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Caffeine Use in Long-Distance Running: Timing, Dosage, and Multi-Dimensional Effects on Performance and Perceived Effort. A Review

Authors

Joanna Duda[1]*, Jakub Kędzia[1], Kinga Racisz[1], Alicja Obcowska[1] , Paweł Racisz[2], Aleksandra Walendzik[3]

Affiliations

1. Central Clinical Hospital, Medical University of Lodz, Poland
2. John Paul II Memorial Hospital, Belchatow, Poland
3. Medical University of Lodz, Poland

Joanna Duda* (Corresponding Author)

Central Clinical Hospital of the Medical University of Lodz, ul.Pomorska 251, 92-213 Łódź, Poland; joannaduda24@gmail.com
https://orcid.org/0009-0009-6651-7831

Jakub Kędzia

Central Clinical Hospital of the Medical University of Lodz, ul.Pomorska 251, 92-213 Łódź, Poland; jakub.kedzia.1999@gmail.com
https://orcid.org/0009-0006-7971-6280

Kinga Racisz
Central Clinical Hospital of the Medical University of Lodz, ul.Pomorska 251, 92-213 Łódź, Poland; kingaracisz@gmail.com
https://orcid.org/0000-0001-8137-9275?f

Alicja Obcowska
Central Clinical Hospital of the Medical University of Lodz, ul.Pomorska 251, 92-213 Łódź, Poland; aobcowska@gmail.com
https://orcid.org/0009-0003-0390-0661

Paweł Racisz
John Paul II Memorial Hospital, Belchatow, Czapliniecka 123, 97-400 Bełchatów, Poland; pawelracisz@gmail.com
https://orcid.org/0000-0002-6660-7150

Aleksandra Walendzik
Medical University of Lodz, al. Tadeusza Kościuszki 4, 90-419 Łódź, Poland; aleksandra.walendzik@stud.umed.lodz.pl
https://orcid.org/0009-0000-1883-0801

Abstract

Introduction and aim of the study:

Caffeine is one of the most widely used ergogenic aids in endurance sports due to its potential to enhance both physical and cognitive performance. Among long-distance runners, its effectiveness depends on dosage, timing of intake, and individual response. This review aims to summarize current evidence on the effects of caffeine dosage and timing in long-distance running.

Materials and Methods:

A literature review was conducted based on studies published between 2013 and 2024 in PubMed and Google Scholar. Keywords included: “caffeine,” “running,” “endurance,” “performance,” “timing,” “dosage,” “supplementation,” and “perceived exertion.” Included studies focused on recreational and trained long-distance runners, emphasizing randomized controlled trials and systematic reviews.

Results:
Findings suggest that moderate caffeine intake (3–6 mg/kg), consumed 45–60 minutes prior to exercise, enhances endurance performance and lowers perceived exertion. Key mechanisms include stimulation of the central nervous system, increased alertness, improved motor unit recruitment, delayed fatigue, and enhanced post-exercise blood flow. However, individual variability, habitual caffeine use, and potential side effects—such as gastrointestinal discomfort or sleep disruption—affect outcomes.

Conclusion:
Strategically used, caffeine can boost performance and reduce effort perception in long-distance runners. Optimal effects are achieved through personalized dosage and timing, ideally refined during training. Future research should explore long-term use, sex-specific responses, and application in diverse race settings.

Keywords: caffeine, endurance, supplementation, long-distance running, dosage, timing, perceived effort, performance enhancement

Introduction and aim of the study

Caffeine is probably the world's most popular stimulant and psychoactive substance that can be found in varying degrees in more than 60 different plant species, including cacao beans and tea leaves. Depending on where it is found, caffeine may go by different names: guaranine in guarana berries, theine in tea plants, and mateine in yerba mate plants. The main dietary sources of caffeine in the world are roasted coffee beans and tea leaves. In addition to naturally occurring caffeine, it can also be produced artificially in laboratories [1].

The most common dietary sources of caffeine are coffee, tea, chocolate, and soft drinks. On average, a cup of coffee contains between 40 and 150 mg of caffeine. It can also be consumed through prescription and over-the-counter medications, which are used as supplements or to treat conditions such as headaches, fatigue, and low blood pressure. It is said to enhance the pain-relieving effects of some medications. Apart from its pharmaceutical use, caffeine is also used cosmetically and is an active ingredient in several cellulite-reduction treatments.

