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Review Article

An Overview of Caffeine's Impact on Team Ball Sport Performance: Dosing, Gender Differences, and Physiological Considerations

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Abstract

Background: Caffeine is the most consumed psychoactive substance globally, second only to water in beverage consumption. Its impact on athletic performance, particularly in team sports, has been a subject of growing research interest. This review focuses on recent studies investigating caffeine's influence on various aspects of team ball sports performance.

Objectives: This mini-review aimed to (i) synthesize current research findings on caffeine supplementation in team sports, considering different doses, forms, and its effects across genders and (ii) to highlight key considerations for optimal caffeine use in these sports.

Methods: THIS mini-review examined recent studies on caffeine's effects in team ball sports, analyzing variables such as supplementation strategies, habitual consumption, gender, washout periods, individual responses, and supplement forms (capsules or powders). The focus is on studies that have used caffeine doses ranging from 3 to 6 mg·kg $^{-1}$, administered 60 minutes before competition.

Results: Findings suggest beneficial effects of caffeine ingestion (3 to 6 mg·kg $^{-1}$) in enhancing technical and physical aspects of team ball sports. However, results vary based on factors like the supplementation strategy, individual caffeine consumption habits, and gender. Most research has focused on single-dose effects, revealing a lack of comprehensive, gender-specific guidelines for caffeine's optimal use in team sports.

Conclusion: While caffeine supplementation shows promise in enhancing team sports performance, there is a need for more comprehensive research, especially regarding gender-specific effects and optimal consumption strategies. Current evidence points to the potential benefits of caffeine in morning competitions or training sessions but indicates possible detrimental effects in afternoon or evening settings. Further research is needed to develop robust guidelines for caffeine use in team sports, considering dosage, timing, form, and differential gender effects.

Keywords: *Athletic Enhancement, Beverage Consumption, Cognitive Aspects, Ergogenic Aids, Physical Activity, Psychoactive Substances, Soccer, Sports Nutrition.*

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1. Introduction

Caffeine, a compound with active pharmacological properties, is one of the most commonly consumed substances worldwide (1). Since caffeine was removed from the World Anti-Doping Agency's (WADA) list of prohibited substances in 2004, athletes have been free to consume caffeine-containing food and dietary supplements without the risk of anti-doping sanctions (2). This deregulation has coincided with a broader societal acceptance of caffeine, as well as recognition from prestigious sports bodies like the International Olympic Committee and the Australian Institute of Sport, which acknowledge its performance-enhancing benefits (3, 4). Building on the unrestricted use of caffeine and its endorsement by leading sports authorities, the market has seen a surge in the availability of caffeine as a nutritional supplement specifically targeted at athletes. This has augmented athletes' interest, particularly as the stimulant's positive effects on performance in individual sports are already well-established. The effect of caffeine on team sports athletes remains less certain, largely because team sports require a blend of aerobic capacity, sprinting, strength, agility, and sport-specific skills. This complexity leads to diverse caffeine supplementation strategies.

The potential of caffeine supplement across team sports disciplines has been investigated; using different doses varied from low to high but has yielded inconsistent and differing results. Additional factors such as gender, habitual consumption, tolerance, and the time of day have been less thoroughly examined. Therefore, this mini-review aimed to (i) summarize and analyze recent research on the use of caffeine in team sports, focusing on variations in dosage, formulation, and impact on different genders, and (ii) to underline key considerations for optimal caffeine use in these sports.

2. Caffeine

Caffeine is known as 1,3,7-trimethylxanthine. Its daily use spans nearly 80% of the global population, owing to its availability in numerous foods beverages and dietary supplements (1, 5). Its extensive use is influenced by several sociocultural factors (6). caffeine's performance-enhancing and stimulating effects have been studied for more than a century, with the first study published in 1907 (7). As an ergogenic aid widely used for performance enhancement, caffeine is still monitored by WADA, with athletes encouraged to keep urinary caffeine concentration below the limit of 12 µg/ml urine (equivalent to 10 mg·kg−1 orally ingested over several hours)(8, 9). Research has confirmed a high frequency of caffeine supplementation among athletes before or during competitions (5, 10), especially it is most commonly used in endurance sports and its use increases with the athletes' age (10).

3. Pharmacokinetics of Caffeine

Caffeine, is a white, odorless powder that is soluble in both water and fats and carries a bitter taste (11). It is primarily absorbed in the small intestine, but also in the stomach, and is rapidly taken up by the digestive tract (12). Caffeine concentration reaches 65 to 85% of plasma levels in saliva, and this level is often used to non-invasively monitor adherence to caffeine ingestion or abstinence (13). The lipophilic composition of caffeine allows for its distribution throughout the body due to its easy passage across all biological membranes, including the blood-brain barrier (14). Caffeine appears in the blood within minutes, with maximum plasma concentrations of caffeine observed 30 to 120 minutes' post-consumption (15, 16).

