QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

KAWA, Michał, IDZIK, Kamil, GACZOŁ , Agnieszka Anna, KOPCIŃSKA , Paulina, PIOTROWSKA , Gabriela, GRZYBOWSKA, Dominika, URBAŚ , Aleksander, KILIAN, Tomasz, KURNIK , Michał, GRZYB-KURNIK , Weronika, MORTKA , Magdalena and BEDNARZ , Hubert. Caffeine Tolerance in Endurance Sports: Does Habitual Intake Reduce the Effectiveness of Acute Supplementation? Quality in Sport. 2026;66:74008. https://doi.org/10.12775/QS.2026.66.74008

ARTICLE TIMELINE
Received: 24.07.2026. Revised: 02.08.2026. Accepted: 02.08.2026. Published: 08.08.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

Caffeine Tolerance in Endurance Sports: Does Habitual Intake Reduce the Effectiveness of Acute Supplementation?

Michał Kawa [MKa]
Murcki Hospital in Katowice, Poland
michal.kawa2000@gmail.com
https://orcid.org/0009-0001-8083-291X

Kamil Idzik [KI]
Murcki Hospital in Katowice, Poland
kamilidzik99@gmail.com
https://orcid.org/0009-0000-7532-9255

Agnieszka Anna Gaczoł [AAG]
Gabriel Narutowicz Municipal Specialist Hospital in Kraków, Poland
agnieszkagaczol1@gmail.com
https://orcid.org/0009-0008-9020-7123

Paulina Kopcińska [PK]
Gabriel Narutowicz Municipal Specialist Hospital in Kraków, Poland
pjkopcinska@gmail.com
https://orcid.org/0009-0006-1495-1968

Gabriela Piotrowska [GP]
Gabriel Narutowicz Municipal Specialist Hospital in Kraków, Poland
piotrowskagabi24@gmail.com
https://orcid.org/0009-0009-1283-7135

Dominika Grzybowska [DG]
St. Luke's Provincial Hospital in Tarnow, Poland
dominika.grzybowska996@gmail.com
https://orcid.org/0009-0002-0599-8896

Aleksander Urbaś [AU]
Murcki Hospital in Katowice, Poland
urbas41@gmail.com
https://orcid.org/0009-0004-5347-7192

Tomasz Kilian [TK]
Murcki Hospital in Katowice, Poland
kilianowskipl@gmail.com
https://orcid.org/0009-0000-3161-6914

Michał Kurnik [MKu]
Megrez Provincial Multi-Specialist Hospital in Tychy, Poland
michalkurnik95@gmail.com
https://orcid.org/0009-0008-4791-0630

Weronika Grzyb-Kurnik [WGK]
Megrez Provincial Multi-Specialist Hospital in Tychy, Poland
wrgrzyb@gmail.com
https://orcid.org/0009-0001-7622-281X

Magdalena Mortka [MM]
Medical University of Lublin, Lublin, Poland
magdalenamortka2@gmail.com
https://orcid.org/0009-0009-0403-0008

Hubert Bednarz [HB]
Medical University of Lublin, Lublin, Poland
hubertb7809@gmail.com
https://orcid.org/0009-0003-1639-0699

Corresponding Author

Michał Kawa, E-mail: michal.kawa2000@gmail.com

Abstract

Background

Caffeine is a well-established ergogenic aid that improves endurance performance at acute doses of 3–6 mg/kg. Widespread habitual intake, mainly via coffee, raises the question whether chronic exposure blunts this effect.

Aim

To critically assess whether regular caffeine consumption, particularly habitual coffee intake, modifies the acute ergogenic response to pre-exercise caffeine in endurance contexts.

Methods

A structured, non-exhaustive search (January 2020–June 2026) was performed in PubMed/MEDLINE, PubMed Central, Scopus, Web of Science, and the Cochrane Library, with citation tracking. Priority was given to systematic reviews, meta-analyses, randomized placebo-controlled crossover trials, and prospective studies on endurance performance, habitual intake, and acute responses; mechanistic papers were included selectively.

Results

Acute caffeine consistently enhances endurance performance. The largest meta-analysis indicates no significant attenuation of the pooled ergogenic effect with habitual intake. However, longitudinal data suggest that repeated daily exposure may reduce the magnitude of benefit over time without abolishing it, consistent with partial, context-dependent habituation. Inter-individual variability is influenced by dose, timing, delivery form, and training status; genetic effects remain insufficiently defined for clinical personalization.

Conclusions

Habitual caffeine use does not eliminate the ergogenic effect of acute supplementation in most endurance settings, but may attenuate responsiveness in some individuals. Evidence supports individualized strategies based on habitual intake, prior response, timing, and tolerability rather than routine abstinence or dose escalation. Well-controlled longitudinal studies are needed to clarify the extent and mechanisms of habituation.

Key words: caffeine, caffeine tolerance, caffeine habituation, endurance athletes, habitual coffee consumption, ergogenic aids.

1. Introduction

Caffeine is one of the most extensively researched and best-supported ergogenic aids in sport, with acute supplementation shown to enhance multiple aspects of exercise performance in many, although not all, study settings [1]. Among the various exercise domains examined in the literature, the evidence appears most consistent for endurance-related performance, which is of particular practical relevance because even small performance gains may meaningfully influence competitive outcomes in time-based events [1, 2]. According to the International Society of Sports Nutrition (ISSN), the most commonly supported acute dosing range is 3-6 mg/kg body mass, typically ingested approximately 60 minutes before exercise, while higher doses are generally unnecessary to demonstrate ergogenicity and may increase the likelihood of adverse effects [1].

The endurance-specific evidence base further supports this position. In a systematic review and meta-analysis of 44 randomized placebo-controlled studies, acute caffeine ingestion produced a small but clear ergogenic effect on endurance performance, with mean power output improving by 2.92 ± 2.18% and time-trial completion time improving by 2.26 ± 2.60% when caffeine was compared with placebo [3]. These findings are practically important because athletes in endurance sport are often separated by narrow margins, meaning that relatively modest improvements in power output, pacing, or completion time may translate into meaningful competitive advantage [1, 3]. Broader umbrella-level evidence has likewise suggested that caffeine ingestion improves exercise performance across a range of tasks, but that the magnitude of benefit may be greater for aerobic endurance than for anaerobic exercise, while also noting that much of the available literature has been conducted in young men [2].

Recent running-specific data also reinforce the importance of caffeine for endurance exercise while highlighting limitations in the literature. In a 2023 systematic review and meta-analysis including 21 randomized controlled trials and 254 participants, caffeine improved time to exhaustion in running tests and also produced a small but significant benefit in endurance running time-trial performance [4]. However, that review also noted that much of the evidence base has been generated under controlled laboratory conditions and that more data are needed in women and in ecologically valid endurance settings, which limits direct translation to all competitive contexts [4]. This is especially relevant for endurance athletes, who typically consume caffeine as part of a habitual dietary routine rather than only as an isolated pre-test supplement [2, 4].

