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ORIGINAL RESEARCH

Effects of acute ingestion of caffeine on team sports performance: a systematic review and meta-analysis

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ABSTRACT

The aim of this investigation was to perform a systematic review and meta-analysis to determine the efficacy of the acute ingestion of caffeine (from 3 to 6 mg/kg) to increase performance on variables related to team sports. A systematic review was performed in scientific databases from January to April 2018. All studies included had cross-over experimental designs comparing caffeine to an identical placebo condition. A meta-analysis was performed using the random effects model and pooled standardized mean differences (Glass's Δ). Thirty-four studies published between 2001 and 2018 were included in the analysis. The meta-analysis revealed that caffeine increased single (Δ;95% confidence intervals = 0.19;0.14–-0.25; $p < 0.01$) and repeated jump height (0.29;0.16–0.42; $p < 0.01$), single (0.16;0.02–0.30; $p = 0.03$) and repeated sprint velocity (0.14;0.03–0.25; $p = 0.02$), and reduced the time to complete agility tests (0.41;0.04–0.77; $p = 0.03$). During team sport matches, caffeine increased total running distance (0.41;0.20–0.62; $p < 0.01$), distance covered at sprint velocity (0.36;0.12–0.59; $p < 0.01$) and the number of sprints (0.44;0.18–0.69; $p < 0.01$). The acute ingestion of a moderate dose of caffeine had a small but significant positive effect on several aspects related to physical performance in team sports.

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Exercise; physical conditioning; energy drink; soccer; rugby

Introduction

Caffeine (1, 3, 7-trymethylxantine) is a widely used substance in sports with most research and subsequent meta-analyses suggesting that it is ergogenic for endurance exercise (Southward, Rutherfurd-Markwick, & Ali, 2018; Souza, Del Coso, Casonatto, & Polito, 2017), anaerobic-based exercise (Grgic, 2018) and strength/power activities (Grgic, Trexler, Lazinica, & Pedisic, 2018). There is also a growing consensus about the main mechanism behind caffeine ergogenicity during locomotor activities, with a significant quantity of evidence in animal (Davis et al., 2003; El Yacoubi et al., 2000) and human models (Elmenhorst, Meyer, Matusch, Winz, & Bauer, 2012) supporting the ability of caffeine to act as an adenosine A_1 and A_{2A} receptor antagonist. Specifically, the intake of caffeine would blunt the fatiguing effects of adenosine

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through inhibition of the decreased release of the noradrenaline and dopamine, among other neurotransmitters, which in turn would produce an increase performance during intense exercise (McLellan, Caldwell, & Lieberman, 2016). Interestingly, A_1 and A_{2A} receptors are up-regulated with the habitual ingestion of caffeine (Fredholm, 1980) reducing in part the blocking-action of caffeine which might explain the tolerance to the ergogenic effects of this substance.

However, the benefits of caffeine on athletes who compete in team sports have been less established, mainly because these types of sports require a combination of aerobic endurance, running velocity, muscle power, agility, and sport-specific technical/tactical skills. To date, several experiments have been designed to determine the value of caffeine to increase performance in several team sport specialities, but there is no previous systematic review and subsequent meta-analysis that objectively presents the standardized effects of caffeine on team-sports performance. Perhaps this is one of the reasons behind the lower use of caffeine in team sports, as reported by the lower urinary caffeine concentrations found in post-competition samples (Del Coso, Munoz, & Munoz-Guerra, 2011). Recently, Chia, Barrett, Chow, and Burns (2017) systematically reviewed the effects of caffeine on ball games, including some of the most popular team sports. They found that an ample body of research demonstrated that caffeine in doses ranging from 3 to 6 mg/kg increased vertical jump and running performance in simulated matches, but found equivocal results for total distance covered, agility and accuracy. However, the review by Chia et al. (2017) lacked a meta-analysis to assess the magnitude of the ergogenic effects of caffeine on team sports performance. Therefore, this study aims to conduct a systematic review of the literature related to the performance effects of the ingestion of a moderate dose of caffeine in team sport athletes, and subsequently apply a meta-analysis to identify the specific ergogenic effects of caffeine on physical performance variables key for success in team sports.

Materials and methods

Search strategy and selection of studies

This review is reported in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines. The search for published studies on the topic was conducted in the databases PubMed/MEDLINE, Cochrane Library and Scopus from 8 January to 27 April 2018 while no year restriction was applied to the search strategy. Search terms included a mix of Medical Subject Headings (MeSH) and free-text words for key concepts related to caffeine and team sports performance. The full search criteria for the PubMed database can be found in Table 1. The conditions of the search were identical for Cochrane Library and Scopus, but the terms were not included as MeSH in these two databases. All titles and abstracts from the search were downloaded to Endnote X8 (Clarivate Analytics, UK) and manual cross-referencing was performed to identify duplicates and any potential missing studies. Titles and abstracts were then screened for a subsequent full-text review. The search for published studies was independently performed by two authors (JJS and BL) and disagreements were resolved through discussion.

Table 1. Full search criteria for the PubMed/MEDLINE database.