4. Mechanism

While caffeine's action on the central nervous system (CNS) is often understood as the mechanism enhancing performance (17), other mechanisms have been proposed to explain caffeine's ergogenic effect, such as the increase in myofibrils, availability of calcium (18, 19), and availability of energy substrates (20). Importantly, one of the significant mechanisms of caffeine's activity is its direct antagonistic effect on adenosine receptors (21, 22), which is based on preventing the inhibitory effects of adenosine on dopamine release (23) -a neurotransmitter stimulating alertnesss (24). Moreover, adenosine, play a crucial role as a homeostatic regulator and neuromodulator of the nervous system, contributes to the decrease in the concentration of numerous CNS neurotransmitters, including serotonin, dopamine, acetylcholine, norepinephrine, and glutamate (23). However, caffeine, having a molecular structure similar to adenosine, binds to adenosine receptors, thereby increasing the concentration of these neurotransmitters (22). Consequently, this mechanism could explain caffeine's positive effects on mood, alertness, and concentration in most individuals, but not all of them (25, 26). This blocking of A1 and A2A adenosine receptors helps prevent the decrease in neuronal activity and promotes the recruitment of muscle fibers (27). Furthermore, the focus has shifted to caffeine's effects on the peripheral nervous system during exercise, which could alter the rate of perceived exertion (RPE)(28, 29), muscle pains and skeletal muscle capacity to generate force (30). Caffeine appears to have direct effects on muscles that might contribute to its ergogenic properties through the mobilization of calcium ions (Ca^{2+}), which facilitates the production of force by each motor unit during muscle contraction (18, 31). Additionally, caffeine ingestion might alleviate fatigue caused by the progressive reduction of Ca^{2+} release. Similarly, caffeine could act, in part, peripherally by improving the activity of the sodium/potassium (Na^+/K^+) pump, potentially improving the excitation-contraction coupling necessary for muscle contraction (32). Another caffeine mechanism could be the inhibition of phosphodiesterase, leading to an increase in the concentration of cyclic adenosine monophosphate (cAMP), an increase in the secretion of catecholamines (23), and the inhibition of gamma-aminobutyric acid (GABA) receptors (33). Caffeine seems to utilize its effects at various levels (i.e., central and peripheral), but the strongest evidence suggests that the primary target is the CNS, which is now widely accepted as the main mechanism through which caffeine could enhance cognitive and physical performances (34).

5. Forms and Doses

Regarding sports supplementation, caffeine, a known ergogenic aid, has traditionally been administered orally via capsules or tablets 60 min before the exercise. However, other methods including coffee, energy drinks (35), caffeinated sports drinks, nasal spray, and chewing gum have also been explored (36). Interestingly, caffeinated gum expedites the absorption rate of caffeine. Regardless of the form, peak caffeine concentration is achieved between 0.5 to 2 hours' post-ingestion (37). The choice of delivery method is typically influenced by the athlete's preference, market availability of the product, and its taste rather than any physiological considerations (36).

Concerning the caffeine dosage, determining the optimal dosage of caffeine for the best results is a challenging task. Most studies examining the effects of caffeine ingestion on exercise use a single dose of caffeine (38), making it doubtful whether higher doses may yield more pronounced effects on performance. Moreover, studies using varying doses of caffeine do not necessarily show a linear dose-response relationship between the caffeine dose and the extent of its ergogenic effect (38). In team sports, doses of caffeine between 3 and 6 $mg.kg^{-1}$ have been found sufficient to enhance performance (39). In numerous studies, caffeine is typically given in moderate to high doses (3 to 6 $mg.kg^{-1}$), with 6 $mg.kg^{-1}$ being the most prevalent. An increasing curiosity has been noted concerning the impact of lower doses of caffeine (≤3 $mg.kg^{-1}$) on exercise performance, as such quantities often render beneficial outcomes with negligible side effects. However, it remains uncertain whether these lower doses can deliver the same performance enhancement effects as the traditionally recommended dosages (i.e., 3 to 6 $mg.kg^{-1}$)(40). The supportive evidence for the performance-boosting effects of low caffeine doses primarily stems from tests related to aerobic endurance (41). There are limited studies investigating the influence of such caffeine doses on high-intensity, short-duration exercise performance (41). Thus, further investigations involving the administration of higher doses of caffeine (i.e.,6–9 $mg.kg^{-1}$), as opposed to the use of lower doses of caffeine (≤3 $mg.kg^{-1}$), should be carried out(42).

Nevertheless, the question arises whether higher doses could potentially lead to more pronounced improvements in performance. This concept warrants further investigation, as it could potentially broaden our understanding of caffeine's ergogenic effects. It's plausible that a higher dosage might extend endurance, enhance strength, or accelerate recovery. However, it is also crucial to consider the risk of possible side effects, such as jitteriness or sleep disturbances, which could negatively impact performance. Thus, any research into higher doses of caffeine must strike a balance between potential performance enhancement and the risk of adverse effects.

