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ORIGINAL ARTICLE

Caffeine-containing energy drink improves sprint performance during an international rugby sevens competition

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Abstract The aim of this study was to determine the effects of a caffeine-containing energy drink on physical performance during a rugby sevens competition. A second purpose was to investigate the post-competition urinary caffeine concentration derived from the energy drink intake. On two non-consecutive days of a friendly tournament, 16 women from the Spanish National rugby sevens Team (mean age and body mass = 23 ± 2 years and 66 ± 7 kg) ingested 3 mg of caffeine per kg of body mass in the form of an energy drink (Fure®, ProEnergetics) or the same drink without caffeine (placebo). After 60 min for caffeine absorption, participants performed a 15-s maximal jump test, a 6 × 30 m sprint test, and then played three rugby sevens games against another national team. Individual running pace and instantaneous speed during the games were assessed using global positioning satellite (GPS) devices. Urine samples were obtained pre and post-competition. In comparison to the placebo, the ingestion of the energy drink increased muscle power output during the jump series (23.5 ± 10.1 vs. 25.6 ± 11.8 kW, $P = 0.05$), running pace during the games (87.5 ± 8.3 vs. 95.4 ± 12.7 m/min, $P < 0.05$), and pace at sprint velocity (4.6 ± 3.3 vs. 6.1 ± 3.4 m/min, $P < 0.05$). However, the energy drink did not affect maximal running speed during the repeated sprint test (25.0 ± 1.5 vs. 25.0 ± 1.7 km/h). The ingestion of the energy drink resulted in a higher post-competition urine caffeine concentration than the placebo (3.3 ± 0.7 vs. 0.2 ± 0.1 µg/mL; $P < 0.05$). In summary, 3 mg/kg of caffeine in the form of a commercially available energy drink considerably enhanced physical performance during a women's rugby sevens competition.

Keywords GPS technology · Team sports · Ergogenic aids · Exercise · Doping · Sprint performance

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Introduction

Rugby union is a traditional team sport characterized by two teams competing with 15 players per side on a 100 × 50 m natural turf pitch for 80 min (2 halves of 40 min). Rugby sevens is a recent variant of traditional rugby with the same basic rules and scoring. However, this modality fields seven players per team, game durations of 14 min (2 halves of 7 min with 1 min break time), but is played on a field of similar dimensions to that of traditional rugby. Because only seven rugby players per side have to play on a full-dimension pitch and the time to obtain scores is reduced, the physiological demands of rugby sevens are much higher in comparison with those of rugby union games (Suarez-Arrones et al. 2011b; Cunniffe et al. 2009). In addition, more than two games are played on the same day, which in turn increases the physiological stress that rugby sevens players support during a competition (Rienzi et al. 1999). National and international rugby sevens tournaments have been held since the 1990s, but the scientific interest in rugby sevens has increased in recent years because this sport was chosen to be included in the list of

Olympic Summer sports for Rio 2016 (Engebretsen and Steffen 2010).

The assessment of movement patterns during rugby sevens games has been the topic of a few studies (Higham et al. 2012; Lopez et al. 2012; Suarez-Arrones et al. 2011a, b; Rienzi et al. 1999). With the use of Global Positioning System (GPS) devices, experimenters have obtained real-time measurements of physiological demands during games and tournaments. In addition, the comparison of running demands between rugby union versus sevens has allowed coaches and trainers to implement specific training routines for rugby sevens. For example, while male rugby union players run at a pace between 62 and 84 m/min (Coughlan et al. 2011; Cunniffe et al. 2009; McLellan et al. 2011), rugby sevens players obtain average velocities of between 106 and 120 m/min (Suarez-Arrones et al. 2011b; Higham et al. 2012). Interestingly, elite female rugby sevens players run at a pace of 103 m/min (Suarez-Arrones et al. 2011a), in the low range of their male counterparts. Thus, overall running demands during match play are augmented during rugby sevens games in comparison to traditional rugby.

Like in other team sports, rugby players combine periods of high-intensity exercise interspersed with periods of lower-intensity exercise or recovery. The ability to repeatedly sprint during a game is considered essential for scoring and defending since sprint actions are always performed when the ball is close to the player (Bishop et al. 2011). Studies with rugby sevens players indicate high-intensity movements (running velocity above 18 km/h) represent 13.7 % of the total match time for men (Suarez-Arrones et al. 2011b) and 9.1 % for women (Suarez-Arrones et al. 2011a), while these demands represent only 2 % in male rugby union players (Cunniffe et al. 2009). In addition, the work-to-rest ratio is 1:0.4 during rugby sevens (Suarez-Arrones et al. 2011a, b), while it is increased to 1:6 during rugby union matches (King et al. 2009). All this information indicates that players of rugby sevens rely more on high-intensity actions than traditional rugby players.

Different training methods and ergogenic aids have been investigated to determine their effectiveness in increasing the sprint actions during team sports (Bishop et al. 2011). It has been found that the use of 5–6 mg per kg of pure anhydrous caffeine increases running velocity during team sports specific tests that included sprint bouts (Carr et al. 2008; Glaister et al. 2008; Stuart et al. 2005). Nevertheless, caffeine is currently ingested in the sports setting in the form of energy drinks (Del Coso et al. 2011) with prevalence higher than 70 % in amateur and elite athletes (Froiland et al. 2004; Kristiansen et al. 2005). While the ingestion of 1.3 mg/kg of caffeine via an energy drink did not modify running velocity during a sprint test (Astorino et al. 2011), the ingestion of 3 mg/kg of caffeine in the form of an energy drink increased the maximal running speed during a 7 × 30 m sprint test (Del Coso et al. 2012a) and the distance covered at sprint velocity during simulated soccer (Del Coso et al. 2012a) and rugby union games (Del Coso et al. 2012b). In addition, while an energy drink with 1 mg/kg of caffeine did not influence muscle performance, the same drink with 3 mg/kg of caffeine improved muscle power and muscle force during bench press and half-squat exercises (Del Coso et al. 2012c).

