The influence of caffeine on tolerance to sport-specific high-intensity exercise in young elite soccer players

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Abstract

Background

Modern elite football places extremely high demands on the athlete's body, so it is of practical interest to study the effect of various dietary supplements on load tolerance and post-exercise recovery. Furthermore, there is a lack of research on the effects of caffeine on key measures of load tolerance in football such as delayed onset muscle soreness (DOMS), rate of perceived exertion (RPE), and heart rate (HR) at different time points after the exercise.

Methods

54 young players aged 15-17 years from a leading Russian football academy took part in a randomized trial using the balanced placebo design.

They were divided into 4 groups: 1 - told caffeine/given caffeine, 2 - told caffeine/given placebo, 3 - told placebo/given placebo, 4 - told placebo/given caffeine. All participants consumed two capsules 60 minutes before testing, each containing 200 mg of caffeine or placebo.

Sprinting, counter-movement jump, change of direction run, dribbling, T-test and repeated sprint ability test were used to create conditions for high-intensity sports-specific load.

A visual analogue scale was used to assess the severity of muscle soreness, RPE was assessed using the Borg Rating of Perceived Exertion scale, HR immediately post exercise (HRpe), HR after two minutes of passive rest (HRrest) and recovery HR (HRrec = HRpe - HRrest) were obtained.

Results

The data demonstrated that a single caffeine intake of 400 mg had no statistically significant effect on RPE ($p = 0.948$), HRpe ($p = 0.698$), or HRrec ($p = 0.920$) across the groups. Additionally, the severity of DOMS 24 hours post-exercise did not differ significantly between the groups ($p = 0.077$).

Conclusion

The acute caffeine ingestion does not affect the subjective and objective indicators of training load in young football players aged 15-17 years with low levels of anxiety and low levels of daily caffeine intake.

Highlights

- A single caffeine ingestion at a dose of about 6 mg/kg has no significant effect on RPE, DOMS severity, and HR recovery in elite football players aged 15-17 years with low levels of anxiety and daily caffeine intake
- Caffeine expectations have no significant effect on the analysed indices and do not contribute to the final effect of the substance in elite football players aged 15-17 years, who have low levels of anxiety and daily caffeine intake.
- Neither caffeine at a dosage of about 6 mg/kg nor beliefs about its use had a significant effect on maximal HR of elite 15-17-year-old football players during high-intensity sport-specific physical activity.

Keywords: young athletes; football; placebo effect fatigue; workload capacity

Introduction

Understanding various methods and tools to enhance performance and post-exercise recovery remains a critical focus of modern sports science and medicine. Among athletes, dietary supplements and pharmacologic substances are frequently used to boost performance and optimize recovery (1, 2). However, many of these substances have limited evidence supporting their efficacy (3-6). Caffeine is one of the few supplements with well-established ergogenic benefits (7, 8). It is widely consumed among athletes of various ages (9-12), both as a common part of a diet

and supplement due to its proven positive impact on athletic performance, including strength, endurance, jump height, sprint time, and repeated sprint ability (13-17). However, there are few studies involving youth football players, and only a small number of these studies have included participants who could be considered elite (18-21). In addition, these studies mainly evaluated the effects of caffeine on physical performance and sport-specific skills, with little evaluation of its effects on exercise tolerance.

Additionally, caffeine use is permitted under anti-doping regulations, making it a viable option for professional athletes.

It is important to consider their influence on load tolerance when assessing the effects of dietary supplements on performance. Although performance may improve, a decrease in load tolerance can elevate the risk of incomplete recovery, potentially leading to non-functional overreaching (22, 23). Key measures of load tolerance include heart rate (HR) during various phases of exercise, blood lactate and creatine kinase levels rate of perceived exertion and delayed onset muscle soreness (DOMS) at different post-exercise intervals (24-26).