This real-world context complicates the interpretation of caffeine's ergogenic value. Athletes are often not caffeine-naive and may consume caffeine daily through coffee, tea, energy drinks, or supplements, meaning that acute pre-exercise ingestion frequently occurs against a background of regular exposure rather than pharmacological novelty [5]. This distinction is important because habitual use raises the possibility of partial habituation or tolerance, whereby repeated caffeine exposure may alter the magnitude or consistency of the acute ergogenic response [5, 6]. From an applied perspective, this issue is highly relevant in endurance sport, where athletes may simultaneously rely on daily coffee consumption and strategic race-day caffeine supplementation [5].

The 2023 ISSN Position Stand on coffee and sports performance is particularly useful in framing this problem because it expands the discussion beyond isolated anhydrous caffeine and addresses coffee as a common and ecologically valid source of habitual caffeine exposure. That position stand emphasizes that coffee is a complex matrix containing numerous bioactive compounds in addition to caffeine, that the operational definition of "coffee" varies substantially between studies, and that performance outcomes may be influenced by dose, timing, habituation to a small degree, nutrigenetics, gut microbiota, sex, and training status. At the same time, the same position stand concludes that coffee and/or its components can improve performance in a broad range of activities, including those in the aerobic time domain, but also notes a relative scarcity of coffee-specific ergogenic and recovery research compared with the much larger caffeine supplementation literature [5].

Given the established ergogenic evidence base, the more relevant applied question is whether regular caffeine consumption — particularly habitual coffee intake — attenuates the pre-exercise ergogenic effect in endurance settings [1, 3, 5]. This question remains unresolved because cross-sectional and meta-analytic evidence often suggests preserved acute efficacy in habitual users, whereas mechanistic reasoning and some longitudinal data indicate that repeated exposure may reduce responsiveness under certain conditions [6]. Clarifying this issue is important not only for theoretical understanding of caffeine habituation, but also for the development of evidence-based race-day strategies in endurance athletes who use caffeine both habitually and strategically [4, 5].

The aim of this narrative review is therefore to critically appraise and synthesize the literature on whether regular caffeine consumption, with particular emphasis on habitual coffee intake, modifies the acute ergogenic effect of caffeine in endurance-related exercise. Particular attention is given to the distinction between preserved efficacy and partial habituation, the methodological differences that may explain divergent findings, and the practical implications of current evidence for endurance athletes and practitioners [1, 4, 5].

2. Methodology

2.1. Review design and scope

This manuscript was designed as a narrative literature review examining whether habitual caffeine consumption attenuates the acute ergogenic effect of caffeine in endurance-related exercise. A narrative format was chosen because the available literature spans meta-analyses, RCTs, longitudinal interventions, and mechanistic reviews that differ too substantially in design and outcomes to support meaningful quantitative pooling. The review was therefore intended to evaluate the consistency, limitations, and applied implications of the available evidence rather than to provide a formal systematic review or quantitative meta-analysis.

2.2. Literature search strategy

A structured, non-exhaustive literature search was conducted to identify relevant publications published between January 2020 and June 2026. Searches were performed in PubMed/MEDLINE, PubMed Central, Scopus, Web of Science, and the Cochrane Library using combinations of terms related to caffeine tolerance, caffeine habituation, habitual caffeine intake, coffee consumption, endurance performance, withdrawal, and acute exercise response. Reference list screening and citation tracking were also used to identify additional relevant sources, particularly when recent reviews or primary studies provided important contextual or mechanistic insight not fully captured by the initial database search.

2.3. Study selection

We prioritized peer-reviewed systematic reviews, meta-analyses, randomized controlled trials, placebo-controlled crossover studies, and prospective longitudinal studies directly relevant to endurance exercise, habitual caffeine exposure, or the acute ergogenic response to caffeine. Studies involving endurance athletes, cyclists, runners, triathletes, mountain bike athletes, and physically active adults were considered most relevant to the primary question of the review. Additional narrative reviews and mechanistic papers were included selectively when they contributed necessary background on caffeine pharmacology, tolerance mechanisms, genotype-related variability, or differences between coffee and anhydrous caffeine, but such sources were treated as contextual rather than direct evidence for the core research question. Studies focused exclusively on animal models, case reports, or exercise domains unrelated to endurance performance were not used as primary evidence in the main synthesis.

2.4. Appraisal and synthesis

Because this manuscript was conducted as a narrative review, no formal risk-of-bias tool or GRADE framework was applied. Instead, the literature was appraised qualitatively with attention to study design, population relevance, sample size, placebo control, blinding, randomization, duration of repeated caffeine exposure, ecological validity, and directness to the review question. Greater interpretive weight was assigned to meta-analyses, systematic reviews, and longitudinal or controlled intervention studies than to narrative reviews or indirect contextual sources. The evidence was synthesised thematically, with emphasis on four issues: the established ergogenic effect of caffeine in endurance exercise, the influence of habitual intake on the acute response, the distinction between cross-sectional and longitudinal evidence, and the practical implications of partial or context-dependent habituation for endurance athletes.

3. Results and thematic review

3.1. Ergogenic effects of caffeine in endurance performance — general context

Before addressing the specific question of habituation, it is necessary to establish that caffeine has a well-supported acute ergogenic effect in endurance exercise under many experimental conditions. Across the broader sports nutrition literature, caffeine has consistently been shown to improve exercise performance, with the strongest and most practically relevant evidence observed in aerobic and endurance-related tasks [1, 2]. The dose range most commonly supported for acute use remains 3–6 mg/kg body mass, although lower doses may be effective in some settings and there is substantial inter-individual variability in response [1].

Evidence specific to endurance running supports this general conclusion. Wang et al. reported in a systematic review and meta-analysis of 21 randomized controlled trials involving 254 participants that caffeine ingestion improved time to exhaustion in running tests and also produced a small but significant improvement in running time-trial performance. Importantly, these effects were observed across both recreational and trained runners, supporting the view that caffeine's ergogenic potential is not restricted to a single performance level within endurance sport [4].

Comparable findings have been reported in cycling. Wu et al. showed in a recent systematic review and meta-analysis of 20 trials involving 226 cyclists that acute caffeine ingestion significantly reduced cycling time-trial completion time and increased mean power output, while not significantly altering heart rate or ratings of perceived exertion (RPE) at the pooled level [7]. Chen et al. likewise reported that caffeine improved cycling time-trial performance in cyclists, although the magnitude of benefit appeared to depend partly on dose and protocol characteristics [8].

Taken together, these findings provide an important foundation for the present review. The question is not whether caffeine is ergogenic in endurance exercise in general, because that point is already supported by a substantial body of evidence, but whether habitual caffeine exposure modifies the size or consistency of that established acute effect [1, 4, 7]. This distinction is central, because evidence for baseline ergogenic efficacy should not be conflated with evidence about tolerance, attenuation, or the practical consequences of regular use [9, 10].

