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ARTICLE

Caffeine-containing energy drink improves physical performance of elite rugby players during a simulated match

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Abstract: The purpose of this study was to investigate the effectiveness of a caffeine-containing energy drink in enhancing rugby players' physical performance during a simulated match. A second purpose was to determine the urinary caffeine excretion derived from the energy drink intake. In a randomized and counterbalanced order, 26 elite rugby players (mean ± SD for age and body mass, 25 ± 2 y and 93 ± 15 kg) played 2 simulated rugby games (2 × 30 min) 60 min after ingesting (*i*) 3 mg of caffeine per kilogram of body mass in the form of an energy drink (Fure, ProEnergetics) or (*ii*) the same drink without caffeine (placebo). During the matches, the individual running distance and the instantaneous speed were measured, and the number of running actions above 20 km·h^{-1} (i.e., sprints) were determined, using global positioning system devices. The number of impacts above 5 *g* during the matches was determined by accelerometry. The ingestion of the energy drink, compared with the placebo, increased the total distance covered during the match (4749 ± 589 vs 5139 ± 475 m, $p < 0.05$), the running distance covered at more than 20 km·h^{-1} (184 ± 38 vs 208 ± 38 m, $p < 0.05$), and the number of sprints (10 ± 7 vs 12 ± 7, $p < 0.05$). The ingestion of the energy drink also resulted in a greater overall number of impacts (481 ± 352 vs 641 ± 366, $p < 0.05$) and a higher postexercise urine caffeine concentration (0.1 ± 0.1 vs 2.4 ± 0.9 μg·mL^{-1}, $p < 0.05$). The use of an energy drink with a caffeine dose equivalent to 3 mg·kg^{-1} considerably enhanced the movement patterns of rugby players during a simulated match.

Key words: GPS technology, team sports, ergogenic aids, exercise, doping, sprint.

Résumé : Cette étude se propose d'analyser l'efficacité d'une boisson énergétique contenant de la caféine pour améliorer la performance physique de joueurs de rugby au cours d'un match simulé. Cette étude se propose aussi d'évaluer l'excrétion urinaire de café due à la consommation de la boisson énergétique. Selon un plan expérimental contrebalancé, 26 joueurs de rugby de niveau élite âgés de 25 ± 2 ans et pesant 93 ± 15 kg participent à deux matchs simulés (2 × 30 min) 60 min après avoir consommé (*i*) une boisson énergétique (Fure, ProEnergetics) contenant 3 mg de caféine par kg de masse corporelle ou (*ii*) la même boisson sans caféine (placebo). Au cours des matchs, on évalue au moyen d'un appareil GPS la distance individuelle de course, la vitesse instantanée et le nombre de sprints effectués à une vitesse supérieure à 20 km/h. On évalue par accélérométrie le nombre d'impacts supérieurs à 5 *g* au cours des matchs. Comparativement au placebo, la boisson énergétique améliore la distance totale franchie au cours d'un match (4749 ± 589 m vs 5139 ± 475 m, $p < 0,05$), la distance courue à une vitesse supérieure à 20 km/h (184 ± 38 m vs 208 ± 38 m, $p < 0,05$) et le nombre de sprints (10 ± 7 vs 12 ± 7, $p < 0,05$). La consommation de la boisson énergétique est aussi associée à un plus grand nombre d'impacts (481 ± 352 vs 641 ± 366, $p < 0,05$) et à une plus grande excrétion urinaire postexercice de caféine (0,1 ± 0,1 μg/mL vs 2,4 ± 0,9 μg/mL; $p < 0,05$). La consommation d'une boisson énergétique contenant 3 mg/kg de caféine améliore grandement les modalités de déplacement des joueurs de rugby au cours d'un match simulé. [Traduit par la Rédaction]

Mots-clés : technologie GPS, sports d'équipe, facteurs ergogènes, exercice physique, dopage, sprint.