There are a number of studies involving physically healthy subjects and athletes at different levels that have examined the effects of caffeine on HR (18, 27, 28), DOMS (27, 29-32) and RPE (21, 28). And the results of these studies are contradictory. For instance, Stadheim et al. (2014) found that a single dose of 3.5 to 4.5 mg/kg of caffeine administered 45 minutes before a 10-minute cross-country skiing test increased HR and DOMS in elite cross-country skiers (33). In contrast,

Black et al. (2015) observed a significant reduction in RPE and muscle pain without significant effects on HR during a 30-minute submaximal cycling bout in recreational athletes (27). Acker-Hewitt et al. (2012) found no significant impact on HR or RPE during a 20-minute cycling test at 60% VO2max, followed by a 20-kilometer time trial, after a single dose of 6 mg/kg of caffeine in collegiate cyclists (28). However, many of these studies did not incorporate sport-specific, high-intensity exercises, and most participants were adult amateur rather than elite athletes.

The mechanisms of action of caffeine that lead to the development of ergogenic effects after its ingestion are still not well understood. The competitive antagonism of caffeine at central and peripheral adenosine receptors can be considered as the best studied and justified (34, 35). However, some studies show that manipulating information about caffeine intake has a significant effect on outcomes, and this effect can be observed without caffeine consumption (36, 37). Shabir et al. found that 13 out of 17 studies observed varying degrees of contribution of the expectancy effect to performance on a range of physical tests and cognitive tasks (38). It should be noted that the classic double-blind, placebo-controlled, randomised study design has been most commonly used in studies evaluating the effects of caffeine on various performance parameters in young athletes (18-21). However, the disadvantages of this type of design include the inability to assess the contribution of the placebo effect (expectancy effect) to the 'total' effect of taking the drug (39). To overcome these limitations, the use of a balanced placebo design

has been proposed, in which participants are divided into 4 groups according to what information they are told about the intended treatment, allowing the contribution of the expectancy effect to the 'total' treatment effect to be analysed (40).

Given the widespread use of caffeine among athletes and the conflicting data regarding its effects on load tolerance, the aim of this study was to evaluate the influence of caffeine on load tolerance in young elite football players during sport-specific high-intensity exercises. It can be hypothesised that the use of caffeine may lead to an increase in a number of aspects of physical performance with a concomitant increase in the effect on the exercise tolerance parameters analysed.

Methods

Participants

A randomized controlled trial using a balanced placebo design was conducted with 60 young elite football players from three senior age groups (U15-U17) of a leading Russian football academy. A total of 54 participants ((Median; IQR; min-max): age – 16.5; 1.2; 15.1-17.8 years, height – 180; 9.5; 157-199 cm, weight – 69.2; 9.97; 46.4-94.8 kg, BMI – 21.4; 2.07; 17.9-23.9 kg/m², somatic maturation 98.6; 2; 91-100) completed the study. All participants met the inclusion criteria, and the cohort included 48 field players and 6 goalkeepers.

Participant groups

Using block randomization stratified by age group and position (field player or goalkeeper), but not stratified by baseline caffeine intake, as all participants had

low habitual caffeine intake at baseline according to the Caffeine Consumption Questionnaire-Revised (CCQ-R) (41).

Participants were assigned to four groups:

- Group 1 (n=14): caf/caf – informed they received caffeine, given caffeine,
- Group 2 (n=12): caf/pla – informed they received caffeine, given placebo,
- Group 3 (n=15): pla/pla – informed they received placebo, given placebo,
- Group 4 (n=13): pla/caf – informed they received placebo, given caffeine.

While the randomization plan aimed for 60 subjects (15 per group), 6 subjects dropped out during screening. Due to stratified randomization, the final group sizes varied. No replacements were made due to the specificity of the population (highly trained athletes from the same club).

Inclusion and Exclusion Criteria

Inclusion criteria included: participation in regular football training for at least six years, consistent member of elite youth football academy and experience in the tests utilised in the study. Exclusion criteria were:

- The presence of injuries and illnesses that caused the missing of more than three training sessions within three months prior to the time of the study;
- Refusal to participate in the study at any stage;
- An anxiety score above 10 points on the GAD-7 questionnaire;
- An injury sustained during the study that prevented full study completion;
- Any allergic reactions linked to caffeine in the participant's medical history or during the study;

- Administration of medications potentially affecting the pharmacokinetics or pharmacodynamics of caffeine within 24-hours prior to the start of the study;
- Administration of any other ergogenic substance in the 48-hours prior to the start of the study;
- Smoking and use of psychoactive substances within 72-hours before the start of the study. Administration or medications that could influence post-exercise recovery within 24 hours before or after testing.