A further practical point is that preserved average ergogenicity at the group level does not imply identical responses across all athletes. Even in studies showing overall benefit, individual variability remains substantial, and not all participants improve to the same degree under the same dose and timing conditions [1, 11]. This is especially relevant when considering habitual users, because the central issue may not be complete loss of effectiveness, but rather a shift in the magnitude, reliability, or predictability of response in some individuals over time [10].

3.2. Pharmacological mechanisms of caffeine and the molecular basis of tolerance

3.2.1. General mechanisms of action

The ergogenic effects of caffeine are generally explained by a combination of central and peripheral mechanisms, although current evidence suggests that central actions are likely the most important at the doses commonly used in sport [1, 6]. Caffeine is a methylxanthine that acts primarily as a non-selective antagonist of adenosine receptors, particularly the A_1 and $A_{2}A$ receptor subtypes, thereby reducing the inhibitory effects of endogenous adenosine within the central nervous system. Through this mechanism, caffeine may enhance arousal, vigilance, and wakefulness, while also reducing sensations of fatigue and lowering RPE during exercise, which is especially relevant in endurance performance where tolerance to sustained effort is critical [1, 12].

This central adenosinergic mechanism is currently considered the most plausible explanation for caffeine's ergogenic effects under real-world physiological conditions. Earlier mechanistic models often emphasized peripheral actions such as phosphodiesterase inhibition, increased catecholamine release, enhanced lipolysis, or direct effects on skeletal muscle contractility; however, many of these pathways appear to require higher concentrations than those typically achieved after standard pre-exercise doses in athletes. Accordingly, the main in vivo mechanism at commonly used doses is now generally interpreted as adenosine receptor antagonism rather than a dominant metabolic or purely muscular effect [1, 6].

Nevertheless, peripheral mechanisms should not be dismissed entirely. Caffeine may still influence exercise performance through altered motor unit recruitment, excitation-contraction coupling, calcium handling in skeletal muscle, and changes in catecholamine-mediated substrate availability, but the direct contribution of these effects to endurance performance remains less certain and appears more variable across study designs and exercise modes [6, 12]. In particular, the long-standing hypothesis that caffeine improves endurance mainly by increasing fat oxidation and sparing glycogen is no longer viewed as a sufficient standalone explanation, as human exercise studies have produced inconsistent metabolic findings and performance improvements are often observed even in the absence of large changes in classical metabolic markers [1, 6].

From a practical perspective, caffeine's pharmacokinetic profile also helps explain why it is typically consumed before exercise. After oral ingestion, caffeine is rapidly absorbed and usually reaches peak plasma concentration within approximately 30 to 60 minutes, although the precise time course may vary according to the delivery form, gastrointestinal conditions, and individual metabolic characteristics [1, 12]. This is one reason why pre-exercise protocols most commonly recommend ingestion about one hour before the onset of activity, while also recognizing that effective timing may differ somewhat between capsules, beverages, gum, and other delivery modes [1, 13].

An additional complication is that caffeine is not always consumed in isolation. In many athletes, habitual exposure occurs mainly through coffee, which contains numerous bioactive compounds beyond caffeine and may therefore differ slightly from anhydrous caffeine with respect to absorption kinetics, matrix effects, and tolerability, even if the principal central mechanism of action remains shared across both forms [5, 13]. This distinction is relevant for the present review because discussions of habituation should not assume that all caffeine exposure is pharmacologically identical simply because the nominal caffeine content appears comparable [5, 13].

Overall, the current literature supports a model in which caffeine enhances endurance-related performance primarily through central antagonism of adenosine signaling, with peripheral and metabolic effects acting as possible secondary contributors rather than primary explanatory mechanisms [1, 6, 12]. This interpretation is particularly important for the question of habituation, because if the ergogenic effect is driven mainly by central signaling pathways, then repeated caffeine exposure may plausibly alter responsiveness over time through adaptive changes in adenosine-related systems, even if the magnitude and practical importance of such adaptations remain incompletely understood in athletes [6, 12].

3.2.2. Central mechanisms: adenosine, neurotransmitters and perceived exertion

The central effects of caffeine are currently regarded as the most plausible explanation for its ergogenic action in endurance exercise, particularly at the doses most commonly used in sport [1, 6]. Caffeine acts primarily as a non-selective antagonist of adenosine receptors, especially the A_1 and A_2A subtypes, thereby attenuating the inhibitory neuromodulatory actions of adenosine within the brain [1]. Because adenosine normally promotes sleep pressure, sedation, and reductions in neural excitability, its blockade by caffeine contributes to increased wakefulness, heightened alertness, and maintenance of attentional function during prolonged exercise [1, 12].

This mechanism has important implications for the concept of central fatigue. Central fatigue refers broadly to a progressive reduction in the central nervous system's capacity to sustain motor drive and effort during prolonged or demanding exercise, and adenosine signaling is thought to contribute to this process by suppressing excitatory neurotransmission [6, 12]. By antagonizing adenosine receptors, caffeine may delay the rise of central fatigue, allowing athletes to sustain effort for longer and tolerate higher exercise intensities before fatigue becomes behaviorally limiting [1, 12]. This interpretation aligns with the repeated observation that caffeine often improves performance even when changes in classical peripheral physiological markers are small or inconsistent [6].

Adenosine antagonism is also closely linked to changes in other neurotransmitter systems relevant to exercise performance. In particular, blockade of A_2A receptors may enhance dopaminergic signaling in brain regions involved in motivation, arousal, and reward processing, while indirect effects on noradrenergic activity may support vigilance and task engagement during sustained effort [1]. These central actions provide a biologically plausible basis for the commonly reported reduction in subjective effort after caffeine ingestion, even when the external workload remains unchanged [1, 6].

The influence of caffeine on RPE, pain perception, and exercise tolerance is especially relevant in endurance settings. Several reviews indicate that caffeine may reduce the conscious perception of effort and discomfort, thereby enabling athletes to maintain pace, power output, or task persistence under conditions in which fatigue would otherwise induce self-selected slowing [1, 12]. This effect is not merely psychological in a trivial sense; rather, it reflects altered integration of central fatigue signals, nociceptive input, and motivational state, all of which contribute to pacing behavior and endurance capacity [6].

These central mechanisms also help explain why caffeine's ergogenic effects are often more pronounced in endurance and cognitively demanding exercise contexts than would be expected from a purely muscular explanation. Endurance performance depends not only on substrate availability and muscular contractility, but also on sustained attention, decision-making, tolerance of discomfort, and the ability to preserve central drive over time. Consequently, a compound that shifts subjective effort, alertness, and central motor activation may confer meaningful performance benefits even when measurable peripheral metabolic changes are modest [1, 6].

