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Human Kinetics
BRIEF REVIEW

Can Caffeine Change the Game? Effects of Acute Caffeine Intake on Specific Performance in Intermittent Sports During Competition: A Systematic Review and Meta-Analysis

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Background: The benefits of oral caffeine intake to enhance several aspects of physical performance, such as aerobic endurance, strength, power, and muscle endurance performance, are well supported. However, how the physical performance benefits of caffeine supplementation are translated into better specific actions in intermittent sports during real or simulated competition has been the topic of fewer investigations, and their results need to be appropriately reviewed and meta-analyzed. ***Objective:*** The aim of the study was to investigate the effects of acute caffeine intake on specific actions in intermittent sports involving decision making and high-intensity efforts (eg, team, racket, and combat sports) during real or simulated competitions. ***Methods:*** All studies included had blinded and crossover experimental designs, and we conducted a risk-of-bias analysis. In total, we included 24 studies. A meta-analysis was performed using the random-effects model to calculate the standardized mean difference (SMD) estimated by Hedges *g* and 95% CIs. ***Results:*** Caffeine ingestion increased high-intensity sport-specific actions during competition, such as the number of sprints (SMD: 0.48; 95% CI, 0.23–0.74), body impacts (SMD: 0.28; 95% CI, 0.08–0.49), accelerations (SMD: 0.35; 95% CI, 0.06–0.63), decelerations (SMD: 0.63; 95% CI, 0.12–1.14), and high-intensity offensive efforts (SMD: 0.36; 95% CI, 0.11–0.61). Additionally, caffeine ingestion induced a higher positive or success rate of actions during real or simulated competition (SMD: 0.44; 95% CI, 0.19–0.69). ***Conclusion:*** The current meta-analysis provides evidence of caffeine supplementation in increasing high-intensity efforts and the success rate of sport-specific actions during real or simulated competition.

Keywords: elite athlete, ergogenic aid, high-intensity exercise, physical performance, sports nutrition

Oral caffeine (1,3,7-trimethylxanthine) intake is among the most common supplementation strategies athletes use to enhance their physical performance in many sports disciplines.[1,2] Preexercise caffeine supplementation improves various aspects of physical performance, explaining the high use of this substance in the exercise and sports contexts.[3] Widely, evidence for the ergogenic effects of caffeine intake has been examined on unspecific or isolated aspects of physical performance, such as 30-second all-out sprinting, vertical jumps, and handgrip.[4,5] Additionally, the potential benefits of caffeine have been tested in more sport-specific tasks, such as the measurement of agility, velocity, or endurance with physical performance tests[6–8] (eg, Yo-Yo test), but performed out of real or simulated competition conditions, which limits the application of their results to real sports conditions. The systematic reviews and meta-analysis that have summarized the outcomes of the research investigating the effect of acute caffeine intake on sport-specific physical tests have confirmed, almost unanimously, that caffeine increases several aspects of physical performance such as aerobic and anaerobic activities, and strength, and power.[2,9,10] However, the ecological validity of applying these results obtained with caffeine supplementation in this type of physical testing to sports involving decision making or requiring complex interactions between teammates, such as team sports, combat sports, or racket sports, still needs to be investigated.

Complex athletic disciplines, such as team sports, racket sports, and combat sports need high levels of physical performance (eg, high-intermittent efforts, power actions, aerobic/anaerobic capacities, and technical/tactical skills).[11,12] The high-intensity efforts in these sports are susceptible to being improved by caffeine supplementation. Traditionally, it has been less accepted that caffeine may improve overall performance in team sports, racket sports, and combat sports as evidence is not clear to determine whether caffeine's ergogenicity may be translated into better sport-specific performance. Although evidence is clear about enhanced physical performance in high-intensity intermittent exercise with caffeine, it is still possible that this potential benefit could not be expressed during sports competition due to the impact of chaotic factors associated with these sports such as opponent's level and tactics, and the environment stressors associated with the nature of competition. Still, this traditional view about the use of caffeine in complex sports may be changing as a recent study in English professional football has shown that 97% of the clubs surveyed provided caffeine before or during the game to their players to enhance performance.[13] Last, it is essential to note that this substance may produce several side effects, such as insomnia, nervousness, and activeness, which should be considered when deciding to use caffeine in a competitive context, especially in athletes making decisions under pressure and during multiple-day competitions.[14]

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The ability to repeat intermittent high-intensity efforts over time is considered a critical performance factor in team sports, and racket sports (eg, sprints, accelerations, decelerations, or body impacts), or combat sports (eg, throws, kicks, or punches).[9,15] This is because these high-intensity actions are linked with the most decisive situations and their success in several sports, such as soccer, rugby, basketball, handball, judo, boxing, and tennis.[9,15–17] In this way, the study of the influence of caffeine supplementation on high-intensity efforts during real or simulated competition has been the topic of several investigations.[8,18–20] Since caffeine's effect on increasing high-intensity efforts is only a part of the story, it is noteworthy to find out the ecological relevance of caffeine intake in the success of sport-specific actions during real or simulated competitions. The findings of these investigations have been mixed, but with most studies reporting enhanced responses during the game with caffeine, such as numbers of positive serves, blocks, and receptions in volleyball, rebounds and assists in basketball, and total points won on service in tennis, among other benefits.[17,21–24] Still, 2 studies have failed to observe significant effects of caffeine in the total points scored during a volleyball match or the number of throwing techniques (ie, grappling actions that involve off-balancing or lifting an opponent, and throwing them to the ground) in sports combats.[25,26]

To date, all these investigations have not been reviewed and systematically analyzed to determine if caffeine effectively enhances high-intensity efforts such as sprints, accelerations, decelerations, body impacts, or offensive actions and the total number of points or succession actions such as serves, receptions, assists, rebounds, throws (combat sports) on during real or simulated competition in intermittent sports. The meta-analysis of the outcomes of these more ecologically valid investigations can add significant information to complement previous analyses on the effect of caffeine in physical testing,[2,9,10] as it may reveal whether caffeine's ergogenicity in physical performance tests is translated into better sport-specific actions during competition. The aim of this study was to systematically review the effects of acute caffeine intake on specific actions in intermittent sports involving decision making and high-intensity efforts (eg, team, racket, and combat sports) during real or simulated competitions. We hypothesized that caffeine would effectively increase the repetition of high-intensity efforts and the success rate in sport-specific actions during competition.

Material and Methods

Literature Search Strategy

For this systematic review with meta-analysis, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[27] This systematic review was not registered in PROSPERO as it does not entail the analysis of health-related variables. The search terms included a mix of Medical Subject Headings and free-text words for key concepts related to the effect of caffeine on team sports, racket sports, and combat sports. Articles were systematically identified using the following search syntax: (concept 1) (caffeine OR coffee) AND (concept 2) (supplement OR supplementation OR ergogenic aid) AND (concept 3) (basketball OR football OR rugby OR soccer OR hockey OR volleyball OR handball OR netball OR tennis OR padel OR badminton OR team sports OR combat OR martial arts OR Brazilian jiu-jitsu OR wrestling OR boxing OR judo OR taekwondo OR karate OR mixed martial arts OR simulation combat). This search syntax was applied in 3 different databases, PubMed/MEDLINE, Cochrane Library, and Web of Science. The search was conducted without any publication year restriction and no filters were used. All titles and abstracts from the search were downloaded to a Microsoft Excel spreadsheet, and manual cross-referencing was performed to identify duplicates. Titles and abstracts were then screened for a subsequent full-text review. The literature search was carried out by was performed by 2 separate authors (Diaz-Lara and Nieto-Acevedo) and concluded on March 8, 2023.