Search criteria for PubMed/MEDLINE
(((((“caffeine”[MeSH Terms] OR “caffeine”[All Fields]) OR (“energy drinks”[MeSH Terms] OR (“energy”[All Fields] AND “drinks”[All Fields]) OR “energy drinks”[All Fields] OR (“energy”[All Fields] AND “drink”[All Fields]) OR “energy drink”[All Fields])) OR caffeinated[All Fields]) OR (“tea”[MeSH Terms] OR “tea”[All Fields])) OR (“coffee”[MeSH Terms] OR “coffee”[All Fields])) AND ((((((((((((((team[All Fields] AND (“sports”[MeSH Terms] OR “sports”[All Fields] OR “sport”[All Fields])) OR (“volleyball”[MeSH Terms] OR “volleyball”[All Fields])) OR (“soccer”[MeSH Terms] OR “soccer”[All Fields])) OR (“football”[MeSH Terms] OR “football”[All Fields])) OR (“basketball”[MeSH Terms] OR “basketball”[All Fields])) OR (“hockey”[MeSH Terms] OR “hockey”[All Fields])) OR handball[All Fields]) OR croquet [All Fields]) OR netball[All Fields]) OR “water polo”[All Fields]) OR waterpolo[All Fields]) OR futsal[All Fields]) OR (“football”[MeSH Terms] OR “football”[All Fields] OR “rugby”[All Fields])) OR (“baseball”[MeSH Terms] OR “baseball”[All Fields])) OR floorball[All Fields]) OR (“baseball”[MeSH Terms] OR “baseball”[All Fields] OR “softball”[All Fields])).

For the articles obtained in the search, the following inclusion criteria were applied to select studies: 1) testing the effects of an acute dose of caffeine on team sport-specific tests and/or real or simulated matches; 2) with a blinded and randomized cross-over design in which there was an experimental condition that included the ingestion of caffeine or a caffeine-containing product which was compared to an identical experimental situation without caffeine; 3) with clear information regarding the administration of caffeine (relative dose of caffeine per kg of body mass and or absolute dose of caffeine with information about body mass; timing of caffeine intake before the onset of performance measurements, etc.); 4) where participants carried out a previous caffeine wash-out period of at least 24 h; 5) on team sport athletes; 6) with data available for calculation of effect size. The following exclusion criteria were applied to the experimental protocols of the investigation: 1) the use of caffeine doses below 2 mg/kg, based on previous investigations that did not find any ergogenic effect with < 2 mg/kg of caffeine in other forms of exercise (Astorino, Terzi, Roberson, & Burnett, 2010; Del Coso, Salinero, Gonzalez-Millan, Abian-Vicen, & Perez-Gonzalez, 2012; Turley, Eusse, Thomas, Townsend, & Morton, 2015, p. 2) the absence of a placebo condition. Team sports were defined as any sport activity involving two or more players working together towards a shared objective and where individuals were organized into opposing teams to compete for winning.

Figure 1 depicts the details of the study selection methodology. After the removal of duplicates and the application of inclusion/exclusion criteria, a total of 34 studies were considered for the qualitative and quantitative synthesis. Using Cohen’s kappa coefficient, the overall agreement rate between the two extractors of information prior to correcting discrepant items was 0.915.

Data extraction

Once the inclusion/exclusion criteria were applied, data on study source, study design, study quality, sample size, characteristics of the participants, caffeine administration form, habitual caffeine intake of the participants, modality of team sports, and final outcomes of the interventions were extracted independently by two authors (JJS and BL) using a spreadsheet (Microsoft Excel 2016, USA). Subsequently, disagreements were resolved through discussion until a consensus was achieved. Experiments were clustered by the type of test used to assess team sport performance and groups of experiments

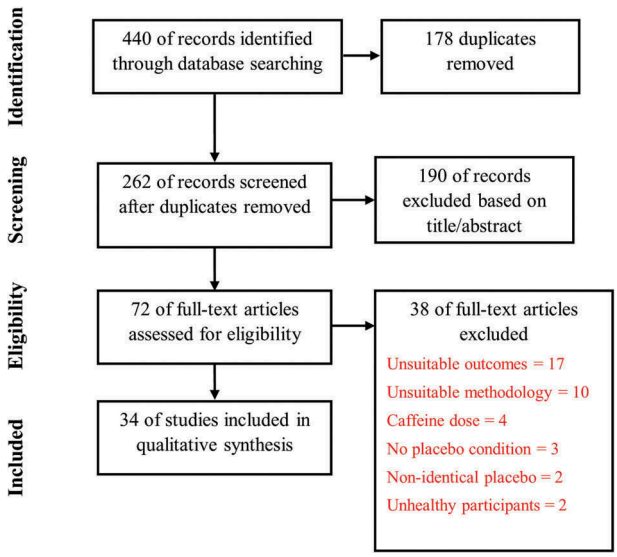

Figure 1. Selection of studies.

were created which assessed the effect of caffeine on jump performance (single and repeated jumps), sprint performance (single and repeated sprints), agility performance, and team sport-specific endurance performance (different tests of Yo-Yo). For the experiments that included performance measurements on a real or simulated match, experiments were grouped to assess the effect of caffeine on total running distance, sprint distance, and number of sprints. Finally, experiments in which the rate of perceived exertion was measured were also clustered. Several studies included measurements in two or more types of performance outcomes (e.g. jump performance and sprint performance), or even two types of tests for the same performance outcome (e.g. different forms of single jump tests). In these cases, each test was treated as a single and independent set of data for the meta-analysis and included in the appropriate performance outcome. Those performance outcomes assessed in two or less experiments (e.g. reaction time) or those assessed with very different methodological approaches (e.g. sport-specific accuracy/skill tests) were not included in the meta-analysis.

Quality assessment of the experiments

The quality of each experiment was assessed using the Physiotherapy Evidence Database Scale (PEDro) which has been reported to be valid and reliable to assess the internal validity of randomized controlled trials (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). The PEDro scale scores studies using an 11-point scale and includes information about randomization, blinding procedure, statistical analysis, and presentation of the results in the evaluated research. All assessments for the application of the PEDro scale were conducted in duplicate by JJS and BL via independent analyses, and any disagreements were resolved through consensus. Any experiments with a PEDro score below 6 points would have been excluded from the systematic review, though none of the studies examined were excluded by this criterion.