From the perspective of habituation, the central mechanism is particularly important because it identifies a plausible biological target for adaptation. If acute ergogenic effects are mediated primarily through repeated antagonism of adenosine signaling, then chronic caffeine exposure may induce compensatory changes in receptor density, receptor sensitivity, or downstream neural responsiveness, thereby attenuating the size of the acute response over time [6, 12]. Although direct evidence for these processes in athletic populations remains limited, the central adenosinergic model provides the most coherent mechanistic framework for understanding why tolerance might emerge in habitual caffeine users [1, 12].

3.2.3. Pharmacokinetics, habitual exposure and the biological basis of habituation

An understanding of caffeine pharmacokinetics is essential for interpreting both its acute ergogenic effects and the possibility of habituation with repeated use. After oral ingestion, caffeine is rapidly and efficiently absorbed, with peak plasma concentrations typically occurring within approximately 30 to 60 minutes, although the exact time course depends on the delivery form, gastrointestinal conditions, co-ingested nutrients, and individual metabolic characteristics [1, 12]. This pharmacokinetic profile underlies the common practical recommendation to ingest caffeine roughly one hour before exercise, while also recognizing that the time of maximal effect may vary across athletes and supplementation formats [1, 13].

Caffeine metabolism is characterized by marked inter-individual variability, which complicates attempts to apply a uniform supplementation strategy. Hepatic metabolism is driven primarily by cytochrome P450 1A2, and the elimination half-life of caffeine may vary substantially according to genetic polymorphisms, sex hormone status, age, smoking behavior, habitual intake, and possibly training-related factors [1, 12]. As a result, two athletes consuming the same relative dose may experience different peak concentrations, durations of action, side-effect profiles, and recovery trajectories, even if the nominal dosing protocol is identical [12].

The form in which caffeine is consumed introduces an additional layer of variability. Although the active alkaloid is the same, anhydrous caffeine, coffee, caffeinated gum, gels, and energy drinks differ in absorption kinetics, matrix composition, dose precision, and ecological validity [5, 13]. Coffee is especially relevant in endurance populations because it is often the dominant source of habitual caffeine exposure, yet its caffeine content can vary markedly according to bean type, roast level, brewing method, serving size, and preparation standardization [5]. This means that habitual exposure is often estimated imprecisely in both research and practice, which may partly explain why the relationship between daily intake and acute ergogenic responsiveness remains difficult to quantify [5, 6].

These pharmacokinetic considerations are directly relevant to the concept of habituation. In pharmacological terms, habituation or tolerance implies that repeated exposure to a given dose produces a reduced effect over time, often because the target system undergoes adaptive counter-regulation. In the case of caffeine, the most widely discussed mechanism is compensatory adaptation within adenosine-related pathways, including possible upregulation or altered sensitivity of adenosine receptors after chronic receptor antagonism [12]. This framework is biologically plausible, but the magnitude and functional significance of such adaptations in athletes remain incompletely established [6].

The current human exercise literature suggests that habituation is best viewed as partial, variable, and method-dependent rather than uniform or inevitable. Cross-sectional and meta-analytic studies often report preserved acute ergogenic effects in habitual users, whereas longitudinal studies with controlled repeated administration more often indicate attenuation over time, suggesting that “habitual intake” and “experimentally induced tolerance” are related but not identical constructs [6, 12]. Importantly, most available studies do not quantify long-term free-living intake with sufficient precision, rarely control all caffeine sources, and seldom follow participants long enough to characterize the full time course of adaptation and re-sensitization [5, 12].

For this reason, the biological basis of habituation should be presented cautiously. It is reasonable to state that repeated caffeine exposure may attenuate responsiveness through adaptations in central adenosinergic systems, but it would be overstated to claim that a fixed degree of tolerance predictably develops in all athletes after a specific dose or duration of use [6, 12]. A more defensible interpretation is that pharmacokinetic variability, form of intake, habitual exposure pattern, and inter-individual biological differences jointly shape the extent to which acute ergogenic benefits are preserved or diminished over time [1, 5, 12].

3.3. Evidence from cross-sectional studies: habitual consumption does not modify the ergogenic response

The strongest evidence suggesting that habitual caffeine use does not meaningfully alter the acute ergogenic response comes from cross-sectional studies and meta-analytic syntheses of acute supplementation trials [9]. In this part of the literature, the central finding is not that habituation is absent in a biological sense, but that regular caffeine users often continue to demonstrate measurable performance benefits following acute caffeine ingestion [9, 14].

The most comprehensive analysis to date is the systematic review and meta-analysis by Carvalho et al., which included 60 studies reporting sufficient information on habitual caffeine intake and acute exercise response. Across these studies, caffeine produced a significant overall ergogenic effect compared with placebo, and relative habitual caffeine consumption did not significantly modify that effect at the pooled level. Importantly, this lack of moderation by habitual intake was also observed across exercise type, sex, and training status, suggesting that the preserved acute response is not confined to a single subgroup of participants [9].

The subgroup findings from Carvalho et al. are particularly relevant to practical interpretation. Acute caffeine remained ergogenic when the administered dose was lower than habitual intake and also when it was higher than habitual intake, and beneficial effects were observed across different pre-trial withdrawal durations. These results do not support the idea that habitual users must necessarily abstain before competition or that an acute dose must always exceed habitual daily exposure in order to remain effective. At the same time, these findings should be interpreted as evidence of preserved acute responsiveness rather than proof that chronic exposure never attenuates response under repeated-use conditions [9, 10].

Evidence from individual crossover trials is broadly consistent with this interpretation. Clarke and Richardson examined recreationally active men and women performing a 5-km cycling time trial after ingestion of caffeinated coffee providing 3 mg/kg caffeine and found that habitual caffeine consumption did not alter the performance benefit of acute coffee ingestion. Both low and high habitual caffeine users improved by a similar magnitude, and the interaction between habitual intake and ergogenic response was not significant, supporting the argument that regular caffeine exposure does not necessarily abolish the performance-enhancing effect of an acute pre-exercise dose [15].

Taken together, cross-sectional evidence supports a relatively conservative conclusion: many habitual caffeine users remain responsive to acute caffeine supplementation, and habitual intake alone does not appear to explain a large proportion of the variability in ergogenic outcomes observed across studies [9, 15]. However, this evidence cannot fully resolve the question of tolerance, because comparing habitual users and non-users at a single point in time is not the same as measuring whether the same individual becomes less responsive after repeated exposure over days or weeks [10, 14]. For that reason, cross-sectional findings should be interpreted as evidence of retained efficacy in many habitual users, not as definitive evidence that habituation is irrelevant [9, 10].

3.4. Evidence from longitudinal studies: progressive attenuation with chronic administration

Longitudinal studies provide a more direct way of examining habituation than cross-sectional comparisons, because they assess whether the response to caffeine changes within the same individual after repeated exposure over time [14, 16]. For this reason, they are particularly important when the research question concerns tolerance rather than the mere presence or absence of an acute ergogenic effect in habitual users.