Experimental Design

Testing Conditions

All participants were tested twice on control and experimental days, spaced seven days apart. On the experimental day each participant had been given 400 mg caffeine presented as either caffeine or placebo, either placebo presented as placebo or caffeine. Similar doses of caffeine have previously been used in studies of children aged between 7 and 16 years, with no adverse health effects reported in the participants (18, 42, 43). Subjects were familiar with all the tests and had performed them at least twice in the past six months.

All tests were performed between 11:00 am and 3:00 pm indoors (temperature 21-23 degrees Celsius, humidity 45-50%) on an artificial football surface habitual to athletes. Participants were dressed in their regular training kit (shorts, t-shirt and boots).

In the 48 hours prior to testing, participants had no intense exercise (there were either two days of rest or one day of rest plus one day of light exercise) and were asked to abstain from using caffeine-containing products and any ergogenic aids for 48 hours prior to testing. All participants were advised to adhere to their normal diet, which included a standardised breakfast at least 3 hours prior to testing.

On the control day, the Generalised Anxiety Disorder Questionnaire (GAD-7) and the Caffeine Consumption Questionnaire-revised (CCQ-r) were completed before the physical performance and sport-specific skills tests. All participants were instructed on the rules for completing the questionnaires. A study coordinator was present with the participants to ensure that the questionnaires were completed correctly.

Measurement of Standing Height and Body Weight

Height, weight, and BMI were measured, followed by a standard FIFA 11+ warm-up lasting 12-15 minutes, with a three-minute rest before testing to minimize acute fatigue.

Height was measured using a Seca 217 portable stadiometer (Seca, Hamburg, Germany) placed on a solid, flat surface, following International Society for the Advancement of Kinanthropometry guidelines by a trained specialist. Weight was measured using Seca-813 floor scales (Seca, Germany), with participants in shorts and t-shirts, without shoes. Parents' height was obtained via phone or in-person meetings.

High-Intensity Sport-Specific Load Testing Protocol

The high-intensity sport-specific load protocol followed a strict sequence of the following tests:

- A 30-meter linear sprint with splits of5, 10, and 20 meters.
- A countermovement jump.
- A change-of-direction (COD) run.
- The T-test for agility.
- A speed dribbling test.
- The Repeated Sprint Ability (RSA) test (6 x 40 meters sprints, alternating between 20-meter sprints, with 20 seconds of passive rest in between).

The rest period between each test was three minutes. Participants were instructed to perform all exercises with maximum effort. No verbal encouragement was provided by the coordinators or coaching staff, as this has recently proven to have a positive effect in football players.

Sprint performance was measured using the SmartSpeed Plus timing system (VALD Performance, Australia), with gates set at 5, 10, 20, and 30 meters, 100 cm above the surface. Each participant performed two attempts, and times were recorded to the nearest hundredth of a second. Participants started all sprint and change-of-direction tests from a two-point stance, with the front foot placed 30 cm ahead of the starting line.

For strength assessment, vertical jump height was measured using the SmartJump mat (VALD Performance, Australia), with three attempts recorded in centimetres, and the best result used for analysis. Speed dribbling was evaluated using the

SmartSpeed Plus system, six cones, and a familiar football ball inflated to 0.9 atmospheres. Two attempts were performed, with a three-minute recovery between trials.

In the RSA test, participants completed six 40-meter sprints with maximum effort (two linear 20-meter segments with a 180-degree turn). After each sprint, participants walked back to the start line, with 20 seconds of recovery between sprints. This RSA variant closely mimics competitive match conditions, including directional changes, lactate levels, recovery time, and sprint distance (44).

Load Tolerance Assessment

Heart rate (HR) was measured using the Activio Sport Solution GPS tracking system. HR immediately post-exercise (HRpe), HR after two minutes of passive rest (HRrest), and recovery HR (HRrec = HRpe - HRrest) were recorded (45).

Load tolerance was evaluated using the Borg Rating of Perceived Exertion (25) scale (46), previously used in studies with young football players and super-sprint triathletes (47-49).

