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Systematic Review and Meta-Analysis

Effects of Acute Caffeine Ingestion on Physical Performance and Skill Execution in Volleyball Players: A Systematic Review and Meta-Analysis

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Abstract

International Journal of Exercise Science 18(6): 922-948, 2025. https://doi.org/10.70252/FRCN1471 It is well established that oral caffeine administration (3-9 mg/kg) is ergogenic, enhancing numerous aspects of physical performance including strength and power. However, the extent to which these effects translate to volleyball-specific skills remains unclear. The purpose of this study was to systematically review the effects of acute caffeine ingestion on performance outcomes in volleyball-specific actions. A systematic review of published studies was conducted using scientific databases from their inception through December 2024 (registered in PROSPERO, CRD420251006314). We included studies with blinded crossover experimental designs that compared caffeine ingestion to a placebo in samples of volleyball players performing physical performance tests or volleyball-specific tasks. The data from these studies were meta-analyzed to calculate standardized mean differences (Hedges' g) between placebo and caffeine conditions, using a random-effects model. The Q and I^2 statistic was calculated to verify the degree of similarity in the observed mean differences and the degree of heterogeneity, respectively. In total, after examining 60 effect sizes include 9 RCTs, 123 volleyball players with caffeine doses 1.7–6.4 mg/kg and administered 15–60 min pre-exercise, the meta-analysis indicated that caffeine improved performance in jumping activities (g = 0.24, p =0.009), strength-based tasks (g = 0.31, p =0.006) and performance in volleyball-specific skill tasks (g = 0.52, p =0.001). Specifically, subgroup analysis indicated significant improvement with caffeine in attack (g = 0.52, p =0.003), serve (g = 0.44, p =0.046) and accuracy (g = 0.68, p =0.001) tasks, but not in the velocity-based tasks (g = 0.26, p =0.168). Moreover, The I^2 statistics showed low heterogeneity for the studies (I^2 = 0 - 34.6). Acute caffeine ingestion appears to enhance physical performance in volleyball, with positive effects translating in jump and strength-based tests translated into improved skill execution during volleyball-specific tasks. Further research is needed to refine dosing strategies, account for individual differences based on habitual caffeine intake and player position, and assess long-term outcomes of caffeine intake.

Keywords: 1,3,7-trimethylxanthine, elite athletes, intermittent sports, sports performance, team sports

Introduction

Volleyball is a high-intensity team sport that has been part of the Olympic program since its debut at the Tokyo 1964 Olympic Games. Over the past decades, volleyball has experienced exponential growth in popularity and participation. Recent evidence highlights an increasing interest among spectators and enthusiasts, solidifying volleyball's position as one of the most widely played and followed sports worldwide.[1] Each volleyball team consists of six players on a court measuring 18 x 9 meters, divided into two equal halves by a net set at 2.43 m for men and 2.24 m for women. These fundamental rules help define the unique characteristics of volleyball as each player is responsible for covering a small specific section of the court during defensive actions, which involve short, quick movements. Therefore, a combination of agility, reaction, speed, rapid multidirectional movements and special skills (e.g., diving or digging) is required in this sport. Additionally, offensive actions always require attacking the ball over the net, demanding players with tall stature and exceptional jumping ability. Consequently, volleyball players require a combination of excellent jumping and power abilities interspersed with sport-specific skills such as ball striking and blocking. These dynamic actions form the foundation of the fundamental skills and mechanics essential to volleyball[1, 2] and the physical performance nature is characterized by intermittent 3–9-s efforts with high-intensity with 10–20 s periods of recovery between them.[3, 4] In other words, an elite volleyball player is expected to possess high levels of power, agility, speed, and anaerobic capacity, as well as the ability to repeat high-intensity efforts over time. In addition, advanced technical skills—such as serving, spiking, blocking, and ball control in both offensive and defensive actions—are essential for competitive performance. Evidence suggests that improving the ability to perform skill-related ball tasks plays a pivotal role in determining the outcomes of volleyball matches.[2, 5] Therefore, developing strategies to enhance volleyball-specific tasks is crucial for training and pre-competition preparation for both coaches and players, as it is directly linked to a higher likelihood of winning matches and achieving success.

Nutritional strategies such as sports supplements have always been attractive and have received considerable interest from researchers, athletes and coaches. Among these, caffeine (1,3,7-trimethylxanthine) stands out as one of the most widely utilized and studied nutritional supplements in sports.[6, 7] Caffeine is the most widely consumed psychoactive substance in the world, naturally found in various plant species such as coffee and cocoa. Its potent stimulant effects have led to its inclusion in dietary supplements, sports-specific products, over-the-counter medications, and a vast array of food and beverage items.[8, 9] The ergogenic potential of caffeine has been studied and identified since 1907[10] and has been consistently confirmed by numerous investigations across various domains of physical performance, including aerobic and anaerobic capacity,[11] agility,[12] linear and repeated sprints,[9] strength, high-intensity exercise[7-9] and resistance exercise.[13] In addition, over the past few decades, the ergogenic aid of caffeine has been studied and proven for athletes in various team-based sports, including basketball,[14] football[15] and rugby.[16] As a result, the systematic review of these studies have suggested that oral caffeine intake between 3 and 9 mg/kg and around 60 min before exercise is an effective supplementation strategy to enhance physical aspects of teams sports performance.[9] While the physical performance benefits of caffeine supplementation are well-documented, fewer studies have explored how these benefits translate into improved sport-specific actions.[17] Recent reviews and meta-analyses[17, 18] have addressed this gap, revealing that caffeine ingestion enhances the success rate of actions in real or simulated competition across team, racket, and combat sports. Additionally, caffeine has been associated with increased high-intensity sport-specific actions, such as the number of sprints, accelerations, and offensive efforts during real and simulated sports competitions. These documented benefits may be attractive to a volleyball coach or physical trainer, and seem to be able to influence a volleyball player's performance. However, despite sharing a high-intensity, intermittent nature, team sports, racket sports, and combat sports differ significantly in their characteristics. Therefore, the ergogenic effects of caffeine observed in other sports cannot be directly extrapolated to volleyball, a sport characterized by unique motor patterns, rapid transitions between offensive and defensive actions, and a heavy reliance on explosive and technically demanding skills.[8] As such, sport-specific investigations are essential to determine whether caffeine supplementation truly enhances both physical and skill-based performance in volleyball.

For this reason, over the past decade, a growing body of research has been conducted to identify the potential ergogenic effects of caffeine in volleyball. The physical performance demands, anthropometric profiles, and training status of volleyball players are considerably different from those of athletes in other sports. Therefore, it is essential not only to evaluate the ergogenic effects of caffeine on general physical attributes, but also to determine whether these benefits translate into improved volleyball-specific performance. For this reason, over the past decade, a growing body of research has been conducted to identify the potential ergogenic effects of caffeine in volleyball players. Volleyball, in particular, is unique due to the short duration of its actions and the requirement to play over the net. Physical performance, anthropometric profiles, and training status of volleyball players are considerably different from other athletes. Therefore, generalizing findings from studies conducted in other athletes such as football to volleyball players may lead to substantial inaccuracies. Therefore, analyzing the effects of caffeine in volleyball players and their specific actions is essential to fully understand its impact as a performance-enhancing stimulant and it can bring important achievements and information to volleyball coaches and athletes so that they can benefit from the possible ergogenic aids of caffeine to improve performance and enhance the level of physical performance of themselves or the players under their leadership. However, despite the growing interest, the available evidence has not been conveniently summarized, making it difficult to draw clear, sport-specific conclusions about caffeine's ergogenicity in volleyball and therefore, it is not possible to provide comprehensive and accurate guidance and recommendations to volleyball coaches and players. To address this scientific gap, the current study systematically reviewed the effects of acute caffeine ingestion on both physical and skill-based performance outcomes in volleyball players. We hypothesized that oral caffeine intake would effectively increase the several physical performance variables in volleyball players and it would enhance performance in volleyball-specific technical actions.