Introduction

The alkaloid caffeine (1,3,7-trimethylxanthine) is a natural component of coffee and chocolate beans, tea leaves, and kola nuts. The strong stimulant properties of this substance have favored the consumption in most civilizations of natural derivates of caffeine (mainly coffee and tea infusions) on a daily basis for several centuries (Welsh and Marston 1982). Nowadays, caffeine can also be synthesized artificially, and it is frequently included in manufactured nutritional products, such as energy drinks. These beverages contain moderate-to-high amounts of caffeine, in addition to carbohydrates, taurine, glucuronolactone, and B-group vitamins (Higgins et al. 2010) in an attempt to improve physical and mental performance. Since Red Bull was introduced in Austria at the end of the 1980s, the energy drink market has grown exponentially, with dozens of brands marketed in the past few years (Reissig et al. 2009). In 2005, Red Bull enjoyed a 65% share of the $650 million energy drink market in the United States alone (Bryce and Dyer 2007).

Caffeine-containing energy drinks have become the most popular supplements in sports, with a prevalence of more than 50% in the athletic population (Froiland et al. 2004; Kristiansen et al. 2005; Hoffman 2010). However, the effects of energy drink utilization on athletes have been the subject of only a few studies. According to previous investigations, it seems that the ergogenic properties of caffeine-containing energy drinks depend on the amount of the product consumed, and thus the amount of caf-

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feine ingested. Various investigations have found that one 250-mL serving of an energy drink (equivalent to ~1 mg of caffeine per kilogram of body mass) failed to enhance maximal aerobic capacity (Ferreira et al. 2004), peak power during the Wingate test (Forbes et al. 2007; Hoffman et al. 2009), or running velocity during "all-out" sprints (Astorino et al. 2011; Gwacham and Wagner 2012), although this is not always the case (Alford et al. 2001). The ingestion of 2 servings of an energy drink (~2 mg·kg^{-1} of caffeine) improved performance during a cycling time trial (Ivy et al. 2009) but did not prolong time-to-exhaustion during a running test at 80% of maximal oxygen consumption (Candow et al. 2009). However, the ingestion of 3 servings of an energy drink (~3 mg·kg^{-1} of caffeine) increased jump height, running speed, and distance covered at high intensity during a simulated soccer match (Del Coso et al. 2012*a*). Finally, only 1 study has compared the dose-dependent effects of energy drink ingestion on performance. Del Coso et al. (2012*b*) found that 1 mg·kg^{-1} of caffeine in the form of a lyophilized energy drink (similar to 1 serving) did not affect muscle power output during bench press or half-squat exercises, but 3 mg·kg^{-1} of caffeine significantly improved muscle power output in both exercises. Thus, at least 3 servings of 250 mL, equivalent to 3 mg·kg^{-1} of caffeine, may be necessary to improve physical performance.

Although the outcomes of caffeine ingestion in endurance activities are well established (Burke 2008), the effectiveness of this substance in team sports has been less well studied. Rugby union is a heavy-contact sport in which high-intensity actions are interspersed with periods of lower-intensity exercise or recovery (Cunniffe et al. 2009). Recent advances in notational analysis technology such as the global positioning system (GPS) have allowed experimenters to obtain real-time measurements of movement patterns during rugby games. These devices measure the activity profile of team sports players on the field without hindering normal game actions. Using this methodology, it has been found that rugby players run at a pace of between 62 and 84 m·min^{-1} (Cunniffe et al. 2009; Coughlan et al. 2011; McLellan et al. 2011). Rugby players spend the major portion of their games standing or walking, although crucial actions during the match are related to running at sprint speed (Cunniffe et al. 2009; Coughlan et al. 2011). As in other team sports, the ability to perform repeated sprints with minimal recovery between bouts is one of the most crucial capacities for rugby players (Barbero-Álvarez et al. 2009). However, no study has investigated the effects of ingesting a caffeine-containing energy drink on movement patterns during a rugby match. The aim of the current study was to determine the effectiveness of an energy drink (3 mg·kg^{-1} of caffeine) on the activity profiles of elite rugby players during a simulated match. We hypothesized that 3 mg of caffeine per kilogram of body mass in the form of an energy drink would increase the capacity of rugby players to perform repeated sprints.