DOMS was evaluated using a visual analogue scale (VAS), previously employed by Larsen et al. and Maridakis et al. (29, 50). Pain intensity was recorded before and 24 hours after testing, with the difference (VAS diff) used for analysis.

Anxiety and Caffeine Consumption Assessment

The Generalized Anxiety Disorder Screener (GAD-7) was used to assess anxiety levels, as previously used in studies with football players (51, 52). This questionnaire is validated for use in Russia. Participants are considered to have symptoms of generalised anxiety disorder if they score 10 or more (51). Given the

available evidence that caffeine has anxiogenic effects and that its use should be limited in individuals with high levels of anxiety (53), as well as the potential influence of anxiety levels on the effects of anticipating caffeine use (54) and on the interpretation of perceived exertion levels (55), it was decided to exclude subjects with a GAD-7 score of 10 or more from the study.

Habitual caffeine consumption was assessed using the CCQ-R (41), adapted for use in Russian participants and previously applied in studies with active individuals (56).

Nutritional aid

White, elongated capsules containing either 200 mg of caffeine or placebo (starch) were provided by the pharmaceutical company CJSC Evalar. The capsules were indistinguishable in appearance, colour, and taste. The qualitative and quantitative compositions of the capsules were verified by high-performance liquid chromatography with ultraviolet detection in an independent laboratory.

Before the capsules were administered, they were transferred from the manufacturer's containers into four identical containers, of which two were numbered and signed as ‘caffeine’ and two as ‘placebo’ according to what was told to each participant group at the time of administration which was necessary to facilitate the deception of the subjects. From these containers, the blinded coordinator administrated the capsules according to a randomisation list that included the participants' identity and the number of according container. The moment the capsules were administrated to participant a coordinator either told: ‘You get caffeine’ or ‘You get placebo’, according to what was written on the container. Each participant was given 2 capsules, totalling 400 mg, which

amounted to 4.24-8.64 mg/kg body weight of the participants. No statistical significance was found between groups for this parameter.

Statistical Analysis

Statistical analysis was performed using Jamovi 2.2.5 and Microsoft Excel. The Shapiro-Wilk test was used to assess normality. For normally distributed data, the mean and standard deviation are reported. For non-normally distributed data, the median and interquartile range are used. However, for simplicity, mean values were presented in all tables, and the distribution of each variable was considered in the analysis. Frequency analysis was used to examine distribution by age, maturation, caffeine consumption, and anxiety levels across groups.

ANOVA was used for between-group comparisons of normally distributed variables, and the Kruskal-Wallis test for non-normally distributed variables. Paired t-tests were used for within-group comparisons of normally distributed data, while Wilcoxon signed-rank tests were used for non-normally distributed data. Results were considered statistically significant at $p < 0.05$.

Ethics

This study was conducted in accordance with the Declaration of Helsinki and approved by the Sechenov University Ethics Committee (No. 05-2, 10.03.2021). Participants and their legal representatives were informed of the study's potential risks and consented to participation.

Results

All groups were comparable in terms of age (p = 0.981), weight (p = 0.554), height (p = 0.846), BMI (p = 0.450), somatic maturation (p = 0.818), caffeine consumption (p = 0.108), and anxiety levels (p = 0.875). No participants displayed clinically significant anxiety (GAD-7 ≥10) or high daily caffeine intake. The descriptive statistics for anthropometric data and biological maturation are presented in Table 1.

Table 1. Descriptive statistics for anthropometric data and biological maturation of participants across all groups