6. Caffeine and Team ball sports

In the context of team sports, recent meta-analyses have demonstrated beneficial effects of ingesting 3 to 6 $mg \cdot kg^{-1}$ of caffeine 60 minutes before exercise in male (39, 43) and female athletes (44). Further, this stimulant has been evidenced to enhance the total distance covered in rugby (45) and soccer for both men (46) and women (47). It has been found that consuming a caffeinated energy drink prior to exercise improved the ability to perform repeated sprints and the total high-intensity running distance in a simulated game among soccer players (46). With the same caffeine dose, an increase in running speed and total distance during a simulated game was observed among female soccer players (47). Moreover, the number of sprints executed post-caffeine ingestion was elevated in several studies across different team sports such as hockey (48), rugby (45), and soccer for both men and women (46, 47). Additionally, running speed was improved after caffeine ingestion in several football studies for women (47) and rugby (49). However, caffeine consumption did not enhance running speed and dribbling among basketball players (50). As for agility, few studies have assessed the effect of caffeine intake on agility performance. Among volleyball players, agility was improved with caffeine ingestion (51). Conversely, consuming a caffeinated energy drink did not enhance performance in the T-agility test amidst female soccer players (52). Similarly, caffeine did not improve agility within well-trained rugby players (53). Regarding vertical jump, numerous studies (46, 51, 54) have shown beneficial effects of caffeine on this parameter. In this regard, it was found that pre-exercise ingestion of a caffeinated energy drink improved the vertical jump and muscular power during the jump among soccer players (45, 46). Recently, it was observed among handball players that taking 3 $mg.kg^{-1}$ of caffeine before exercise improved the ball throwing speed (350.8 [41.2] vs 361.6 [46.1] N), the jump height (28.5 [5.5] vs 29.8 [5.5] cm), sprint performances, and the frequency of accelerations and decelerations among elite handball players (55). Previous studies investigating the effects of energy drinks on volleyball players found that these products improved spikes, jumps, and overall performance in male players (51). Other studies with similar protocols have produced comparable results with female players (56). However, other investigations found no significant differences between energy drinks and a placebo, perhaps due to a lower dose given (57). A study on basketball players suggested that caffeinated drinks could enhance jumping performance, especially when the caffeine dose was more than 3 $mg.kg^{-1}$ (54).

To the best of our knowledge, only a limited amount of research has been conducted on the effects of caffeine on young athletes. The majority of these studies primarily involve adult male subjects, and the findings from these studies cannot be directly applied to younger individuals.

7. Conclusion

The majority of research regarding the effects of caffeine on exercise performance has traditionally focused on single-dose protocols. These studies have indeed provided valuable insights into the performance-enhancing effects of caffeine. Caffeine supplementation has attracted significant research interests in the last decade and is in increasing demand. Although most research on caffeine 's effects on exercise performance have typically centered on single-dose protocols, their outcomes offer crucial insights into how caffeine can enhance performance. In spite of an increasing recognition of the necessity for research specific to women's exercise and dietary requirements, the existing studies on widely used performance enhancers including caffeine is still insufficient. Employing the findings of these studies in practical scenarios remains challenging, primarily due to the potential variance in hormonal levels between men and women, and among women during different stages of the menstrual cycle. With these differences not yet conclusively supported by robust evidence in the context of exercise performance, it continues to hinder the formulation of comprehensive guidelines for women in sports. In this context, recent findings underline the need for gender-specific guidelines in athletics, highlighting that findings observed in male groups may not correspond to females due to potential gender differences. There is a pressing need for research focused on women to uncover specific guidelines related to the optimal dosage, timing, and overall effectiveness of caffeine in enhancing technical, cognitive and physical performance. Furthermore, rigorous investigation into the administration protocols for various forms of caffeine is necessary to determine the most effective dosage, timing, habitual caffeine consumption, and supplement form for each gender in team sports. Notably, the timing of supplementation, whether in the morning or afternoon, should be considered due to potential secondary effects. Recent findings suggest that caffeine supplementation may be beneficial for morning competitions or training, but not for events in the afternoon or evening. This is because it appears to have no impact on afternoon performance and may even have negative effects the day after supplementation. Moreover, further consensus should be established regarding the protocol for pre-exercise caffeine intake for various groups, such as lower consumers, moderate consumers, and heavy consumers of caffeine. Optimal dosages for each group should be determined, taking into consideration the appropriate washout periods before and between experimental sessions, as well as the effectiveness of the placebo used. Finally, genetic variability in response to caffeine should be considered before any administration, especially for elite athletes, to ensure the benefits outweigh any potential harm.

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Competing Interests

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Authors' Contributions

H.B and N.S: conception and design.
H.B, A.S, A.A, and N.S: analysis and interpretation of the data.
H.B, A.S, A.A, and N.S: drafting of the paper.
H.B, A.S, A.A, and N.S: investigation.
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Declaration

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