Study Selection

We defined the inclusion criteria according to the principles of population, intervention, comparison, outcome, and study design (PICOS).[27] We only incorporated studies with crossover experimental designs in which the ingestion of caffeine was compared with a placebo in a single- or double-blind randomized manner, and the outcomes were associated with sport-specific performance during real or simulated competition (Table 1). We considered any form of caffeine intake to be included in the review, but only if the effect of caffeine could be isolated. To be included, studies had to use a caffeine dose between 3 and 6 mg/kg as it is the range of dose with more evidence to support the ergogenic benefits of caffeine.[31] Additionally, we only considered samples that were categorized as athletes or trained individuals with experience in the sport(s) tested. Specifically, the following inclusion criteria were applied to select studies: (1) testing the effects of an acute dose of oral caffeine supplementation in real or simulated competition; (2) with a blinded and randomized crossover design in which there was an experimental condition that included the ingestion of caffeine which was compared with an identical experimental situation without caffeine; (3) on a team sport, racquet sport, or combat sports; (4) with data available for calculation of the effect size associated to caffeine on any sport-specific performance variable; (5) athletes participated in a real or simulated match or combat played on an official court and followed the corresponding Federation's official rules. The only exception was the duration of the matches: players completed the same time in both trials, but in some studies, the researchers shortened the official duration of the matches, for example, 2 parts of 40 minutes instead of 45 minutes in soccer. All these changes are described in Table 2; (6) use global positioning system (GPS; eg, sprints, accelerations, decelerations), accelerometer (eg, body impacts), or video-analysis devices (eg, offensive actions in sport combats). Systematic reviews and meta-analyses were excluded, in addition, nor peer-reviewed articles, opinion pieces, commentaries, case reports, and editorials. See Table 2 below for details of the inclusion criteria.

Data Extraction

The following information was extracted from the included studies: (1) details on the study design, (2) sample size and characteristics, (3) caffeine dose and form of administration, (4) sport(s) investigated, (5) participants' sports performance level to categorize the sample according to McKay et al[40] classification framework, (6) competitive context where performance was evaluated, and (7) data on the effect of caffeine on high-intensity sport-specific and the rate of success of sport-specific actions. Additionally, participants' habituation to caffeine and the prevalence of side effects were also extracted in those studies that incorporated this information.

Table 1 PICOS Criteria for the Inclusion of Crossover Experimental Designs in Which the Ingestion of Caffeine Was Compared With a Placebo in a Single- or Double-Blind Randomized Manner in Studies Associated With High-Intensity and Positive Actions in Real or Simulated Sport Competitions

Parameter	Inclusion	Exclusion	Extraction
Population	Team sport, racket sport, or combat sport players/athletes	Athletes of individual sports	Number of participants, gender, sport, and habituation to caffeine through daily intake
Intervention	Caffeine	Use caffeine doses lower than 3 or higher than 9 mg/kg	Dosage and form of caffeine administration
Comparison	Placebo	Trials without a true placebo/control situation	None
Outcome	Sport-specific actions in real or simulated competitions	Not a real or simulated match on an official court following the Federation's official rules	Sprints, accelerations, decelerations, body impacts, offensive actions, and rate of positive/neutral/negative actions
Study design	Single- or double-blind randomized controlled trials published in peer-reviewed journals	Systematic reviews, conference abstracts, graduate student dissertations, and editorials	Experimental design and date of publication

Abbreviation: PICOS, Population, Intervention, Comparison, Outcome, and Study Design.

Table 2 Summary of the Effects of Caffeine Ingestion Compared With Placebo During Real and Simulated Competition Studies: Study Design, Sample Characteristics, Sport Investigated, Form and Dose of Caffeine Administration, and Main Performance Outcomes of the Studies Included in the Systematic Review

Reference	Study design	Sample	Training level	Sport	Caffeine form and dose	Habituation to caffeine	Side effects	Performance context	Performance outcome
Coswig et al[18]	RDB	10 M	2	Boxing	Capsule 6 mg/kg	Not reported	Not reported	One simulation combat 3×2 min with 1 min between rounds. Video analysis	Number of offensive actions: PLA: 4.4 (0.9) CAF: 6.5 (1.8)
Del Coso et al[28]	RDB	19 M	3	Football	Energy drink 3 mg/kg	Habitual caffeine users <60 mg/d	Not reported	2×40 min simulated soccer football match game. GPS	Number of sprints: PLA: 24 (8) CAF: 30 (10)
Del Coso et al[29]	RDB	26 M	4	Rugby	Energy drink 3 mg/kg	Habitual caffeine users <60 mg/d	Not reported	Rubgy simulated match. GPS and accelerometer	Number of sprints: PLA: 10 (7) CAF: 12 (7) Number of impacts: PLA: 481 (352) CAF: 641 (366)
Del Coso et al[19]	RDB	16 F	4	Rugby	Energy drink 3 mg/kg	Habitual caffeine users <60 mg/d	No side effects	3 rugby seven game matches. GPS	Number of sprints: PLA: 4.6 (3.3) CAF: 6.1 (3.4)
Del Coso et al[22]	RDB	15 M	2	Volleyball	Energy drink 3 mg/kg	Habitual caffeine users <30 mg/d	Insomnia	3-set simulated games matches. Video analysis	Positive game actions (%): PLA: 25 (14) CAF: 34 (16) Neutral game actions (%): PLA: 51 (12) CAF: 41 (8) Negative game actions (%): PLA: 24 (13) CAF: 25 (12)
Del Coso et al[30]	RDB	13 M	4	Hockey	Energy drink 3 mg/kg	Habitual caffeine users <100 mg/d	No side effects	Hockey simulated match. GPS	Number of high-intensity actions: PLA: 23 (5.6) CAF: 27.4 (7) Number of sprints: PLA: 4.5 (1.9) CAF: 6.3 (2.9)

(continued)

Table 2 (continued)

