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Caffeine supplementation in cyclists: performance outcomes, physiological responses and interactions – a narrative review

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Abstract

Background

Cycling is a highly demanding endurance sport, in which small improvements in performance may significantly influence results. Caffeine is one of the most commonly used ergogenic aids among athletes, due to its potential to enhance physical performance and delay fatigue. Understanding its effects on cycling performance and physiological responses is important for both athletes and sports science practitioners.

Aim

The aim of this narrative review was to evaluate the effects of caffeine supplementation on cycling performance and physiological responses in cyclists, as well as to analyse the potential mechanisms underlying its ergogenic effects.

Materials and Methods

This narrative review is based on a literature search conducted using the PubMed database. The search was conducted using keywords related to caffeine, cycling and cycling performance. Filters were used to identify clinical trials published from 2016 onward. This led to 54 publications. After manual full-text analysis 25 articles found with the mentioned search were included.

Results and conclusions

The studies showed that caffeine administered orally in various forms is effective in improving performance in endurance and time-trial protocols. Its effect in short-duration maximal exercise tests was observed, although the results are inconclusive. Several studies reported increased blood lactate concentrations and reduced perceived exertion following caffeine ingestion. Evidence suggests that central nervous system mechanisms contribute substantially to the ergogenic effects of caffeine. Doses of 2.7–6 mg/kg administered approximately 60 minutes before exercise were most commonly associated with performance benefits. Current evidence does not demonstrate additive ergogenic effects of caffeine when combined with other ergogenic substances. Heat, time of day, habitual

caffeine consumption and abstinence and genetic factors may influence ergogenic effects of caffeine.

Key words: caffeine, cycling, ergogenic aid, endurance exercise, time trial, fatigue, sports supplementation

1. Introduction

Cycling is a highly demanding endurance sport, in which small improvements in performance may significantly influence competitive results. Achieving great results requires both mental and physical endurance. From the cellular perspective, performance is dependent on resynthesis of ATP in skeletal muscles. Depending on the intensity and duration of effort, ATP is restored through different mechanisms. In long, low intensity efforts beta-oxidation of fats is the most dominant process, while glycolysis is crucial during sprints. Oxidative phosphorylation, despite being slower than glycolysis, is the most effective source of ATP (Rowland A et al., 2026). Given the physiological demands of cycling, nutritional and pharmacological strategies aimed at delaying fatigue and enhancing performance have attracted considerable interest.

Caffeine is the most commonly used central nervous system stimulant worldwide. It causes various physiological effects through its interaction with different receptors. Caffeine acts primarily as an adenosine receptor antagonist. It is also a weak phosphodiesterase inhibitor and mobilizes intracellular calcium in striated muscles. Caffeine’s half-life in plasma is 5 hours. It is mainly metabolised to paraxanthine, which accumulates and is thought to cause tolerance for caffeine (Institute of Medicine (US) Committee on Military Nutrition Research, 2001).

2. Methodology

This narrative review is based on a literature search conducted using the PubMed database. The search was conducted using keywords related to caffeine, cycling and cycling performance. Filters were used to identify clinical trials published from 2016 onward. This led to 54 publications. After manual full-text analysis 25 Articles found with the mentioned search were included. Articles that were not directly relevant to caffeine supplementation and cycling-related outcomes were excluded.

An additional search was performed for literature regarding pharmacology of caffeine and physiology of cycling.

The analysed studies evaluated various performance and physiological parameters, including time-trial performance, power output, time to exhaustion, fatigue perception, cardiovascular responses, metabolic variables, and central nervous system-related mechanisms. Not all studies had endpoints related to performance.

In the analysed studies, caffeine was administered orally in multiple forms: capsules, soluble coffee, carbohydrate drink with caffeine, coffee fruit extract, and doses ranging from 2.7 to 7.5 mg/kg. Acute and chronic supplementation were tested. Acute doses were administered up to 60 minutes before the beginning of exercise, just before the beginning or during exercise.