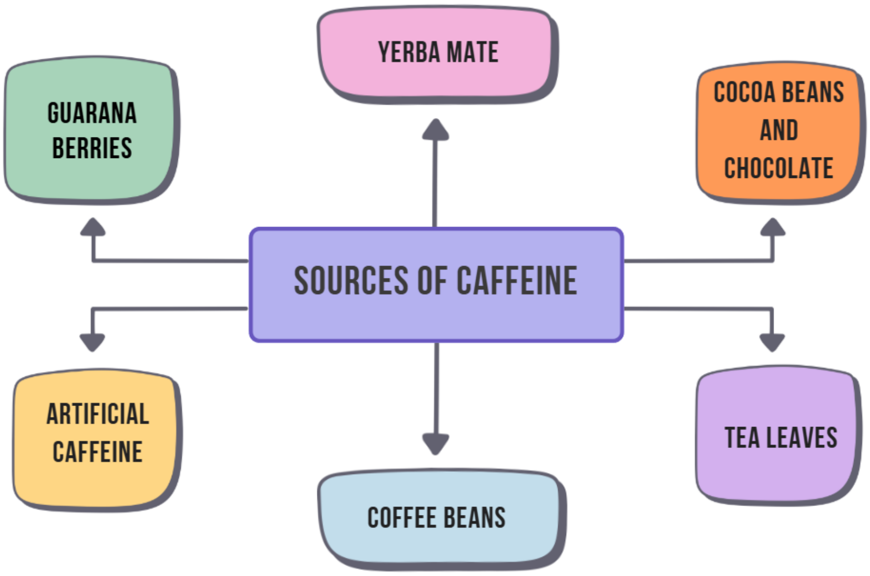


Figure 1. *Main sources of caffeine. Caffeine can be found in coffee beans, tea leaves, cocoa beans, chocolate, yerba mate, guarana berries, and is also produced artificially.*

Caffeine's energy-boosting, ergogenic properties also make it one of the most widely used performance-enhancing supplements among athletes in various sports, particularly endurance sports such as running and cycling [1,2].

Additionally, caffeine is said to have many health benefits, including anti-oxidative, anti-proliferative, and neuroprotective properties.

This paper aims to summarise the information on the usefulness of caffeine supplementation in endurance sports and its impact on improving performance, with a focus on dosage, timing, factors differentiating the effect in individual athletes, and the side effects of caffeine supplementation. It encapsulates the most important information, providing in-depth insights into the latest literature on this popular supplement and offering condensed recommendations for its use.

Materials and methods

A literature review was conducted using studies published between 2013 and 2024 in PubMed, Google Scholar, and other scientific resources. Keywords included: “caffeine,” “running,” “endurance,” “performance,” “timing,” “dosage,” and “perceived exertion.” Studies involving recreational and trained long-distance runners were included, with a focus on randomized controlled trials and systematic reviews. The main focus of the researchers was the practical application of article data. The articles selected were limited to those published in English. They were then narrowed down to recent and relevant articles. The last search was conducted on July 2nd, 2025.

Results

1. Caffeine mechanisms of action

Caffeine (1,3,7-trimethylxanthine) is a methylxanthine derivative with a molecular formula of $C_8H_{10}N_4O_2$. It is considered to be an alkaloid compound as it is a metabolite of nitrogen metabolism. Caffeine is a heterocyclic organic compound with a purine base. The most common caffeine intake route is oral ingestion in the form of coffee, tea, energy drinks, tablets, chewing gums, etc.

After oral ingestion, almost 100% of caffeine is absorbed, and it reaches peak plasma concentrations in approximately 45 minutes to 1 hour after consumption. 80% of caffeine is absorbed through the lower gastrointestinal tract, while the remaining 20% is absorbed by the stomach.

The peak plasma concentration time can be delayed with food intake. Food, especially containing high amounts of fiber, slows gastric emptying. Different types and volumes of food consumed can affect the rate of plasma absorption. For instance, caffeine absorption from tea and coffee proceeds faster than with soft drinks. More rapid absorption through the oral mucosa can be achieved by chewing caffeine-containing products, like gum or other preparations.