Reference	Study design	Sample	Training level	Sport	Caffeine form and dose	Habituation to caffeine	Side effects	Performance context	Performance outcome
Diaz-Lara et al[24]	RDB	14 M	4	Brazilian jiu-jitsu	Capsule 3 mg/kg	Light caffeine users <60 mg/d	Increased vigor/ activeness	2 simulated 8-min combats with 20 min of rest. Video analysis	Number of offensive actions (C1): PLA: 4.2 (4.6) CAF: 5.4 (5.1) Number of offensive actions (C2): PLA: 4.2 (4.6) CAF: 5.4 (5.1) Number of successful actions (C1): PLA: 2.4 (2.8) CAF: 3.6 (3.4) Number of successful actions (C2): PLA: 4.2 (4.6) CAF: 5.4 (5.1)
Durkalec-Michalski et al[31]	RDB	22 M	4	Judo	Capsule 3 mg/kg 6 mg/kg 9 mg/kg	Noncaffeine consumers: <160 mg/d; n = 12 Caffeine consumers: >160 mg/d; n = 10	Not reported	3 simulated 4-min combats 4 min with 4.5-min rest. Video analysis	Number of offensive actions (6 mg/kg) (C1): PLA: 11.5. (3.9) CAF: 12.3 (4.7) Number of offensive actions (6 mg/kg) (C2): PLA: 11.2. (3.2) CAF: 12.6 (3.8)
Filip-Stachnik et al[26]	RDB	12 F	3	Basketball	Caffeinated chewing gum ~6.4 mg/kg	Not reported	No reported	Video analysis	Total points: PLA: 5.1 (3.9) CAF: 5.7 (5.0) Total errors: PLA: 1.9 (1.5) CAF: 1.8 (1.6)
Gallo-Salazar et al[17]	RDB	14 M	3	Tennis	Energy drink 3 mg/kg	All participants were light caffeine consumers (less than 1 can of soda or energy drink per day)	Not reported	Simulated singles match (best of 3 sets). GPS	Number of sprints: PLA: 12.1 (1.7) CAF: 13.2 (1.7) First serves won (%): PLA: 59.7 (12.2) CAF: 68.0 (13.9) Total points won (%): PLA: 48.3 (7.2) CAF: 51.8 (6.8)
Lara et al[32]	RDB	18 F	2	Football	Energy drink 3 mg/kg	Habitual caffeine users <60 mg/d	No side effects	2 × 40 min simulated football games football match. GPS	Number of sprints: PLA: 16 (9) CAF: 21 (13)

(continued)

Table 2 *(continued)*

Reference	Study design	Sample	Training level	Sport	Caffeine form and dose	Habituation to caffeine	Side effects	Performance context	Performance outcome
López-Samanes et al[8]	RDB	16 M	3	Futsal	Energy drink 3 mg/kg	Habitual caffeine users <1 mg/kg/d	No side effects	2 × 7.5 min simulated futsal match. GPS	Number of sprints (number/min): PLA: 0.25 (0.15) CAF: 0.31 (0.13) Number of impacts (number/min): PLA: 8.17 (2.66) CAF: 8.89 (3.16) Number of accelerations (number/min): PLA: 18.12 (1.23) CAF: 18.82 (0.98) Number of decelerations (number /min): PLA: 18.01 (1.23) CAF: 18.74 (0.99)
Lopez-Silva et al[33]	RDB	10 M	4	Taekwondo	Capsule 5 mg/kg	Not reported	Not reported	1 × simulated combat including 3 × 2 min with 1-min rest between rounds. Video analysis	Number of offensive actions (C1): PLA: 27.3 (7.5) CAF: 26.8 (6.6)
Merino-Fernández et al[25]	RDB	11 M 11 F	3	Traditional jiu-jitsu	Capsule 3 mg/kg	Not reported	Not reported	3 × simulated combats with 10 min of rest. Video analysis	Technique with high score possibility: PLA: 1 (0.6) CAF: 1.2 (1.1)
Muñoz et al[16]	RDB	15 F	3	Handball	Capsule 3 mg/kg	All participants were considered low caffeine consumers (50 mg/d)	Not reported	2 × 20 min simulated handball match. GPS (wireless inertial movement unit)	Number of body impacts: PLA: 20 (8) CAF: 22 (10) Frequency of accelerations: PLA: 18.1 (1.2) CAF: 18.8 (1.0) Frequency of decelerations: PLA: 18.0 (1.2) CAF: 18.7 (1.0)
Muñoz et al[34]	RDB	16 M 15 F	3	Handball	Capsule 3 mg/kg	All participants were considered as low caffeine consumers (60 [25] mg/d or 0.76 mg/kg/d)	No reported	2 × 20 min simulated handball soccer match games. GPS (wireless inertial movement unit)	Frequency of accelerations: PLA: 19.13 (1.16) CAF: 18.75 (1.57) Number of body impacts: PLA: 23.28 (11.46) CAF: 26.25 (13.6)

(continued)

Table 2 (continued)

Reference	Study design	Sample	Training level	Sport	Caffeine form and dose	Habituation to caffeine	Side effects	Performance context	Performance outcome
Pérez-López et al[21]	RDB	13 F	3	Volleyball	Energy drink 3 mg/kg	Not reported	Nervousness and activeness	3-set simulated volleyball game match. Video analysis	Total number of impacts: PLA: 6970 (1807) CAF: 7358 (1393) Positive game actions (%): PLA: 34 (9) CAF: 45 (9) Neutral game actions (%): PLA: 39 (7) CAF: 41 (7) Negative game actions (%): PLA: 28 (7) CAF: 14 (9)
Pettersen et al[35]	RDB	22 M	3	Football	Energy drink 6 mg/kg	Not reported	Not reported	Football simulated match. GPS and Accelerometer	Number of accelerations: PLA: 123 (31) CAF: 126 (24) Number of impacts: PLA: 481 (352) CAF: 641 (366)
Portillo et al[36]	RDB	16 F	4	Rugby	Energy drink 3 mg/kg	Habitual caffeine users <60 mg/d	Not reported	7 rugby seven competition matches. GPS and accelerometer	Rate of body impacts: PLA: 3.8 (1.5) CAF: 4.7 (2.6)
Puente et al[23]	RDB	10 M 10 F	3	Basketball	Capsule 3 mg/kg	Habitual caffeine users <100 mg/d	During testing: Self-perceived muscle power. 24 h after: Insomnia	2 × 10 min simulated game basketball match. GPS and video analysis	Number of body impacts: PLA: 396 (43) CAF: 410 (41) Performance index rating: PLA: 8.4 (8.3) CAF: 11.6 (7.3)
Puente et al[37]	RDB	10 M 9 F	3	Basketball	Capsule 3 mg/kg	All participants were light caffeine consumers	No reported	2 × 10 min simulated basketball match game. GPS and accelerometer	Number of body impacts: PLA: 786 (84) CAF: 815 (71)
Raya-González et al[20]	RDB	14 M	3	Basketball	Capsule 6 mg/kg	All players were light caffeine consumers (<100 mg/day)	Insomnia and urine	3 × 7 min simulated basketball game. Local positioning system technology	Frequency of accelerations: PLA: 6.6 (1.9) CAF: 6.4 (0.9) Number of body impacts: PLA: 8.2 (6.3) CAF: 7.5 (2.9)
Saldanha da Silva Athayde et al[38]	RDB	12 M	3	Judo	Capsule 5 mg/kg	Not reported	Not reported	3 × 5-min simulation combat 5 min with 15-min rest. Video analysis	Number of offensive actions (C1): PLA: 6 (3) CAF: 6 (3) Number of offensive actions (C2): PLA: 5 (2) CAF: 6 (2)

(continued)

Table 2 (continued)

Reference	Study design	Sample	Training level	Sport	Caffeine form and dose	Habituation to caffeine	Side effects	Performance context	Performance outcome
Santos et al[39]	RDB	10 M	1	Taekwondo	Capsule 5 mg/kg	Not reported	Not reported	2 × simulation simulated combat including 3 × 2 min with 1-min rest between rounds. Video analysis	Number of offensive actions (C1): PLA: 13.4 (12.9) CAF: 12.6 (11.5) Number of offensive actions (C2): PLA: 8.9 (3.2) CAF: 12.2 (6.7)

Abbreviations: C1, first combat of trial; C2, second combat of trial; CAF, caffeine; F, female; M, male; PLA, placebo; GPS, Global Positioning System; RDB, randomized, double-blind crossover. Note: Training level: tier 1, recreationally active; tier 2, trained/developmental; tier 3, highly trained athletes; and tier 4, elite/international level.