Materials and methods

Subjects

Thirty elite rugby players from the same team (First division, Spanish Rugby League) volunteered to participate in the study. Three of these players did not finish the experimental trials (muscle injuries) and 1 player presented a pre-exercise urine caffeine concentration above 1 μg·mL^{-1}, so their data were excluded. The 26 players who completed the study had a mean ± SD for age, body mass, height, and maximal heart rate of 25 ± 2 y, 93 ± 15 kg, 180 ± 7 cm, and 191 ± 9 beats·min^{-1}, respectively. All participants had experience in national rugby competitions of at least 5 y and had trained for ~2 h·day^{-1}, 4–5 days·week^{-1} (including a weekly competition) during the previous 3 years. No participant had a history of cardiopulmonary disease. Potential participants taking medications during the investigation were excluded from the study sample. Participants were nonsmokers, but all were light caffeine consumers (<60 mg·day^{-1} or ~1 cup of coffee). Before the experimental trials, participants were fully informed of any 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

Each player performed 2 experimental trials (i.e., 2 simulated rugby matches) under the same experimental conditions (13 ± 1 °C dry temperature, 51% relative humidity) and at the same time of day (in the afternoon). On 1 occasion, participants ingested a powdered caffeine-containing energy drink (Fure, ProEnergetics, Spain) dissolved in 250 mL of tap water. The amount of the energy drink was individually set to provide a dose of 3 mg of caffeine per kilogram of body mass. On the other occasion, players ingested the same drink with no caffeine content (0 mg·kg^{-1}, placebo). The energy drink used for this investigation contained 100 mg of caffeine per 1 gram of product but it also included maltodextrin (300 mg·g^{-1} of product), taurine (400 mg·g^{-1} of product), L-carnitine (40 mg·g^{-1} of product), B-group vitamins (10 mg·g^{-1} of product), and sodium bicarbonate (100 mg·g^{-1} of product). To avoid the effect of these substances on the results of the study, the energy drink manufacturer provided us with a placebo drink that had ingredients, appearance, and taste identical to the energy drink but with no caffeine content. Thus, the use of this "placebo-energy drink" enabled us to eliminate the confounding effects of these other substances on the outcomes of the current investigation. Finally, the amount of carbohydrate administered in both experimental trials was 1.3 ± 0.2 g of carbohydrate, equivalent to 6 cal.

The beverages were ingested 60 min before the onset of the experimental trials to allow complete caffeine absorption (Armstrong 2002) and they were supplied in opaque plastic bottles to avoid identification. The participants were divided into 2 groups according to their position in the field and they were supplied with the drinks in a counterbalanced and randomized order. Thus, during experimental trials, players on the same rugby team received different experimental treatments (caffeine or placebo). Trials were separated by 4 days to allow for a complete recovery. An alphanumeric code was assigned to each trial to blind participants and investigators to the drink tested. This code was revealed after the analysis of the variables.

Experimental protocol

The day before each experimental trial, participants refrained from strenuous exercise and were encouraged to abstain from all dietary sources of caffeine (coffee, tea, cola drinks, chocolate, etc.) and alcohol. Verbal reminders were given to ensure compliance. Participants were also instructed to have their habitual precompetition meal at least 3 h before the start of the experimental trials. In the afternoon, participants arrived at their habitual training 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 at a later date. After that, participants were weighed nude (±50 g, Radwag Balances and Scales, Radom, Poland) and the beverage assigned for the trial was supplied and consumed individually. Players then dressed in a T-shirt, shorts, and cleats and put on chest rugby armor. They also wore a GPS–accelerometer–heart rate device inserted in a purpose-built back-pack (GPS, SPI PRO X, GPSports, Australia) and a heart rate monitor (Polar T31, Finland) attached to their chest. Players wore the same GPS unit for each experimental trial to reduce measurement error (Jennings et al. 2010). Participants then performed a standardized warm-up for 15 min and began the simulated match exactly 60 min after beverage ingestion. Postexercise nude body mass was obtained within 10 min of the end of the match. Thirty to 60 min after the end of the match, participants voided again, and a urine sample was obtained. During each experimental trial, players drank water ad libitum. Players were instructed to drink only from their own individually labeled bottles and not to spit out or spill any fluid. Fluid intake was measured from the change in bottle mass using a scale (±0.1 g, Delicia, Tefal, France). Sweat rate was estimated from body mass loss, total fluid intake, and experimental trial duration.