Once caffeine is absorbed, there is no hepatic first-pass effect, which means that the caffeine plasma concentration is similar whether the substance is administered by mouth or intravenously. Interestingly, caffeine molecules can pass through all biological membranes, including the blood-brain barrier and the placental barrier.

Caffeine has several mechanisms through which it exerts its effects. It is an adenosine receptor antagonist that causes an increase in cellular cyclic adenosine monophosphate (cAMP) concentration. This increase in cAMP in the central nervous system is what makes the ingesting person feel less drowsy, more energetic, and alert. By blocking adenosine receptors in pacemaker cells in the heart, caffeine removes the braking effect of adenosine, leading to activation of cAMP and acceleration of heart rate [1,2,32].

Caffeine also inhibits the phosphodiesterase enzyme, whose main role is to break down cAMP. This effect leads to higher cAMP levels, which cause enzymes like lipase in adipose tissue to activate and stimulate lipolysis. This leads to the release of fatty acids and glycerol into the bloodstream, which is needed for excretion. The increased availability of these fuels in skeletal muscle acts to spare the consumption of muscle glycogen and hence helps to use body energy storage more efficiently. An increase in cAMP could also result in higher levels of catecholamines in the blood, which can cause vasoconstriction in the periphery and elevate blood pressure.

Caffeine in very high doses can also stimulate calcium release from intracellular stores. This can facilitate neurotransmission since synaptic transmission depends on calcium influx into nerve endings. Also, caffeine restricts the uptake and storage of calcium by the sarcoplasmic reticulum. This action increases the strength and endurance of cardiac and skeletal muscles. However, the calcium release action of caffeine is probably physiologically irrelevant, as it is observed mainly at toxic concentrations of caffeine.

In addition to its stimulant effects on the cardiovascular system and central nervous system (CNS), caffeine exerts several effects on peripheral tissues. Caffeine acts as a diuretic by inhibiting sodium and water reabsorption in the renal tubules of the kidneys, thereby increasing urine output. Additionally, caffeine causes relaxation of the muscular tissue in bronchioles, which opens up airways, while also stimulating smooth muscle contraction in the colon and gastrointestinal tract, which can promote bowel movements. Moreover, caffeine increases the secretion of gastric acid, leading to irritation of the stomach lining and damage to the protective mucous layer. This can result in the formation of new ulcers or the exacerbation of existing ulcerative disease.

The most important effects of caffeine regarding the performance of long-distance runners seem to be overall CNS stimulation leading to an increase in alertness and a decrease in the perception of fatigue, cardiac stimulation with an increase in coronary blood flow as well as smooth muscle relaxation in the respiratory system and bronchial dilatation, possibly aiding in more effective ventilation [1,2].

2. Timing of caffeine intake

When discussing the timing of caffeine intake, three key aspects should be considered.

Firstly, when considering the additional advantages of ingestion connected with circadian rhythm, the most favorable time of the day to ingest caffeine appears to be the morning, as caffeine absorbed early in the day can significantly reduce the natural decline in morning performance. According to studies, evening training is performed most often with greater intensity, higher power output, and shorter training completion time. Also, the concentration of total testosterone, free testosterone, insulin, and cortisol concentrations was notably higher in the morning, whereas the growth hormone was doubled in the evening [3,9].

The study provided further evidence supporting previous findings that caffeine enhances morning performance, especially among trained individuals. Additionally, when it comes to high-performing athletes often subjected to sleep deprivation, caffeine supplementation of a 1-5mg/kg dose allows for a similar performance to when they are well-rested, in contrast to the performance decline typically observed in sleep-deprived subjects receiving placebo [3, 9].

The second aspect to consider is the timing of supplementation before the actual training time. Typical timing windows are 30-90 minutes before the workout. As previously stated, caffeine reaches its peak concentration in blood about 45 min to 1 hr after ingestion, with a half-life time of 4 - 6 hours in total. A shorter time of ingestion before exercise (< 30 minutes) can significantly decrease the absorption abilities and inhibit the total caffeine concentration during the workout. Some studies have suggested that waiting 3 hours may be more optimal because the caffeine-induced effect on lipolysis is greater than at earlier times after ingestion. However, the main effect of caffeine is based on its adenosine receptor antagonism and on phosphodiesterase enzyme inhibition, which is mostly observed around the peak blood concentration time [1,4].