These studies suggest the need of ingesting an amount of energy drink to provide at least 3 mg/kg of caffeine to obtain better sprint performance during team sports specific actions. Because rugby sevens rules increase the physiological demands of the players in comparison with those of traditional rugby, especially the importance of high-intensity actions, the use of caffeine-containing energy drinks may be more effective to increase sprint performance in this sport. The aim of the present investigation was to determine the effectiveness of a commercially available energy drink (3 mg/kg of caffeine) on the running activity profiles of elite female rugby sevens players during an international tournament. We hypothesized that a caffeine-containing energy drink would increase the distance covered at sprint velocity during the tournament.

Methods

Subjects

Sixteen women from the Spanish rugby sevens National Team volunteered to participate in this investigation. They had a mean ± SD age of 23 ± 2 years, body mass of 66 ± 7 kg, height of 166 ± 7 cm, body fat of 16.6 ± 2.8 %, and maximal heart rate of 191 ± 10 bpm. All participants had previous rugby experience of at least 4 years and had trained for ~2 h/day, 4–5 days/week (including a weekly competition) during the three previous years. Participants had no previous history of cardiopulmonary diseases and they were not taking medications during the study. In addition, participants were non-smokers but all of them were light caffeine consumers (<60 mg per day, ~1 cup of coffee maximum). One week before the onset of the investigation, the team's medical staff and the participants were fully informed of the risks and discomforts associated with the experiments and they gave their informed written consent to participate. The study was approved by a Research Ethics Committee in accordance with the latest version of the Declaration of Helsinki.

Experimental design

A double-blind, placebo controlled and randomized experimental design was used in this study. The Spanish and Dutch Rugby Federations arranged a friendly rugby sevens tournament during the third week of January 2012. However, only the Spanish rugby players participated in the investigation. The friendly tournament consisted of two competition days in the same week (Monday and Thursday) during the players' physical preparation stage. During each competition day, the National Teams played three rugby sevens games, separated by 15 min of recovery between them to reproduce the routines of a real competition. During these games, player's changes were standardized to minimize the effects of substitutions on the results of the investigation. The competition days started at 1600 hours and they were held in the same stadium and under similar environmental conditions (18 ± 4 °C; 45 ± 5 % of relative humidity). During the days without competition, the National Team followed their habitual training routines, while training and diet the day before competition were standardized.

Each rugby player took part in the two competition days. In a randomized order, participants ingested a powdered caffeine-containing energy drink (Fure®, ProEnergetics, Spain) dissolved in 250 mL of tap water to provide a dose of 3 mg of caffeine per kg of body mass or the same drink with no caffeine content (0 mg/kg; placebo). Thus, during the competition days, players of the Spanish rugby team received different experimental treatments (8 players with caffeine and 8 players with placebo for each competition day). At the request of the experimenters, the placebo drink was provided by the manufacturer and had the identical appearance and taste of the caffeine-containing energy drink. The drinks also contained taurine (2,000 mg), sodium bicarbonate (500 mg), L-carnitine (200 mg), and maltodextrin (705 mg), but the amounts of these substances were identical in the two experimental trials. The trials differed only in the amount of caffeine administered to each player (0 mg with placebo vs. 198 ± 20 mg with the energy drink). The beverages were prepared in opaque plastic bottles to avoid identification and they were ingested 60-min before the onset of the experimental trials to allow complete caffeine absorption. An alphanumeric code was assigned to each trial to blind participants and investigators to the drink tested. This code was only accessible to investigators after the analysis of the variables.

Experimental protocol

Two days before the experimental trials, participants were nude-weighed to calculate the energy drink dosage. On this day, their body fat percentage was also calculated using six skin folds. The day before each experimental trial, the rugby players performed similar exercise routines. They were encouraged to abstain from all dietary sources of caffeine (coffee, cola drinks, chocolate, etc.) and alcohol for 48 h before the onset of the experimental trials. These standardizations were reported to the technical staff of the National Team to ensure compliance. On the day of the experimental trials, participants had a pre-competition meal 3 h before the start of the tests. In the afternoon, participants arrived at the stadium and voided in a sterilized container. A representative urine sample was obtained and immediately frozen at −30 °C for the measurement of caffeine concentration. Then, the beverage assigned for the trial was individually supplied and consumed. The exchange of bottles between players was not allowed and investigators encouraged players to drink the beverage in its entirety. Then, players were weighed (Radwag, Poland) and dressed in a T-shirt, shorts, and cleats and put on chest rugby armor. They also wore a GPS/Accelerometer/HR device inserted in an adjustable neoprene harness (GPS, SPI PRO X, GPSports®, Australia) and a heart rate monitor (Polar® T31, Finland) attached to their chest. Participants then performed a standardized warm-up and a 6 × 30-m sprint test on the grass pitch. Thirty minutes after the sprint test, participants initiated the three competition games. After the games, participants performed a 15-s jump test on a force platform. More detailed information on these physical tests is presented below. After completion of all testing procedures, post-exercise body weight was obtained. Thirty minutes after the end of the game, participants voided again and a urine sample was obtained. After that, participants were required to fill out a questionnaire about their sensations of power, endurance, and perceived exertion (RPE) during the whole competition day. This questionnaire included a 1–10 point scale to assess each item, and participants were previously informed that 1 point meant minimal amount of that item and 10 points meant maximal amount of the item. In addition, participants were provided with a survey to be filled out the following morning about sleep quality, nervousness, gastrointestinal problems, and other discomforts. This survey included eight items on a yes/no scale and has been previously used to assess side-effects derived from energy drink ingestion (Del Coso et al. 2012c).