Group	All participants n=54	Caf/Caf (n=14)	Caf/Pla (n=12)	Pla/Pla (n=15)	Pla/Caf (n=13)	p-value
Age (years); (Me; IQR; min-max)	16; 2; 15-17	16; 1.75; 15-17	16; 1.3; 15-17	16; 1.5; 15-17	16; 1; 15-17	0.981
Maturation (%) (Me; IQR; min-max)	98.6; 2; 91-100	98; 3; 95-100	98; 2.5; 91-99.7	99; 0.9; 95-100	98.6; 2; 95-10	0.818
Height (cm); (Me; IQR; min-max)	180; 9.5; 157-199	182; 7.5; 168-192	182; 20.8; 157-199	179; 6.5; 166-189	180; 6; 170-188	0.846
Weight (kg); (Me; IQR; min-max)	69.2; 9.97; 46.4-94.8	70.6; 8.5; 53.9-78.1	71.2; 19.8; 46.4-59.2	68.8; 7; 59.2-82.3	66.7; 4.2; 51.6-73.5	0.554
BMI (kg/m2); (Me; IQR; min-max)	21.4; 2.07; 17.9-23.9	21.5; 2.2; 19.1-23.5	22.1; 2.36; 18.8-23.9	21.5; 1.06; 18.8-23.6	21.0; 1.1; 17.9-22.4	0.450
GAD-7 (Me; IQR; min-max)	1; 2; 0-8	1; 2; 0-3	0; 1.25; 0-8	1; 1.5; 0-4	0; 2; 0-6	0.875
Caffeine consumption (mg/day) (Me; IQR; min-max)	53.5; 42.5; 0-339	38; 36.5; 0-91	48; 33.5; 10-339	60; 32; 13-167	72; 56; 21-130	0.108

Effect of Caffeine on Delayed Onset Muscle Soreness (DOMS)

On the control day, the groups were comparable in VAS scores both before (p = 0.944) and after (VAS after: p = 0.956) exercise. The VAS diff between the groups was also not statistically significant (p = 0.674).

On the experimental day, the VAS before testing in each group was similar to the control day values. The groups remained comparable in VAS scores before (p =

0.978) and after (p = 0.077) exercise on the experimental day, with no significant difference in VAS diff between the groups (p = 0.924).

In all groups, there was a statistically significant increase in DOMS 24 hours after the high-intensity exercise on the control day (Caf/Caf: p = 0.006; Caf/Pla: p = 0.006; Pla/Pla: p = 0.002; Pla/Caf: p = 0.013). However, on the experimental day, the increase in VAS diff was significantly lower for the Caf/Caf, Caf/Pla, and Pla/Pla groups compared to the control day, while no significant change was observed in the Pla/Caf group (p = 0.098) (Table 2).

Table 2. Effect of a Single 400 mg Caffeine Dose on VAS Scores in Young Elite Soccer Players

Group	CafCaf (n=14)		CafPla (n=12)		PlaPla (n=15)		PlaCaf (n=13)	
	contr	exp	contr	exp	contr	exp	contr	exp
VAS before (Me; IRQ; min-max)	1.5; 2.7; 0-5	1; 1.7; 0-4	1; 2.2; 0-4	1; 1.2; 0-4	2; 3; 0-6	2; 1.5; 0-3	2; 4; 0-5	2; 2; 0-5
p	0.855**		0.182**		1.000**		0.831**	
VAS after (Me; IRQ; min-max)	4; 1; 1-7	2; 2.7; 0-7	4.5; 3.5; 0-7	2; 1.2; 0-4	5; 3; 0-7	3; 3; 0-6	5; 5; 1-8	2; 1.9; 0-6
p	**0.007***		**0.017***		**0.004***		**0.027***	
VAS after – VAS before (Me; IRQ; min-max)	2; 1; -1-4	1; 1.75; -3-3	4; 4.25; -2-6	1; 3; -3-3	3; 1.5; -4-6	1; 2.5; -2-3	3; 3; -3-8	0; 2; -5-6
p	**0.037***		**0.011***		**0.015****		0.098**	

Abbreviations: contr – control day, exp – experimental day.

** Wilcoxon signed-rank tests

*Student's t-test

Effect of Caffeine on Rate of Perceived Exertion (25)

On the control day, no statistically significant difference was found in RPE between the groups (p = 0.773). Similarly, on the experimental day, there was no significant difference in RPE between groups (p = 0.948), nor were there

significant changes in RPE within each group when comparing the control and experimental days (Table 3).

Table 3. Effect of a Single 400 mg Caffeine Dose on RPE in Young Elite Soccer Players

Group	CafCaf (n=14)		CafPla (n=12)		PlaPla (n=15)		PlaCaf (n=13)	
	contr	exp	contr	exp	contr	exp	contr	exp
RPE (Me; IRQ; min-max)	5; 2.0; 3-10	5; 2.5; 3-10	5; 2.7; 3-10	5; 2.2; 3-9	5; 3.0; 4-10	6; 3.5; 1-9	5; 1.0; 3-8	5; 2.0; 1-8
p	0.971**		0.104*		0.891**		0.515*	

Abbreviations: contr – control day, exp – experimental day.