Statistical analyses

Descriptive analyses were performed using a spreadsheet (Microsoft Excel 2016, USA). Descriptive data of the participants' characteristics are reported as mean ± standard deviation (SD). The meta-analytic statistics were performed using a meta-analysis software (Review Manager 5.3, USA) which uses a generic inverse variance method and a random-effects model (Higgins & Green, 2011). The standardized mean difference (SMD), the number of participants and the standard error of the SMD for each research protocol were used to quantify changes in the performance variables when comparing the acute ingestion of caffeine versus a placebo. For this investigation, we have calculated pooled standardized mean differences (Glass's Δ; (Glass, McGaw, & Smith, 1981)) accompanied of 95% confidence intervals (CI) in both figures and text to reduce the effects of the interindividual differences in response to acute caffeine intake. The level to consider a standardized mean difference as statistically significant was set at $p < 0.05$ and the size of standardized mean difference was interpreted as: <0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large and; >4.0, extremely large (Hopkins, Marshall, Batterham, & Hanin, 2009).

The Q statistic was calculated to verify whether the degree of similarity in the observed mean differences were significant. The Q statistic was then converted into a standardized measure of homogeneity (I^2 statistic) and to gauge the level of heterogeneity in the included sample. An I^2 value between 25% and 50% represents a small amount of inconsistency, where as an I^2 value between 50% and 75% represents a medium amount of heterogeneity and an I^2 value > 75% represents a large amount of heterogeneity. 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. The sensitivity analyses were performed by repeating the meta-analysis with the removal of studies with smaller samples or by removing those studies with unexpected results (Higgins & Green, 2011).

Results

Descriptions of studies included

The general data of the experiments included in this systematic review are depicted in Table 2. The 34 experiments obtained in the systematic search were published between 2001 and 2018 and therefore reflect the physical and physiological variables of modern team sports. From the 34 experiments included in the meta-analysis, a total of 86 caffeine-placebo comparisons were made for the different performance variables. The total sample consisted of 466 athletes (326 males, 140 females) with an age of 22 ± 3 years (from 15 to 28 years, as an average for the experiment sample). Most of the experiments studied individuals with low-to-moderate daily caffeine intakes. In 30 out of 34 studies caffeine was administered based on an individual´s body mass, while an absolute dose was provided for all participants in 4 studies. Overall, the mean caffeine dose administered was 4.5 ± 1.4 mg/kg. In 15 studies the caffeine dosage was about 3 mg/kg, in 2 studies it was 4 mg/kg, in 3 studies it was 5 mg/kg, and in 14 studies the dose was 6 mg/kg. Regarding the form of administration, 16 investigations used capsules filled with caffeine, 10 investigations used caffeinated energy drinks, 6

Table 2. Summary of studies included in the systematic review.

Study	Design	Age (years)	Sample	Team sport	Habitual caffeine intake (mg/day)	Caffeine form	Caffeine dose (mg/kg)	Timing (min)	PEDro score	Performance outcome
(Abian-Vicen et al., 2014)	RDB	15 ± 1	16F	Basketball	60	Energy drink	3	60	10	CMJ 15-s RJ Yo-Yo IR1 Shooting accuracy
(Ali, O'Donnell, Foskett, & Rutherfurd-Markwick, 2016)	RDB	24 ± 4	10F	Various	0–300	Capsules	6	60	10	CMJ Knee flexors and extensors muscle strength
(Ali et al., 2015)	RDB	24 ± 4	10F	Various	0–300	Capsules	6	60	10	RPE Choice reaction time
(Assi et al., 2016)	RDB	22 ± 2	9M	Rugby	0–300	Liquid	6	60	10	RPE Passing accuracy test
(Buck, Guelfi, Dawson, McNaughton, & Wallman, 2015)	RDB	26 ± 2	12F	Various	Undefined	Capsule	6	60	10	RSA (6 × 20 m) RPE
(Clarke, Highton, Close, & Twist, 2016)	RDB	21 ± 2	8M	Rugby	Undefined	Liquid	3	60	10	CMJ RPE Movement demands in simulated match
(Coso et al., 2013)	RDB	23 ± 2	16F	Rugby	<60	Energy drink	3	60	10	RSA (6 × 30 m) 15 s RJ; Movement demands in real competition
(Del Coso et al., 2012)	RDB	21 ± 2	19M	Football	<60	Energy drink	3	60	10	RSA (7 × 30 m sprints) 15 s RJ Movement demands in simulated match
(Del Coso et al., 2014)	RDB	22 ± 7	15M	Volleyball	<30	Energy drink	3	60	10	Volleyball-specific jumps CMJ 15 s RJ Agility T-test Handgrip strength Game-related statistics RPE
(Del Coso et al., 2016)	RDB	23 ± 4	13M	Hockey	<100	Energy drink	3	60	10	RPE Movement demands in simulated match
(Del Coso et al., 2013)	RDB	25 ± 2	30M	Rugby	<60	Energy drink	3	60	10	Movement demands in simulated match Body accelerometry
(Duncan, Taylor, & Lyons, 2012)	DB	21 ± 1	13M	Hockey	250	Liquid	5	60	9	RPE Hockey skill performance tests
(Eaton et al., 2016)	SB	22 ± 2	10M	Football	Undefined	Capsules	3	60	7	RSA (6 × 4 s)
(Ermolao et al., 2017)	RDB	23 ± 2	12M	Football	Undefined	Liquid	4	60	11	RSA (11 × 20 m)
(Evans et al., 2017)	RDB	21 ± 1	18M	Various	Undefined	Chewing gum	~3	10	10	RSA (10 × 40 m)
(Fernández-Campos, Dengo, & Moncada-Jiménez, 2015)	RDB	22 ± 5	19F	Volleyball	Undefined	Energy drink	6	30	9	CMJ SJ Handgrip strength
(Foskett et al., 2009)	RDB	24 ± 5	12M	Football	0–350	Capsules	6	60	11	CMJ 1 × 15 m
(Jordan, Korgaokar, Farley, Coons, & Caputo, 2014)	RDB	14 ± 1	17M	Football	~50	Capsules	6	60	10	RPE Reactive agility test
(Kopec, Dawson, Buck, & Wallman, 2016)	RDB	20 ± 2	11M	Various	<160	Capsules	6	60	10	RSA (6 × 20 m) RPE
(Lara et al., 2014)	RDB	21 ± 2	18F	Football	<60	Energy drink	3	60	10	CMJ RSA (7 × 30 m) Movement demands in simulated match RPE

(*Continued*)

Table 2. (Continued).