Methods

Literature search strategy

This systematic review with meta-analysis was registered in PROSPERO (code: CRD420251006314), was conducted in accordance with the methods outlined in the Cochrane Handbook.Tthe literature search and writing process was performed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [19]. The PRISMA checklist is provided as Supplemental Appendix A. The literature search was performed in 7 databases: MEDLINE (via PubMed), Scopus, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, Google Scholar, SPORTDiscus, and Embase to identify related studies in English. The search terms included a mix of Medical Subject Headings (MeSH) and free-text words for key concepts related to the effect of caffeine on volleyball. Articles were systematically identified using the following search syntax: concept 1 ("caffeine" OR "energy drink" OR "caffeinated chewing gum") AND concept 2 volleyball AND concept 3 ("spike" OR "serve" OR "block" OR "fitness" OR "jump" OR "power" OR "strength" OR "agility" OR "sprint" OR "performance"). The search was conducted without any publication year restriction and no filters were used. The literature search concluded on December 31, 2024. All titles and abstracts from the search were downloaded to the EndNote software (X8; Clarivate Analytics, New York, USA) and manual cross-referencing was performed to identify duplicates. Studies that potentially investigated the effect of caffeine on physical performance and skill-based tasks of volleyball players were selected based on the title and abstract screening. . Subsequently, studies were screened for a full-text review. Reviews, meta-analyses, and references from the related articles were screened for additional records. Literature search was conducted by two independent reviewers who screened each article based on the title, keywords and abstract to ensure that all articles were captured. Cases of disagreement were resolved via discussion between the researchers.

Study selection

To warrant inclusion in the current review, potential studies were required to meet the following PICOS criteria:[20]

Participants. Studies involving young or adult volleyball players (15 years or older) were included, without restrictions on skill level (professional or amateur) or playing position (e.g., setter, libero, etc.).

Intervention. Studies involving caffeine ingestion with clear details on its administration (e.g., dosage, timing of intake) were eligible for analysis. Caffeine intake in any form (e.g., capsule, gum, or energy drink) was considered. We considered any form of caffeine intake to be included in the review, but only if the effect of caffeine could be isolated. Only studies investigating acute caffeine ingestion were included in the systematic review and meta-analysis. Studies with chronic ingestion of caffeine or those with combined caffeine ingestion with an exercise program or other interventions (e.g., post-activation protocols) were excluded.

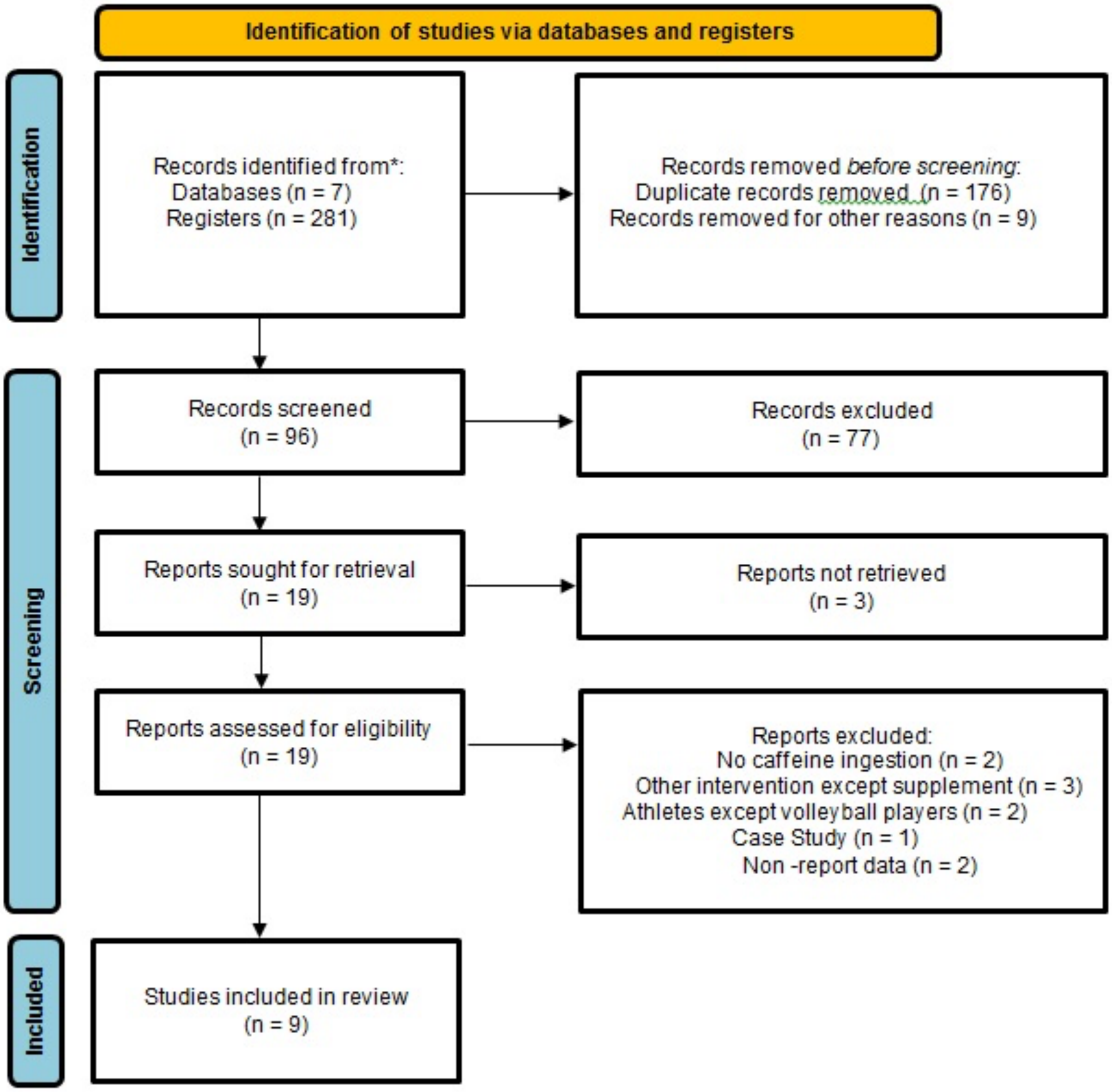

Figure 1. Flow diagram of the literature search and selection criteria.

Comparison. Studies that compared the effects of caffeine to a placebo were deemed eligible. Studies without a placebo or control condition, including those with only a single caffeine ingestion condition, were excluded.

Outcomes. The primary focus of the analysis was the difference in physical performance variables and skill-based tasks between the caffeine and placebo/control conditions in volleyball players.

Study designs. Studies with a single or double-blinded and randomized crossover design in which there was an experimental condition that included the ingestion of caffeine which was compared to an identical experimental situation without caffeine. Studies were included only if they had data available for the calculation of the effect size associated with caffeine on any volleyball-specific performance variable. Systematic reviews and meta-analyses were excluded, in addition to those original studies with no full-text available, no peer-reviewed articles, opinion pieces, commentaries, case reports and editorials.

Outcome measures and data extraction

For all studies meeting the inclusion criteria, the information extracted included data on study source, study design, study quality, sample size, characteristics of the participants (i.e., age, level and gender), habitual caffeine intake by the participants, caffeine form administration (i.e., dose and timing) and main performance. Data were extracted independently by the two authors and disagreements were resolved through discussion. Experiments were clustered by the type of performance test used to assess the effect of caffeine on volleyball-specific performance (jumping, strength-based, power-based, running-based and skill-based tests). Additionally, if essential information (e.g., data required for effect size calculation) was unavailable, the corresponding author was contacted via email to obtain the necessary data

Quality assessment of the included studies

Methodological quality within the included studies was evaluated with the original 11-item Physiotherapy Evidence Database (PEDro) scale, which is described in detail elsewhere [21]. This scale characterizes the methodological quality based on 11 criteria and each criterion was rated with '1' (indicating that the criterion has been met) or '0' (indicating that the criterion has not been met), whereby score 0-4 reflect low methodological, 5 or 6 reflect fair, and 7-10 reflect high methodological quality.[22] Two authors independently rated studies and obtained an inter-rater correlation coefficient (ICC) of 0.86 ($p = 0.002$). Cases of disagreement were resolved via discussion between the researchers.