Maximal running velocity test

After their habitual warm-up routines, the rugby players performed a 6 × 30-m sprint test at maximal running velocity with 30 s of active recovery between repetitions. The test was carried out on the grass turf and the running velocity was measured by means of the GPS device so all players performed the test at the same time. The GPS was set to assess velocity at a frequency of 5 Hz. The maximal velocity obtained during each sprint was used for statistical analysis. A good reliability of the GPS to assess maximal running speed during sprint test has been previously reported (coefficient of variation of 1.2 %; Barbero-Álvarez et al. 2009). Verbal instructions were given to indicate the onset of each sprint, and oral feedback was given by the technical staff to encourage players to produce maximal performance in each repetition.

Competition games

In each experimental trial, the participants completed three rugby sevens games, separated by 15 min for recovery. Each game consisted of two halves of 7 min with a 1-min half-time break. The games were always played against the Dutch National Team to avoid the effects of the rival level on the results of this study. The games were played on a regular rugby field (95 × 55 m) with seven players per side, while a professional referee made decisions on play disputes. The match followed the rules of the International Rugby Board. Participants played in their habitual position, while first-team players and changes were managed by the coach. Participation of players ranged from 14 to 35 min, but they were similar for each player on both competition days. During the games, the GPS device and the heart rate belt monitored data on distance covered, instantaneous running speed, player impact data, and mean heart rate at 5 Hz. The rugby players wore the same GPS unit for both experimental trials to reduce measurement error (Jennings et al. 2010). With the GPS devices, coefficient of variation for measuring movement demands of team sports players has been found to be ~2 % (Barbero-Álvarez et al. 2009; Coutts and Duffield 2010). For each player, an average of the running paces for the three games was used for statistical analysis. All the data analyses were performed with a specific software package (Team AMS software V R1.2011.6, GPSports, Australia). During each experimental trial, players drank water ad libitum only from their own individually labeled bottles and they were instructed not to spit out or spill any fluid. Fluid intake was measured from the change in bottle weight using a scale (Delicia, Tefal, France). Sweat rate was estimated from pre-post-competition body mass change, total fluid intake, and game duration.

Fifteen seconds maximal jump test

Within 10 min after the last game, leg muscle power output was measured during a 15-s rebound jump series using a force platform (Quattrojump, Kistler, Switzerland). For this test, participants began stationary in an upright position with their weight evenly distributed over both feet. Each subject placed their hands around their waist to remove the influence of the arms on the jump. On command, the participants flexed their knees and jumped as high as possible while maintaining their arms on their waist, repeating this jumping action for 15-s. Verbal feedback was given to encourage the rugby players to produce maximal performance in each repetition. Muscle power output during the concentric phase of each jump was determined from ground reaction forces, while total power output during the 15-s was calculated from power output in each jump and the number of jumps.

Urine analysis

The urine specimens obtained before and after each experimental trial were analyzed for caffeine, paraxanthine, theobromine, and theophylline concentrations using an Agilent Technologies HPLC 1200 system (Santa Clara, CA, USA) coupled to a triple quadrupole/ion trap mass spectrometer (MS, API 400, USA). All the reagents used for these measurements were purchased from Cambridge Isotope Laboratories (Spain). For this measurement, 20 µL of the internal standard theophylline-D_6 (2 µg/mL) and 20 µL of the internal standard $^{13}C_3$-caffeine (5 µg/mL) were added to 100 µL of urine. A volume of 900 µL of mobile phase (acetic acid, 0.1 %) was added to the urine sample, and then 5 µL of this sample were then directly applied to the HPLC–MS system. To calibrate the system, aqueous solutions of caffeine, paraxanthine and theobromine (ranging from 0.1 to 7 µg/mL), and theophylline (from 0.04 to 1 µg/mL) were used before each batch of samples. The correlation coefficients for the calibration of caffeine and its main metabolites were always >0.99. The lower limit for the accurate quantization of these methylxanthines was 0.25 and 0.1 µg/mL for theophylline.

Statistical analysis

Maximal running speed during the repeated sprint test and leg muscle power output during the 15-s jump test were analyzed using a two-way ANOVA (beverage × repetition) with repeated measures. After a significant F test (Geisser-Greenhouse correction for the assumption of sphericity), differences between means were identified using Tukey's HSD post hoc procedure. Running paces during the game, heart rate, sweat rate, and the urinary concentrations of caffeine, paraxanthine, and theobromine were examined using paired t tests. To analyze the effects of the energy drinks on side-effects, we used a non-parametric test for dichotomic variables and related samples (Cochran test). The data were analyzed with the statistical package SPSS v 18.0 (SPSS Inc., Chicago, IL). The significance level was set at $P < 0.05$. The results are presented as mean ± SD.