Study	Design	Age (years)	Sample	Team sport	Habitual caffeine intake (mg/day)	Caffeine form	Caffeine dose (mg/kg)	Timing (min)	PEDro score	Performance outcome
(Marriott, Krustrup, & Mohr, 2015)	RSB	21 ± 1	12M	Various	Undefined	Capsules	6	70	8	Yo-Yo IR2 RPE
(Paton, Hopkins, & Vollebregt, 2001)	RDB	22 ± 3	16M	Various	Undefined	Capsules	6	60	10	RSA (10 × 20 m)
(Pereira et al., 2011)	RDB	15 ± 2	11M	Football	Undefined	Capsules	6	60	10	RSA (6 × 40 m)
(Pérez-López et al., 2015)	RDB	25 ± 5	13F	Volleyball	Undefined	Energy drink	3	60	10	Volleyball-specific jumps CMJ SJ Agility T-test Handgrip strength Body accelerometry in simulated match Game-related statistics
(Pettersen et al., 2014)	RDB	18 ± 1	19M	Football	Undefined	Capsules	6	55	9	Yo-Yo IR2 Movement demands in simulated match Body accelerometry in simulated match
(Portillo et al., 2017)	RDB	23 ± 2	16F	Rugby	<60	Energy drink	3	60	10	Body accelerometry in real competition Rugby skill performance tests
(Puente et al., 2017)	RDB	28 ± 6	10M 10F	Basketball	<100	Capsule	3	60	11	Abalakov jump Agility CODAT test Body accelerometry in simulated match Game-related statistics RPE
(Ranchordas, King, Russell, Lynn, & Russell, 2018)	RDB	19 ± 1	10M	Football	100	Chewing gum	~3	5	10	CMJ Yo-Yo IR1 1 × 20 m
(Ribeiro et al., 2016)	RDB	22 ± 3	6M	Handball	~60	Capsules	6	60	10	4 × 30 s RJ
(Roberts et al., 2010)	RSB	22 ± 4	8M	Rugby	<100	Liquid	4	60	10	1 × 15 m Agility test Motor skill test RPE
(Stuart et al., 2005)	RDB	25 ± 5	9M	Rugby	Undefined	Capsules	6	70	9	Rugby-specific performance test)
(Wellington, Leveritt, & Kelly, 2017)	RDB	19 ± 5	11M	Rugby	Undefined	Capsules	~4	60	9	RSA (3 × 20 m) RPE
(Woolf, Bidwell, & Carlson, 2009)	RDB	20 ± 2	17M	Am. Football	~20	Liquid	5	60	11	1 × 37 m Agility test Bench press repetition RPE
(Zbinden-Foncea et al., 2018)	RDB	19 ± 2	10M	Volleyball	~60	Capsules	5	60	10	CMJ

RDB: randomized double blind; RSB: randomized single blind; DB: double blind; SB: single blind; F: females; M: males. CMJ: Countermovement jump. SJ: Squat jump. RJ: Repeated jumps. RSA: Repeated sprint ability (running). RPE: Rate of perceived exertion. IR: Intermittent recovery. Movement demands in match: total running distance, sprint distance and/or number of sprints during a real or simulated match.

investigations used caffeine powder diluted in drinks (i.e. liquid) and 2 investigations employed caffeinated chewing gums. Most investigations administered the caffeine 30–70 minutes before the onset of the testing, except for two investigations in which caffeine was administered 5–10 minutes before trials (the studies where caffeine was administered in the form of chewing gum). Only six investigations measured the success of the blinding procedures during experimental trials while all of them resolved that participants were effectively blinded to the experimental treatments because they were unable to identify the ingestion of caffeine. For all studies included in this review, the PEDro Scale score ranged from 7 to 10 points and thus, the quality of these investigations can be considered as of moderate to high quality.

Physical performance meta-analysis

Figure 2 through 7 show the overall effect of caffeine intake on different physical aspects of team sports performance. The pre-exercise ingestion of caffeine significantly increased the vertical height in a single jump (Glass's Δ; 95% CI; effect size interpretation; I^2 = 0.19; 0.14–0.25; trivial; 0%; $p < 0.01$), and in repeated jumps (0.29; 0.16–0.42; small; 0%; $p < 0.01$). The combined effects of these two types of jumps also showed a significant increase after the ingestion of caffeine (0.21; 0.16–0.26; small; 0%; Figure 2; $p < 0.01$). An ergogenic effect of caffeine was also found in single sprint velocity (0.16; 0.02–0.30; trivial;