Simulated rugby match

In each experimental trial, the participants completed a 2 × 30-min rugby match, including a 10-min half time. The match was played on a regular rugby field (95 × 55 m) with 15 players per side, and a professional referee made decisions on play disputes during the game. The match followed the rules of the International Rugby Board, except for the time, which was agreed upon with the team technical staff to minimize the influence of the experiments on their training routines. During the match, the technical staff continuously encouraged the players to perform at maximal level, as in an official match. Participants were divided into 2 rugby teams according to their outfield position, to allow them to play in their habitual positions. In each team, a similar number of players received the energy drink or placebo (8 received the energy drink, 7 received the placebo and vice versa). During the match, the GPS-accelerometer device and heart rate belt monitored data on distance covered, instantaneous running speed at 15 Hz and players' impact data and heart rate at 1 Hz. The validity and reliability of the GPS devices to assess team sports player movement have been analyzed previously with satisfactory results (Coutts and Duffield 2010; Johnston et al. 2012). Preliminary data indicated that total running distance (277 ± 60 m, coefficient of variation = 5.8%) and running at sprint velocity (7 ± 7 m, coefficient of variation = 6.4%) presented acceptable variability during 2 consecutive games under similar conditions.

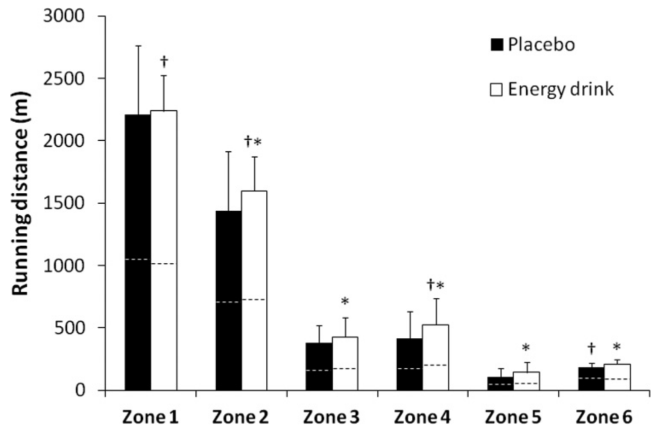
Movement patterns during the match

The rugby players' movement patterns during the match were analyzed using 6 speed zones, based on a previous study with rugby players (Cunniffe et al. 2009): standing and walking (zone 1, 0–6 $km\cdot h^{-1}$), jogging (zone 2, 6–12 $km\cdot h^{-1}$), cruising (zone 3, 12–14 $km\cdot h^{-1}$), striding (zone 4, 14–18 $km\cdot h^{-1}$), high-intensity running (zone 5, 18–20 $km\cdot h^{-1}$), and sprinting (zone 6, faster than 20 $km\cdot h^{-1}$). Each running action with a speed higher than 20 $km\cdot h^{-1}$ and a distance covered greater than 5 m was considered a sprint bout. The number of sprint bouts during each experimental trial was used for analysis. The total number of impacts during a match (body load) was determined by accelerometry and recorded. The impact intensity was also graded using 6 zones following Cunniffe et al. (2009): light impact, hard acceleration, deceleration, change of direction (zone 1, 5–6 *g*); light-to-moderate impact, player collision, contact with the ground (zone 2, 6–6.5 *g*); moderate-to-heavy impact, tackle (zone 3, 6.5–7 *g*); heavy impact (zone 4, 7–8 *g*); very heavy impact, scrum engagement (zone 5, 8–10 *g*); and severe impact, tackle, collision (zone 6, higher than 10 *g*). All data analyses were performed with a specific software package (Team AMS software VS R1.2011.6, GPSports).

Urine analysis

After urine homogenization, a representative (3-mL) specimen of each sample was analyzed for caffeine, paraxanthine, and theobromine concentrations using an Agilent Technologies HPLC 1200 (Santa Clara, Calif., USA) coupled to a triple quadrupole ion trap mass spectrometer (MS, API 3000, USA). Caffeine, paraxanthine, theobromine, and the internal standard (7-β-hydroxy-ethyltheophylline) were purchased from Sigma–Aldrich (Spain). The internal standard used for caffeine ($^{13}C_3$ –caffeine) was purchased from Cambridge Isotope Laboratories (Spain). For this measurement, 20 μL of the internal standard 7-β-hydroxy-ethyltheophylline (60 $\mu g\cdot mL^{-1}$) and 20 μL of the internal standard $^{13}C_3$ –caffeine (5 $\mu g\cdot mL^{-1}$) were added to 200 μL of urine. A volume of 200 μL of mobile phase