The third aspect is how many days of continuous supplementation are needed to reach the optimal outcome. Research suggests that increased performance outcomes can be expected after even one dose of caffeine, with the greatest improvement occurring during the first 15 days of continuous usage. VO_2 max improves for the first four days of successive supplementation, after which the effect remains constant unless the caffeine dose is increased. It can therefore be concluded that appropriate caffeine supplementation should be started around 10–15 days before the competition, with the best results being achieved around the 4th–10th day of use [5].

3. Dosage

In the papers reviewed for this study, the most popular, as well as the most researched, safe, and proven ergogenic dose is 3 to 6 mg of caffeine per kg. Most often, doses lower than 3 mg/kg are considered low, and doses higher than 6mg/kg are considered high [10].

Lower doses, although they have some ergogenic potential [8], are significantly less researched and can be understimulating for frequent caffeine users. Research suggests that for athletes, daily ingesting around 3 mg/kg of caffeine in the form of coffee, the dose needed to stimulate better performance results might be higher, up to 6-7 mg/kg.

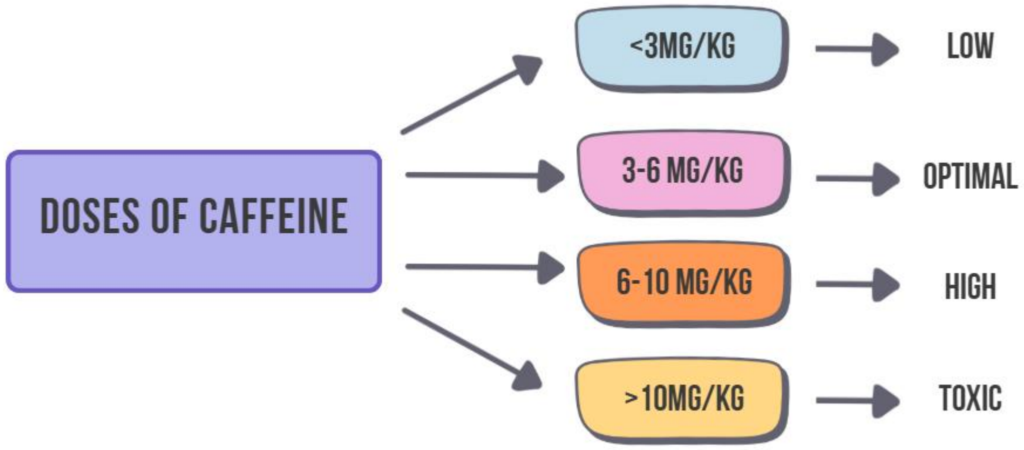
Low doses of caffeine may offer a performance improvement, but it seems to be less significant than with higher doses, and small doses are widely under-researched [6]. Some studies, however, show that a dose of 2mg/kg of caffeine improves lower-body muscle endurance similar to the effect acquired with high doses of caffeine [7].

It is worth noticing that in a study by Grgic et al. [7], there was a linear correlation between caffeine dose and objective performance improvement of upper body endurance, and possibly an undocumented similar correlation when it comes to the lower body.

Another study by Pickering et al. suggests doses as high as 6-9mg/kg, as approved for supplementation [8].

Toxic doses of caffeine start at 10 mg/kg. As it is hard to precisely estimate the caffeine dose, especially if it is supplemented by drinking coffee, high doses of caffeine can be dangerous and pose more adverse effects than lower doses. The research suggests that medium doses of 3-6mg/kg are safer while providing similar performance-enhancing outcomes [11].

Figure 2. *Caffeine dosage ranges relative to body weight (mg/kg) and their classification: doses <3 mg/kg are considered low, 3–6 mg/kg optimal/moderate, 6–10*



mg/kg high, and >10 mg/kg potentially toxic.