Data analysis

The Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA) was used for the meta-analyses. Meta-analyses were conducted to compare the acute effects of caffeine versus placebo on performance outcomes, using group means, standard deviations, and the number of participants for each outcome in each study. Standardized mean differences (SMD) were calculated using Hedges' *g*, with 95% confidence intervals (CI) included. As recommended previously[23] and due to the lack of reporting correlation in the reviewed studies, a 0.5 correlation was assumed for all trials. The effect sizes were categorized as small (SMD ≤ 0.2), medium (SMD 0.2–0.5), large (SMD 0.5–0.8), and very large (SMD > 0.8).[24] The Q and I^2 statistic was calculated to verify the degree of similarity in the observed mean differences and the degree of heterogeneity, respectively. An I^2 value ≤ 50%, 50 – 75% and > 75% indicated low, moderate and high level of heterogeneity, respectively. Funnel plots were constructed asymmetrically by plotting the standard error against the effect size. The random-effects model was used for the analysis of all outcomes due to the heterogeneity found and $p < 0.050$ was considered as the statistical significance threshold to identify the ergogenic effect of caffeine in any performance variable. Sensitivity analyses were performed for all the performance variables included in the meta-analysis to examine the robustness in the magnitude and direction of the performance effects of caffeine by repeating the meta-analysis with the removal of studies with unexpected results.[25]

Based on the type of test used to assess performance, a meta-analysis was performed to assess the effect of caffeine ingestion on jumping tests (e.g. squat hump), running-based tests (agility and sprint), power-based tests (e.g. Wingate anaerobic test), strength tests (e.g. hand grip strength test), and skill-based tasks of volleyball (e.g., attack accuracy). In studies that included performance measurements on a simulated match, negative and positive actions were used to assess the effect of caffeine. In cases where two or more types of performance outcomes (e.g., agility and strength) were measured, each experiment was treated as an independent data set for the meta-analysis. Similarly, when multiple types of experiments assessed the same performance outcome (e.g., countermovement jump and squat jump), each was considered separately. Performance outcomes evaluated in two or fewer eligible studies were excluded from the meta-analysis. Lastly, if a study utilized different caffeine doses, each dose was treated as an independent data set for analysis. Subgroup analyses were performed for the following study characteristics: a) gender, b) caffeine dosage (low dose: 1-4 mg/kg or moderate dose: ≥ 5 mg/kg), c) time of caffeine consumption (morning or evening), d) caffeine consumption form (chewing gum, energy drink or capsule), e) time interval between caffeine consumption and performance assessment, f) experiments type, and g) participants' habitual caffeine intake.

Results

Search results

The search through the 7 databases produced a total of 281 documents in the initial stage, and only 9 studies[26-34] were eligible to be included in this review after removing duplicates and applying the inclusion and exclusion criteria (figure 1).

Selected studies and participants

The included studies were published between 2014 and 2024. All studies were randomized controlled trials with a double-blind experimental protocol. The characteristics of the 9 eligible studies regarding participation and caffeine administration protocols are reported in Table 1. The pooled number of participants across the included studies was 123 participants; 68 of them were males (55%) and 55 of them were females (45%). Of the studies included, four focused exclusively on female athletes[27, 29, 32, 34], another four examined only male athletes[28, 30, 31, 33], and one included participants of both sexes.[26] The participants' age was more than 15 years (15-35 years); therefore, all participants were classified as young or adolescents. The majority of athletes recruited in the eligible studies were professional or semi-professional volleyball players. However, three studies included collegiate-level players.[28, 31, 33]Additionally, five studies required a minimum level of sports experience for inclusion, specifying that participants had at least four years of volleyball training experience.[26, 28-30, 34] The PEDro Scale score was 9 points in seven studies and 10 points in two studies, indicating that the quality of these investigations can be classified as high.

The average dose used in the studies was 5.69 ± 2.72 mg/kg (if the weighting effect of sample size is considered: 4.22±164 mg/kg), with a minimum and maximum range of 1.6[27] to 6.4 mg/kg[32], respectively. Five studies used low doses of caffeine[26-29, 31] and 5 studies used moderate doses.[30-34] It is worth noting that one study compared low and moderate doses of caffeine.[31] The most common timing for caffeine ingestion was 60 min before the experiment, as reported in six studies.[28-31,34] In contrast, ingestion 15 minutes prior was used in two studies,[26,32] while 30 minutes[27] or immediately before[33] were each reported in one study. The forms of caffeine administered included capsules (three studies),[30, 31, 33] energy drinks (three studies),[27-29] chewing gum (two studies),[26,32] and liquid (one study).[34] Four studies conducted caffeine ingestion in the evening,[26,28,32,34] three in the morning,[27, 30, 31] and two did not provide timing details.[29,33] Regarding habitual caffeine intake, three studies reported consumption of ≤100 mg/day,[28,30,34] three studies reported >100 mg/day,[26, 32, 33] and three studies did not disclose this information.[27,29,31]

The performance tests conducted in the eligible studies were classified into 5 categories including: jumping performance, running-based performance, strength-based performance, power-based performance and skill-based tasks of volleyball. Among the experiments conducted to evaluate jumping performance (8 studies), the CMJ test was the most frequent (6 studies), followed by the squat jumping (4studies). Among the experiments carried out to evaluate running-based performance (5 studies), the agility T test was the most frequent test (3 studies). In addition, 5 studies (of 5 studies) used hand grip strength and 2 studies (of 4 studies) used a 15-second jump test to elevate strength and power performance, respectively. Finally, out of the 6 studies focusing on skill-based task of volleyball, 4 studies examined experiments related to attack, 3 studies examined experiments related to serve, and 3 studies examined overall results of caffeine on the volleyball games.

Meta-analysis results

Physical performance.

Figure 2 shows the overall effect of caffeine intake on the jumping performance of volleyball players. Results of the meta-analysis indicated a jumping performance benefit of caffeine over the placebo (g = 0.24, 95% CI = 0.053-0.415, medium effect, p = 0.009). The I^2 statistics showed low heterogeneity for the studies assessing jumping performance (I^2 = 0.0; p = 0.943). When the study that used an energy drink with very low caffeine content[27] was removed from the analysis, the results were still statistically significant (g = 0.25, 95%CI = 0.63-0.444, medium effect, p = 0.009). The analysis of funnel plots did not reveal substantial asymmetry. A subgroup analysis indicated an ergogenic effect of caffeine at moderate dose (g = 0.49, 95% CI = 0.129-0.853, medium effect, p = 0.008) but not at low dose (g = 0.16, 95% CI = -0.043-0.356, medium effect, p = 0.124). An ergogenic effect of caffeine was observed exclusively with capsule administration (g = 0.56, 95% CI: 0.127–1.001, large effect, p = 0.011). When comparing habitual caffeine intake, low consumers demonstrated a significant effect following caffeine ingestion (g = 0.55, 95% CI:

Table 1. Summary of the studies included in the systematic review.

Study	Design	PEDro score	Age (years)	Sample size and sex	Level of players	Caffeine form	Caffeine dose (mg/kg)	Ingestion timing (min)	Ingestion time	Habitual caffeine intake	Performance tests
Kaszuba et al. 2023	RDB	10	23±3	9 male 3 female	At least 5 years of volleyball training experience	Chewing gum	3.2±0.4	15	Evening	2.7±2.2 mg/kg/day	CMJ, SqJ, Attack and block jump, 5 and 10 m sprints, modified agility t-test, Attack and service velocity, Spike and serve accuracy
Fernández-Campos et al. 2015	RDB	9	22.3±4.9	19 female	Elite league of Costa Rica	Energy drink	1.67	30	Morning	NA	Hand grip strength, CMJ, SqJ, Wingate anaerobic test
Del Coso et al. 2014	RDB	9	21.8±6.9	15 male	College volleyball team at least 4 years of volleyball	Energy drink	3.0	60	Evening	<30 mg/day	Hand grip strength, Attack velocity, SqJ, CMJ, 15-s jump, Agility T-test, Game action

					training experience						
Perez-Lopez et al. 2014	RDB	9	25.2±4.8	13 female	Second division of the Spanish National league at least 6 years of volleyball training experience	Energy drink	3.0	60	NA	NA	Hand grip strength, Attack and block jump, Attack velocity, SqJ, CMJ, Agility T-test, Game actions
Zbinden-Foncea et al. 2018	RDB	9	18.8±2	10 male	Chilean national team at least 6 years of volleyball training experience	Capsule	5.0	60	Morning	61.60±54.32 mg/day	CMJ
Nemati et al. 2023	RDB	9	20.8±1	15 male	collegiate volleyball players	Capsule	3.0 and 6.0	60	Morning	NA	Hand grip strength, Upper body explosive power, SJ, Illinois agility, Attack

											and serve accuracy
Filip-Stachnik et al. 2022	RDB	10	20±2	12 female	Second division of the Polish National league	Chewing gum	6.4±0.2	15	Evening	2.7±2.1 mg/kg/day	Attack and block jump, Game actions
Soares et al. 2016	RDB	9	24±4	19 male	college volleyball players	Capsule	6.0	Immediately before	NA	171±132 mg/day	Serve accuracy
Siquier-Coll et al. 2024	RDB	9	17-25	8 female	Spanish Women's Superleague 2 at least 5 years of volleyball training experience	Liquid	5.0	60	Evening	<100 mg/day	Hand grip strength, CMJ, COD 505 agility test, 15-s jump

0.151–0.942, large effect, p = 0.007), whereas no significant effect was observed in high consumers (g = -0.01, 95% CI: -0.319–0.312, small effect, p = 0.983). The remaining subgroup analysis for jumping performance results are demonstrated in Table 2.