In the included studies, there were several different outcome variables used to assess the effects of acute caffeine intake on sports performance related to technical–tactical and time–motion variables, and we grouped the outcomes in the following performance categories: (1) number of sprints; (2) number of body impacts, measured in gravitational force (*g*), both defensive and offensive, from zone 1 (eg, 0*g* to ≤5*g*) to zone 3 (eg, 8*g* to ≤10*g*), (3) total number of accelerations, from zone 1 (eg, 0–1 m/s^2) to zone 4 (eg, 3–4 m/s^2); (4) total number of decelerations, from zone 1 (eg, 0 to 1 m/s^2) to zone 4 (eg, −3 to 4 m/s^2); (5) number of high-intensity offensive actions (action identified as advance or progress with power or muscle strength such as punches, takedowns, etc), (6) positive/successful actions (an action that ended with a score or a benefit in the individual or team's performance), (7) negative actions/errors (when the athlete committed an error that led the opponent to obtain a score or a performance advantage), and (8) neutral actions (involving in the game/match's continuity but not directly related to a positive or negative action). Examples of positive, negative, and neutral actions would be a successful throw in Brazilian jiu-jitsu, a double fault in a tennis serve, and when the block touches the ball and allows the continuity of the next play action in volleyball, respectively. Due to these actions being specific to the characteristics of each sport, we recommend consulting the original articles for a more specific description of this categorization system.

Methodological Quality

The Cochrane Risk of Bias tool for randomized clinical studies was used, and the level of quality for the selected studies was assessed following the Cochrane Collaboration Guidelines.[41] This tool is focused on 7 domains to evaluate the studies' bias: sequence generation and allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other sources of bias (other bias). The application of the risk of bias tool for the included studies was performed by 2 separate authors (Diaz-Lara and Nieto-Acevedo) and disagreements were resolved through discussion.

Statistical Analysis

Meta-analyses comparing the acute effect of caffeine versus placebo ingestion were carried out using standardized mean differences (SMDs) and their respective 95% CIs. For each outcome, the SMD was calculated using mean and SD values from the caffeine and placebo trials, the sample size from each study, and the correlations between the trials. Given that none of the studies reported correlation values for the effect of caffeine ingestion data between caffeine and placebo conditions, a .5 correlation was assumed for all trials per recommendations by Follmann et al.[42] The magnitude of the effect of caffeine in each outcome was interpreted by using the following SMD scale: <0.2 (trivial), 0.2 toTable 2 0.6 (small), 0.6 to 1.2 (moderate), 1.2 to 2.0 (large), 2.0 to 4.0 (very large), and >4.0 (extremely large). For each outcome, a minimum of 2 studies were required to perform the meta-analysis.[43] One study used multiple doses of caffeine administration (3, 6, and 9 mg/kg).[31] We opted to select the intermediate dose (6 mg/kg) in the main analyses, per recommendations in the Cochrane Handbook.[44] Heterogeneity was assessed using the I^2 statistic and interpreted as 0% to 40% (might not be important), 30% to 60% (may represent moderate heterogeneity), 50% to 90% (may represent substantial heterogeneity), and 75% to 100% (considerable heterogeneity). All meta-analyses were performed using the random-effects model. The statistical significance threshold was set at $P < .05$ for all statistical analyses. The data analyses were performed using Review Manager (version 5.3, Cochrane Collaboration).[45]

Results

Search Results

The search through the databases produced a total of 465 search results. Of these records, 182 duplicates were removed, and 27 articles were included for the screening based on title and abstract. Of that number, 256 papers were considered suitable in the first stage, and 27 studies were full text read in the second stage to apply inclusion and exclusion criteria. Finally, 24 studies were included in the review. The flow diagram of the search is presented in Figure 1.

Study Characteristics

The studies that were finally included corresponded to 24 randomized controlled trials, all of them with a double-blind experimental protocol (none of the studies that fulfilled the inclusion criteria was single-blinded). The pooled number of participants across the included studies was 399 (males n: 264, females n: 135). Of these, 58 were rugby players, 59 were football players, 53 were basketball players, 46 were handball players, 40 were volleyball players, 34 were judo athletes, 22 were traditional jiu-jitsu athletes, 20 were taekwondo athletes, 16 were futsal players, 14 were tennis players, 14 were Brazilian jiu-jitsu athletes, 13 were hockey players, and 10 were boxing athletes. Following the athlete's performance classification by McKay et al,[40] the participants of the studies in the present review were categorized as follows: tier 1, recreationally active (1 study); tier 2, trained/developmental (3 studies); tier 3, highly trained athletes (13 studies); and tier 4, elite/international level (7 studies). Acute doses of caffeine among the included studies ranged from ~3.0 to ~6.4 mg/kg. Most studies used doses of 3 or 6 mg/kg. Regarding the form of administration, 12 investigations used capsules filled with caffeine, 11 investigations used caffeinated energy drinks, and 1 research used chewing gums. Most investigations administered caffeine 45 to 60 minutes before the onset of the testing. Regarding caffeine habituation, 16 investigations registered this item, and most participants were considered low caffeine consumers (ie, 30–100 mg/d).[8,16,17,19,20,22–24,28–32,34,36,37] Several different outcome variables were used to assess performance, related to technical–tactical and time–motion variables (ie, number of offensive actions, number of sprints, body impact, accelerations, decelerations, rate of positive/negative/neutral actions, etc; Table 2).