Results

Maximal running velocity test

In comparison to the placebo drink, the intake of the caffeine-containing energy drink did not increase maximal running speed during the 6 × 30 m sprint test (Fig. 1; $P = 0.91$). The average maximal running speed was 25.0 ± 1.5 km/h with the placebo and 25.0 ± 1.7 km/h with the caffeinated energy drink.

Competition games

During the competition games, the mean running pace with the ingestion of the placebo drink was 87.5 ± 8.3 and 95.4 ± 12.7 m/min with the ingestion of the caffeinated energy drink ($P < 0.05$). To analyze the rugby players movement patterns during the games, we set six speed zones following previous studies (Cunniffe et al. 2009): standing and walking (zone 1 = 0–6 km/h); jogging (zone 2 = 6–12 km/h); cruising (zone 3 = 12–14 km/h); striding (zone 4 = 14–18 km/h); high-intensity running (zone 5 = 18–20 km/h); and sprinting (zone 6 = higher than 20 km/h). In comparison to the placebo, the utilization of the caffeinated energy drink produced a significant rise in running pace corresponding to zone 3 ($P < 0.05$), zone 4 ($P < 0.05$), zone 5 ($P < 0.05$), and zone 6 ($P < 0.05$; Fig. 2). In contrast, there was no difference between the energy drink and the placebo in the distance covered by walking (zone 1; $P = 0.91$) and jogging (zone 2; $P = 0.22$).

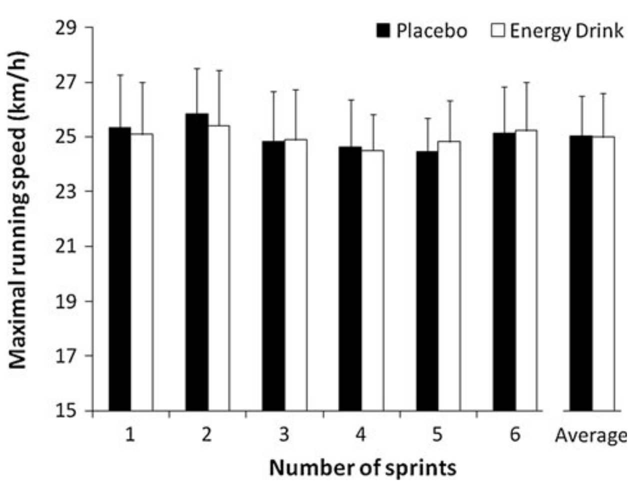

Fig. 1 Maximal running speed during a 6 × 30-m sprint test with the ingestion of a caffeine-containing energy drink (3 mg of caffeine/kg of body mass) or the same drink without caffeine. Data are mean ± SD for 16 rugby sevens players

Exercise heart rate and sweat rate

While the energy drink increased mean heart rate during the three competition games respect to placebo (168 ± 7 vs. 164 ± 6 beats/min, respectively; $P < 0.05$), it did not affect maximal heart rate (189 ± 10 vs. 188 ± 9 beats/min; $P = 0.62$). Sweat rate (1.4 ± 0.3 vs. 1.4 ± 0.5 L/h; $P = 0.99$), rehydration rate (1.0 ± 0.4 vs. 1.0 ± 0.3 L/h; $P = 0.74$), and dehydration level attained at the end of the competition (0.5 ± 0.5 vs. 0.6 ± 0.6 %; $P = 0.67$) were unaffected by the energy drink intake.

Fifteen seconds maximal jump test

During the jump series, the rugby players produced a higher leg muscle power output with the intake of the energy drink than with the placebo, although the differences were statistically significant only during the second, fourth, sixth, and seventh jump (Fig. 3; $P < 0.05$). In addition, the total leg muscle power generated during the 15-s jump test was higher with the energy drink than with the control drink (25.6 ± 11.8 vs. 23.5 ± 10.1 kW, $P = 0.05$).

Urine caffeine excretion and urinary variables

Pre-exercise urine samples presented low concentrations of caffeine, paraxanthine, and theophylline, and they were

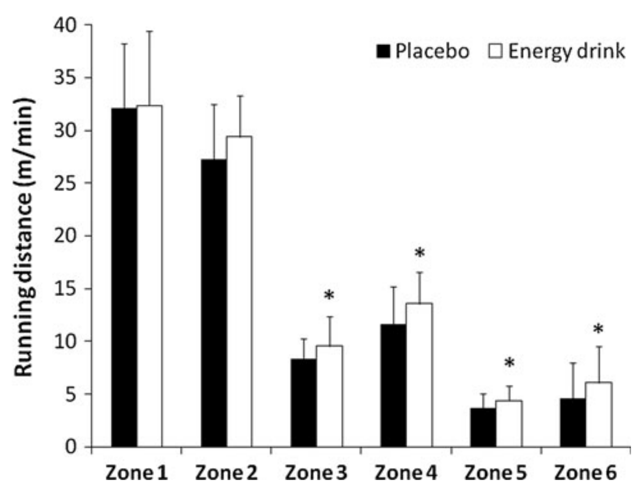

Fig. 2 Running paces covered at different speeds during three competition games of rugby sevens with the ingestion of a caffeinated energy drink (3 mg of caffeine/kg of body weight) or the same drink without caffeine. Data are mean ± SD for 16 rugby sevens players. Different from placebo (*$P < 0.05$). Standing and walking (zone 1 = 0–6 km/h); jogging (zone 2 = 6–12 km/h); cruising (zone 3 = 12–14 km/h); striding (zone 4 = 14–18 km/h); high-intensity running (zone 5 = 18–20 km/h); and sprinting (zone 6 = higher than 20 km/h)