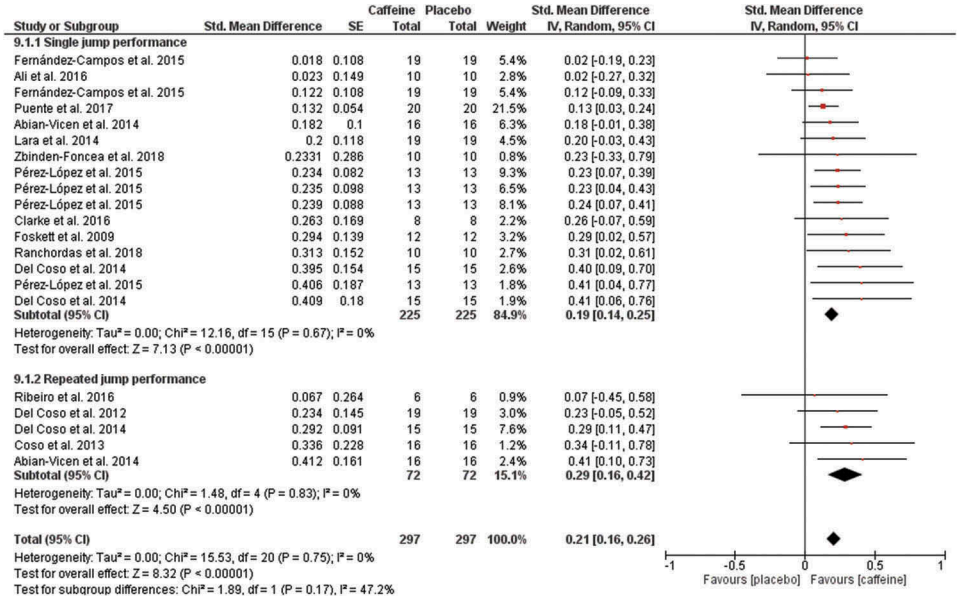

Figure 2. Effect of caffeine ingestion as compared to a placebo on jump performance in team sport athletes.

Forest plot shows standardized mean differences with 95% confidence intervals (CI) for 16 tests that included a single jump and 5 tests that included repeated jumps. Subgroup analysis show the results for single and repeated jump performance. The diamond at the bottom of the graph and at the bottom of the subgroup analysis represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

37%; $p = 0.03$), and for repeated sprint velocity (0.14; 0.03–0.25; trivial; 11%; $p = 0.02$). The effect of caffeine on the combination of these types of sprints was also positive and significant (0.15; 0.06–0.23; trivial; 24%; Figure 3; $p < 0.01$). Caffeine was also effective in reducing the time required to complete agility tests (0.41; 0.04–0.77; small; 87%; Figure 4; $p = 0.03$) and it showed a positive effect to increase the distance covered during the different modalities of the Yo-Yo test (0.22; 0.00–0.44; small; 67%; Figure 5; $p = 0.05$).

Figure 6 depicts the effect of caffeine on different variables related to players' displacements during real or simulated matches. Caffeine demonstrated an ergogenic effect in increasing the total running distance (0.41; 0.20–0.62; small; 47%; panel A; $p < 0.01$), the running distance covered at sprint velocity (0.36; 0.12–0.59; small; 64%; panel B; $p < 0.01$), and the number of sprint actions (0.44; 0.18–0.69; small; 46%; panel C; $p < 0.01$). On the other hand, caffeine did not produce any significant effect on reducing the rate of perceived exertion during the performance tests mentioned above (-0.07; -0.44–0.29; trivial; 75%; Figure 7; $p = 0.69$).

Discussion

The purpose of this systematic review and meta-analysis was to summarize evidences for the effect of acute caffeine ingestion on variables related to team sports performance.

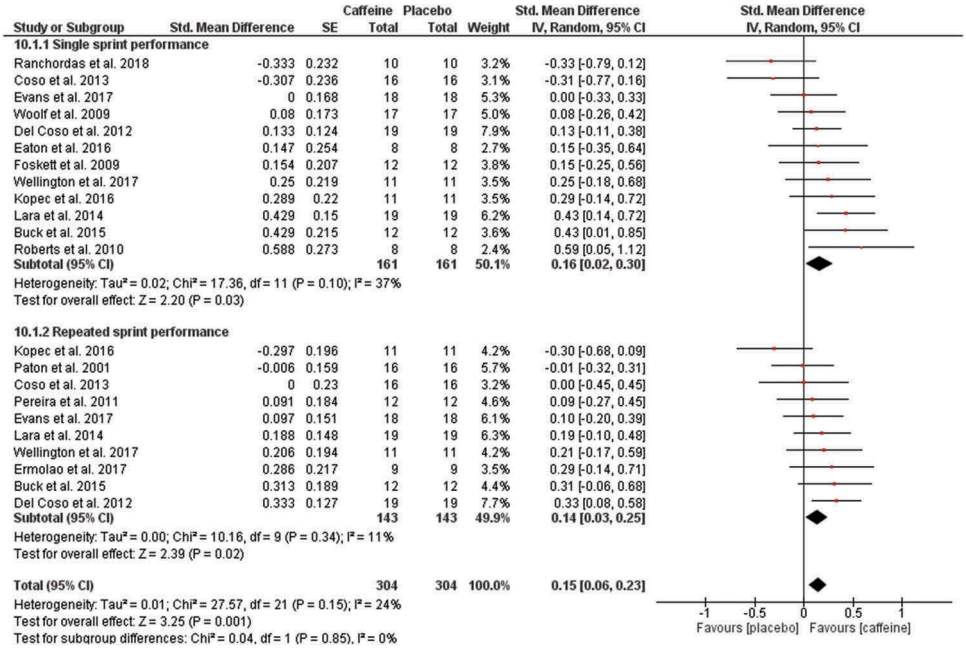

Figure 3. Effect of caffeine ingestion as compared to a placebo on sprint performance in team sport athletes.