One of the clearest endurance-relevant examples comes from Ruiz-Moreno et al., who examined the time course of tolerance to 3 mg/kg/day caffeine administered for twenty consecutive days in trained cyclists, using workload at the second ventilatory threshold as the primary outcome [16]. In that study, caffeine increased wattage at the second ventilatory threshold on days 1, 4, 6, and 15 compared with placebo, but the magnitude of the ergogenic effect progressively declined over the course of treatment, suggesting attenuation rather than abrupt loss of efficacy [16]. Improvements in oxygen uptake and heart rate at the second ventilatory threshold were also more evident early in the treatment period, which further supports the interpretation that repeated daily exposure may reduce responsiveness over time under controlled conditions [16].

At the same time, very short-term repeated exposure does not appear to produce the same pattern consistently. In a randomized, double-blind, crossover study in cyclists, four days of caffeine supplementation did not induce detectable tolerance to the ergogenic effects of an acute pre-exercise dose on physiological, metabolic, or performance outcomes, suggesting that attenuation may depend on the duration and context of repeated exposure rather than occurring immediately after a few days of use [17]. This is an important nuance, because it indicates that habituation is unlikely to be a simple all-or-none process and may emerge only after longer or more consistent intake patterns [17, 16].

More recent evidence from Khodadadi et al. strengthens the case for partial habituation while also showing that the picture is more complex than simple desensitization. In that study, repeated caffeine exposure reduced the ergogenic effect of acute caffeine intake, yet performance benefits relative to placebo were still present, indicating that habituation diminished the response without abolishing it completely [10]. The same study also suggested that training status modifies the response, that a higher acute dose may partially compensate in some trained individuals, and that one week of abstinence may restore some responsiveness, although these findings were obtained in healthy young men rather than a competitive endurance cohort and therefore require cautious extrapolation to race settings [10].

Based on the longitudinal literature, repeated daily caffeine exposure can attenuate the magnitude of the acute ergogenic response, particularly over longer periods of controlled intake, but the available evidence does not support complete or universal loss of efficacy in habitual users [10, 16]. A more defensible conclusion is therefore that habituation is real, but partial, time-dependent, and likely influenced by exposure pattern, training status, outcome measure, and study design [10, 16, 17].

3.5. Coffee as a caffeine source — distinct pharmacology

An important practical consideration in this field is that many endurance athletes do not consume caffeine only in capsule or powder form, but habitually obtain it through coffee [18]. This distinction matters because coffee is not simply a caffeine delivery vehicle; it is a complex matrix containing numerous bioactive compounds in addition to caffeine, and its composition varies substantially according to bean type, brew method, serving size, and preparation characteristics [5]. As a result, the physiological and practical effects of coffee may overlap with, but do not necessarily replicate exactly, those of anhydrous caffeine delivered in a standardized supplemental form [5, 19].

The ISSN position stand on coffee and sports performance concludes that coffee and/or its components can improve performance across a range of exercise tasks, including aerobic exercise, while also emphasizing that the operational definition of "coffee" varies substantially across studies and complicates direct comparison with other forms of caffeine delivery [5]. This is particularly relevant in the context of habitual use, because athletes who consume coffee daily may differ from capsule users not only in caffeine exposure, but also in timing habits, serving-size variability, co-ingested compounds, and the ecological context in which caffeine is consumed [5, 18].

Direct exercise evidence suggests that coffee can function as an effective ergogenic source of caffeine in endurance-related settings. Trujillo-Colmena et al. reported that ingestion of 3 mg/kg caffeine in the form of soluble coffee significantly improved performance in a cross-country cycling time trial in recreational cyclists, reducing completion time by nearly 5% compared with placebo. These findings support the practical view that coffee may be a viable pre-exercise strategy in some endurance contexts, particularly when dose, timing, and individual tolerability are appropriately managed [5, 20].

At the same time, coffee introduces greater uncertainty in dose standardization than isolated caffeine supplementation. The caffeine content of coffee can vary meaningfully between preparations, and this makes it more difficult to estimate habitual intake precisely or to match race-day dosing reliably on a milligram-per-kilogram basis [5, 19]. For a review concerned with habituation, this is not a trivial issue: if habitual exposure is estimated imprecisely, then the relationship between baseline intake and acute performance response also becomes harder to interpret [5, 18].

Taken together, these observations suggest that coffee should be treated as both an ergogenic option and a distinct habitual exposure source in endurance sport. This distinction is especially important in the context of caffeine habituation, because variability in coffee composition, serving size, preparation method, and real-world consumption patterns makes habitual intake more difficult to quantify and race-day dosing less precise than with standardized anhydrous caffeine [5, 19]. As a result, studies examining habitual caffeine use in endurance athletes may partly capture not only biological differences in responsiveness, but also measurement imprecision related to how coffee-derived caffeine exposure is estimated. For this reason, coffee is best understood as an ecologically valid but methodologically complex source of caffeine, and this complexity is central rather than peripheral to the interpretation of habituation and acute ergogenic response in habitual users [5, 18].

4. Discussion

4.1. Synthesis of key findings

The literature reviewed between 2020 and 2026 supports a nuanced rather than binary interpretation of caffeine habituation in endurance-related settings. On the one hand, the broader ergogenic effect of acute caffeine ingestion is well established across endurance exercise, and current evidence does not support the view that habitual caffeine users become uniformly non-responsive to pre-exercise supplementation [1, 2, 9]. On the other hand, the available longitudinal literature suggests that repeated daily exposure may reduce the magnitude of the ergogenic response under some conditions, indicating partial attenuation rather than complete preservation or complete loss of efficacy [10, 16].

This distinction helps reconcile what initially appears to be a contradiction in the literature. Cross-sectional studies and meta-analyses largely address whether habitual users still improve acutely after caffeine ingestion, whereas longitudinal studies are better positioned to detect whether the same individual becomes less responsive over time after repeated exposure [9, 10, 14]. When interpreted in this way, the available evidence is not necessarily conflicting; rather, it reflects different methodological approaches to different versions of the same question [14].

A central conclusion of the present review is therefore that habitual caffeine consumption does not appear to abolish the acute ergogenic effect of caffeine in most endurance-relevant contexts, but it may alter the size, reliability, or predictability of that response in some individuals [9, 10]. The concept of tolerance is thus most defensible when framed as partial, context-dependent, and influenced by exposure pattern, outcome measure, and athlete characteristics, rather than as a uniform pharmacological endpoint that can be assumed from habitual use alone [10, 14, 16].

The reviewed evidence also reinforces the importance of ecological context. Much of the strongest acute ergogenic literature has been generated under tightly controlled laboratory conditions using standardized caffeine doses, whereas real-world endurance practice often involves habitual coffee consumption, variable dosing, flexible timing, and different forms of caffeine delivery [5, 18]. This discrepancy helps explain why caffeine remains one of the best-supported ergogenic aids in sports nutrition while the specific question of habituation in everyday athletic practice remains incompletely resolved [9, 14].