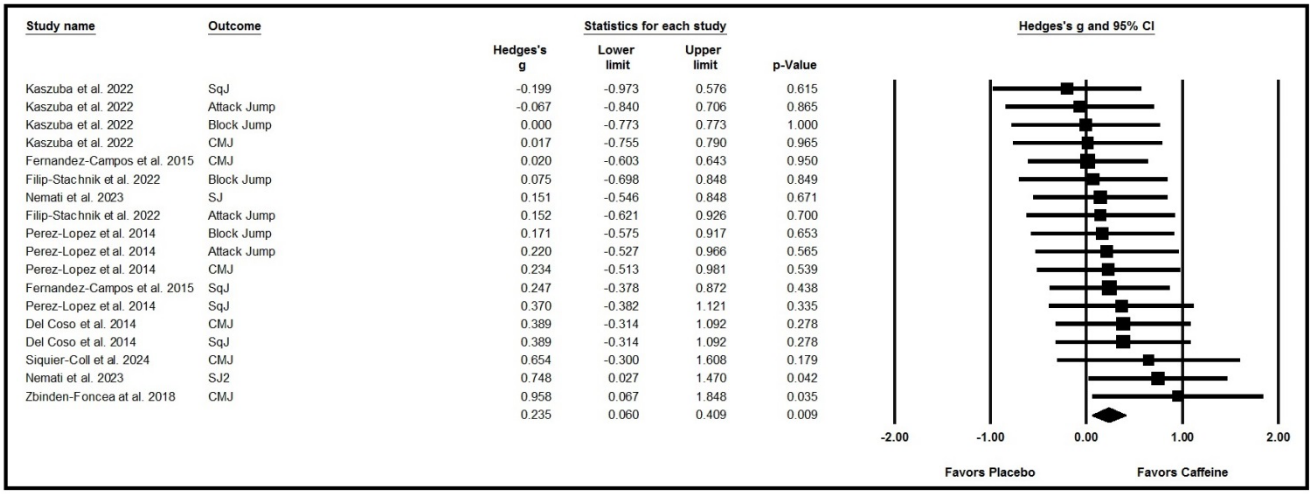

Figure 2. Forest plot showing the effect of oral acute caffeine intake over placebo on jumping performance in volleyball players. The size of the plotted squares reflects the relative statistical weight of each study. The diamond at the bottom of the graph represents the pooled standardized mean difference following random effects meta-analyses using the Hedges' g. CMJ: countermovement jump; SqJ: squat jump; SJ: Sargent jump; 2: experiment at 6 mg/kg caffeine ingestion condition in Nemati et al. 2023.

Figure 3 shows the overall effect of caffeine intake on running-based performance tests in volleyball players. Results of the meta-analysis indicated no significant difference (Hedge's g = 0.28, 95%CI = -0.007-0.570, medium effect, p = 0.056) between the placebo and caffeine trials, suggesting potential practical relevance despite statistical non- significance. The I^2 statistic showed low heterogeneity for the studies assessing running performance (I^2 = 12.47; p = 0.33). The analysis of funnel plots did not reveal substantial asymmetry. Subgroup analysis demonstrated that caffeine ingestion 60 min before the onset of performance assessment significantly enhanced running-based performance (Hedge's g = 0.43, 95%CI = 0.087-0.767, medium effect, p = 0.014). The remaining subgroup analysis for jumping performance results are demonstrated in Table 2.

Figures 4 and 5 show the overall effect of caffeine intake on power and strength performance tests, respectively. Results of the meta-analysis indicated a significant difference between the placebo and caffeine trials for strength-based performance tests (g = 0.31, 95% CI = 0.098-0.529, medium effect, p = 0.006) but not for power-based performance (g = 0.30, 95% CI = -0.019-0.621, medium effect, p = 0.065). When the study that used an energy drink with a very low caffeine content[27] was removed from the analysis, the results did not change. The I^2 statistic showed low heterogeneity for the studies assessing strength and power performance (I^2 = 0.0 and 0.0; p = 0.641 and 0.923, respectively). The analysis of funnel plots did not reveal substantial asymmetry. An ergogenic effect of caffeine for strength performance was found in right hand (g = 0.37, 95% CI = 0.061-0.684, medium effect, p = 0.019) but not in left hand (g = 0.25, 95% CI = -0.065-0.557, medium effect, p = 0.121).

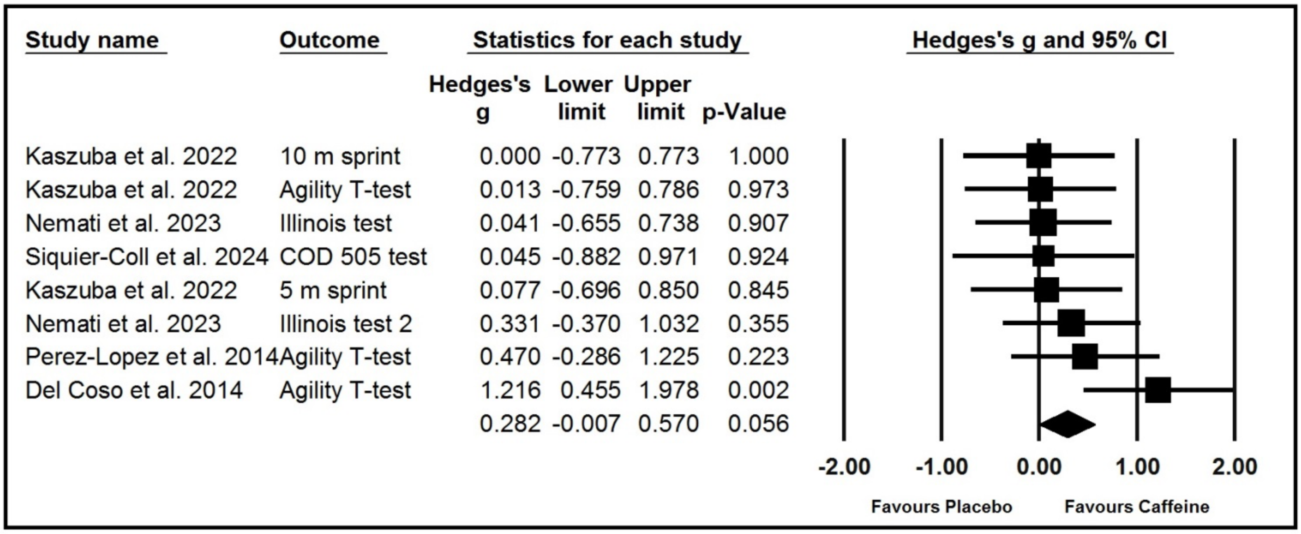

Figure 3. Forest plot showing the effect of oral acute caffeine intake over placebo for running-based performance tests in volleyball players. The size of the plotted squares reflects the relative statistical weight of each study. The diamond at the bottom of the graph represents the pooled standardized mean difference following random effects meta-analyses using the Hedges' *g*. COD 505 test: change of direction speed test; 2: experiment at 6 mg/kg caffeine ingestion condition in Nemati et al. 2023.

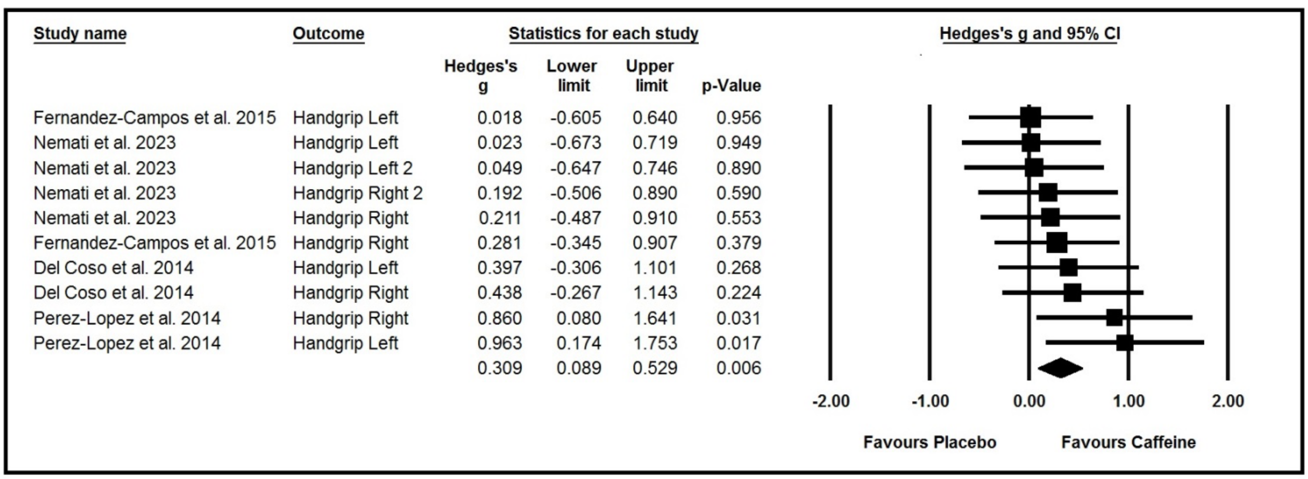

Figure 4. Forest plot showing the effect of oral acute caffeine intake over placebo for strength-based performance tests in volleyball players. The size of the plotted squares reflects the relative statistical weight of each study. The diamond at the bottom of the graph represents the pooled standardized mean difference following random effects meta-analyses using the Hedges' g. 2: experiment at 6 mg/kg caffeine ingestion condition in Nemati et al. 2023.