Forest plot shows standardized mean differences with 95% confidence intervals (CI) for 12 tests that included a single sprint and 10 tests that included repeated sprints. Subgroup analysis show the results for single and repeated sprint performance. The diamond at the bottom of the graph and at the bottom of the subgroup analysis represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

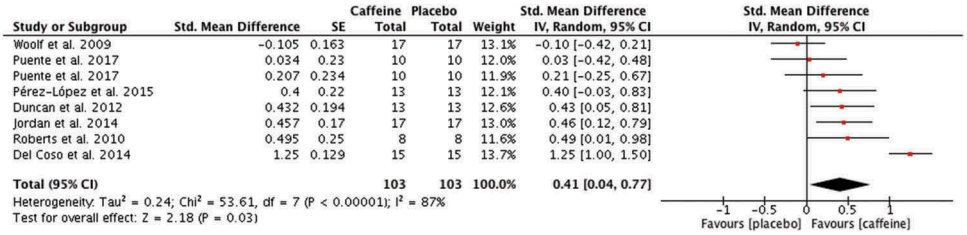

Figure 4. Effect of caffeine ingestion as compared to a placebo on agility tests in team sport athletes.

Forest plot shows standardized mean differences with 95% confidence intervals (CI) for 8 tests. The diamond at the bottom of the graph represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

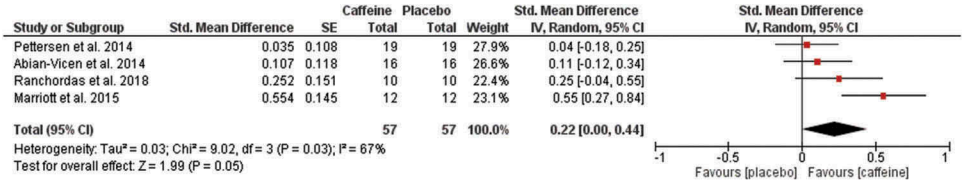

Figure 5. Effect of caffeine ingestion as compared to a placebo on the different types of the Yo-Yo test in team sport athletes.

Forest plot shows standardized mean differences with 95% confidence intervals (CI) for 4 tests. The diamond at the bottom of the graph represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

The principle results indicate that pre-exercise ingestion of a moderate dose of caffeine (from 3 to 6 mg/kg) leaded to small/trivial, but statistically significant improvements, on jump performance, sprint performance, agility, team sport-specific endurance performance, while it increased the running distance and sprint running distance during team sport matches. On the other hand, the ingestion of caffeine did not affect the rate of perceived exertion during exercise. Thus, this meta-analysis suggests that caffeine may have utility as an ergogenic aid for team sports players because this stimulant enhanced several physical aspects related to success in these types of sports.

All the investigations included in the meta-analysis used an acute dose of caffeine provided between 10 and 70 minutes before the onset of exercise. Caffeine is rapidly absorbed by the gastrointestinal track, reaching peak plasma concentrations approximately 30–60 min after ingestion, and then remains relatively constant for several hours (Magkos & Kavouras, 2005; Sadek et al., 2017). Thus, it is likely that performance testing in the investigations included in this meta-analysis was completed when caffeine concentrations were near peak in plasma. In addition, the pre-experimental standardizations and controls used in the research protocols suggest that the performance benefits found in this meta-analysis are primarily attributed to the acute ingestion of caffeine. The dose of caffeine administered in the experiments ranged from ~3 to ~6 mg/kg and thus, the ergogenic effects of caffeine on team sports players must be attributed this range of

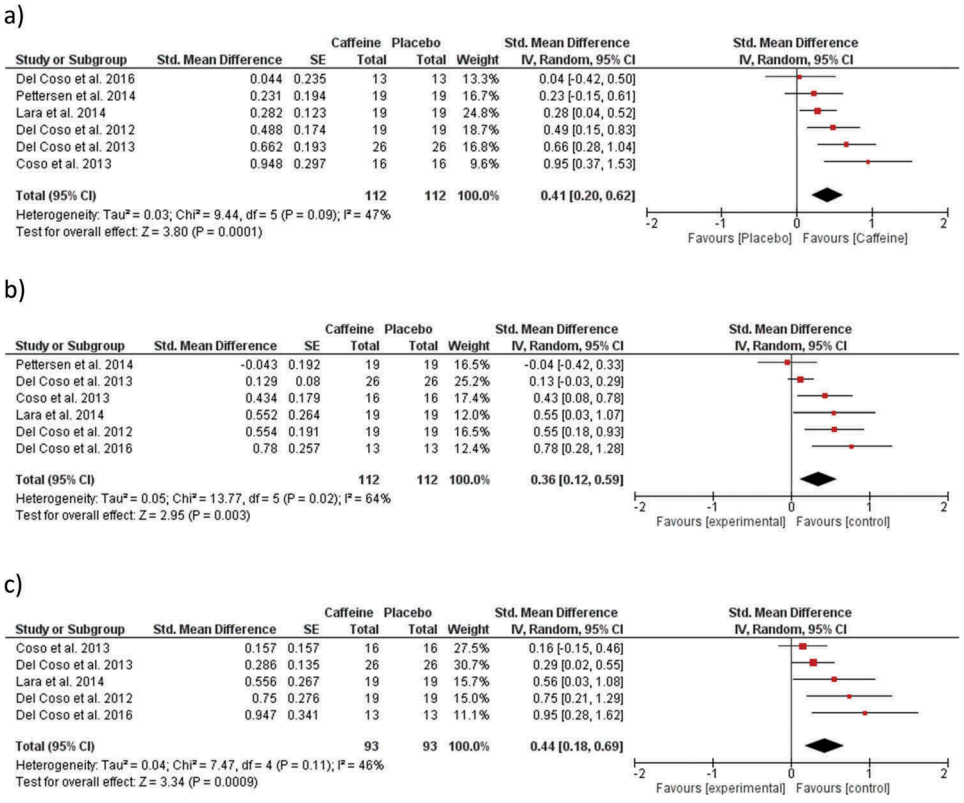

Figure 6. Effect of caffeine ingestion as compared to a placebo on (a) total running distance, (b) running distance covered at sprint velocity (c) number of sprints during a real or simulated match of different team sport specialties.