*Student's t-test
** Wilcoxon signed-rank tests

Effect of Caffeine on Heart Rate (HR) at Different Time Points Post-Exercise

On the control day, no statistically significant differences were observed between the groups in HRpe (p = 0.689), HRrest (p = 0.555), or HRrec (p = 0.719). On the experimental day, no significant differences were found between the groups in HRpe (p = 0.698), HRrest (p = 0.823), or HRrec (p = 0.920). Furthermore, there were no significant changes in HR within each group when comparing the control and experimental days (Table 4).

Table 4. Effect of a Single 400 mg Caffeine Dose on HR in Young Elite Soccer Players

Group	CafCaf (n=14)		CafPla (n=12)		PlaPla (n=15)		PlaCaf (n=13)	
	contr	exp	contr	exp	contr	exp	contr	exp
HRpe (Me; IRQ; min-max)	193.0; 6.5; 180-203	193.0; 6.5; 186-203	189.0; 13.5; 179-200	192.0; 11.5; 174-199	194.0; 6.0; 175-205	191.0; 7.0; 182-201	191.0; 9.0; 180-211	191.0; 9.0; 181-209
p	0.399*		1.000*		0.692*		0.195*	
HRrest (Me; IRQ; min-max)	149.0; 13.0; 132-165	152.0; 7.7; 125-160	144.0; 13.5; 123-160	143.0; 15.5; 128-159	153.0; 21.5; 132-170	148.0; 11.0; 117-160	145.0; 12.0; 126-176	146.0; 20.0; 120-163
p	0.777*		0.556*		0.088*		0.510*	
HRrec (Me; IRQ; min-max)	42.0; 12.0; 27-63	42.5; 6.7; 32-67	44.5; 9.7; 32-56	47.0; 7.0; 38-62	39.0; 11.5; 27-59	43.0; 12.0; 36-73	48.0; 18.0; 25-61	47.0; 13.0; 27-70
p	0.209*		0.471*		0.187**		0.209*	

Abbreviations: contr – control day, exp – experimental day.

*Student's t-test
** Wilcoxon signed-rank tests

Discussion

This study demonstrated that a single oral dose of 400 mg caffeine, consumed 60 minutes before sport-specific high-intensity exercise, or the expectation of receiving caffeine, did not significantly affect key measures of exercise tolerance, such as HRpe, HRrest, HRrec, RPE, or DOMS, in young elite football players. It is important to note that the participants had low levels of anxiety and low habitual caffeine intake, which should be considered when interpreting the results. Currently, the research on the effects of caffeine on exercise tolerance is presents contradictory findings. Many studies focus on caffeine's impact on HR during and after exercise, often involving participants from the general population across various age groups (57-61).For instance, Temple et al. found that caffeine intake in healthy adolescents aged 12–17 reduced HR and increased blood pressure at rest (62, 63), while Yeragani et al. demonstrated that caffeine at 5 mg/kg increased post-exercise HR in healthy adult females and males(64). Similarly, Bunsawat et al. found that 400 mg of caffeine increased maximal HR after a treadmill run to exhaustion in young adults (65). Similar results were obtained in a study by Astorino et al., in which 6 mg/kg of caffeine was given 60 minutes before young resistance-trained men performed resistance exercises, including barbell bench press and leg press. They observed caffeine-induced changes in cardiovascular function, including an increase in HR during the exercises (66). However, Gonzaga

et al. noted no effect of 300 mg of caffeine on HR during or after a 30-minute test at 60% VO2max in young adults (67), while Glaister et al. reported a significant reduction in HR during and after exercise in cyclists following a 5 mg/kg caffeine dose (68). These contrasting findings highlight the complexity of caffeine's cardiovascular effects under different conditions, including population and exercise protocol.