Fig. 1. Running distance covered at different speeds during a simulated rugby match with the ingestion of a caffeinated energy drink (3 mg of caffeine per kilogram of body mass) or the ingestion of a placebo drink. Data are presented as means ± SD for 26 rugby players. Dashed lines indicate the half time. Speed zones were as follows: standing and walking (zone 1, 0–6 $km\cdot h^{-1}$), jogging (zone 2, 6–12 $km\cdot h^{-1}$), cruising (zone 3, 12–14 $km\cdot h^{-1}$), striding (zone 4, 14–18 $km\cdot h^{-1}$), high-intensity running (zone 5, 18–20 $km\cdot h^{-1}$), and sprinting (zone 6, faster than 20 $km\cdot h^{-1}$). *, Different from placebo ($p < 0.05$); †, different from the first half ($p < 0.05$).



(acetic acid 0.1%) was added to the urine sample, and then 10 μL of this sample was directly applied to the HPLC-MS. To calibrate the instrument, aqueous solutions of caffeine, paraxanthine, and theobromine (ranging from 0.1 to 7 $\mu g\cdot mL^{-1}$) 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 $\mu g\cdot mL^{-1}$.

Statistical analyses

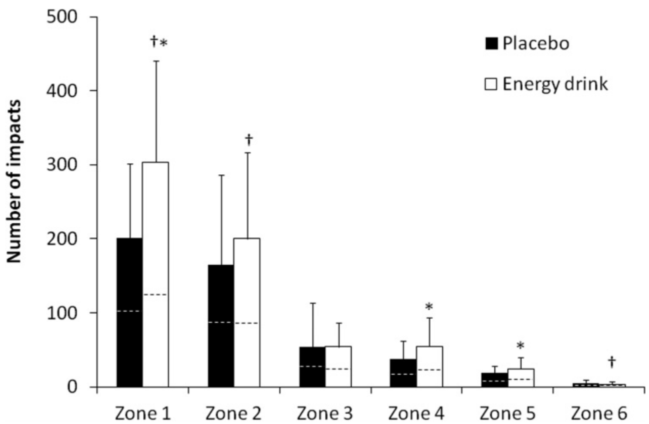
The total running distance during the simulated match, the running distance at different speeds, the number of sprints bouts, and the sweat rate were examined using paired Student's *t* tests. Data on the prematch and postmatch urinary concentrations of caffeine, paraxanthine, and theobromine were examined using 2-way analysis of variance (ANOVA). For each difference found in this study, we calculated the effect size (ES) proposed by Cohen. The data were analyzed with the statistical package SPSS v. 18.0 (SPSS Inc., Chicago, Ill., USA). The significance level was set at $p < 0.05$. The results are presented as means ± SD.

Results

Running distance and running speed during a simulated rugby match

The total running distance during a 2 × 30-min simulated rugby match was 5139 ± 475 m after the ingestion of the energy drink and 4749 ± 589 m after the ingestion of the placebo drink ($p = 0.01$, ES = 0.74). Although there were no differences in the running distance covered during the first half (2366 ± 263 vs 2327 ± 232 for the energy drink and the placebo drink, respectively, $p = 0.51$), the ingestion of the energy drink significantly increased the running distance during the second half (2772 ± 308 vs 2416 ± 443, $p = 0.01$, ES = 0.94). Figure 1 illustrates the distance covered at different speeds, ranging from standing and walking (zone 1) to sprinting (zone 6). The utilization of the caffeinated energy drink, compared with the placebo, produced a significant rise in the distance covered at jogging (zone 2, $p = 0.03$, ES = 0.41), at cruising (zone 3, $p = 0.04$, ES = 0.31), at striding (zone 4, $p = 0.01$, ES = 0.52), at high-intensity running (zone 5, $p = 0.01$, ES = 0.47), and at sprint velocity (zone 6, $p = 0.01$, ES = 0.62). In contrast, there were no

Fig. 2. Body accelerations during a simulated rugby match with the ingestion of a caffeinated energy drink (3 mg of caffeine per kilogram of body mass) or the ingestion of a placebo drink. Data are presented as means ± SD for 26 rugby players. Dashed lines indicate the half time. The impact intensity zones were as follows: light impact, deceleration, or change of direction (zone 1, 5–6 *g*); moderate impact, player collision, contact with the ground (zone 2, 6–6.5 *g*); moderate to heavy impact, tackle (zone 3, 6.5–7 *g*); heavy impact (zone 4, 7–8 *g*); very heavy impact, scrum engagement (zone 5, 8–10 *g*); and severe impact, tackle, collision (zone 6, higher than 10 *g*). *, Different from placebo (p < 0.05); †, different from the first half (p < 0.05).