Forest plots shows standardized mean differences with 95% confidence intervals (CI) for 6 comparisons in total running distance, 6 comparisons for sprint distance and 5 comparisons in the number of sprints. The diamond at the bottom of the graph represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

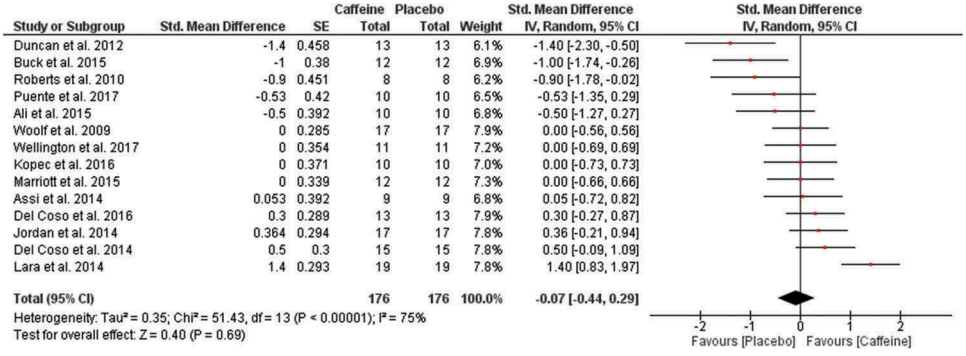

Figure 7. Effect of caffeine ingestion as compared to a placebo on rate of perceived exertion in team sport athletes.

Forest plot shows standardized mean differences with 95% confidence intervals (CI) for 14 comparisons. The diamond at the bottom of the graph represents the pooled standardized mean difference with the 95% CI for all trials following random effects meta-analyses. The size of the plotted squares reflects the relative statistical weight of each study.

dosing. However, further information is required to determine the existence of a caffeine dosage threshold to improve performance in team sports, as recently suggested (Chia et al., 2017). Based on previous investigations with other different forms of exercise (Astorino et al., 2010; Del Coso et al., 2012; Turley et al., 2015), or in team sports (Astorino et al., 2012), it can be suggested that doses below 2 mg of caffeine per kg of body mass might not be effective to increase team sports performance.

Caffeine was administered in cross-over designs to team sport players with a wide range of daily caffeine intakes (see Table 2 for further details), although they can be catalogued as low-to-moderate caffeine consumers. The investigations were always carried out after a wash-out period in which dietary sources of caffeine were avoided for a several hours before testing. Under these circumstances, caffeine has been ergogenic for team sport athletes, but this is not always the scenario of caffeine use in team sports because the presence of light and heavy caffeine consumers on teams. In this regard, the efficacy of caffeine ingestion to improve performance may be reduced in individuals who consume moderate-to-high doses of caffeine daily (130–300 mg) in comparison to low caffeine consumers (40–50 mg/day; (Bell & McLellan, 2002; Evans et al., 2017) or individuals that consume 1.5–3.0 mg/kg of caffeine for 28 consecutive days (Beaumont et al., 2017). Nevertheless, several other investigations have determined that habitual caffeine consumers might also benefit from the ergogenic effects of pre-exercise caffeine ingestion (Dodd, Brooks, Powers, & Tulley, 1991; Goncalves et al., 2017; Irwin et al., 2011; Tarnopolsky & Cupido, 2000). Therefore, although the current meta-analysis determined the efficacy of acute ingestion of caffeine in athletes with low-to-moderate habituation to caffeine, it is still possible that the effects of caffeine on increasing performance are lower in team sports athletes who consume higher doses of caffeine on a day-to-day basis. Perhaps, the de-habituation to caffeine or the use of higher doses of 6 mg of caffeine per kg of body mass might be more advantageous for those heavy caffeine consumers who would like to use caffeine as an ergogenic aid in team sports(Sokmen et al., 2008), although this should be further investigated.

Most of the experiments included in this systematic review presented the performance outcomes after the acute ingestion of caffeine as a group mean. In fact, the meta-analysis employed the data of the placebo-caffeine comparisons of each experiment as a group of individuals, indicating that, in general, caffeine is effective in increasing performance in team sports. However, recent investigations have shown that not all individuals experience enhanced physical performance after the ingestion of moderate doses of caffeine (Doherty, Smith, Davison, & Hughes, 2002; Grgic & Mikulic, 2017; Lara et al., 2015; Skinner, Jenkins, Coombes, Taaffe, & Leveritt, 2010). These studies have identified the presence of athletes who obtain minimal ergogenic effects or only slightly ergolytic effects after acute administration of caffeine, and such participants have been catalogued as "non-responders to caffeine" (Pickering & Kiely, 2018). To date, there is still no clear explanation for the lack of ergogenic effects after the acute administration of caffeine in some individuals. Factors such as training status, habitual daily caffeine intake or tolerance to caffeine, and genotype variation have been proposed as possible modifying factors for the ergogenicity of caffeine (Pickering & Kiely, 2018). Whilst the ingestion of 3–6 mg/kg of caffeine is generally ergogenic in team sports, it might not be optimal for everyone. The inter-individual variability in the ergogenic response to acute caffeine ingestion suggests that caffeine should be recommended in an individualized manner.