Methodological Quality

The following information was obtained according to the quality and risk of bias assessment: in the overall analysis, all 24 studies were determined as low-risk bias; 3 studies included in the review were categorized as unclear risk of bias only in the "random sequence generation" or "allocation concealment" because the information about randomization was not detailed. In addition, 4 studies were categorized as unclear risk regarding "blinding of outcome or participants/researchers" because the information about the blinding procedures used for participants, researchers,

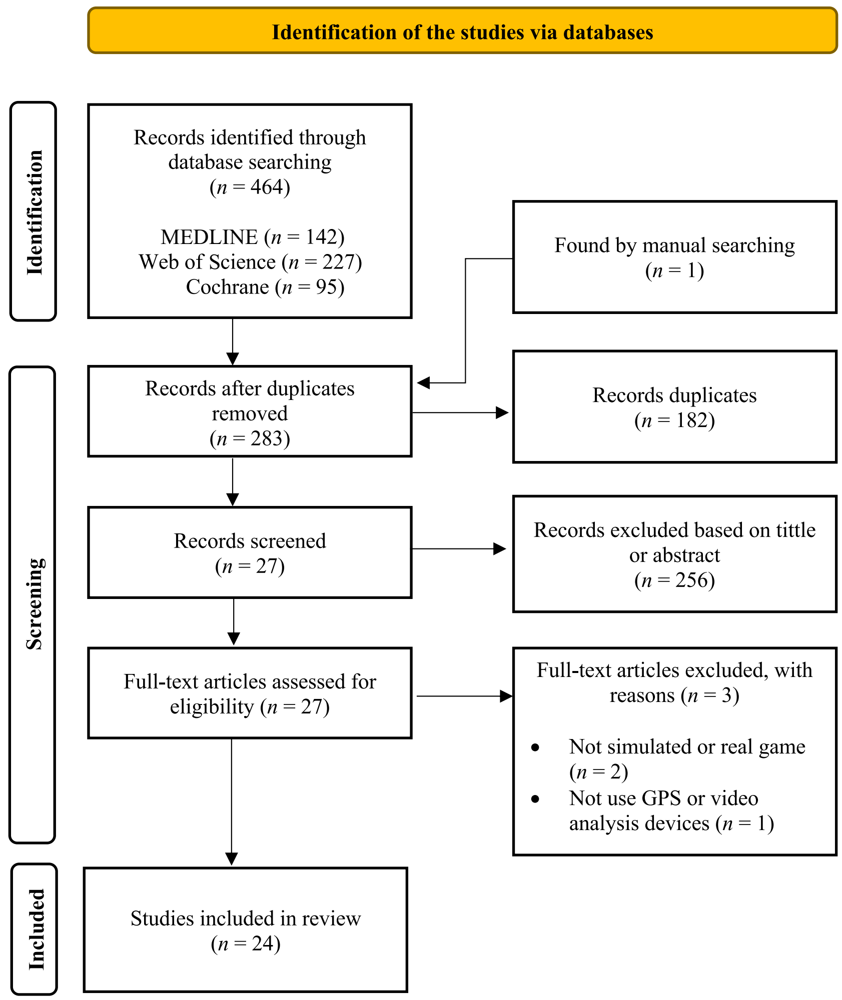

Figure 1 — Flow diagram of the search process.

or outcomes and during data extraction and analysis was not detailed. All the studies were defined as low risk in the "incomplete outcome data," "selective outcome reporting," and "other sources of bias" categories. This information is detailed in Figures 2 and 3.

Reporting Sex- and Gender-Based Analyses

The study population included women practitioners of several sports, such as rugby, volleyball, soccer, handball, jiu-jitsu, and basketball. Despite constituting 34% of the total study sample, this percentage varies between analyses until reaching 45% of the female population in some cases. We argue the influence of gender in the "Discussion" section.

Meta-Analysis Results

High-Intensity Actions in Competition

Compared with the placebo, there was a significant ergogenic effect of caffeine on the number of sprints performed during the sports competition (SMD: 0.48; 95% CI, 0.23–0.74; $P < .001$; $I^2 = 0\%$; 7 studies from 5 sports [rugby, futsal, football, tennis, and hockey]; n = 122; Figure 4A). Caffeine ingestion also enhanced the number of body impacts (SMD: 0.28; 95% CI, 0.08–0.49; $P = .006$; $I^2 = 0\%$; 10 studies from 5 sports [basketball, handball, futsal, football, and rugby]; n = 189; Figure 4B), the number of accelerations (SMD: 0.35; 95% CI, 0.06–0.63; $P = .02$; $I^2 = 0\%$; 6 studies from 4 sports [basketball, football, handball, and futsal]; n = 95; Figure 4C), and the number of decelerations during competition (SMD: 0.63; 95% CI, 0.12–1.14; $P = .02$; $I^2 = 0\%$; 2 studies from 2 sports [handball and futsal]; n = 31; Figure 4D). Finally, there was a significant ergogenic effect of caffeine on the number of high-intensity offensive actions (SMD: 0.42; 95% CI, 0.17–0.66; $P < .001$; $I^2 = 1\%$; 10 studies from 4 sports [taekwondo, judo, Brazilian jiu-jitsu, and boxing]; n = 136; Figure 4E).

Rate of Positive, Negative, and Neutral Actions in Competition

In the meta-analyses conducted for sport-specific actions categorized as positive or successful during competition, there was a significant increase in the rate of positive/successful actions in the caffeine trials with respect to the placebo trials (SMD: 0.44; 95% CI, 0.19–0.69; $P < .001$; $I^2 = 0\%$; 8 studies from 5 sports [volleyball, basketball, tennis, Brazilian and traditional jiu-jitsu]; n = 124: Figure 5A). However, compared with the placebo, there were no significant differences in the rating of negative and neutral actions with caffeine (Figure 5B and 5C).