4. Differences resulting from the method of administration and individual predispositions

According to the available literature, there are many factors that influence the effectiveness of caffeine supplementation.

Some of them slow down caffeine metabolism, which prolongs its effects. These factors include postmenopausal age and the use of oral contraceptives. This is because both estrogens and caffeine are metabolized using cytochrome CYP1A2 [1].

On the contrary, smoking cigarettes accelerates the metabolism of caffeine, shortening its activity time but not increasing its potency. This effect is mediated by an acceleration in caffeine demethylation [1].

Some studies suggest that daily caffeine intake accelerates caffeine metabolism, which can lead to a smaller increase in performance efficacy. According to Lara et al. [5], individuals who consume moderate to high doses of caffeine daily (130–300 mg/day) experience a lesser ergogenic effect and shorter performance enhancement than low caffeine consumers (40–50 mg/day). Similarly, as Bell et al. [4] concluded, non-habitual users of the drug experienced greater improvements in exercise time to exhaustion, and these improvements lasted longer.
However, according to recent research by de Salles Painelli et al. [13], habitual caffeine consumption does not appear to influence the ergogenic potential of caffeine, and results for non-users are comparable to those of the caffeine-using group.

When considering the differences in the form of caffeine used in supplementation, it is worth mentioning the various options for its intake. In addition to coffee, energy drinks, matcha, teas, chewing gum, tablets, drops, and others are also available on the market. According to the latest research, forms of caffeine administered intravenously, rectally, or in any other parenteral manner do not increase its bioavailability; hence, the most popular route is oral. This route is preferred due to its nearly 100% bioavailability and ease of supplementation; because of that, most products can be administered orally [1,15].

The type of product consumed is also important in terms of the additional substances contained in the drink. For example, in a study conducted by Souza et al., patients consuming energy drinks reported significantly increased training capacity compared to the group consuming pure coffee, but it turned out that the dose of taurine contained in the energy drink had the greatest impact and not the form itself [14].

In a study conducted by Whalley et al. [15], amateur runners completed runs preceded by the ingestion of a placebo or one of three forms of caffeine supplement: gum, dissolvable mouth strips, or a tablet with a similar dose of caffeine, 15 minutes before working out. The results of the caffeine treatment were not significantly different between the individual subjects. Tablets provided slightly better results than other forms.

Research indicates that it is reasonable to use caffeinated beverages as a form of supplementation. It is particularly important to note that they are most effective when they are special sports drinks that also contain electrolytes. Caffeinated sports drinks have been shown to offer significant benefits, particularly during prolonged exercise such as long-distance running, when the dual purpose of rehydration and caffeine supplementation is crucial. Energy drinks are also effective as a supplement, though they do not offer additional hydration benefits or replenish lost fluids. Rather, they are best used as an additional boost to enhance the ergogenic effect before training [26].

Caffeine supplementation in the form of coffee is an effective solution, with an appropriate dose of approximately 3-8.1 mg/kg (1.36-3.68 mg/lb) of caffeine being recommended. This is a safe alternative to anhydrous caffeine for improving endurance performance [25].

Another factor influencing the effectiveness of supplementation is genetic predisposition. The CYP1A2 cytochrome genotype has been identified as a key factor in this regard. Individuals carrying the CC genotype exhibited reduced caffeine effectiveness and experienced a decline in athletic performance following caffeine intake. In individuals who have at least one A allele in their genotype (AA or AC genotype), caffeine has been shown to improve performance in exercise tests [16, 17].

Studies describing all of the above variables suggest that caffeine supplementation will not produce the expected results in everyone.

5. Effects on performance

The ergogenic effect of caffeine seems to be indisputable and is confirmed in every study cited in the bibliography of this paper. As previously stated, caffeine has been shown to enhance athletic performance due to its multifaceted effects, which include increasing blood pressure, increasing minute ventilation, reducing fatigue, and enhancing alertness, speed, and reaction time [19].

According to Southward et al. [22], moderate doses of caffeine have been shown to lead to improvements in mean power output and time-trial completion time of approximately 2.9% and 2.3%, respectively. The impact of caffeine is especially evident during periods of aerobic activity. The importance of caffeine intake in endurance sports such as long-distance running is well-documented [23, 25].