In our study, no significant effects of caffeine were observed on HRpe, HRrest, or HRrec, indicating that caffeine intake had no impact on HR following sport-specific high-intensity exercise in young elite football players. This may be attributed to the unique characteristics of the study population as this is the first study involving elite youth football players, direct comparisons with other studies may be challenging.

The findings related to RPE, one of the key measures of internal load, are also inconsistent across the literature (57, 58). Shabir et al. found that a 3 mg/kg dose of caffeine reduced RPE and increased performance in the Loughborough Soccer Passing Test in young amateur players, largely due to expectancy effects (69). In contrast, Jordan et al. reported an increase in RPE and improved performance in a reactive agility test, among young elite football players after 6 mg/kg of caffeine (18). Most research involving both male and female football players demonstrate no significant effect of caffeine on RPE following various physical and sport-specific skill tests (70-73). It is essential to consider that significant improvements in physical performance could potentially lead to an increase in RPE. In this study,

caffeine did not affect RPE, aligning with the previous findings in football players (74).

DOMS is a common response to exercise-induced muscle damage (EIMD) (75, 76). EIMD, particularly following football-specific exercise, is part of the normal adaptation and recovery process, which is associated with varying degrees of DOMS and increased markers of inflammation, muscle damage, and oxidative stress (77-79). While severe DOMS can lead to missed training sessions (80), moderate levels are typically expected following high-intensity exercise. The results of this study showed that caffeine had no significant impact on DOMS 24 hours after exercise. These findings align with the conclusions of Mielgo-Ayuso et al. systematic review, which found no evidence supporting caffeine's influence on haematological markers of muscle damage or the severity of DOMS in football players (58). The studies included in this review used caffeine doses ranging from 1 mg/kg to 7.2 mg/kg of body weight. However, in several studies involving female students and moderately trained males a 5 mg/kg caffeine dose was shown to reduce muscle soreness both immediately after exercise and 24 hours later (29-32). It is important to note that in some of these studies (29, 32), caffeine was administered both before and after exercise. Therefore, the potential positive effect of caffeine on DOMS could be linked to its established analgesic properties (81, 82). In the present study, the VAS scores after the experimental day were significantly lower than on the control day across all groups. This result is most

likely attributable to participant adaptation to the testing protocol, rather than to caffeine administration.

The results obtained in this study should be interpreted taking into account the possible influence of factors such as metabolism, which may differ between age groups, on the effects of caffeine, as well as the previously described influence of various genetic polymorphisms, as described previously (83). It should also be noted that the study participants were elite (highly trained) athletes whose bodies adapt quickly to physical activity, and that the results of studies examining differences in response to caffeine according to training status are also inconclusive (84, 85).

Practical implications

The findings should be taken into account by practitioners when deciding whether to use caffeine in young elite athletes, especially at doses considered high in the general population. Caffeine use should also account habitual caffeine intake, which may be quite high given that many young men use commercial products that are high in caffeine (e.g. dietary supplements, energy and sweet carbonated drinks, tea, coffee, chocolate).

Limitations

This study has several limitations. First, it does not include haematological markers of load tolerance measured before and after exercise. Second, data on average and maximal HR during exercise were not collected. Third, the monitoring period for DOMS was short due to differences in training loads across player positions in the

days following the tests. Fourth, we did not assess other data that might influence the variables studied, such as hydration levels, sleep quantity and quality, and calorie and diet composition (86, 87). We also did not conduct the post-study survey of participants, which would help to account for potential bias associated with unblinding. Furthermore, future research should include tests to exhaustion such as the Yo-Yo test (88), and explore various caffeine dosing protocols before, during, and after exercise.

Conclusion

A single dose of 400 mg caffeine, taken 60 minutes before high-intensity sport-specific exercise, does not significantly influence key measures of exercise tolerance, such as heart rate during different recovery phases perceived exertion, or DOMS in young elite football players. This finding applies for athletes with high levels of somatic maturity, low daily caffeine consumption, and low anxiety.

The lack of caffeine's effect on these markers, particularly in a population of well-trained young athletes, suggests that caffeine may not provide a substantial ergogenic benefit in terms of exercise tolerance during high intensity sport-specific activities in this group.

Conflicts of interest statement

Authors declare no conflicts of interest.

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