3. Results

3.1 Effects of caffeine on cycling performance

The studies showed that caffeine administered orally in various forms (capsules, soluble coffee, carbohydrate drink with caffeine) is effective in improving performance during cycling time trials varying from 5 km to 40 km (Pavis GF et al., 2026; Sampaio-Jorge F et al., 2021; Morales AP et al., 2020; Masters C et al., 2026), in 13.9 km cross-country time trial (Trujillo-Colmena D et al., 2024) and all-out cycling tests varying from 15 seconds to 6 minutes (Ruiz-Moreno C et al., 2022; Salinero JJ et al., 2017; Jessen S et al., 2021). The effect was not statistically significant during a 3-minute all-out cycling test (Hagele AM et al., 2026). This finding further indicates that the ergogenic effects of caffeine during short-duration maximal exercise remain inconsistent.

Sex does not appear to significantly influence the ergogenic effects of caffeine, as similar improvements in cycling performance were observed in both men and women (Clarke ND et al., 2019).

Overall, the available evidence suggests that caffeine supplementation is effective in improving cycling performance, particularly in endurance and time-trial events, whereas its benefits appear to be less consistent during short high intensity exercise protocols.

3.2 Physiological responses to caffeine supplementation

In addition to its effects on performance, caffeine supplementation influenced several physiological responses during cycling exercise. The most frequently reported changes involved metabolic, cardiovascular, and respiratory parameters.

Ruíz-Moreno et al. (2020) reported that caffeine increased muscle oxygen saturation at several workloads during a maximal incremental cycling test, accompanied by higher peak oxygen uptake and maximal power output.

Increased blood lactate concentrations following caffeine ingestion were observed in several studies, suggesting alterations in glycolytic metabolism during exercise (Morales AP et al., 2020; Glaister M et al., 2016).

The effects of caffeine on heart rate were inconsistent across studies. Some investigations reported higher exercise heart rates following caffeine supplementation, which may reflect an increased ability to sustain greater exercise intensity (Trujillo-Colmena D et al., 2024; Morales AP et al., 2020). In contrast, other studies observed slight reductions in heart rate during submaximal exercise (Glaister M et al., 2016). These findings suggest that cardiovascular responses to caffeine may depend on exercise intensity, training status, and study design.

Caffeine also affected several respiratory parameters. Increases in ventilation and alterations in expired oxygen and carbon dioxide fractions were reported, indicating a potential influence on respiratory regulation during exercise (Morales AP et al., 2020). Furthermore, caffeine supplementation was associated with higher blood glucose concentrations during prolonged exercise and reduced exercise-induced ammonemia, suggesting beneficial effects on energy metabolism and fatigue-related metabolic pathways (Prado E et al., 2021). Coffee co-ingested with carbohydrates after exercise was also shown to enhance muscle glycogen resynthesis during recovery compared with carbohydrate intake alone (Loureiro et al., 2021).

Interestingly, one study reported that caffeine increased performance while simultaneously promoting favourable changes in autonomic nervous system regulation, characterized by enhanced parasympathetic activity and a potential cardioprotective effect during intense exercise (Sampaio-Jorge F et al., 2021). Collectively, these findings indicate that caffeine influences multiple physiological systems that may contribute to its overall ergogenic effect in cyclists.

3.3 Central nervous system and neuromuscular mechanisms

The available evidence suggests that central nervous system mechanisms contribute substantially to the ergogenic effects of caffeine. Current knowledge indicates that caffeine acts primarily as a nonselective antagonist of adenosine receptors, resulting in enhanced dopaminergic and noradrenergic neurotransmission (Institute of Medicine (US) Committee on Military Nutrition Research, 2001). These effects may contribute to increased alertness, reduced perception of effort, improved motor unit recruitment, and delayed onset of central fatigue.

Several studies included in this review support the hypothesis that caffeine influences performance through centrally mediated pathways. During prolonged cycling exercise, caffeine prevented fatigue-related impairments in oculomotor control, maintaining saccadic eye movement velocity despite the development of exercise-induced fatigue (Connell CJ et al., 2016). Similar findings were observed in a study comparing caffeine with the norepinephrine-dopamine reuptake inhibitor bupropion (Connell CJ et al., 2017). Both interventions attenuated fatigue-related declines in eye movement velocity, suggesting that increased dopaminergic and noradrenergic activity may play a key role in the anti-fatigue effects of caffeine.

In addition to its effects on motor control, caffeine reduced ratings of perceived exertion during exercise. Several studies reported improved exercise tolerance, indicating that caffeine may alter fatigue perception and allow athletes to sustain higher exercise intensities (Morales AP et al., 2020; Trujillo-Colmena D et al., 2024).