Skill-based task of volleyball.

Figure 6 depicts the results of the meta-analysis for the effect of oral acute caffeine intake over placebo in skill-based tasks of volleyball. Caffeine demonstrated an ergogenic effect in improving performance in these tasks of volleyball (g = 0.515, 95% CI = 0.302-0.728, large effect, p = 0.001). The I^2 statistic showed low heterogeneity for the studies assessing jumping performance (I^2 = 34.61; p = 0.07). The analysis of funnel plots did not reveal substantial asymmetry. A subgroup analysis indicated an ergogenic effect of low (g = 0.459, 95% CI = 0.257-

0.661, medium effect, p = 0.001) and moderate (g = 0.636, 95% CI = 0.308-0.963, large effect, p = 0.001) dose of caffeine. Moreover, the results emphasized the ergogenic effect of caffeine for total point (g = 0.578, 95% CI = 0.171-0.984, large effect, p = 0.005), serve (g = 0.437, 95% CI = 0.008-0.869, medium effect, p = 0.046) and attack (g = 0.524, 95% CI = 0.176-0.871, large effect, p = 0.003) tasks. Moreover, the results revealed an ergogenic effect of caffeine in the accuracy tasks (g = 0.678, 95% CI = 0.338-1.018, large effect, p = 0.001), but not in the velocity tasks (g = 0.263, 95% CI = -0.111-0.636, medium effect, p = 0.168). The remaining subgroup analysis for skill-based tasks results are depicted in Table 2.

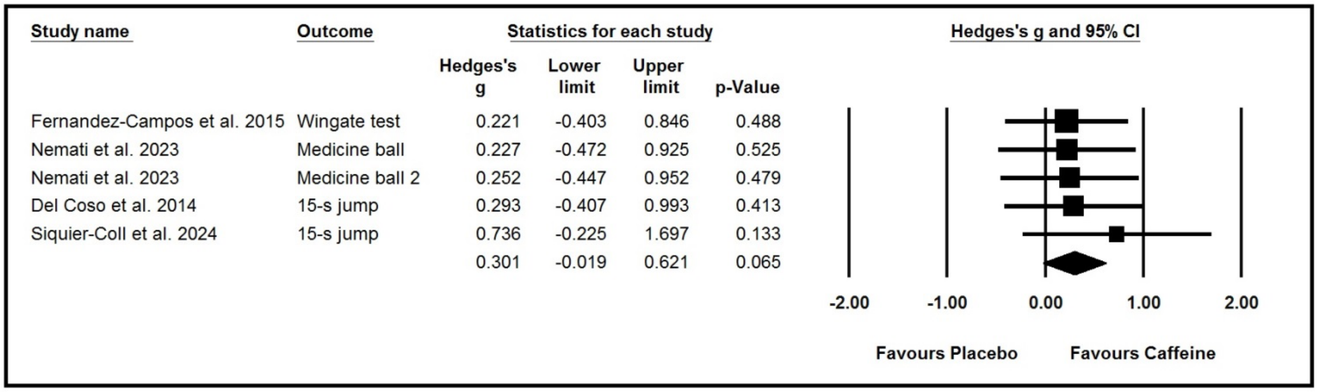

Figure 5. Forest plot showing the effect of oral acute caffeine intake over placebo for power-based performance tests in volleyball players. The size of the plotted squares reflects the relative statistical weight of each study. The diamond at the bottom of the graph represents the pooled standardized mean difference following random effects meta-analyses using the Hedges' g. 2: experiment at 6 mg/kg caffeine ingestion condition in Nemati et al. 2023.

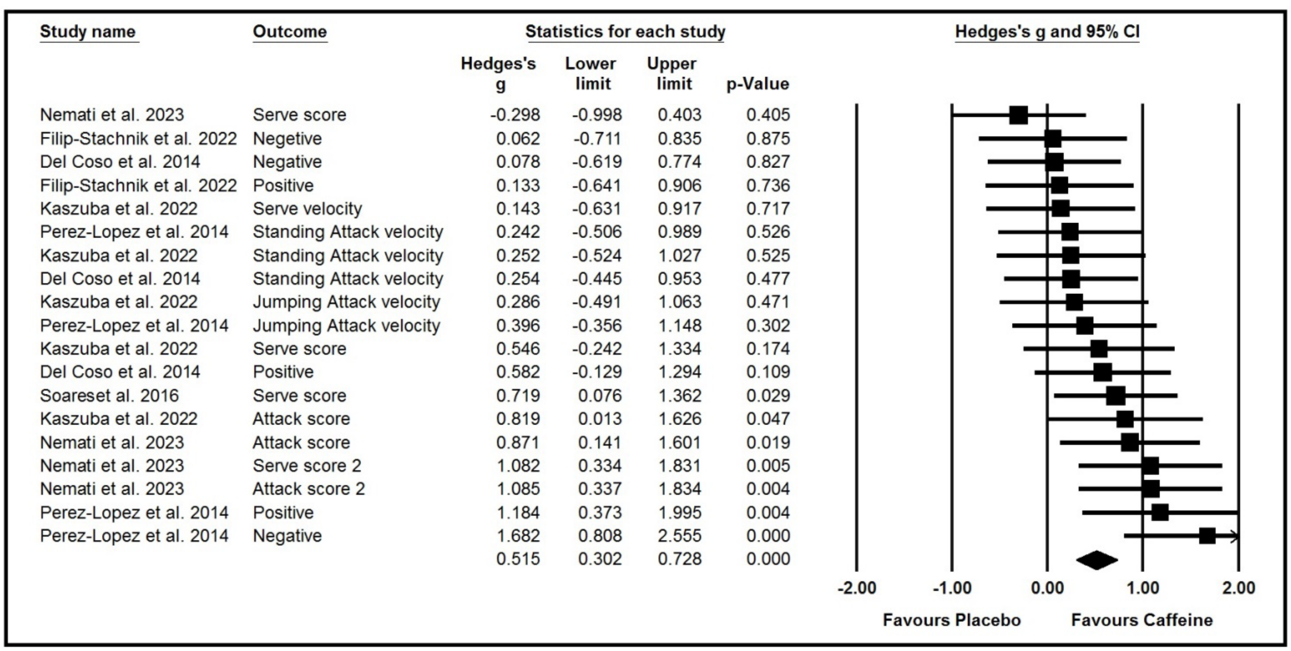

Figure 6. Forest plot showing the effect of oral acute caffeine intake over placebo for skill-based tasks in volleyball players. The size of the plotted squares reflects the relative statistical weight of each study. The diamond at the bottom of the graph represents the pooled standardized mean difference following random effects meta-analyses using the Hedges' g. 2: experiment at 6 mg/kg caffeine ingestion condition in Nemati et al. 2023.

Table 2. Subgroup meta-analyses showing the effect of oral acute caffeine intake over placebo on several aspects of physical performance in volleyball players.

