Acute Effects of Low-Dose Caffeine Intake on Endurance Performance: A Scoping Review and Meta-Analysis

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[Introduction]

Caffeine (1,3,7-trimethylxanthine) is the most commonly consumed psychoactive substance globally and occurs naturally in numerous plant species, such as tea and cocoa. Caffeine exerts a wide range of effects. For instance, it binds to adenosine receptors in the brain, thereby promoting wakefulness and reducing the perception of fatigue during exercise. Additionally, pre-exercise caffeine intake has been reported to elevate blood epinephrine levels, activating the sympathetic nervous system. Furthermore, caffeine consumption is associated with an increase in the release of free fatty acids into the bloodstream, thereby enhancing fat utilization as an energy source.

Many studies have shown that caffeine intake enhances sports performance, with its ergogenic effect improving a wide range of physical activities, including endurance, strength, muscular endurance, team sports, repeated high-intensity exercise, and anaerobic performance.

The International Society of Sports Nutrition has stated that moderate doses of caffeine (3-6 mg/kg) taken 60 minutes before exercise can effectively improve sports performance, but high doses (≥9 mg/kg) do not provide additional benefits. In addition, high doses of caffeine are associated with a high incidence of side effects such as dizziness, increased heart rate, anxiety, tremors, and insomnia. Therefore, to optimize athletic performance and avoid the side effects associated with high doses, it is essential to gather more evidence to explore the dose-response relationship between caffeine and performance enhancement.

This study aims to investigate the effect of low-dose caffeine on endurance performance, hypothesizing that acute intake of low-dose caffeine will improve endurance performance, but to a lesser extent than medium/high-dose caffeine.

[Methods]

The present review builds upon the prior review by Pickering and Kiely (2019), which examined the ergogenic effects of low-dose caffeine on exercise performance, and the data included therein spanned studies published from March 1995 to October 2019. To extend this evidence and incorporate recent advancements in the literature, we searched the PubMed database on 1 July 2024, targeting studies published between 1 January 2019 and 1 July 2024. Search terms included the words "caffeine", "exercise", "performance", and "low dose". Titles and abstracts were carefully read and screened for subsequent full-text review and data extraction. The search for published studies was independently conducted by two authors (JIN and LI), while disagreements between these authors were settled through discussion, with a third author (DW and MM) consulted for input if consensus could not be reached. A total of 241

articles were initially identified. We evaluated 109 full-text articles, and after applying inclusion and exclusion criteria, we included 22 articles in qualitative synthesis (Figure 1).

Study quality was evaluated using the Physiotherapy Evidence Database (PEDro) scale.

Among the studies that evaluated endurance performance, the mean PEDro methodological quality score was 9.77, with the values for individual studies ranging from 6 to 10.

[Results]

A total of 419 participants were included, consisting of 351 males and 68 females (Table 2). According to meta-analysis, caffeine intake led to a pooled improvement of 1.61% in endurance performance (95% CI: 0.90, 2.33). Significant improvements were observed in time to exhaustion (4.08%, 95% CI: 1.54, 6.63; $p < 0.001$), power (2.36%, 95% CI: 0.30, 4.42; $p = 0.02$), and time trial time (1.24%, 95% CI: 0.37, 2.12; $p = 0.01$). On the other hand, there was no significant improvement in work (2.48%, 95% CI: -2.12, 7.07; $p = 0.29$) and maximal/peak oxygen uptake (1.42%, 95% CI: -1.85, 4.69; $p = 0.40$).

Both low (<1mg/kg/day) and high (>3mg/kg/day) habitual caffeine intake groups showed improvements (low: 2.39%, 95% CI: 0.05, 4.73; $p = 0.045$; high: 2.29%, 95% CI: 0.03, 4.56; $p = 0.047$).

Low-dose (<3mg/kg) caffeine did not significantly improve performance (1.01%, 95% CI: -0.21, 2.23; $p = 0.11$), but medium/high-dose (≥3 mg/kg) caffeine resulted in a significant improvement (1.97%, 95% CI: 1.05, 2.89; $p < 0.001$).

[Conclusion]

Acute caffeine intake before exercise can improve endurance performance. Caffeine consistently enhances time to exhaustion, power, and time trial time, but shows no significant effect on work and VO_2 max/peak. These effects are not observed with acute intake of low-dose (<3mg/kg) caffeine. Habitual caffeine intake has no effect on the acute ergogenic effects of caffeine.

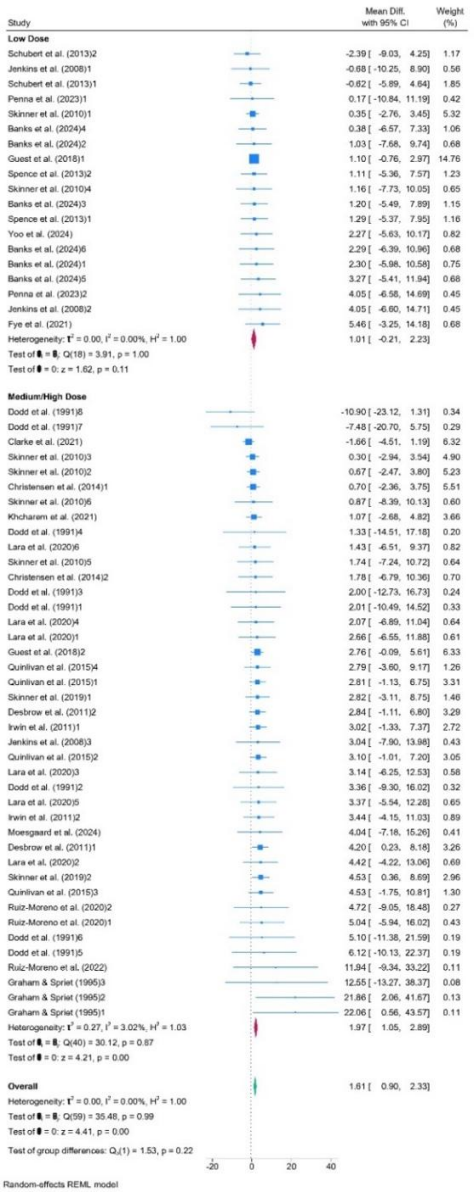

Figure 1. Forest plot of acute effects of caffeine ingestion on endurance performance in the low-dose group (upper) and medium/high-dose group (lower)