The findings of the analysed studies suggest that the beneficial effects of caffeine on cycling performance cannot be explained solely by metabolic or cardiovascular adaptations. Instead, the available evidence supports the view that modulation of central nervous system function, particularly through adenosine receptor antagonism and enhanced catecholaminergic neurotransmission, represents one of the primary mechanisms responsible for the ergogenic effects of caffeine in cyclists.

3.4 Influence of supplementation protocol, dosage and duration of trial

The studies included in this review used caffeine doses ranging from 2.7 to 7.5 mg/kg body mass, with 5–6 mg/kg being the most frequently applied dosage. In most studies, caffeine was administered orally approximately 60 minutes before exercise, corresponding to the time required to achieve peak plasma caffeine concentrations.

The ergogenic effects of caffeine were observed following both acute and short-term supplementation protocols. Morales AP et al. (2020) concluded that 4-day caffeine supplementation does not induce tolerance. However, most studies investigated acute caffeine ingestion. Furthermore, the effectiveness of caffeine appeared to depend on exercise duration, with more consistent benefits reported during prolonged endurance exercise and time-trial protocols than during short-duration maximal efforts. These findings suggest that exercise characteristics and supplementation strategy may influence the magnitude of caffeine's ergogenic effects in cyclists.

3.5 Factors modifying the ergogenic effects of caffeine

Habitual caffeine consumption, pre-exercise abstinence, and tolerance may influence the ergogenic response to caffeine; however, the available evidence remains inconsistent. Clarke and Richardson (2021) reported similar improvements in 5-km cycling time-trial performance in low and high habitual caffeine consumers, suggesting that habitual caffeine intake does not attenuate the ergogenic effects of caffeine. In contrast, Weippert et al. (2025) found no improvement in time to exhaustion after 2.5 or 6 mg/kg of caffeine in participants who maintained their habitual caffeine consumption without prior caffeine restriction and suggested that some previously reported ergogenic effects may partly reflect the reversal of withdrawal symptoms induced by pre-trial caffeine abstinence. Morales et al. (2020) demonstrated that caffeine supplementation at 6 mg/kg for four consecutive days did not induce tolerance to the performance-enhancing effects of an acute caffeine dose during a 16-km cycling time trial. However, Lara et al. (2019) observed that the ergogenic effect of caffeine progressively decreased during 20 days of daily supplementation, suggesting the gradual development of tolerance. Therefore, the effects of habitual caffeine consumption, pre-exercise abstinence, and tolerance on the ergogenic response remain inconclusive and require further investigation.

Ambient temperature may also modify the physiological and ergogenic effects of caffeine. John et al. (2024) reported that caffeine supplementation did not significantly improve time to exhaustion during cycling in a hot environment (35°C, 40% relative humidity). Moreover, caffeine increased heat production and resulted in a higher mean core temperature compared with placebo, suggesting an increased thermal load during exercise in the heat. In contrast, Yu et al. (2024) demonstrated an improvement in time to exhaustion following caffeine supplementation during cycling at 35°C and 65% relative humidity. Similarly, a mixture of caffeine and taurine did not improve time to exhaustion in hot conditions in comparison to placebo (Aggett et al., 2025). Therefore, the ergogenic effects of caffeine in hot environments remain inconclusive, while its potential influence on thermoregulatory responses should be considered.

Time of day may modify the ergogenic effects of caffeine. Boyett et al. (2016) reported that caffeine improved 3-km cycling time-trial performance both in the morning and evening; however, the effect was greater in the morning. Among trained cyclists, caffeine improved performance in the morning, whereas no ergogenic benefit was observed in the evening. These findings suggest that caffeine supplementation may be particularly effective during morning exercise and that time of day should be considered as a potential factor influencing individual responses to caffeine.

Considerable inter-individual variability in the ergogenic response to caffeine has been reported, with some individuals showing minimal or even negative responses (Ruiz-Moreno C et al., 2022). Genetic factors, particularly CYP1A2 and ADORA2A polymorphisms, may contribute to this variability; however, current findings remain inconsistent (Masteret al., 2026). Del Coso et al. (2019) demonstrated that all participants showed an ergogenic response in at least some repeated trials.