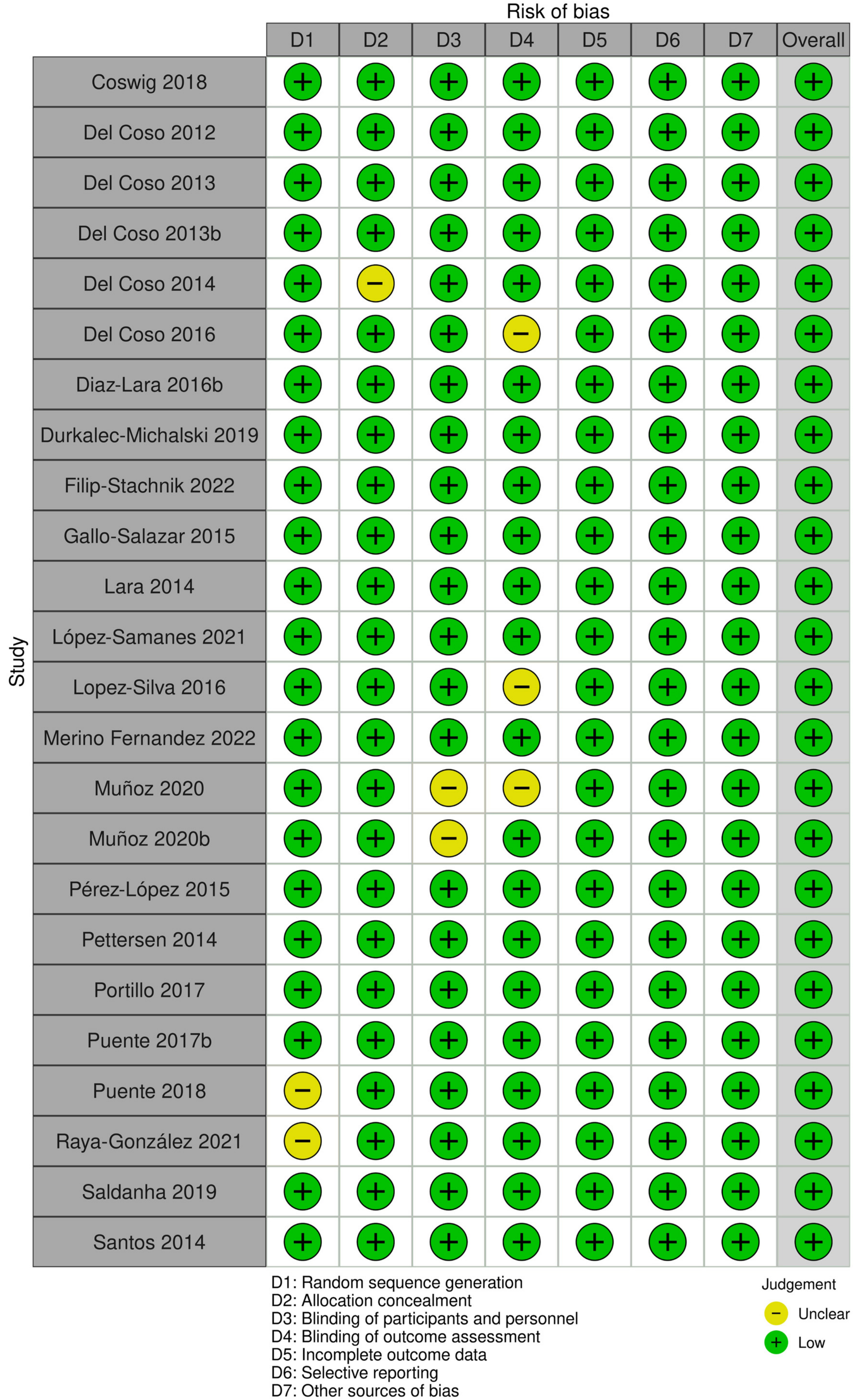

Figure 2 — Quality assessment and risk of bias.

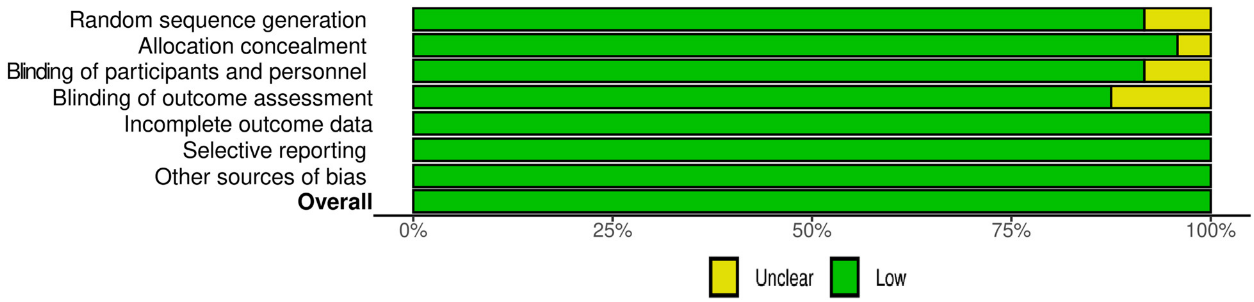

Figure 3 — Risk-of-bias summary.

Discussion

Summary of Main Findings

In an attempt to understand how the physical performance benefits of caffeine supplementation are translated into better sport-specific actions, we have systematically reviewed and meta-analyzed studies on the effects of acute caffeine intake on specific actions during real or simulated sports competitions. The present meta-analysis study found that caffeine ingestion effectively enhanced several increased ecological sports-specific actions, such as the number of sprints, body impacts, accelerations, decelerations, and high-intensity offensive efforts during matches or simulated matches. Also, a moderate precompetition intake of caffeine effectively induced a higher percentage of positive or successful actions during competition. Although the size of the ergogenic effect obtained with caffeine was categorized as small to moderate in the previously mentioned variables, the benefits in almost all sport-specific actions investigated suggest that caffeine may be considered a potent ergogenic substance. From a practical standpoint, this investigation's meta-data suggest an effective transference of the ergogenic effect of caffeine supplementation on increasing the frequency of physical performance variables (eg, sprints, accelerations, decelerations, body impacts, offensive combat sports actions) into better sports performance during the competition (eg, numbers of positive serves and receptions in volleyball, rebounds and assists in basketball, the total points won in tennis, and throws in Brazilian jiu-jitsu).[17,21–24]

High-Intensity Actions During Competition

Analyzing athletes' movement patterns during the competition using accelerometers/gyroscopes and GPS devices has provided a unique approach to understanding the physical demands of the different team sports.[46] In this sense, the quantification of the number of high-intensity efforts such as sprinting, accelerations, decelerations, or body impacts is critical to assess the external load of the games but also to categorize more successful athletes/teams as they represent crucial activities, such as changes of direction speed, specific movement patterns at sprint velocity, and collisions with opponents.[8,15,21,36] The meta-analysis of these investigations revealed that caffeine induced a statistically significant increase in the number of sprints in rugby, futsal, football, tennis, and hockey; body impacts in basketball, handball, futsal, football, and rugby; accelerations in basketball, football, handball, and futsal; and decelerations in handball and futsal (Figure 4A–4D). Overall, this ergogenic effect in all these performance variables suggests that caffeine has the potential to enhance the athlete's capacity to repeat specific high-intensity efforts in several intermittent sports disciplines, which could represent a higher involvement of players during the game and clear improvement of sports-specific performance in those sports that have been the subject of this meta-analysis such as football, rugby, handball, or basketball among others.[12,47–49] Finally, the pooled sample percentage of this meta-analysis section was approximated in both women and men (eg, ~30% in sprints and accelerations; ~45% in body impacts and decelerations), suggesting that caffeine ingestion increased sport-specific performance to a similar extent in both men and women athletes, in the same vein as the findings obtained in a laboratory-based scenario by Skinner et al.[50]

To determine the mechanism(s) of action that enabled caffeine supplementation to enhance performance in real or simulated sports competitions is complex. Caffeine ingestion and posterior distribution of the substance through body tissues (including the brain) produce the blockage of adenosine A_1 and A_{2A} receptors. As adenosine exerts some "fatiguing" effects during exercise through the inhibition of the release of excitatory neurotransmitters, the blockage of its receptors after caffeine intake would produce just the contrary effect: a higher release of excitatory neurotransmitters, such as dopamine and noradrenaline.[51] This mechanism would explain the higher physical performance with caffeine due to reduced fatigue and lesser pain perception during exercise.[52] Additionally, this mechanism may also be associated with the promotion of a more favorable mood, and increased attention and arousal, that may also contribute to athletes' performance during competition.[53]

Time–motion analysis techniques in ecological sports settings (eg, real and simulated competitions) have been employed in several investigations assessing the effect of caffeine on sports performance. In the current investigation, this methodological approach was mostly used in several combat sports (taekwondo, judo, boxing, Brazilian jiu-jitsu, and traditional jiu-jitsu), as the assessment of movement patterns by GPS or accelerometers may not represent key performance indicators in combat sports. The present investigation revealed an ergogenic effect of caffeine on the number of high-intensity offensive actions performed during combats/matches (Figure 4E). As the type of high-intensity offensive actions varies among combat sports, they all imply that athletes tried to progress in the fight with clear vigor, muscle strength, or power (eg, throws, punches, and kicks). Interestingly, several studies included in the meta-analysis of high-intensity offensive actions measured the effect of caffeine on 2 different combats/matches performed consecutively.[31,38,39] In those studies, the effect of caffeine was higher in the second combat (identified as C2 in Figure 4E) than in the first combat (identified as C1).