Finally, the evidence base remains limited by several recurring issues, including heterogeneous definitions of habitual intake, reliance on self-reported caffeine exposure, underrepresentation of women in performance trials, and the relatively small number of longitudinal endurance-specific studies directly designed to evaluate habituation [2, 9, 14]. These limitations do not negate the practical value of the current literature, but they do require caution when translating findings into firm prescriptive recommendations for race-day caffeine strategy [1, 10].

4.2. Methodological comparison — why studies produce divergent results

A major reason why the literature on caffeine habituation appears inconsistent is that studies often operationalize both “habitual caffeine use” and “ergogenic response” in different ways [9, 14]. Some studies classify habitual intake using self-reported daily consumption, whereas others impose repeated caffeine exposure experimentally over a defined number of days or weeks, and these approaches do not measure the same phenomenon even when both are discussed under the label of tolerance [9, 10, 16]. As a result, divergence in findings may reflect methodological heterogeneity as much as true biological disagreement [14].

A second issue concerns the quantification of habitual intake itself. In many studies, baseline caffeine consumption is estimated through self-report, food recall, or questionnaire-based categorization, which is practical but inherently imprecise, especially when coffee is the dominant source and serving size or caffeine content varies substantially across preparations [5, 18]. This creates uncertainty not only in group classification, but also in the interpretation of whether an acute pre-exercise dose is actually low, equivalent, or high relative to an athlete’s habitual exposure [5, 9].

Study design also shapes the meaning of the outcome. Cross-sectional or single-visit crossover studies are useful for determining whether habitual users still respond to acute caffeine ingestion, but they are not designed to determine whether responsiveness has declined relative to an earlier, less-exposed state in the same individual [9, 14]. By contrast, longitudinal intervention studies are better suited to detecting attenuation over time, but they may do so under highly standardized conditions that do not fully reflect real-world caffeine behavior in athletes [10, 16, 18]. This means that cross-sectional and longitudinal studies are not directly interchangeable forms of evidence, even when they appear to address the same applied question [14].

Another source of heterogeneity lies in the performance outcomes selected. Some studies examine time trial completion, others time to exhaustion, ventilatory thresholds, mean power output, or mixed aerobic and anaerobic outcomes, and these measures may not be equally sensitive to habituation effects [4, 10, 16]. Moreover, athlete populations vary considerably across studies with respect to sex, training status, sport discipline, and habitual exposure patterns, while relatively few longitudinal protocols have been conducted in clearly defined competitive endurance populations [2, 14].

Finally, ecological validity remains a persistent challenge. Laboratory studies often use carefully standardized doses such as 3–6 mg/kg taken approximately 60 minutes before exercise, yet survey data suggest that many endurance athletes consume caffeine in more variable ways, often through coffee, at doses lower than those commonly used in research, and with inconsistent timing relative to training or racing [1, 18]. This gap between controlled protocols and real-world behavior helps explain why the literature can simultaneously show strong overall ergogenic efficacy and continued uncertainty about the practical consequences of habitual use in day-to-day sport settings [14, 18].

4.3. Practical implications for endurance athletes

From an applied perspective, the current evidence supports the continued use of caffeine as a potentially effective ergogenic aid in endurance sport, including among many habitual users, but it does not support a rigid one-size-fits-all protocol [1, 9]. The most defensible practical position is therefore not that habitual intake is irrelevant, nor that tolerance inevitably eliminates benefit, but that athletes should expect variability in response and plan supplementation accordingly [9, 10].

For most athletes, a reasonable starting strategy remains an acute dose in the range of 3–6 mg/kg body mass taken approximately 60 minutes before exercise, particularly when using a standardized caffeine source such as capsules, gels, or other supplements with known caffeine content [1]. However, survey data indicate that many endurance athletes consume smaller doses and often use timing that is closer to exercise than is typical in laboratory protocols, which may partly explain why real-world outcomes are less predictable than controlled studies suggest [18]. This gap between research protocols and field practice reinforces the importance of testing caffeine strategies during training rather than relying solely on generalized recommendations [14, 18].

Habitual coffee users deserve particular consideration because coffee is one of the most common real-world sources of daily caffeine exposure in endurance athletes [5, 18]. Coffee may be ergogenic and ecologically relevant, but it introduces greater variability in caffeine dose and composition than anhydrous caffeine, which makes precise intake matching and race-day standardization more difficult [5]. For athletes whose goal is maximal repeatability of intake, supplemental caffeine may therefore be preferable, whereas coffee may remain a practical option for those who tolerate it well and can reproduce their routine consistently [5, 19].

The current literature also suggests caution with more prescriptive strategies often discussed in applied settings. There is insufficient evidence to recommend that all habitual users should routinely abstain from caffeine before competition, and there is likewise insufficient evidence to recommend that the acute pre-race dose should always exceed habitual daily intake [9, 10]. Such strategies may help some individuals, but they should be treated as optional, testable interventions rather than default rules for endurance athletes as a group [1, 10].

In practical terms, the most appropriate recommendation is individualized caffeine periodization based on prior response, gastrointestinal tolerance, sleep sensitivity, source of caffeine, and the demands of the event itself [1, 14]. Athletes and practitioners should evaluate these variables in training, refine race-day protocols gradually, and avoid introducing unfamiliar caffeine strategies immediately before important competition [1, 18].

4.4. Limitations of the current evidence

Several limitations constrain the interpretation of the current literature on habitual caffeine use and ergogenic response. First, habitual caffeine intake is commonly estimated using self-report methods, dietary recall, or questionnaire-based categorization, which are practical for research but introduce measurement error, especially when caffeine is consumed through variable sources such as coffee, energy drinks, or mixed dietary patterns [5]. This reduces confidence in the precision with which participants can be classified as low, moderate, or high habitual users and complicates comparisons between studies using different intake metrics [9].

Second, the literature remains methodologically heterogeneous. Studies differ in participant training status, exercise modality, caffeine dose, timing of ingestion, source of caffeine, withdrawal duration, and outcome measure, while the operational definition of both "habitual use" and "tolerance" varies considerably across papers [9, 14]. As a result, pooled conclusions are informative at a broad level but may obscure meaningful differences in response that are specific to certain populations, protocols, or performance tests [9, 10].

Third, much of the evidence base remains limited in external validity. Many of the primary studies included in broader caffeine meta-analyses were conducted in young men, and women remain underrepresented in several areas of exercise caffeine research, which limits confidence in the generalizability of findings across sexes [2, 4]. This issue is especially relevant for habitual-use questions, where sex-specific differences in caffeine metabolism, hormonal context, or symptom profile could plausibly affect both exposure patterns and acute response, yet remain insufficiently studied in endurance-specific designs [2, 21].