The available evidence does not consistently demonstrate additive ergogenic effects when caffeine is combined with other potentially ergogenic substances. Co-ingestion with acetaminophen did not improve cycling performance beyond caffeine alone (Jessen S et al., 2021). Similarly, combined caffeine and dietary nitrate supplementation did not provide additional performance benefits (Hagele AM et al., 2026), while caffeine and taurine co-ingestion failed to improve time to exhaustion in the heat (Aggett J et al., 2025). Trexler et al. (2016) found no significant improvement in cycling sprint performance when caffeine or coffee consumption was incorporated into a creatine-loading protocol. These findings suggest that combining caffeine with other ergogenic substances does not necessarily produce additive or synergistic effects.

3.6 Limitations of current evidence

Several limitations should be considered when interpreting the current evidence. Studies included relatively small sample sizes, which may limit the generalizability of the findings. Furthermore, the majority of participants were male cyclists, while female athletes remain underrepresented.

Considerable heterogeneity was also observed among studies regarding caffeine dosage, supplementation protocols, exercise tests, and outcome measures. This variability makes direct comparisons between studies difficult. In addition, some investigations focused primarily on physiological or neurological responses rather than direct measures of cycling performance.

Finally, individual responses to caffeine may be influenced by factors such as habitual caffeine consumption, training status, and genetic variability, which were not consistently controlled across studies. Therefore, further well-designed studies involving larger and more diverse populations are needed to better understand the effects of caffeine supplementation in cyclists.

4. Discussion

The findings of this narrative review indicate that caffeine is generally an effective ergogenic aid in cycling; however, the magnitude and consistency of its effects appear to depend on the exercise protocol and individual and environmental factors. Performance improvements were frequently observed during endurance and time-trial exercise, including 5–40 km cycling trials (Pavis et al., 2026; Sampaio-Jorge et al., 2021; Morales et al., 2020; Masters et al., 2026). Nevertheless, beneficial effects were also reported during short-duration maximal exercise, including 15-s and 30-s Wingate tests and a 6-min all-out trial (Ruiz-Moreno et al., 2022; Salinero et al., 2017; Jessen et al., 2021), whereas no significant benefit was observed during a 3-min all-out test (Hagele et al., 2026). Therefore, current evidence does not support a simple relationship between exercise duration and caffeine effectiveness, although the ergogenic effects appear more consistently demonstrated in endurance and time-trial protocols. The performance-enhancing effects of caffeine are likely multifactorial, with central nervous system mechanisms playing an important role. Caffeine acts primarily as a non-selective antagonist of adenosine receptors and may indirectly enhance dopaminergic and noradrenergic neurotransmission (Connell et al., 2017). Studies assessing oculomotor control demonstrated that caffeine attenuated fatigue-related impairments in eye movement velocity during prolonged cycling, while comparable effects were observed following norepinephrine–dopamine reuptake inhibition (Connell et al., 2016; Connell et al., 2017). These findings support the involvement of central mechanisms in caffeine-induced attenuation of fatigue. Furthermore, reduced ratings of perceived exertion despite maintained or improved exercise performance suggest that modulation of fatigue perception may contribute substantially to caffeine ergogenicity (Glaister et al., 2016).

However, the effects of caffeine cannot be explained exclusively by central mechanisms. Changes in blood lactate concentration, ventilation, glucose availability, muscle oxygen saturation and autonomic nervous system activity were observed across the analysed studies. Glaister et al. (2016) demonstrated increased blood lactate concentrations and reduced perceived exertion during submaximal exercise, whereas Ruíz-Moreno et al. (2020) reported increased muscle oxygen saturation at several workloads together with higher peak oxygen uptake and maximal power output. Prado et al. (2021) additionally observed altered ammonia, glucose and lactate responses during prolonged cycling following a ketogenic diet. The heterogeneity of these physiological responses suggests that caffeine exerts multiple central and peripheral effects, although the direct contribution of individual physiological changes to improved cycling performance remains uncertain.

An important finding of this review is that the ergogenic response to caffeine appears to be context-dependent. Habitual caffeine consumption did not attenuate the improvement in 5-km cycling performance reported by Clarke and Richardson (2021), whereas Weippert et al. (2025) found no improvement in time to exhaustion when participants maintained their habitual caffeine consumption. The latter authors suggested that some ergogenic effects observed after pre-trial caffeine restriction may partly reflect reversal of withdrawal symptoms. Similarly, evidence regarding tolerance remains inconsistent. Morales et al. (2020) found that four consecutive days of caffeine supplementation did not reduce the ergogenic response to an acute 6 mg/kg dose, whereas Lara et al. (2019) demonstrated a progressive reduction in the magnitude of performance benefits during 20 days of daily caffeine intake. These findings suggest that short-term and prolonged caffeine exposure may differently influence the development of tolerance and highlight the need to distinguish habitual consumption, acute withdrawal and chronic supplementation when interpreting caffeine studies.