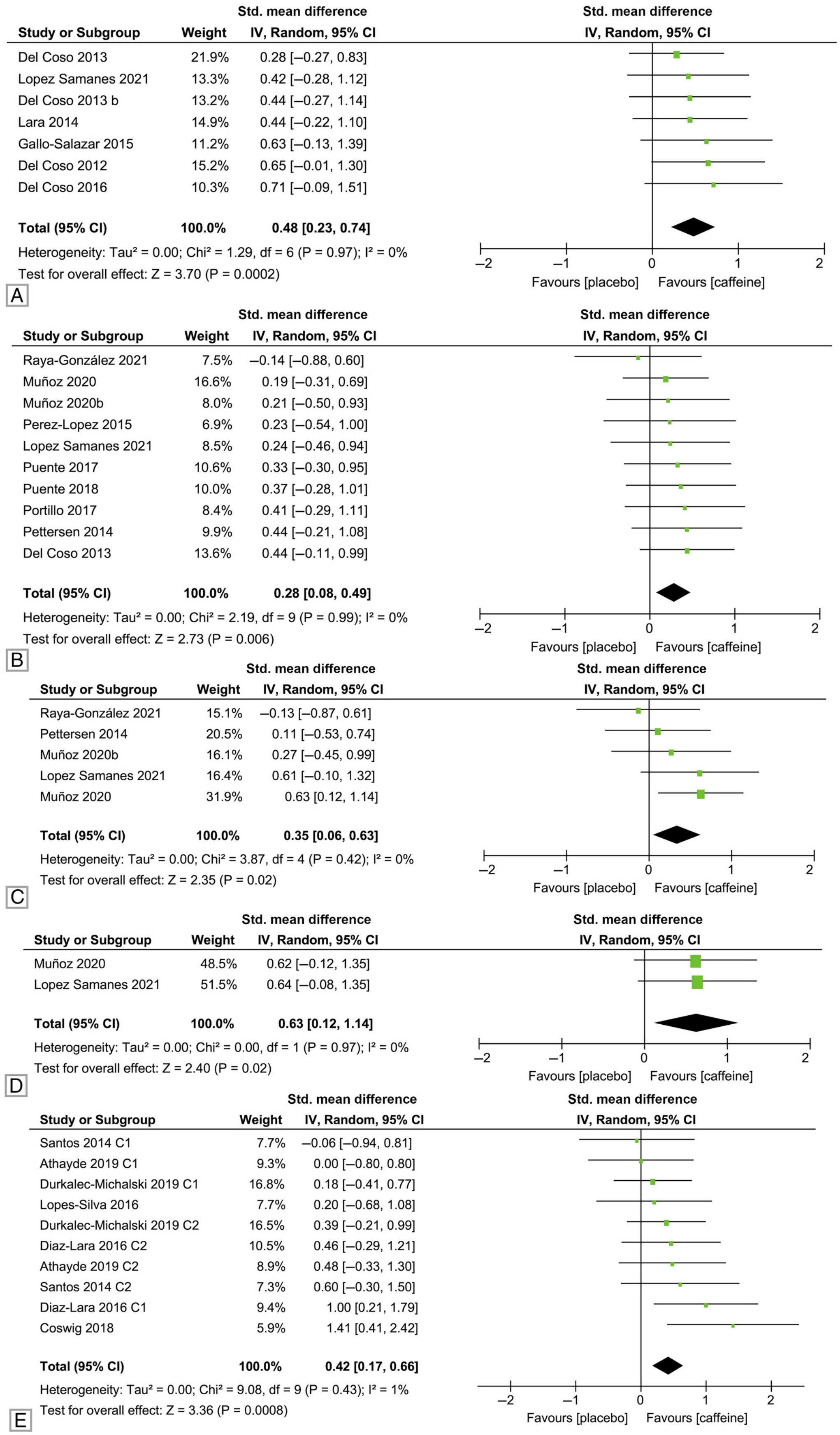

Figure 4 — Effect of caffeine ingestion compared with placebo on high-intensity actions during real and simulated competition. The forest plot shows standardized mean differences with 95% CIs of (A) number of sprints (8 studies), (B) number of body impacts (10 studies), (C) number of accelerations (5 studies), (D) number of decelerations (2 studies), and (E) number of high-intensity offensive actions (10 studies). The diamond at the bottom of each graph represents the pooled standardized mean difference following random-effects meta-analyses.

Successful or Positive Actions During Competition

As explained above, caffeine increased several physical performance variables measured during real competition; the question remains whether these improvements were transferred directly to sport-specific performance. A match in team/combat sports would go far beyond physical performance because other crucial aspects throughout the game play a role, such as good decision making, intelligent efforts, technical precision, and passing/shot accuracy.[54,55] One major novelty of the present meta-analysis is that we meta-analyzed the effect of caffeine on sport-specific actions by categorizing them into 3 levels (positive/successful, neutral, and negative/errors). The meta-analysis of these sport-specific actions revealed that caffeine increased the proportion of positive actions during matches/games, while the effect of caffeine to reduce the rate of neutral or negative actions did not reach statistical significance (Figure 5). Although the definition of positive/successful, neutral, and negative/error actions varied among investigations, essentially by the differences in sports' characteristics, a positive action always meant that the athlete performed an action that ended with a score or a benefit for the individual or team's performance. Some of the positive actions that have been part of this meta-analysis are serve, reception, spikes, and digs (volleyball),[21,32] percentage of points won in a match (tennis)[23] or the number of