Perhaps, the most tested research hypothesis to explain the existence of "non-responders to caffeine" is the occurrence of one or various genetic polymorphism that preclude(s) in part the physiological effects derived from acute caffeine ingestion. Specifically, the polymorphisms in the *CYP1A2* (-163C>A; rs762551) and *ADORA2A* genes (1976C>T; rs5751876) have been postulated as modifiers of the ergogenic response to caffeine ingestion. Several investigations, using endurance-like tests to assess performance, have found that AA homozygotes of the *CYP1A2* gene obtained inferior ergogenic benefits from acute caffeine intake than C-allele carriers (Guest, Corey, Vescovi, & El-Sohemy, 2018; Rahimi, 2018; Womack et al., 2012), likely due to a faster capacity to metabolize caffeine into paraxanthine (Djordjevic, Ghotbi, Jankovic, & Aklillu, 2010). However, other investigations have found that AA homozygotes have a similar (Pataky et al., 2016) or even a higher ergogenic response to caffeine than C-allele carriers (Algrain et al., 2016; Salinero et al., 2017). A recent investigation carried out with basketball players found that both AA homozygotes and C-allele carriers similarly increased their physical performance in basketball during specific testing and a simulated match after the administration of an acute dose of caffeine (Puente, Abian-Vicen, Del Coso, Lara, & Salinero, 2018). Regarding the *ADORA2A* gene, it has been found that C-carriers showed a decreased ergogenic response to caffeine in comparison to TT homozygotes (Loy, O'Connor, Lindheimer, & Covert, 2015). While it seems clear that genetics affects the magnitude of the ergogenic effects derived from caffeine supplementation, and contributes to the interindividual differences in response to acute caffeine ingestion, future research should determine which genes unequivocally affect the ergogenicity of caffeine, as well as the mechanisms behind this effect (Southward, Rutherfurd-Markwick, Badenhorst, & Ali, 2018).

Caffeine is a potent drug that produces a wide range of metabolic, hormonal, and physiologic effects (Sokmen et al., 2008). Some of these effects can aid in an increase in sports performance, but others may counteract the benefits derived from caffeine ingestion. For example, it has been found that caffeine ingestion increases the perceived muscle power during simulated competitions of athletes in different sport disciplines (including athletes of rugby, volleyball, soccer, and hockey (Salinero et al., 2014)). However, caffeine also increases levels of perceived nervousness and activeness and the prevalence of gastrointestinal complaints and insomnia after exercise (Pallares et al., 2013; Salinero et al., 2014). One might argue that despite its positive effects on physical variables, caffeine should not be used by team sport athletes because of its influence on these draws of the technical and/or tactical components of team sports. Accuracy in different team sport-specific skills is also a key factor for success, and several side effects associated with caffeine ingestion, such as tremors and nervousness, could be associate with deteriorated accuracy performance (Chia et al., 2017). However, the current evidence disputes that caffeine negatively affects the technical and/or tactical performance in team sports. For example, acute ingestion of caffeine improved the rate of technical actions qualified as positive for the game in male (Del Coso et al., 2014) and female volleyball players (Pérez-López et al., 2015). In basketball players, caffeine was found to increase the number of rebounds, assists, and the overall performance index (Puente et al., 2017). In soccer players, a higher passing accuracy has also been suggested during a test that measured physical and technical performance in soccer players (Foskett, Ali, & Gant, 2009). These positive

effects of caffeine on technical actions are added to the increased number of body impacts during real or simulated matches (Del Coso et al., 2013; Pérez-López et al., 2015; Portillo, Coso, & Abián-Vicén, 2017; Puente et al., 2017). The higher number of body impacts probably indicates a higher involvement of players during the game, although body accelerometry does not allow to discriminate between the type of offensive and defensive actions. Finally, it has been suggested that caffeine likely benefited several rugby-specific skills (Stuart, Hopkins, Cook, & Cairns, 2005), although a neutral effect of caffeine has also been reported on the quality of the technical actions performed during a rugby official and simulated competition (Assi & Bottoms, 2014; Portillo et al., 2017). In brief, caffeine can increase the feelings of activeness and nervousness, especially after exercise, but it seems that these side-effects do not have a detrimental effect on the technical/tactical aspects of the game. However, athletes, nutritionists, and physicians should certainly take into account the drawbacks of caffeine ingestion when deciding whether or not to recommend this stimulant for team sport athletes, especially the drawbacks found post exercise.

This meta-analysis presents some limitations related to the different research protocols and performance tests used in the investigations included. Although most of the performance variables included in the meta-analysis had good-to-moderate values of homogeneity, the I^2 statistic was superior to 75% for agility tests and the rate of perceived exertion (RPE), which indicates a large amount of heterogeneity in the studies included to calculate the effects of caffeine on these two variables. The meta-analysis of the effects of caffeine on team sports athletes' agility and on their ratings of perceived exertion should be confirmed with more homogeneous research protocols. The threshold of running velocity to be considered a sprint action was different among various investigations that measured the effects of caffeine during matches (Figure 6). Although all of the investigations based their respective speed thresholds in values specific for each team sport discipline, this must be considered when comparing the outcomes of the current investigation to other team sports specialties. Finally, although we selected investigations in which caffeine was compared to an identical situation without caffeine administration, in some investigations, caffeine was co-ingested with other ingredients (e.g. carbohydrates, sodium bicarbonate, etc). It is still possible that some of these ingredients produced a synergistic or antagonistic effect on performance. Despite these limitations, this meta-analysis suggests a positive effect of caffeine in increasing physical performance in team sports. However, team sports are complex disciplines in which physical performance is only one of several factors necessary for succeeding. In this respect, further investigations are necessary to determine the effects of caffeine on complex and ecological sport-specific tests, especially decision-making situations.

Conclusion

In summary, the pre-exercise ingestion of a moderate dose of caffeine was found to be effective in increasing several physical performance variables in team sports athletes during sport-specific testing and matches. Although the size of the ergogenic effects can be categorized as small/trivial, caffeine significantly increased jump performance, sprint performance, agility, team sport-specific endurance performance, the running distance

and sprint running distance during team sport matches, which can contribute to obtain a higher likelihood of success in this type of sports. The moderate-to-high quality of the investigations, the relatively good consistency of tests included in the meta-analysis and the effectiveness of caffeine to increase several aspects of team sports performance suggest that this substance may have utility as an ergogenic aid in team sports. Nevertheless, the use of caffeine should only be recommended after a careful evaluation of the draw-backs typically associated with the use of caffeine.

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