Fourth, the number of longitudinal studies directly designed to examine habituation remains relatively small compared with the much larger body of acute caffeine performance trials [10, 14]. This creates an imbalance in the evidence base: there is strong support for acute ergogenic efficacy, but less direct evidence on how repeated exposure changes that response over time in ecologically realistic endurance settings [14, 18]. Relatedly, some longitudinal studies use tightly controlled intake protocols that improve internal validity but may not reflect how athletes actually consume caffeine in daily training and competition contexts [10, 18].

Finally, ecological validity remains a persistent limitation across this literature. Laboratory protocols typically standardize dose and timing, often using anhydrous caffeine, whereas real-world endurance athletes frequently use coffee or mixed sources, consume suboptimal or inconsistent doses, and integrate caffeine into training and racing in more flexible ways than study protocols assume [5, 18]. Consequently, the current evidence can support cautious practical guidance, but not highly prescriptive universal recommendations regarding dose escalation, abstinence, or source selection for all habitual caffeine users [1, 9, 10].

5. Conclusion

Current evidence supports the view that caffeine remains an effective ergogenic aid for endurance-related performance, including in many athletes who consume caffeine habitually [1, 9]. At the same time, the available longitudinal literature suggests that repeated daily exposure may attenuate the magnitude of the acute response in some individuals, indicating partial and context-dependent habituation rather than complete loss of efficacy [10, 16].

The most defensible interpretation is therefore that habitual caffeine use does not abolish ergogenic potential, but may modify how strongly and how consistently an athlete responds to acute supplementation [9, 10]. Accordingly, caffeine use in endurance sport should be approached through individualized and practice-tested strategies rather than universal rules regarding abstinence, dose escalation, or source selection [1, 18].

Further progress in this area will depend on more ecologically valid longitudinal studies, more precise quantification of habitual intake, and broader inclusion of diverse athlete populations, especially women and well-defined endurance cohorts [2, 14, 21].

6. Directions for future research

Future research should move beyond repeatedly asking whether caffeine is ergogenic and instead focus more directly on the conditions under which habitual use modifies the magnitude, consistency, and practical utility of the acute response. This requires a clearer separation between studies of preserved acute efficacy in habitual users and studies specifically designed to quantify longitudinal changes in responsiveness after repeated exposure [10, 14].

A major priority is the development of better methods for quantifying habitual caffeine exposure. Future studies should aim to standardize the reporting of habitual intake in both absolute and relative terms, distinguish habitual coffee use from other caffeine sources, and improve the precision of intake assessment through more robust dietary recording or repeated monitoring approaches [5]. Without more precise exposure assessment, it will remain difficult to determine whether apparent tolerance reflects true biological adaptation or simply imprecise classification of baseline intake [9].

More longitudinal endurance-specific research is also needed. Existing evidence suggests that repeated caffeine exposure may attenuate performance benefits over time, but the number of studies directly testing this in ecologically relevant endurance contexts remains limited, and protocols vary substantially in duration, dose, outcome measure, and participant training status [10, 16]. Future studies should therefore compare repeated-exposure models across different training levels, include competitive endurance athletes, and determine whether responses differ between laboratory outcomes, field-based time trials, and race-simulated settings [14, 18].

Another key priority is improved external validity. Survey data suggest that many endurance athletes use lower doses and different timing strategies than those typically employed in laboratory protocols, and many obtain caffeine primarily through coffee rather than standardized supplements [18]. Accordingly, future work should examine real-world supplementation strategies more directly, including lower-dose protocols, flexible timing, mixed caffeine sources, and repeated use across multi-session training or competition formats [5, 18].

The evidence base would also benefit from broader and more representative participant inclusion. Women, older athletes, and diverse performance levels remain underrepresented in much of the caffeine literature, despite clear reasons to expect variability in pharmacokinetics, tolerability, and practical response patterns across populations [2, 21]. In addition, more work is needed to clarify the role of training status, sleep sensitivity, withdrawal effects, and genetic variability as modifiers of response, while avoiding premature translation of these factors into rigid individualized protocols before stronger evidence is available [10, 14, 22].

DISCLOSURE

AUTHORS' CONTRIBUTION

Conceptualization: MKa, MKu, KI, AAG, PK

Methodology: MKa, GP, DG, AU, TK

Software: MKa, MKu, WGK, MM, HB

Check: MKa, KI, DG, AU, MM

Formal Analysis: MKa, AAG, PK, GP, HB

Investigation: MKa, MKu, TK, WGK, DG

Resources: MKa, KI, AU, MM, HB

Data Curation: MKa, AAG, PK, GP, WGK

Writing-Rough Preparation: MKa, MKu, DG, TK, MM

Writing-Review and Editing: MKa, KI, AAG, GP, HB

Visualization: MKa, PK, AU, WGK, DG

Supervision: MKa, MKu, TK, MM, HB

Project Administration: MKa, KI, AAG, PK, GP

All authors have read and agreed with the published version of the manuscript.

Funding statement: This review was not externally funded.

Statement of the institutional review board: Not applicable.

Statement of informed consent: Not applicable.

Statement of data availability: Not applicable.

Conflict of interest: The authors report no conflicts of interest.

References

1. Guest NS, VanDusseldorp TA, Nelson MT, Grgic J, Schoenfeld BJ, Jenkins NDM, Arent SM, Antonio J, Stout JR, Trexler ET, Smith-Ryan AE, Goldstein ER, Kalman DS, Campbell BI. International society of sports nutrition position stand: caffeine and exercise performance. J Int Soc Sports Nutr. 2021 Jan 2;18(1):1. doi: 10.1186/s12970-020-00383-4. PMID: 33388079; PMCID: PMC7777221.
2. Grgic J, Grgic I, Pickering C, Schoenfeld BJ, Bishop DJ, Pedisic Z. Wake up and smell the coffee: caffeine supplementation and exercise performance-an umbrella review of 21 published meta-analyses. Br J Sports Med. 2020 Jun;54(11):681-688. doi: 10.1136/bjsports-2018-100278. Epub 2019 Mar 29. PMID: 30926628.
3. Southward K, Rutherfurd-Markwick KJ, Ali A. The Effect of Acute Caffeine Ingestion on Endurance Performance: A Systematic Review and Meta-Analysis. Sports Med. 2018 Aug;48(8):1913-1928. doi: 10.1007/s40279-018-0939-8. Erratum in: Sports Med. 2018 Oct;48(10):2425-2441. doi: 10.1007/s40279-018-0967-4. PMID: 29876876.
4. Wang Z, Qiu B, Gao J, Del Coso J. Effects of Caffeine Intake on Endurance Running Performance and Time to Exhaustion: A Systematic Review and Meta-Analysis. Nutrients. 2022 Dec 28;15(1):148. doi: 10.3390/nu15010148. PMID: 36615805; PMCID: PMC9824573.
5. Lowery LM, Anderson DE, Scanlon KF, Stack A, Escalante G, Campbell SC, Kerksick CM, Nelson MT, Ziegenfuss TN, VanDusseldorp TA, Kalman DS, Campbell BI, Kreider RB, Antonio J. International society of sports nutrition position stand: coffee and sports performance. J Int Soc Sports Nutr. 2023 Dec;20(1):2237952. doi: 10.1080/15502783.2023.2237952. PMID: 37498180; PMCID: PMC10375938.
6. Martins GL, Guilherme JPLF, Ferreira LHB, de Souza-Junior TP, Lancha AH Jr. Caffeine and Exercise Performance: Possible Directions for Definitive Findings. Front Sports Act Living. 2020 Dec 11;2:574854. doi: 10.3389/fspor.2020.574854. PMID: 33345139; PMCID: PMC7739593.
7. Wu J, Xu K, Yin M, Ding X, Wang T, Zhang Q, Wu X, Xiao N. Effect of caffeine ingestion on cycling performance: a systematic review and meta-analysis. Front Nutr. 2026 Jan 12;12:1745472. doi: 10.3389/fnut.2025.1745472. PMID: 41601907; PMCID: PMC12832238.