Subgroup analysis		**Hedge's g**	**Lower limit**	**Upper limit**	***p*-value**
Jumping performance					
Eperiments type	CMJ and SqJ	0.269	0.036	0.501	**0.024***
	Attack and block jump	0.156	-0.224	0.536	0.421
Dosage	Low dose	0.157	-0.043	0.356	0.124
	Moderate dose	0.491	0.129	0.853	**0.008***
Gender	Male	0.248	-0.046	0.542	0.098
	Female	0.361	0.098	0.625	**0.007***
Caffeine form	Capsule	0.564	0.127	1.001	**0.011***
	Energy drink	0.247	-0.001	0.494	0.051
	Chewing gum	-0.003	-0.319	0.312	0.983
Time interval between consumption and experiments	60 min before the experiments	0.401	0.162	0.639	**0.001***
	< 60 min before the experiments	0.043	-0.214	0.300	0.744
Time of caffeine consumption	Morning	0.296	-0.100	0.691	0.143
	Evening	0.149	-0.108	0.405	0.256
Habitual caffeine intake	≤ 100 mg/day habitual intake	0.547	0.151	0.942	**0.007***
	> 100 mg/day habitual intake	-0.003	-0.319	0.312	0.983
Running-based performance					
Experiments type	Agility tests	0.360	0.025	0.696	**0.035***
Dosage	Low dose	0.300	-0.055	0.656	0.098
	Moderate dose	0.218	-0.424	0.861	0.506
Gender	Male	0.496	0.046	0.947	**0.031***
	Female	0.295	-0.330	0.920	0.354
Caffeine form	Energy drink	0.840	0.304	1.376	**0.002***
	Chewing gum	0.030	-0.416	0.476	0.895
Time interval between consumption and experiments	60 min before the experiments	0.427	0.087	0.767	**0.014***
	< 60 min before the experiments	0.030	-0.418	0.479	0.895
time of caffeine consumption	Evening	0.286	-0.121	0.694	0.168
Habitual caffeine intake	> 100 mg/day habitual intake	0.030	-0.429	0.489	0.898
Strength performance					
Experiments type	Right hand	0.372	0.061	0.684	**0.019***
	Left hand	0.246	-0.065	0.557	0.121
Dosage	Low dose	0.356	0.110	0.602	**0.005***
Gender	Male	0.197	-0.043	0.437	0.108
Caffeine form	Capsule	0.119	-0.230	0.467	0.505
	Energy drink	0.436	0.152	0.719	**0.003***
Time interval between consumption and experiments	60 min before the experiments	0.362	0.108	0.616	**0.005***
Power performance					
Experiments type	Lower body power	0.345	-0.075	0.764	0.107
Dosage	Low dose	0.260	-0.235	0.754	0.303

	Moderate dose	0.420	-0.146	0.985	0.146
Gender	Male	0.247	-0.093	0.586	0.154
Caffeine form	Energy drink	0.253	-0.213	0.719	0.288
Time interval between consumption and experiments	60 min before the experiments	0.329	-0.043	0.710	0.083
Time of caffeine consumption	Evening	0.446	-0.120	1.012	0.122
Habitual caffeine intake	≤ 100 mg/day habitual intake	0.460	-0.127	1.048	0.125
Skill-based task					
experiments type	Total point	0.578	0.171	0.984	**0.005***
	Attack tasks	0.524	0.176	0.871	**0.003***
	Serve tasks	0.438	0.007	0.869	**0.046***
	Accuracy tasks	0.678	0.338	1.018	**0.001***
	Velocity tasks	0.263	-0.111	0.636	0.168
Actions	Positive actions	0.621	0.050	1.192	**0.033***
	Negative actions	0.533	-0.044	1.110	0.070
Dosage	Low dose	0.474	0.221	0.727	**0.001***
	Moderate dose	0.629	0.213	1.044	**0.003***
Gender	Male	0.536	0.203	0.870	**0.002***
	Female	0.581	0.171	0.990	**0.005***
Caffeine form	Capsule	0.678	0.274	1.082	**0.001***
	Energy drink	0.582	0.228	0.935	**0.001***
	Chewing gum	0.315	-0.047	0.677	0.088
Time interval between consumption and experiments	60 min before the experiments	0.613	0.334	0.892	**0.001***
	< 60 min before the experiments	0.378	0.046	0.709	**0.026***
Time of caffeine consumption	Evening	0.310	0.039	0.582	**0.025***
Habitual caffeine intake	≤ 100 mg/day habitual intake	0.302	-0.198	0.802	0.236
	> 100 mg/day habitual intake	0.319	-0.039	0.678	0.081

Subgroup analyses for the effect of caffeine were performed for gender, caffeine dosage, timing of caffeine consumption, caffeine consumption form and participants' habitual caffeine intake. Subgroup analysis is only reported if 2 studies were included in the analysis. Low dose: 1-4 mg/kg and moderate dose: ≥ 5 mg/kg.

Discussion

The present systematic review and meta-analysis aimed to summarize the evidence regarding the potential ergogenic effects of caffeine on physical performance and skill-based tasks in volleyball. A total of nine studies met the inclusion criteria for the review, and 60 effect sizes were generated based on the experiments pairwise caffeine-placebo comparisons and different caffeine administration protocols. Overall, the meta-analyses highlighted the ergogenic benefits of caffeine, particularly for improving jumping and strength-based performance in terms of physical performance. In other hand, the meta-analysis did not reach statistical significance for the effect of caffeine on running- and power-based performance tests, but they always reflected a positive effect with g values ranging from 0.28 and 0.31 (p values < 0.07) for these variables. One of the more novel findings of this study is the meta-analysis of caffeine impact on performance in skill-based tasks of volleyball reflected a positive influence of this stimulant, suggesting an ergogenic effect of caffeine not only on physical performance of volleyball players but also in their capacity to execute volleyball-specific actions.

The pooled effects of caffeine on performance variables were medium-to-large while previous evidence suggested that even small improvements in performance may translate to considerable improvements in outcomes in a real competition.[17, 35] Volleyball is classified as a team sport, and when the results of the current study are specifically compared with a previous meta-analysis on team sports athletes,[9] it is clear that despite the similarity in results direction and confirmation of caffeine's ergogenic benefits in both studies, the magnitude of the observed effect size is significantly different. It should be noted that in the meta-analysis of team athletes,[9] less than 15% of the athletes were volleyball players, and most of the athletes included in the analysis were involved in sports such as rugby and football, which have different nature, specific needs, and training from volleyball. In other words, this emphasizes that caffeine consumption should be personalized based on the sport and its needs. Overall, our findings suggest that the physical performance benefits of caffeine may translate into enhanced execution of volleyball-specific actions. As a result, caffeine can be considered as an effective substance to enhance volleyball performance.

The current findings are consistent with the results of several review and meta-analyses studies that have demonstrated the benefits of caffeine ingestion.[12, 17, 36] In a meta-analysis study conducted by Grgic et al. 2018 to determine the effect of caffeine consumption on power and muscle strength,[36] it was found that caffeine provided significant ergogenic effects on power and muscle strength (Hedges' g: 0.17 and 0.20, respectively). Additionally, small to medium effect was reported for caffeine that which was similar to the current finding for strength. The participants analyzed in the current meta-analysis were professional and semi-professional volleyball players, while in the Grgic et al. 2018 study, athletes from all sports and even untrained individuals were included.[36]

Although the mechanisms for the effects of caffeine during sports competition are not fully understood, there is a consensus to establish the ability of caffeine to act as an adenosine A1 and A2A receptor antagonist as the main mechanism to explain caffeine erogenicity during exercises of different nature.[17, 36, 37] In the context of this investigation, the blockade of adenosine receptors by caffeine is believed to influence the release of neurotransmitters associated with reduced fatigue and pain perception. Consequently, oral caffeine intake prior to exercise may lead to an improved physical state, enabling enhanced performance at the same level of fatigue. This improvement could support volleyball players in executing demanding actions such as serving and spiking, as well as in tasks requiring precision, such as accuracy-based skills. Other mechanisms associated with caffeine's ergogenicity are higher muscle calcium release through the modulation of calcium ion channels of cell membranes.[38] In fact, caffeine serves to sensitize the ryanodine receptor to $Ca2+$, thereby promoting endoplasmic reticulum $Ca2+$ release.[38, 39] This process can have a strengthening effect on muscle contraction, thereby augmenting muscle functionality and performance. Therefore, these mechanisms underscore caffeine's multifaceted role in enhancing both physical and skill-based performance in volleyball players.

