterns of misuse in sport. This has allowed some examination of the impact of the removal of caffeine from the prohibited list on caffeine use patterns by athletes. Some recent studies have found a high prevalence of caffeine use for perceived ergogenic effects among select groups of athletes, such as Ironman triathletes (Desbrow and Leveritt 2006) and British track and field athletes and cyclists (Chester and Wojek 2008). However, measurement of over 4600 urine samples undertaken for doping control across 56 sports by a single laboratory in 2004 found no increase in the mean caffeine concentration, compared with results from 1993–2002 (Van Thuyne and Delbeke 2006). The mean caffeine concentration in samples in 2004 was 1.12 μg·mL^{-1}, in comparison to a finding of 1.22 μg·mL^{-1} from over 11 000 samples collected in 1993–2002 (Van Thuyne et al. 2005). The 2004 study noted differences in caffeine use among sports, with an increased average concentration and a larger percentage of higher urinary caffeine concentrations (defined as >4 μg·mL^{-1}) in cycling and strength and (or) power sports than in other sports. Cycling showed an apparent increase in the percentage of higher urinary caffeine concentrations in 2004, while there

Table 8. Examples of potential rulings regarding caffeine use in sport (Burke 2001).

Ruling	Implications and issues
1. Caffeine is a prohibited substance in competition in absolute terms	
Underpinning rationale: (*i*) caffeine is a stimulant; (*ii*) caffeine intake enhances sports performance; (*iii*) caffeine is neither a nutrient nor a necessary part of the diet.	• Athletes would not be able to consume any tea, coffee, cola drinks, chocolate, etc., prior to and during competition. • Strong education messages would be needed to convey this message and its implications to sport. • The limit of urinary caffeine content would need to be set at very low levels. Although some athletes would be able to consume caffeine and remain below this limit, a positive doping offence would also be deemed to occur if the athlete was observed or admitted to consuming a caffeine-containing product during the competition period. • Presumably, the difficulty in removing all caffeine from the normal diet would result in a large number of positive doping offences. • Issues of possession and trafficking would need to consider the sale of tea, coffee, cola, and chocolate at sporting venues, and the sponsorship of athletes, events, and sporting organizations by companies that manufacture these products. These activities would need to be banned to be consistent with the anti-doping code. • Even though caffeine intake would be banned in competition, athletes would still be able to consume caffeine during training in a manner that provides a benefit to their performance and adaptation to the training program.
2. Caffeine is a prohibited substance only when consumed in competition settings in doses that produce urinary caffeine levels above a certain limit (to be determined)	
Underpinning rationale: aurinary caffeine limit can be set that discriminates between social and intentional use of caffeine, or at least only picks up a few cases of high caffeine use.	• It is impossible to find a limit that distinguishes between social and intentional use of caffeine. Caffeine intakes that produce a performance enhancement are indistinguishable from the caffeine intakes reported by the normal population. • Urinary caffeine levels vary among and within individuals, and there is no standardization of the collection of urine samples with regard to the timing between caffeine intake and sampling. Therefore, urinary caffeine limits do not treat caffeine use equally. • Education messages to athletes could contain information about levels of caffeine intake that are unlikely to produce a urinary caffeine level above this limit. • Athletes could not investigate their urinary caffeine concentrations in relation to various levels of intake (trying to find how much caffeine they can take without producing a positive result for caffeine doping), since this would be regarded as controlled doping. • Issues related to possession and trafficking of caffeine (as outlined in ruling 1) could still apply.
3. Caffeine is a prohibited substance only when intentionally consumed in competition settings in doses that produce urinary caffeine levels above a certain limit (to be determined)	
Underpinning rationale: a model similar to drinking and driving laws will prevent accidental cases of high caffeine levels.	As in ruling 2, except that since urinary caffeine levels vary among individuals, and there is no standardization of the collection of urine samples with regard to the timing between caffeine intake and sampling, athletes should be allowed (or encouraged) to investigate what intakes of caffeine can be tolerated without producing a positive test, without any penalty or prejudice. The concept of controlled doping would not be applicable.
4. The prohibition on caffeine use in sport is removed	
Underpinning factors: (*i*) caffeine is so entrenched in the normal diet that it is not practical to try to achieve a ban on intake; (*ii*) there is no unfair advantage if the majority of athletes already consume caffeine, and choose to consume it for social reasons; (*iii*) there are no health disadvantages to the intake of small amounts of caffeine; (*iv*) the ergogenic benefits of caffeine on performance, although worthwhile, are small — they are similar in magnitude to the effects of consuming CHO during an endurance event, but less than the beneficial effects of consuming fluid to minimize dehydration	• Practical solution to overcome challenging situation. • Avoids tainting common foods and (or) drinks or common transactions in sport (e.g., sponsorship of companies that produce these products) with the odium of cheating. • Research should target the smallest dose of caffeine that can produce an ergogenic benefit. Education messages to athletes could promote the message that, if they want to use caffeine (socially or intentionally), small intakes produce maximal effects. Athletes would be encouraged to reduce rather than increase their intake of caffeine, thus minimizing the health implications and cost of using special products. • The market for specialized sports products containing caffeine might increase, unless education messages (as above) remove the perceived benefits of large doses of caffeine or the need for special food products.

Note: CHO, carbohydrate.

was a decrease in this outcome in swimming and basketball. Overall, there was a decrease in the percentage of urine samples showing caffeine concentrations below the detectable range, and no increase in the percentage of samples with concentrations above 12 μg·mL^{-1}. In fact, only 6 samples were found with a concentration above the former cutoff level (Van Thuyne and Delbeke 2006).

Further monitoring needs to take place before firm conclusions can be made. Nevertheless, it seems that there is little evidence of systematic increases in the use or misuse of caffeine at the highest levels of sport. One outcome of the removal of caffeine from the prohibited list is the potential for an increase in research activities and transparent education about the benefits and disadvantages of caffeine use in sport. Greater dissemination of the emerging information that the benefits of caffeine occur at small to moderate doses, and of the presence of individual variability and potential side effects in response to caffeine intake, may actually lead to a reduction in caffeine use by athletes (e.g., lower doses being taken on fewer occasions). There is inadequate information about the total caffeine intakes of athletes and recreational sportspeople and their patterns of caffeine use. However, by choosing to withdraw caffeine intake before key events and by using the minimum ergogenic doses during competition or training sessions, it is possible that athletes will not consume more caffeine than the general population, but rather, consume it in a more targeted manner in relation to their sporting activities.

Summary

Caffeine is widely consumed from a variety of sources as part of a normal diet, as well as in specialized sports foods and supplements that may be used by athletes during training and competition. There is clear evidence that caffeine is an ergogenic aid for a variety of types of sports, although studies involving elite athletes and field situations are lacking. Further research is needed to define the range of caffeine protocols and sports activities that show evidence of performance enhancement, as well as the benefits or harm to other issues underpinning recovery after exercise or preparation for an event. Newer evidence suggests, at least in endurance sports, that the maximal benefits of caffeine are seen at small to moderate caffeine doses (2–3 mg·kg^{-1}), which are well within the normal daily caffeine intakes of the general population. This makes the recent decision to remove caffeine from the list of prohibited substances in sports a pragmatic choice. To date, there is little evidence that this change has increased the use or misuse of caffeine by athletes, at least within the levels of elite and subelite sport, where anti-doping codes apply. Caffeine use may also enhance the performance of sport in recreational athletes, but it is inappropriate and unnecessary for use by young adults. There is a need for strong and transparent education to ensure that the correct messages about caffeine in sport are provided to all athletes.

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