Therefore, caffeine can be a valuable supplement, especially in endurance sports where the finishing times are similar and supplementation can lead to significant differences in placement [18, 21].

A factor that hinders further progress and reduces the chance of achieving a good result in time trials while running is the feeling of exhaustion. As Wang et al. [24] state, caffeine has been shown to minimize this effect. This allows for a significant extension of the duration of training before the onset of perceived fatigue.

According to Schubert et al. [29], caffeine is included in the list of most beneficial ergogenic substances, especially effective for long-distance runners when combined with sodium bicarbonate, sodium citrate, and carbohydrates.

Another study by Clarke et al. [30] demonstrated that 60 minutes after ingesting 9 mg/kg of caffeinated coffee, race performance was enhanced by 1.9% and 1.3% compared with placebo and decaffeinated coffee, respectively.

Research indicates that there is no statistically significant difference in the effect of caffeine on performance when it comes to the impact of gender on improving results, according to studies by Mielgo-Ayuso et al. [20] and Lara et al. [31]. In the majority of experiments, the ergogenic effect was found to be similar in both sexes. Research indicates that, in some cases, men experience slightly higher levels of muscle strength and power benefits from the same amount of caffeine as women. However, it should be noted that this disproportion has not been statistically proven.

Furthermore, it has been demonstrated that caffeine can positively impact the recovery process following periods of physical exertion. Research indicates that caffeine supplementation can enhance blood flow in muscles by up to 17% following exercise. Simultaneously, it enhances the delivery of oxygen and nutrients to the muscles, facilitating improved adaptation to exercise and accelerated recovery [19].

6. Side effects and risks

It is said that adults should not generally absorb more than 400mg of caffeine daily, which equals a 5 to 6 mg/kg dose for an average-weight person. Higher doses may cause some adverse effects. However, the onset of any unwanted symptoms is postponed in patients habitually consuming caffeine. Which is why they can usually safely consume higher doses [1].

Slight overconsumption of caffeine can cause anxiety, nausea, restlessness, sleeplessness, and muscular tremors [33].

Doses of over 9mg/kg may cause hypokalemia, hypocalcemia, and hyperglycemia. This amount of caffeine can also lead to acute myolysis and eventually kidney failure. When it comes to cardiac symptoms, patients who ingested a toxic dose of caffeine present with tachycardia, ST-segment depression, and even atrial fibrillation. Other symptoms include vomiting, hypertension, headache, hallucinations, seizures, and agitation [11].

Long-term over-consumption of caffeine can lead to addiction, insomnia, and chronic headaches [12].

The lethal dose of caffeine is a blood concentration of over 80mg per milliliter.

Discussion

Despite its popularity as a sport accessible to most people, long-distance running still lacks adequate research providing relevant and practical recommendations on supplementation depending on gender, time of intake, training time, and dosage. However, based on the available literature, some basic recommendations can be made regarding caffeine use, for example.

Caffeine is a widely used substance with multiple effects that is easily available and has low toxicity. It is almost 100% bioavailable after oral administration, and thanks to its slight first-pass effect, it can be taken orally.

For long-distance runners in particular, its effects last for 3–6 hours. Caffeine should be taken 45–60 minutes before training to maximize its concentration in the blood during physical activity. The recommended dose is approximately 3–6 mg/kg of body weight. This dose reliably and noticeably improves performance without causing adverse effects. Slightly higher doses may be necessary for people who chronically use caffeine to achieve a similar effect [32].