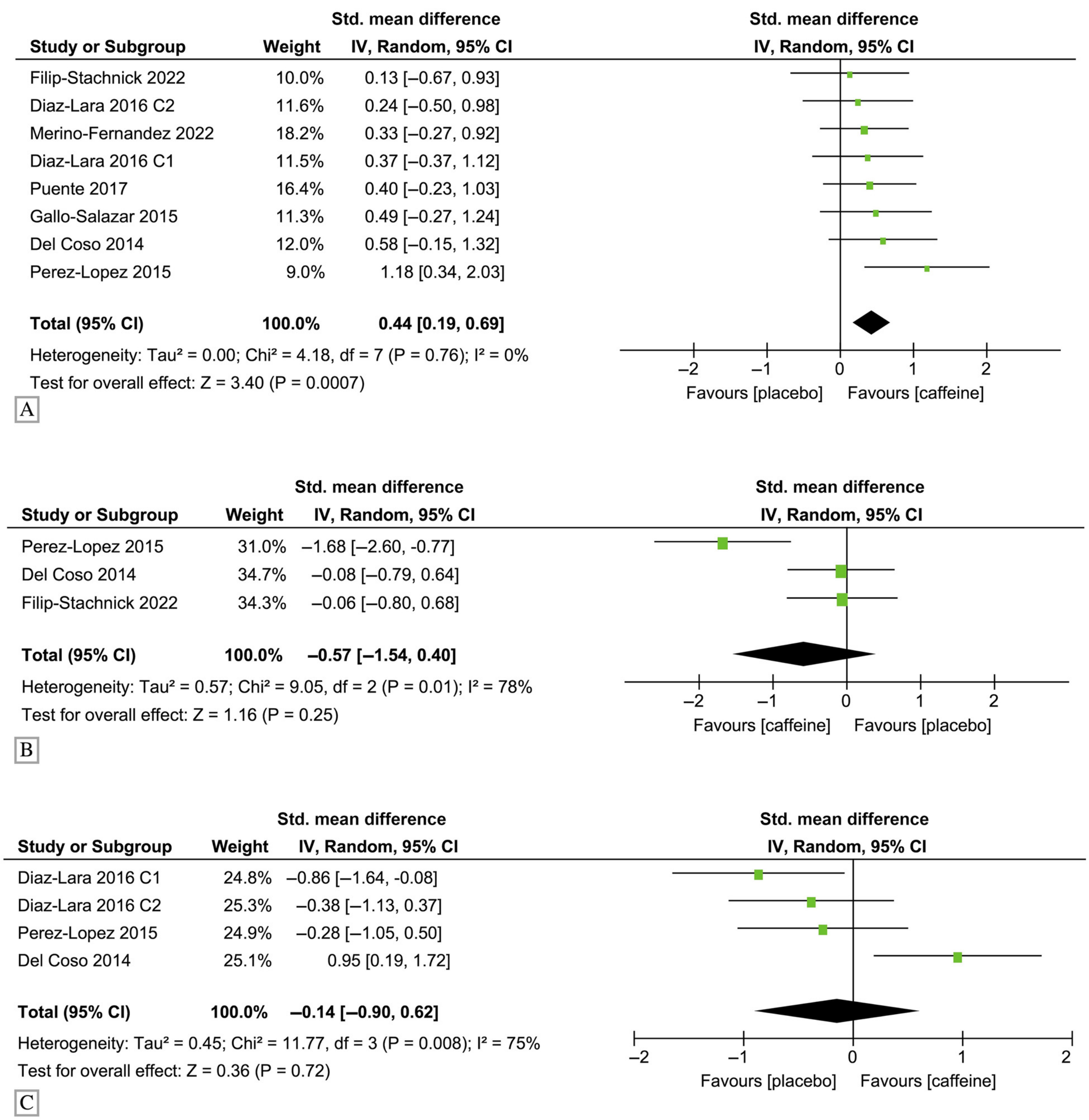

Figure 5 — Effect of caffeine ingestion compared with placebo on positive/successful, negative, and neutral actions during real and simulated competition. The forest plot shows standardized mean differences with 95% CIs of (A) positive actions (8 studies), (B) negative actions (3 studies), and (C) neutral actions (4 studies). The diamond at the bottom of each graph represents the pooled standardized mean difference following random effects meta-analyses.

successful actions or techniques with a high score possibility (eg, throws, sweeps, submissions in Brazilian jiu-jitsu).[24] Collectively, all these data confirm an effective transference of enhanced physical performance with caffeine into better sports performance, at least for team sports, racket sports, and combat sports. Thus, although the current analysis is a first step to providing evidence of the benefits of caffeine on sport-specific performance, more research is required to confirm if caffeine's benefits in sports competitions are translated into intelligent and successful actions by athletes.

The existence of tolerance to caffeine's ergogenic benefits when the substance is ingested chronically, on a daily basis, has been the topic of several previous investigations. Cross-sectional investigations comparing the effect of acute caffeine intake in naïve versus habitual caffeine consumers have found that both groups benefited, in terms of exercise performance, from the acute intake off 3 to 6 mg/kg of caffeine to a similar extent,[56–58] suggesting lack of tolerance to caffeine's ergogenicity. A recent systematic review that summarized these cross-sectional studies concluded that participants' habitual caffeine consumption did not influence the magnitude of the ergogenic effect obtained with acute caffeine intake.[59]

Limitations and Strengths

Although we only selected double-blinded, randomized controlled studies, the form of caffeine administration was diverse among studies, which makes it difficult to determine the best via of administration to obtain the benefits of caffeine on sport-specific actions during competition. A second limitation of this review is that the success of the blinding processes when administering caffeine and placebo treatments was only reported in 2 studies.[8,16] Although we cannot discard that some of the ergogenic effects of caffeine reported in this review are somewhat affected by caffeine expectancy, both investigations reported a successful blinding of the participants because most of them could not recognize the trial in which they had received caffeine as a treatment beyond chance. Future investigation should determine if caffeine expectancy is a modifying factor for caffeine supplementation, as athletes may modify their decisions during sports competition when they expect to obtain ergogenic benefits from caffeine supplementation. As reflected in the introduction, we wanted to focus our review on studies testing the effect of caffeine during real or simulated sports competitions as a step forward to the systematic reviews that have already summarized the effect of caffeine during sport-specific physical testing. To this regard, the potentially higher variability in the performance measurements when using real sport competitions (which is higher than when using validated physical performance tests) may have partially affected the results of this study.

From the pooled study sample of this systematic review, only 34% of the participants were women. The different nature of the studies included in this review precludes a subanalysis by participant's sex. Thus, although the potential benefits of caffeine derived from this review may be applicable irrespective of the athlete's sex, more caution is needed when using caffeine for female athletes of high-intensity sports, as only a minor part of the evidence reported here has been specifically tested in women.

However, the meta-analysis also had strengths, among which we must underline the participants' fitness level, as 20 of 24 studies are categorized as highly trained or elite/international athletes, and the main analysis obtained a low heterogeneity <5%, strengthening the main conclusions.

Practical Applications

Athletes and sports practitioners ingesting a moderate dose of caffeine supplementation (3 mg/kg) in these complex sports now have a scientific background that supports caffeine's benefits for intermittent and decision-making sports disciplines during competition. To make a complete analysis of caffeine utilization as an ergogenic aid, coaches and sports nutritionists might test the effect of this substance in simulated and real competition scenarios, conducting a performance/notational analysis to understand the potential of caffeine intake on technical–tactical actions or sport-action success.

Conclusion

Preexercise caffeine intake increased high-intensity sport-specific actions during real or simulated competitions, such as the number of sprints, body impacts, accelerations, decelerations, and offensive efforts in a combination of team sports, racket sports, and combat sports. Additionally, a moderate dose of caffeine induced a higher proportion of positive/successful actions during real or simulated competition. Overall, these outcomes suggest that caffeine supplementation effectively increases high-intensity efforts and the success of sport-specific actions during real or simulated competition. Therefore, this study confirms the transference of the ergogenic effect of caffeine supplementation on physical performance variables into better performance during competitions in intermittent sports.

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