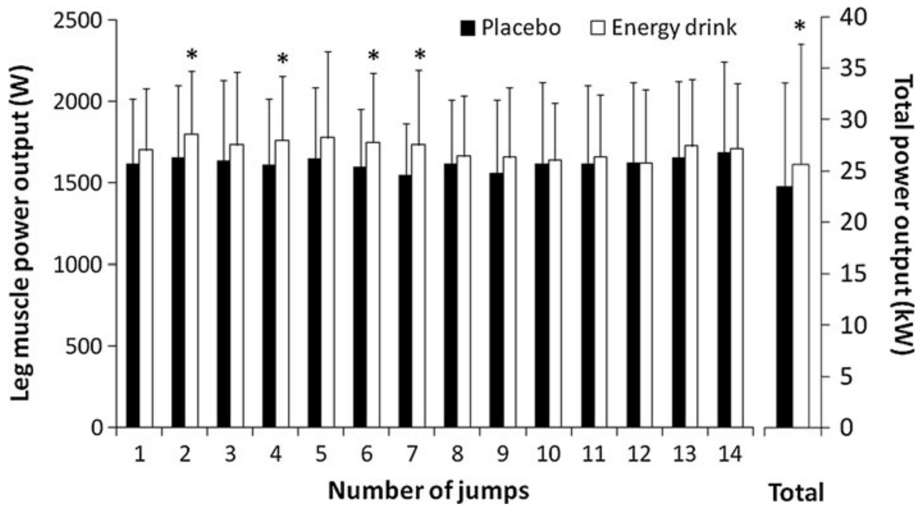

Fig. 3 Leg muscle power output during a 15-s maximal jump test with the ingestion of a caffeine-containing energy drink (3 mg of caffeine/kg of body weight) or the same drink without caffeine. Data mean ± SD of 16 rugby sevens players for 14 jumps because this was the highest number of jumps that all the players completed. The total power output during the test was also calculated from individual power output and the number of jumps. Different from placebo (*$P < 0.05$)

Table 1 Values for pre and post-competition urine caffeine, paraxanthine, theophylline and theobromine concentrations with the ingestion of a caffeinated energy drink (3 mg of caffeine/kg of body weight) or the same drink without caffeine

	Placebo	Energy drink
Caffeine (μg/mL)		
Pre	0.2 ± 0.1	0.2 ± 0.1
Post	0.2 ± 0.1	3.3 ± 0.7*, †
Paraxanthine (μg/mL)		
Pre	1.2 ± 0.9	1.2 ± 0.9
Post	1.3 ± 0.9	2.8 ± 1.4*, †
Theophylline (μg/mL)		
Pre	0.2 ± 0.1	0.1 ± 0.1
Post	0.1 ± 0.1	0.3 ± 0.2*, †
Theobromine (μg/mL)		
Pre	10.2 ± 6.1	12.2 ± 8.6
Post	7.2 ± 4.6 †	8.7 ± 6.0†

Data mean ± SD of 16 rugby sevens players

* Different from placebo ($P < 0.05$)

† Different from Pre ($P < 0.05$)

similar in both experimental trials (Table 1). The ingestion of the caffeine-containing energy drink increased the urine caffeine, paraxanthine, and theophylline concentrations in comparison with the placebo trial ($P < 0.05$). In contrast, urinary theobromine concentration was slightly reduced after the game and it was similar in the caffeine and placebo trials.

Perceptual evaluation and frequency of the side-effects

The pre-exercise energy drink intake increased the perception of power during the rugby sevens competition in comparison to the placebo (Table 2; $P < 0.05$), although the effects on perceived endurance capacity and exertion were not significant. The energy drink intake also tended to increase vigor/activeness and insomnia in the following hours after the rugby sevens competition. However, the remaining side-effects were not affected by the ingestion of the caffeine-containing energy drink (Table 3).

Table 2 Rates of perceived exertion, power and endurance during the rugby sevens competition with the ingestion of a caffeinated energy drink (3 mg of caffeine/kg of body weight) or the same drink without caffeine

Item	Placebo	Energy drink
Power	6 ± 1	8 ± 1*
Endurance	6 ± 2	7 ± 2
Exertion	7 ± 2	6 ± 2

Data mean ± SD of 16 rugby sevens players

* Different from placebo ($P < 0.05$)

Discussion

The main purpose of this investigation was to determine the effectiveness of a commercially available energy drink, in a dose of 3 mg of caffeine per kg of body mass, to improve the physical performance of elite women rugby sevens players. For this purpose, the Spanish National Team volunteered to ingest a caffeine-containing drink or a placebo drink before two competition days during a friendly international tournament. In comparison to the placebo drink, when the players drank the caffeinated beverage before the game they (a) increased their running pace from 87.5 ± 8.3 to 95.4 ± 12.7 m/min ($P < 0.05$) and mean heart from 164 ± 6 to 168 ± 7 beats/min ($P < 0.05$) during the rugby sevens games; (b) enhanced the pace of movement patterns performed at sprint velocity