One major novelty of the current meta-analysis is investigating the possible ergogenic aid of caffeine on skill-based tasks of volleyball. The overall pooled effects of caffeine were large. A volleyball game would go far beyond physical performance because other crucial aspects throughout the game such as accuracy, good decision making and technical precision, play an important role.[1, 40] The most similar meta-analysis available was conducted by Diaz-Lara et al. 2024 which reported small to medium effect of caffeine in several aspects of high-intensity intermittent sports (SMD; 0.44-0.57).[17] Only 8% of eligible studies (2 out of 24 studies) in mentioned review involved volleyball athletes, while the majority of the meta-analysis focused on football, basketball, and rugby players. In other words, sport-specific actions that have been part of this meta-analysis were very extensive and diverse such as serve, spikes, digs (volleyball), successful ball throws (basketball), throws, sweeps, submissions (Brazilian jiu-jitsu) and percentage of points won in a match (tennis).[17] However, the current analysis focused specifically on volleyball to more accurately determine the ergogenic effect of caffeine. We categorize skill-based tasks into 5 group include total point (positive or negative scores), attack, serve, accuracy and velocity tasks (table 2). The analysis revealed significant medium to large effect of caffeine ingestion on all skill-based tasks, expect for velocity tasks. Traditionally, it was argued that despite the positive effects of caffeine on physical performance, it should not be consumed by team sport athletes due to its potential impact on technical and tactical components. However, the findings of the current investigation dispel this myth, clearly demonstrating that caffeine provides measurable benefits in complex sport-specific actions such as serving, attacking, and improving overall performance, including the number of points scored and successful actions. It should also be noted that volleyball players have different tasks and have different physiological and anthropometric characteristics. This means that higher jumps and power can guarantee or at least affect the success of some volleyball players, while some volleyball players need accuracy. The results of the current study indicate that caffeine has an ergogenic effect on jumping performance, which is an important ability for an attacking player but may not be important for a libero player. Similarly, the results of the volleyball skills-based tasks subgroup also indicate that the ergogenic effects of caffeine do not include every type of task, for example, it can improve the tasks of attack (important for the attacking player) and accuracy (important for the server or setter) but had no effect on velocity tasks (important for the libero player). Therefore current results highlight the importance of personalized nutrition approach, especially for caffeine, in athletes.

The doses used in the reviewed studies were mostly 3 and 6 mg/kg, which depict low to moderate doses of caffeine. The ergogenic effect of both dosage of caffeine has been discussed in several previous studies.[9, 13, 17] Generally, it is accepted that with dosages ~3-6 mg/kg improves physical performance, with no additional ergogenic effects with higher caffeine doses (>9 mg/kg).[9, 36, 41] Furthermore, some studies have recently stated that lower doses of caffeine, typically of ≤3 mg/kg, are also accompanied ergogenic effect.[41] Only one of the eligible studies compared doses of 3 and 6 mg/kg.[31] This study found that while jumping and agility performance were significantly better in the 6 mg/kg condition compared the 3 mg/kg condition, there was no difference in strength- and power-based tests.[31] A subgroup analysis also indicated an ergogenic aid of caffeine at a dose of 6 mg/kg for jumping performance and at a dose of 3/kg mg for strength performance. This was despite the fact that both doses associated with improvement in skill-based tasks. Although this is the approved optimal dose of caffeine based on a number of different reviews and positions stands is between 3 and 6 mg/kg,[9, 17, 41, 42] the findings of the current meta-analysis suggest that there may be important differences between the doses of caffeine, depending on the condition and the desired outcome. An issue that needs to be addressed is considerable inter-individual variation in the ergogenic effects of caffeine ingestion.[9] Although due to the lack of accurate reporting of individual subject data in eligible study comprehensive assessment of this case was not possible. Based on the reviewed studies, the recommended dose of caffeine for volleyball players lies between 3 and 6 mg/kg, which represents low to moderate caffeine intake and has been shown to consistently enhance physical and skill-related performance.

Notably, the findings of this meta-analysis highlight potential dose-specific differences depending on the performance outcome. For instance, a 6 mg/kg dose appears to benefit jumping performance, whereas a 3 mg/kg dose may be more effective for strength-based tasks, with both doses improving skill-based actions. However, caution is warranted as there is considerable inter-individual variability in the ergogenic response to caffeine reported in previous studies.[43] Additionally, the data on volleyball-specific outcomes is still scarce, making it essential to approach caffeine supplementation on an individual basis. Athletes are strongly advised to consult with a qualified nutrition practitioner to determine the optimal caffeine dose based on their unique physiological responses and performance goals. Furthermore, any caffeine supplementation strategy should be tested during training sessions or simulated competitions to ensure it is both effective and well-tolerated before being applied in real competition settings.

One of the issues that can affect the ergogenic effect of caffeine is the habitual caffeine intake.[44] The existence of tolerance to caffeine's ergogenic benefits when the substance is ingested chronically is a subject of debate. On the one hand, cross-sectional investigations have reported that caffeine enhances performance in athletes with lower and higher daily intakes of caffeine.[45] On the other hand, cross-over studies including participants that have undergone controlled habituation to caffeine through daily intake of the substance showed that caffeine is more ergogenic the first day of intake, suggesting a progressive ergogenic response to acute caffeine intake.[46, 47] These results indicate tolerance to caffeine’s ergogenicity with a time course of tolerance slow, producing that even athletes with high chronic caffeine intakes still benefit from acute caffeine intake. In the current meta-analysis, participants with < 100 mg/day of caffeine intake obtained greater performance benefits than counterparts with higher daily intakes. This issue becomes more highlighted when some researchers advised participation to maintain their habitual caffeine intake, but some researchers encouraged participation to refrain from all dietary sources of caffeine (wash-out). Since volleyball is a team sport, it is possible that individuals with different habitual caffeine intake may be present on the team (low or heavy caffeine consumers), so a general recommendation for a team cannot be accurate and optimal, and special attention should be paid to individual conditions and characteristics. In this regard, the efficacy of caffeine ingestion to improve performance may be reduced in volleyball players who consume > 100 mg/day caffeine. In practical terms, it may be advisable for volleyball players intending to use caffeine supplementation to reduce their daily caffeine intake and reserve its use for performance-demanding situations, such as competitions or high-intensity or high-volume training sessions.

Caffeine consume in several forms, however, the traditional form in previous athletic studies is capsules along with water.[48] The caffeine capsule is easily swallowed and the majority absorbed into the blood from the intestine and a small amount is absorbed in the buccal mucosa.[49] Over time, multiple forms of caffeine were produced and commercialized, requiring research to be focused on them. Today, caffeine is available in various forms, such as bar, gel, gum and energy drink. Eligible studies included in the meta-analysis also used capsule, energy drink, and chewing gum forms. The results of the meta-analysis showed that consuming caffeine in capsule form was associated with improved jumping performance and skill-based tasks, while consuming caffeine in energy drink form was associated with improved running and strength performance. Subgroup analysis demonstrated no ergogenic aid for the chewing gum form. Chewing gum form of caffeine is absorbed quicker through the buccal mucosa when compared with capsule form;[50] however, total absorption over time is similar. This fact emphasizes the importance of timing the consumption of any form of caffeine. Evidence stated that chewing gum form can improve endurance performance, but this result for repeated sprint and power along with limitations and doubts.[50] Based on the findings, caffeine in capsule form is the most recommended method of administration for volleyball players, as it is associated with improvements in several performance tasks. While energy drinks and caffeinated chewing gums may enhance some aspects of volleyball-specific performance, their use is less advisable due to the difficulties of controlling standardized doses per kg of body mass. Regardless of the form, timing caffeine consumption appropriately is crucial to maximizing its effectiveness.

As mentioned, caffeine absorption and its peak appearance in the blood are an important determinant of its ergogenic effects, which explains why different forms of caffeine are consumed at different times.[39] In the reviewed studies, caffeine was consumed in the form of chewing gum 15 min before the experiments and in capsule form 60 min before the experiments. Energy drink form was also used at two time points, 30 and 60 min before the experiments. Subgroup analysis of the meta-analysis showed that based on the time of consumption, only 60 min before the experiments was associated with an ergogenic effect of caffeine for jumping, running, and strength performance. Beside, both timings of 60 min before or less than 60 min before experiments resulted in improved skill-based tasks of volleyball, although the effect size of the former was almost twice as large (Hedges' g: 0.61 *vs*. 0.38). Therefore, the findings demonstrate the advantage of consuming caffeine 60 min before activity in volleyball players. It seems that the half-life of caffeine (3- 7 h) and the peak plasma concentration (15-120 min), this 60- min timing would assure that peak caffeine concentration especially in capsule form; therefore, several studies have followed this golden timing,[9, 17, 30, 31] although caffeine consumption in chewing gum form leads to its absorption and providing ergogenic effects in 15 to 30 minutes.[26, 32] It appears that various aspects of caffeine administration still need to be studied. One of the reviewed studies used 3 mg/kg of caffeine chewing gum,[26] whereas a previous meta-analysis on caffeine chewing gum suggested that the ergogenic dose required was greater than 3 mg/kg.[50] Another study additionally used an energy drink 30 min beforem[27] which could be associated with a lower level of caffeine absorption in the blood and therefore a suboptimal ergogenic aid.

Accuracy in volleyball is a key factor for success; however, some side effects accompanied caffeine, such as nervousness and tremors[51] can deteriorate skill-based tasks of volleyball. Collectively, although the current meta-analysis is a first step to providing evidence of the ergogenic aid of caffeine on volleyball-specific performance, current findings confirm an effective transference of enhanced physical performance after caffeine intake into better skill-based tasks of volleyball.