8. Chen B, Ding L, Qin Q, Lei TH, Girard O, Cao Y. Effect of caffeine ingestion on time trial performance in cyclists: a systematic review and meta-analysis. J Int Soc Sports Nutr. 2024 Dec;21(1):2363789. doi: 10.1080/15502783.2024.2363789. Epub 2024 Jun 5. PMID: 38836626; PMCID: PMC11155427.
9. Carvalho A, Marticorena FM, Grecco BH, Barreto G, Saunders B. Can I Have My Coffee and Drink It? A Systematic Review and Meta-analysis to Determine Whether Habitual Caffeine Consumption Affects the Ergogenic Effect of Caffeine. Sports Med. 2022 Sep;52(9):2209-2220. doi: 10.1007/s40279-022-01685-0. Epub 2022 May 10. PMID: 35536449.
10. Khodadadi D, Azimi F, Eghbal Moghanlou A, Gursoy R, Demirli A, Jalali P, Behdari R, Seyedheydari M. Habitual Caffeine Consumption and Training Status Affect the Ergogenicity of Acute Caffeine Intake on Exercise Performance. Sports Health. 2025 Sep-Oct;17(5):930-941. doi: 10.1177/19417381251315093. Epub 2025 Feb 4. PMID: 39905628; PMCID: PMC11795567.
11. Vinícius Í, Brietzke C, Franco-Alvarenga P, Vasconcelos G, Saunders B, Santos TM, Pires FO. Efficacy of caffeine as an ergogenic aid in multiple cycling time trials. Eur J Appl Physiol. 2025 May;125(5):1361-1370. doi: 10.1007/s00421-024-05680-3. Epub 2024 Dec 14. PMID: 39673565.
12. WOJCIECHOWSKA, Urszula, Justyna, RAFAŁOWICZ, Adam and ZAJKOWSKA, Izabela. Caffeine as an Ergogenic Aid: A Literature Review of Mechanisms of Action, Performance Effects and Safety Thresholds. Quality in Sport. Online. 12 July 2025. Vol. 43, p. 61460. [Accessed 28 June 2026]. DOI 10.12775/QS.2025.43.61460.
13. Starling-Soares B, Pereira M, Renke G. Extrapolating the Coffee and Caffeine (1,3,7-Trimethylxanthine) Effects on Exercise and Metabolism-A Concise Review. Nutrients. 2023 Dec 7;15(24):5031. doi: 10.3390/nu15245031. PMID: 38140290; PMCID: PMC10745355.
14. Tallis J, Guimaraes-Ferreira L, Clarke ND. Not Another Caffeine Effect on Sports Performance Study-Nothing New or More to Do? Nutrients. 2022 Nov 7;14(21):4696. doi: 10.3390/nu14214696. PMID: 36364958; PMCID: PMC9658326
15. Clarke ND, Richardson DL. Habitual Caffeine Consumption Does Not Affect the Ergogenicity of Coffee Ingestion During a 5 km Cycling Time Trial. Int J Sport Nutr Exerc Metab. 2021 Jan 1;31(1):13-20. doi: 10.1123/ijsnem.2020-0204. Epub 2020 Dec 1. PMID: 33260141.

16. Ruiz-Moreno C, Lara B, Gutiérrez-Hellín J, González-García J, Del Coso J. Time Course and Magnitude of Tolerance to the Ergogenic Effect of Caffeine on the Second Ventilatory Threshold. Life (Basel). 2020 Dec 10;10(12):343. doi: 10.3390/life10120343. PMID: 33321978; PMCID: PMC7764462.
17. Morales AP, Sampaio-Jorge F, Barth T, Pierucci APTR, Ribeiro BG. Caffeine Supplementation for 4 Days Does Not Induce Tolerance to the Ergogenic Effects Promoted by Acute Intake on Physiological, Metabolic, and Performance Parameters of Cyclists: A Randomized, Double-Blind, Crossover, Placebo-Controlled Study. Nutrients. 2020 Jul 16;12(7):2101. doi: 10.3390/nu12072101. PMID: 32708555; PMCID: PMC7400874.
18. Kreutzer A, Graybeal AJ, Moss K, Braun-Trocchio R, Shah M. Caffeine Supplementation Strategies Among Endurance Athletes. Front Sports Act Living. 2022 Apr 6;4:821750. doi: 10.3389/fspor.2022.821750. PMID: 35463835; PMCID: PMC9030507.
19. Pickering C, Grgic J. Is Coffee a Useful Source of Caffeine Preexercise? Int J Sport Nutr Exerc Metab. 2020 Jan 1;30(1):69-82. doi: 10.1123/ijsnem.2019-0092. PMID: 31629349
20. Trujillo-Colmena D, Fernández-Sánchez J, Rodríguez-Castaño A, Casado A, Del Coso J. Effects of Caffeinated Coffee on Cross-Country Cycling Performance in Recreational Cyclists. Nutrients. 2024 Feb 27;16(5):668. doi: 10.3390/nu16050668. PMID: 38474796; PMCID: PMC10933887.
21. Grgic J, Del Coso J. Ergogenic Effects of Acute Caffeine Intake on Muscular Endurance and Muscular Strength in Women: A Meta-Analysis. Int J Environ Res Public Health. 2021 May 27;18(11):5773. doi: 10.3390/ijerph18115773. PMID: 34072182; PMCID: PMC8199301.
22. Barreto G, Esteves GP, Marticorena F, Oliveira TN, Grgic J, Saunders B. Caffeine, CYP1A2 Genotype, and Exercise Performance: A Systematic Review and Meta-analysis. Med Sci Sports Exerc. 2024 Feb 1;56(2):328-339. doi: 10.1249/MSS.0000000000003313. Epub 2023 Oct 11. PMID: 37844569.