Table 3 Prevalence of side-effects during the following hours to the rugby sevens competition with the ingestion of a caffeinated energy drink (3 mg of caffeine/kg of body weight) or the same drink without caffeine

Item	Placebo (%)	Energy drink (%)
Headache	19	0
Abdominal/gut discomfort	6	25
Muscle soreness	63	44
Increased vigor/activeness	0	50
Tachycardia and heart palpitations	0	0
Insomnia	19	63
Increased urine production	0	0
Increased anxiety	0	0

Data frequencies for 16 rugby sevens players

* Different from placebo ($P < 0.05$)

from 4.6 ± 3.3 to 6.1 ± 3.4 m/min ($P < 0.05$); and (c) improved leg muscle power during a 15-s jump test from 23.5 ± 10.1 to 25.6 ± 11.8 kW ($P = 0.05$). In contrast, the ingestion of the energy drink did not modify maximal running speed during a 6 × 30-m test, maximal heart rate, or dehydration during the game. As a result, the pre-exercise ingestion of 3 mg/kg of caffeine in the form of an energy drink significantly improved the running movement patterns of women rugby sevens players during a real game.

Due to the boost in the popularity of this team sport in the last few years, several studies have been geared to determine the particularities of rugby sevens physical performance (Higham et al. 2012; Lopez et al. 2012; Rienzi et al. 1999; Suarez-Arrones et al. 2011a, b). While traditional 15-per side rugby union consists of 80 min of play during an official match, rugby sevens players have to exert their maximal performance only during two halves of 7 min and thus, the exercise intensity of their actions and the exercise-to-rest ratio are significantly increased (Suarez-Arrones et al. 2011b). Men rugby union players run at a pace between 62 and 80 m/min (Coughlan et al. 2011; Cunniffe et al. 2009; McLellan et al. 2011) during official games. In contrast, male rugby sevens players run at between 106 and 120 m/min during international and domestic matches (Suarez-Arrones et al. 2011b; Higham et al. 2012). In the present investigation, that included three games per day, our female rugby sevens players ran at 87.5 ± 8.3 m/min with the placebo drink, while a previous investigation found that elite female rugby sevens players can reach 103 m/min during an official international tournament. Because the level of the rugby players (National Teams) and assessment procedures (GPS technology) were similar between these studies, the differences in running paces could be related to the break-time between games. During an official tournament, the between-games resting period is usually 2 h (Suarez-Arrones et al. 2011a), while the time break between games in our study was only 30 min to follow the demands of the technical staff of the National Teams. Nevertheless, the intake of an energy drink with 3 mg/kg of caffeine significantly increased the rugby players' running pace to 95.4 ± 12.7 m/min, which represents an improvement of 9 ± 3 %. In recent investigations, it has been found that 3 mg/kg of caffeine in the form of energy drinks increases running pace from 92 to 98 m/min (an improvement of 7 %) during a simulated soccer match (Del Coso et al. 2012a) and from 79 to 86 m/min (an improvement of 9 %) during a simulated rugby union game (Del Coso et al. 2012b). All these data suggest that the use of a caffeinated energy drink improves running distance covered during team sports by 7–9 %.

Out of all the running actions performed during rugby games, the actions performed at high-intensity running are the most important for success (Roberts et al. 2008) as they are related with scoring or defending. Cunniffe et al. (2009) divided movement patterns during rugby union into six speed zones to account for from walking to sprinting. Under this classification, high-intensity running was considered when rugby players moved at a velocity greater than 18 km/h, while sprints were categorized as actions with a velocity higher than 20 km/h. Cunniffe's categorization has also been used to classify running demands on rugby sevens players (Suarez-Arrones et al. 2011a, b), while the results are quite different to the ones found in rugby union players. Male rugby union players ran at a slower pace at high-intensity (3.8 vs. 5.7 m/min) and at sprint velocity (5.0 vs. 9.8 m/min) than their rugby sevens counterparts (Cunniffe et al. 2009; Suarez-Arrones et al. 2011b), which indicates that the significance of high-intensity exercise is greater in sevens than in traditional rugby.

Figure 2 depicts the running paces included in the six speed zones during the women's rugby sevens competition. When the players ingested the placebo drink, they ran 3.7 ± 1.4 m/min in zone 5 (high-intensity running) and 4.6 ± 3.3 m/min in zone 6 (sprint running), similar to the results found with other female rugby sevens players (Suarez-Arrones et al. 2011a). The pre-exercise ingestion of the caffeine-containing energy drink increased high-intensity running to 4.4 ± 1.4 m/min ($P < 0.05$) and sprint running to 6.1 ± 3.4 m/min ($P < 0.05$). Interestingly, the energy drink did not affect the pace of walking or jogging during the game (Fig. 2). The enhancement of high-intensity and sprint movements after the ingestion of caffeinated energy drinks has also been found in soccer (Del Coso et al. 2012a) and rugby union (Del Coso et al. 2012b), while the low-intensity movement patterns were unaltered. These results indicate that caffeine modifies the movement patterns of team sports; players increase the movements performed at high-intensity or sprints which probably represent an important physical advantage for obtaining victory during the game.