The current systemic review and meta-analysis presents some limitations related to the different research protocols and performance tests carried out in the included studies. The limited reporting of certain details in the context where participants were tested and the small sample size for some physical performance measures in the included investigations prevented subgroup analyses for some performance outcomes. Most studies have used jumping performance and skill-based tasks of volleyball as outcomes to investigate the ergogenic effect of caffeine, while studies for running-based (agility or sprint) and power-based performance tests have been limited. It is important to recognize that the physical performance characteristics, anthropometric profiles, and training status of volleyball players differ significantly from those of athletes in other sports or untrained individuals. As a result, although, in the current review, the I^2 statistic showed low heterogeneity for the studies assessing physical performance or skill execution in volleyball players and the analysis of funnel plots did not reveal substantial asymmetry, generalizing findings from other populations to volleyball players may lead to substantial inaccuracies. The potential error in generalizing the results to volleyball is exacerbated by the variability of caffeine administration such as dosage and timing. From this perspective, the current review and meta-analysis can be of great help to athletes, coaches, and nutritionists who work in the field of volleyball. Additionally, caffeine was co-ingested with other ingredients (e.g. carbohydrates) in some studies.[27] It is still possible that some of these ingredients produced a synergistic or antagonistic effect on physical performance [9]. Finally, current meta-analysis suggests an ergogenic aid of caffeine in improving physical performance in volleyball as team sport with different playing positions. Sometimes these playing positions differ dramatically in terms of anthropometric characteristics and required skills.[1, 52] For example, while often the tallest volleyball players located in attacking positions (e.g. opposite player or middle block), where the highest scoring and jumping performance are expected, and the main players in digging role (libero) are often short with high agility. No included studies have examined the moderator effect of these factors. Moreover, volleyball is a high speed and complex sport in which physical performance is only one of several factors necessary for succeeding. Therefore, further studies are necessary to cover these scientific gaps about caffeine in volleyball.

Acute caffeine intake significantly enhanced physical performance in volleyball players, including improvements in jumping and strength-based measures. Moreover, caffeine's ergogenic effects extended to skill-based tasks, such as positive and negative scoring during simulated volleyball matches and better performance in serve and attacking actions. These findings indicate that caffeine supplementation not only boosts physical performance but also contributes to the success of sport-specific actions during gameplay. Overall, this review and meta-analysis confirm that the ergogenic effects of caffeine on physical performance variables translate effectively into improved performance during volleyball matches. From a practical standpoint, a moderate dose of caffeine in capsule form, ingested 60 min before their efforts, is the most recommended approach for caffeine supplementation. This strategy appears to be particularly beneficial for individuals with low habitual caffeine intake. The effects of caffeine are not influenced by the sex of volleyball players, making it a viable option for both male and female athletes. However, the prevalence and severity of potential side effects, such as increased nervousness or post-exercise insomnia, should be carefully considered when evaluating the appropriateness of caffeine supplementation for volleyball players. Finally, it seems that the results of this meta-analysis can be used by a wide range of volleyball coaches and players and show that caffeine has ergogenic effect for skill execution of volleyball, and has provided valuable information to increase our knowledge in the field of caffeine consumption and administration.

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Supplemental file

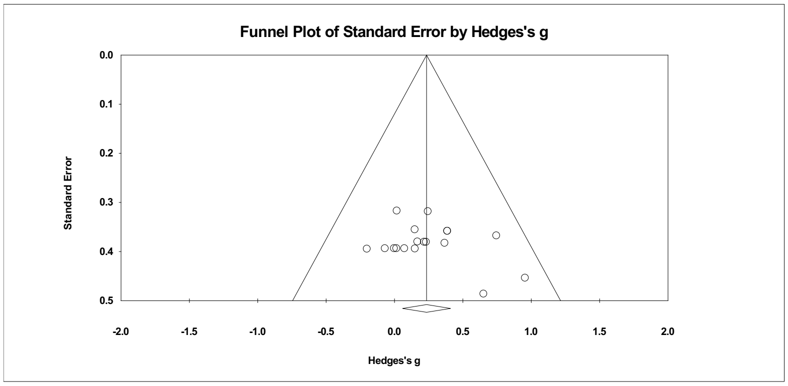

Figure 1 sup. Funnel plot of standard error by Hedges's g for jumping perforemance

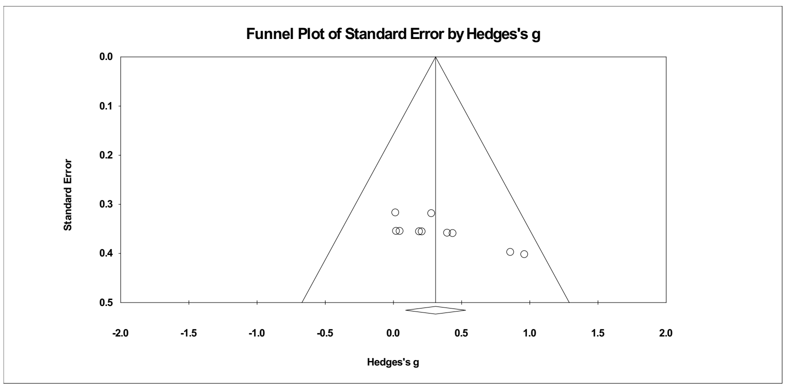

Figure 2 sup. Funnel plot of standard error by Hedges's g for strenght perforemance

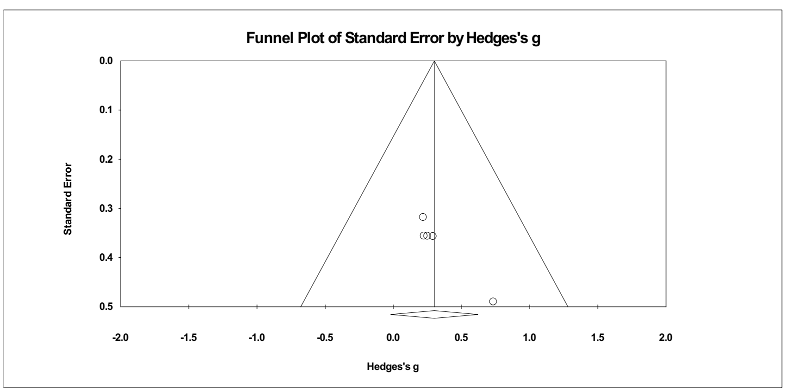

Figure 3 sup. Funnel plot of standard error by Hedges's g for power perforemance

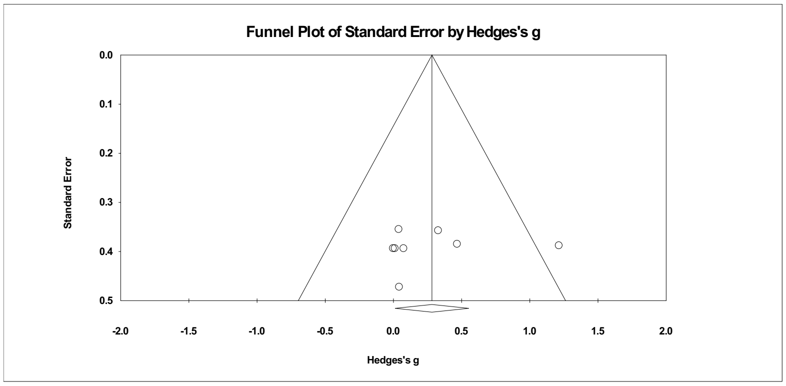

Figure 4 sup. Funnel plot of standard error by Hedges's g for runing perforemance

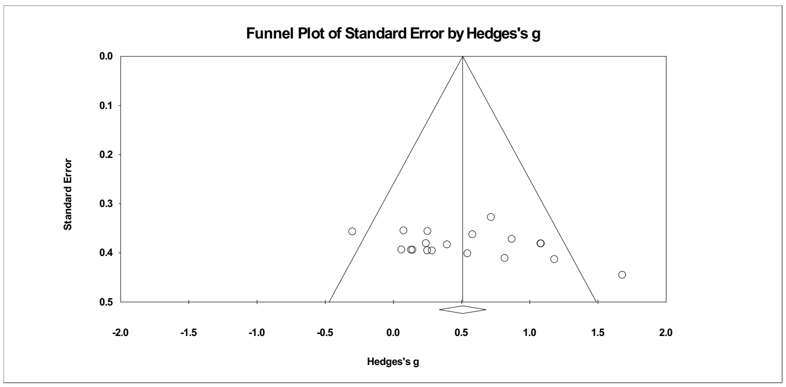

Figure 5 sup. Funnel plot of standard error by Hedges's g for skill-based tasks