Environmental conditions may further modify the response to caffeine. Findings obtained in hot environments were inconsistent, with caffeine increasing thermal load in one study, while Yu et al. (2024) reported improved time to exhaustion at 35°C and 65% relative humidity. The lack of performance improvement following caffeine and taurine co-ingestion in the heat reported by Aggett et al. (2025) further indicates that caffeine-containing supplementation strategies may not provide uniform benefits under thermal stress. Time of day also appears relevant, as Boyett et al. (2016) observed a greater ergogenic effect of caffeine in the morning than in the evening. These findings indicate that environmental temperature and circadian factors should be considered when evaluating caffeine supplementation strategies.

Inter-individual variability represents another major challenge in interpreting caffeine ergogenicity. Ruiz-Moreno et al. (2022) reported individuals with minimal or negative performance responses to caffeine during a 15-s Wingate test. However, Del Coso et al. (2019) challenged the concept of stable caffeine non-responders by demonstrating that all participants showed an ergogenic response in at least some repeated trials. Genetic polymorphisms, particularly CYP1A2 and ADORA2A, have been proposed as potential contributors to individual variability, although current evidence remains inconclusive. Masters et al. (2026) found differences in plasma caffeine concentrations between CYP1A2 genotypes but no significant caffeine–genotype interaction in exercise performance. Therefore, individual responses are likely multifactorial and may reflect interactions between genetic factors, habitual caffeine intake, supplementation protocol and exercise characteristics rather than a stable responder or non-responder phenotype.

The reviewed evidence also does not consistently support additive or synergistic effects when caffeine is combined with other potentially ergogenic substances. Acetaminophen did not enhance cycling performance beyond caffeine alone (Jessen et al., 2021), while combined dietary nitrate and caffeine supplementation failed to improve performance during a 3-min all-out test (Hagele et al., 2026). Similarly, caffeine and taurine co-ingestion did not improve time to exhaustion in the heat (Aggett et al., 2025). Trexler et al. (2016) additionally found no improvement in repeated cycling sprint performance following caffeine or coffee consumption during a creatine-loading protocol; however, this study differed from acute co-ingestion trials and should be interpreted separately. Collectively, these findings indicate that the established ergogenic effects of individual substances cannot be assumed to be additive when supplements are combined.

From a practical perspective, caffeine doses of approximately 2.7–6 mg/kg body mass were most frequently associated with improvements in cycling performance in the analysed studies. However, the considerable heterogeneity of responses indicates that a universal supplementation strategy may be inappropriate. Dose, timing, habitual caffeine consumption, tolerance, exercise protocol, environmental conditions and individual variability should all be considered when developing caffeine supplementation strategies for cyclists. Future studies should include larger and more diverse populations, particularly female cyclists, and should more consistently control habitual caffeine intake and pre-trial abstinence. Repeated caffeine–placebo comparisons may also be necessary to distinguish true inter-individual variability from normal within-individual variation.

5. Conclusions

Caffeine is an effective ergogenic aid in cycling, with performance benefits most consistently observed during endurance and time-trial exercise, while findings for short-duration maximal efforts remain less consistent. Its ergogenic effects appear to involve central nervous system mechanisms, particularly adenosine receptor antagonism and modulation of fatigue perception, although peripheral physiological responses may also contribute. Doses of 2.7–6 mg/kg administered orally were most frequently associated with performance improvements. However, the magnitude of the ergogenic response appears to be context-dependent and may be influenced by habitual caffeine consumption, tolerance, time of day, environmental conditions, and inter-individual variability. Current evidence does not consistently support additive or synergistic effects when caffeine is combined with other potentially ergogenic substances.

Disclosure

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of AI use

Artificial intelligence tools were used solely as a linguistic aid to improve English language clarity and formatting. The scientific content, literature selection, interpretation of results and final manuscript preparation were performed by the authors.

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