Pre-exercise ingestion of 5–6 mg/kg of caffeine via pills has been found effective to increase sprint velocity during running tests that included various sprint bouts (Carr et al. 2008; Glaister et al. 2008; Stuart et al. 2005; Gant et al. 2010). The use of energy drinks on sprint tests has also been investigated in team sports players, with no changes in running performance in comparison to a placebo when the caffeine dose was 1.3 mg/kg (Astorino et al. 2011) but with significant ergogenicity when the caffeine dose was 3 mg/kg (Del Coso et al. 2012a). In the present investigation, maximal running speed was unchanged during a 6×30-m test despite the dose being 3 mg/kg of caffeine (Fig. 1). Nevertheless, the caffeinated energy drink significantly increased leg muscle power during a 15-s test (Fig. 3), as has been previously found during a similar test (Del Coso et al. 2012a) or during half-squat jumps with external loads (Del Coso et al. 2012c). The reason for the lack of ergogenicity during the sprint test, despite the fact that the energy drink increased the sprint performance during the rugby competitions and during the jump test, is not evident. The sprint test was performed before the onset of competitions, and it might be possible that the rugby players were not entirely concentrated for the test despite the continuous motivation of the technical staff. In any case, the enhancement of high-intensity running during the competitions and the muscle performance during the jump test suggests that energy drinks were a potent ergogenic aid in rugby sevens.

The assessment of urinary caffeine concentration is an easy and reliable method that can be used to determine caffeine ingestion in sports. In previous studies after the ingestion of 3 mg/kg of caffeine, we have found 4.1 µg of caffeine per mL of urine for male soccer players (Del Coso et al. 2012a) and 2.4 µg/mL for male rugby players (Del Coso et al. 2012b). In the present investigation with the same caffeine dosage, the urinary caffeine concentration at the end of the tournament was 3.3 ± 0.7 µg/mL, a value within the range found in male team sports players. Human liver metabolizes caffeine into paraxanthine (80 %), theobromine (11 %), and theophylline (5 %), while the remaining 4 % of caffeine is eliminated in urine without transformation (Lelo et al. 1986). In the present investigation, urine paraxanthine and theophylline concentrations were higher after the ingestion of energy drinks (Table 1). However, the magnitude of these increases was lower that the rise in urine caffeine concentration (from 0.2 ± 0.1 to 3.3 ± 0.7 µg/mL). Thus, caffeine concentration was the urinary variable that best identified the consumption of the caffeine-containing energy drink after a rugby sevens tournament.

Early data revealed that caffeine increased lipolysis and enhanced muscle glycogen spare (Costill et al. 1978), although these effects have been subsequently questioned (Graham et al. 2000). However, short-term high-intensity exercise (e.g., sprint actions) is not primarily associated to enhanced carbohydrate and/or fat metabolism, and other mechanisms must explain the ergogenic effects found in this investigation. Caffeine may benefit muscle contraction via enhanced Ca^{++} release from the sarcoplasmic reticulum although this effect has been obtained with supraphysiological plasma caffeine concentration (Magkos and Kavouras 2005). Caffeine also enhances motor unit recruitment by acting as an adenosine antagonist on the central nervous system (Davis et al. 2003). In previous studies with humans, we found that caffeine ingestion improves maximal muscle strength due to a higher voluntary contraction (Coso et al. 2008) and reduces the time to obtain maximal power output (Del Coso et al. 2012c), which suggests a better intra- and inter-muscular coordination during the muscle contraction. Although we did not assess the source of the benefits found with caffeine-containing energy drinks in the present investigation, we speculate that caffeine improved physical performance via improved motor unit recruitment.

In summary, the ingestion of 3 mg/kg of caffeine using a commercially available energy drink increased the overall running pace and the movement patterns performed at sprint velocity during a friendly international competition of rugby sevens. In addition, the energy drink intake produced marginal side-effects during the following hours to the competition, which suggests that this beverage did not represent a potential health risk to the female rugby sevens players, at least with the dosage used in this investigation.

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References

Astorino TA, Matera AJ, Basinger J, Evans M, Schurman T, Marquez R (2011) Effects of red bull energy drink on repeated sprint performance in women athletes. Amino Acids 42(5):1803–1808. doi:10.1007/s00726-011-0900-8

Barbero-Álvarez JC, Coutts A, Granda J, Barbero-Álvarez V, Castagna C (2009) The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. J Sci Med Sport 13(2):232–235

Bishop D, Girard O, Mendez-Villanueva A (2011) Repeated-sprint ability—part II: recommendations for training. Sports Med 41(9):741–756. doi:10.2165/11590560-000000000-00000

Carr A, Dawson B, Schneiker K, Goodman C, Lay B (2008) Effect of caffeine supplementation on repeated sprint running performance. J Sports Med Phys Fit 48(4):472–478

Coso J, Estevez E, Mora-Rodriguez R (2008) Caffeine effects on short-term performance during prolonged exercise in the heat. Med Sci Sports Exerc 40(4):744–751

Costill DL, Dalsky GP, Fink WJ (1978) Effects of caffeine ingestion on metabolism and exercise performance. Med Sci Sports 10(3):155–158

Coughlan GF, Green BS, Pook PT, Toolan E, O'Connor SP (2011) Physical game demands in elite rugby union: a global positioning system analysis and possible implications for rehabilitation. J Orthop Sports Phys Ther 41(8):600–605. doi:10.2519/jospt.2011.3508

Coutts AJ, Duffield R (2010) Validity and reliability of GPS devices for measuring movement demands of team sports. J Sci Med Sport 13(1):133–135. doi:10.1016/j.jsams.2008.09.015

Cunniffe B, Proctor W, Baker JS, Davies B (2009) An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. J Strength Cond Res 23(4):1195–1203. doi:10.1519/JSC.0b013e3181a3928b

