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Differential Time-of-Day Effects of Caffeine Capsule and Mouth Rinse on Cognitive Performance in Adolescent Male Volleyball Athletes: A Randomized Crossover Investigation

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Introduction : Caffeine is a widely used ergogenic aid that improves athletic performance, especially when consumed in doses of 3 to 6 mg·kg^{-1} about 60 minutes before exercise (Guest et al., 2021). It enhances both physical performance and cognitive functions like attention and vigilance, which are crucial for athletes. Its main action is blocking adenosine receptors, which increases alertness and response speed. Recent studies show caffeine helps reduce performance drops in the morning, narrowing differences in performance throughout the day (Bougrine, 2024). This makes caffeine especially valuable for sports like volleyball, where fast reactions and strong cognitive control are essential.

Methods: In a randomized, double-blind, crossover design, 24 well-trained male volleyball players (age: 16.9 ± 0.7 years; body mass: 71.0 ± 4.2 kg; stature: 177.0 ± 3.4 cm) completed three sessions at 08h, 12h, and 18h under three supplementation conditions: caffeine capsule (3 mg·kg^{-1}), caffeine mouth rinse without ingestion (3 mg·kg^{-1} with 250ml of water), and placebo. Cognitive outcomes included simple reaction time (SRT), choice reaction time (CRT),Stroop test performance (completion time and errors)and side effect questionnaire. Repeated-measures ANOVAs tested main effects of TOD and condition, and their interaction.

Results: For SRT, significant effects were observed for time ($F(2,48)=8.27$, $p=0.0008$, $\eta p^2=0.26$), condition ($F(2,48)=4.33$, $p=0.0187$, $\eta p^2=0.15$), and time×condition ($F(4,96)=3.79$, $p=0.0066$, $\eta p^2=0.14$). Capsule and mouth rinse improved SRT versus placebo, with the greatest benefits at 12h and 18h. For CRT, there were significant effects of time ($F(2,48)=4.31$, $p=0.0189$, $\eta p^2=0.15$), condition ($F(2,48)=5.66$, $p=0.0062$, $\eta p^2=0.19$), and time×condition ($F(4,96)=3.33$, $p=0.0135$, $\eta p^2=0.12$). Capsules consistently outperformed placebo, and mouth rinse showed intermediate effects. For Stroop Time, significant effects were detected for condition ($F(2,46)=8.21$, $p=0.0009$, $\eta p^2=0.26$) and time×condition ($F(4,92)=3.14$, $p=0.018$, $\eta p^2=0.12$), whereas time alone was not significant ($p=0.931$). For Stroop errors, only the condition effect was significant ($F(2,46)=4.98$, $p=0.011$, $\eta p^2=0.18$). For the side effects the most common item was perceived performance improvement, which differed by condition at 08h, 12h and 18h . Pairwise, capsules > placebo at 12h and 18h, with a trend at 08h; the rinse was intermediate and exceeded placebo at 18h but not at 08h/12h. Headache showed a condition effect at 08h and 12h, driven by higher reports after capsules at 12h versus placebo and rinse; no differences were observed at 18h .(table1)

	08:00			12:00			18:00		
Symptom	Placebo	Caffeine capsule	Caffeine mouth rinse	Placebo	Caffeine capsule	Caffeine mouth rinse	Placebo	Caffeine capsule	Caffeine mouth rinse
Muscle soreness	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Increased urinary output	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tachycardia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anxiety or nervousness	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Headache §	4.2	16.7	0.0	0.0	25.0	4.2	0.0	0.0	0.0
Gastrointestinal problems	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Insomnia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Increased activity	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perceived performance improvement §	12.5	33.3	20.8	12.5	50.0*	33.3	12.5	37.5	37.5

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Discussion: This randomized, double-blind, placebo-controlled crossover study examined caffeine's effects on cognitive performance in trained volleyball players, focusing on time of day and administration mode. Oral caffeine capsules at 3 mg/kg consistently improved cognition, especially during morning and midday sessions, enhancing reaction time and executive control. Conversely, caffeine mouth rinsing had limited benefits, noticeable only midday and on certain tasks. Effects aligned with circadian alertness, with no capsule benefits in the evening when baseline performance was optimal. Evening caffeine raised sleep disturbance risks, indicating caution for late use. The study emphasizes individual differences like genetics and habitual intake impacting caffeine timing and dosing. Results support taking caffeine capsules 30 to 60 minutes before morning or midday training to boost mental sharpness and response speed, enhancing performance during natural alertness dips. This targeted strategy helps athletes optimize cognitive function in critical periods, improving outcomes and training effectiveness.

Biography

Salma Belhaj Amor, researcher affiliated with the Physical Activity, Sport and Health Research Unit at the National Observatory of Sports, Tunisia, and the High Institute of Sports and Physical Education of El Kef, University of Jendouba, Tunisia. Specializes in sports science, exercise performance, cognitive function, caffeine supplementation, and athletic performance. Her research focuses on the effects of caffeine, time of day, and exercise on cognitive and physical performance in athletes. Her work combines experimental sports research with practical approaches to enhance athletic performance and support evidence-based sports nutrition and exercise strategies.

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