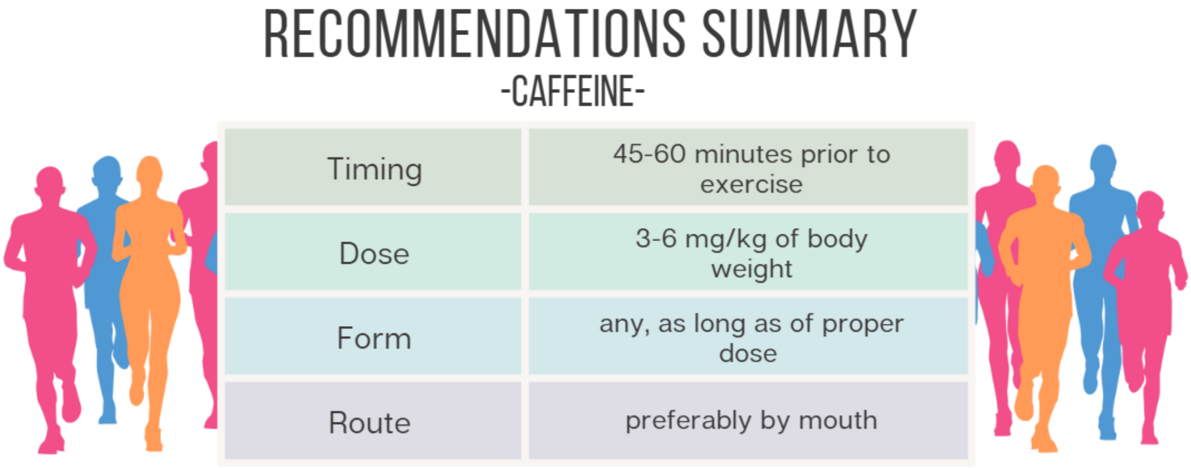


Figure 3. *Summary of evidence-based recommendations for caffeine use concerning physical exercise. Recommended intake is 3–6 mg of caffeine per kg of body weight, consumed preferably by mouth, 45–60 minutes before exercise. The form of caffeine may vary as long as the dosage is appropriate.*

An additional benefit of taking caffeine in the morning is that it evens out performance, bringing it in line with that achieved in the evening, and reduces the risk of injury. However, caffeine metabolism can be disrupted by smoking, chronic coffee drinking, genetic factors, and hormonal changes associated with menopause or hormonal contraception. The type of caffeine supplement used does not seem to matter, as long as the recommended dose is maintained. For long-distance runners, special drinks containing caffeine and electrolytes during exercise, as well as the occasional energy drink beforehand, seem to be the most beneficial. Natural coffee is also a good source of caffeine.

Caffeine has been shown to increase physical performance, alertness, and reaction time, which is particularly important in sports where time is of the essence and results between athletes are very close. Additional caffeine supplementation can alter the order of athletes at the finish line and guarantee new records.

It also increases VO_2 max, blood pressure, and tidal volume, while reducing feelings of fatigue. Another desirable effect is increased blood flow to tired muscles after exercise, facilitating recovery.

Early symptoms of caffeine overdose to watch out for include anxiety, nervousness, muscle tremors, nausea, vomiting, and insomnia. However, caffeine is generally safe when used with caution and provides athletes with significant training benefits.

Conclusion

Caffeine is a safe and widely available supplement that can benefit athletes involved in endurance sports. Ideally, it should be taken orally 45–60 minutes before exercise, at a dose of 3–6 mg per kg of body weight. Its effects last for an average of up to four hours. It may be necessary to adjust the supplementation method according to individual predispositions. When used strategically, caffeine can enhance long-distance runners' performance and reduce their perceived effort. Optimal benefits are achieved by tailoring dosage and timing, ideally through testing strategies during training. Future studies should focus on female runners and the long-term effects of caffeine in various race environments. Further research on this topic should consider individual differences in caffeine metabolism, particularly concerning gender, and the interaction with other medications and supplements.

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Author's contribution

Conceptualization: Joanna Duda
Methodology: Jakub Kędzia, Joanna Duda, Kinga Racisz
Software: Alicja Obcowska, Paweł Racisz
Check: Kinga Racisz, Paweł Racisz, Alicja Obcowska
Formal analysis: Paweł Racisz, Joanna Duda
Investigation: Joanna Duda, Jakub Kędzia, Kinga Racisz
Resources: Joanna Duda, Alicja Obcowska
Data curation: Jakub Kędzia, Aleksandra Walendzik
Writing-rough preparation: Joanna Duda, Jakub Kędzia, Kinga Racisz
Writing-review and editing: Paweł Racisz, Aleksandra Walendzik
Visualization: Aleksandra Walendzik
Supervision: Joanna Duda, Jakub Kędzia
Project administration: Joanna Duda

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Conflict Of Interest

The authors declare no conflict of interest.

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

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