Davis JM, Zhao Z, Stock HS, Mehl KA, Buggy J, Hand GA (2003) Central nervous system effects of caffeine and adenosine on fatigue. Am J Physiol Regul Integr Comp Physiol 284(2):R399–R404. doi:10.1152/ajpregu.00386.2002

Del Coso J, Munoz G, Munoz-Guerra J (2011) Prevalence of caffeine use in elite athletes following its removal from the World Anti-Doping Agency list of banned substances. Appl Physiol Nutr Metab 36(4):555–561. doi:10.1139/h11-052

Del Coso J, Munoz-Fernandez VE, Munoz G, Fernandez-Elias VE, Ortega JF, Hamouti N, Barbero JC, Munoz-Guerra J (2012a) Effects of a caffeine-containing energy drink on simulated soccer performance. PLoS ONE 7(2):e31380. doi:10.1371/journal.pone.0031380

Del Coso J, Ramirez JA, Muñoz G, Portillo J, Gonzalez-Millan C, Muñoz V, Barbero JC, Muñoz-Guerra J (2012b) The ingestion of an energy drink improves performance during a simulated rugby game. Appl Physiol Nutr Metab. http://www.nrcresearchpress.com/doi/abs/10.1139/apnm-2012-0339

Del Coso J, Salinero JJ, Gonzalez-Millan C, Abian-Vicen J, Perez-Gonzalez B (2012c) Dose response effects of a caffeine-containing energy drink on muscle performance: a repeated measures design. J Int Soc Sports Nutr 9(1):21. doi:10.1186/1550-2783-9-21

Engebretsen L, Steffen K (2010) Rugby in Rio in 2016! Br J Sports Med 44(3):157. doi:10.1136/bjsm.2010.71555

Froiland K, Koszewski W, Hingst J, Kopecky L (2004) Nutritional supplement use among college athletes and their sources of information. Int J Sport Nutr Exerc Metab 14(1):104–120

Gant N, Ali A, Foskett A (2010) The influence of caffeine and carbohydrate coingestion on simulated soccer performance. Int J Sport Nutr Exerc Metab 20(3):191–197

Glaister M, Howatson G, Abraham CS, Lockey RA, Goodwin JE, Foley P, McInnes G (2008) Caffeine supplementation and multiple sprint running performance. Med Sci Sports Exerc 40(10):1835–1840

Graham TE, Helge JW, MacLean DA, Kiens B, Richter EA (2000) Caffeine ingestion does not alter carbohydrate or fat metabolism in human skeletal muscle during exercise. J Physiol 529(Pt 3):837–847

Higham DG, Pyne DB, Anson JM, Eddy A (2012) Movement patterns in rugby sevens: effects of tournament level, fatigue and substitute players. J Sci Med Sport 15(3):277–282. doi:10.1016/j.jsams.2011.11.256

Jennings D, Cormack S, Coutts AJ, Boyd LJ, Aughey RJ (2010) Variability of GPS units for measuring distance in team sport movements. Int J Sports Physiol Perform 5(4):565–569

King T, Jenkins D, Gabbett T (2009) A time-motion analysis of professional rugby league match-play. J Sports Sci 27(3):213–219. doi:10.1080/02640410802538168

Kristiansen M, Levy-Milne R, Barr S, Flint A (2005) Dietary supplement use by varsity athletes at a Canadian university. Int J Sport Nutr Exerc Metab 15(2):195–210

Lelo A, Miners JO, Robson RA, Birkett DJ (1986) Quantitative assessment of caffeine partial clearances in man. Br J Clin Pharmacol 22:183–186

Lopez V Jr, Galano GJ, Black CM, Gupta AT, James DE, Kelleher KM, Allen AA (2012) Profile of an American amateur rugby union sevens series. Am J Sports Med 40(1):179–184. doi:10.1177/0363546511427124

Magkos F, Kavouras SA (2005) Caffeine use in sports, pharmacokinetics in man, and cellular mechanisms of action. Crit Rev Food Sci Nutr 45(7–8):535–562

McLellan CP, Lovell DI, Gass GC (2011) Performance analysis of elite Rugby League match play using global positioning systems. J Strength Cond Res 25(6):1703–1710. doi:10.1519/JSC.0b013e3181ddf678

Rienzi E, Reilly T, Malkin C (1999) Investigation of anthropometric and work-rate profiles of Rugby Sevens players. J Sports Med Phys Fit 39(2):160–164

Roberts SP, Trewartha G, Higgitt RJ, El-Abd J, Stokes KA (2008) The physical demands of elite English rugby union. J Sports Sci 26(8):825–833. doi:10.1080/02640410801942122

Stuart GR, Hopkins WG, Cook C, Cairns SP (2005) Multiple effects of caffeine on simulated high-intensity team-sport performance. Med Sci Sports Exerc 37(11):1998–2005

Suarez-Arrones L, Nunez F, Portillo J, Mendez-Villanueva A (2011a) Match running performance and exercise intensity in elite female Rugby Sevens. J Strength Cond Res 26(7):1858–1862. doi:10.1519/JSC.0b013e318238ea3e

Suarez-Arrones LJ, Nunez FJ, Portillo J, Mendez-Villanueva A (2011b) Running demands and heart rate responses in men Rugby Sevens. J Strength Cond Res. doi:10.1519/JSC.0b013e318243fff7