differences between the energy drink and the placebo in the distance covered by walking (zone 1, p = 0.41). Finally, the number of sprint actions during the match was significantly increased with the ingestion of the energy drink (12 ± 7 vs 10 ± 7, p < 0.05, ES = 0.44). There were no differences between the number of sprints performed in the first and second half with the ingestion of the energy drink (6 ± 4 and 6 ± 4 for first half and second half, respectively) and the placebo drink (5 ± 4 and 5 ± 4 for first half and second half, respectively).

Body impacts during a simulated rugby match

The total number of impacts above a 5 *g* force performed during the rugby match was significantly higher with the ingestion of the energy drink compared with the placebo drink (641 ± 366 vs 481 ± 352, p = 0.01, ES = 0.45). Similar to the running distance, there were no differences between treatments during the first half (296 ± 176 vs 227 ± 181, p = 0.23), but the energy drink increased the impacts produced during the second half (346 ± 198 vs 254 ± 179, p = 0.01, ES = 0.48). Figure 2 depicts the categorization of body impacts produced or received during the rugby match according to their level of acceleration. The ingestion of the energy drink, compared with the placebo, significantly increased the number of impacts at zone 1 (p = 0.01, ES = 0.86), zone 4 (p = 0.02, ES = 0.54), and zone 5 (p = 0.05, ES = 0.46), whereas there were no differences in zone 2 (p = 0.30), zone 3 (p = 0.92), or zone 6 (p = 0.09).

Exercise heart rate and sweat rate

Maximal heart rate (189 ± 12 vs 185 ± 12 beats·min^{-1}, p = 0.92) and mean heart rate (151 ± 11 vs 145 ± 8 beats·min^{-1}, p = 0.19) during the match were unaffected by the ingestion of the energy drink, in comparison with the placebo. The ingestion of the energy drink maintained relatively constant both maximal heart rate (189 ± 9 and 187 ± 13 beats·min^{-1} for first half and second half, respectively) and mean heart rate (150 ± 11 and 151 ± 12 beats·min^{-1}) during the whole match. However, maximal heart rate (185 ± 12 vs 180 ± 13 beats·min^{-1}, p = 0.04) and mean heart rate (147 ± 8 and 143 ± 12 beats·min^{-1}, p = 0.04) were significantly reduced from the first to the second half of the match when players ingested the placebo drink. Sweat rate (1.8 ± 0.8 vs 1.8 ± 0.6 L·h^{-1}) and dehydration level attained at the end of the match (1.3% ± 0.9% vs 1.3% ± 0.6%) were unaffected by the energy drink.

Table 1. Urine caffeine, paraxanthine, and theobromine concentrations before and after a simulated rugby match with the ingestion of a caffeinated energy drink (3 mg of caffeine per kilogram of body mass) or a placebo drink.

		Placebo	Energy drink
Caffeine (μg·mL^{-1})	Pre	0.1±0.1	0.1±0.1
	Post	0.1±0.1	2.4±1.0*,†
Paraxanthine (μg·mL^{-1})	Pre	1.6±1.6	1.6±1.7
	Post	0.6±1.0†	2.1±1.1*,†
Theobromine (μg·mL^{-1})	Pre	8.0±4.5	7.2±4.3
	Post	4.0±4.3†	6.2±4.3

Note: Data are presented as means ± SD for 26 rugby players. Pre, prematch; Post, postmatch.

*Different from placebo (p < 0.05).

†Different from Pre (p < 0.05).

Urinary variables

The ingestion of the caffeine-containing energy drink increased the urine caffeine and paraxanthine concentrations after the match, in comparison with the prematch values (p < 0.05) (Table 1). In contrast, urinary caffeine and paraxanthine concentrations remained unchanged or were slightly reduced after the match in the placebo trial. Urine theobromine concentration was elevated even before the ingestion of the experimental beverages (pregame values = 8.0 ± 4.5 and 7.2 ± 4.3 μg·mL^{-1} for placebo and energy drink, respectively) and it was reduced after the match only in the placebo trial (p < 0.05) (Table 1).

Discussion

The main aim of the current investigation was to test the effectiveness of a caffeine-containing energy drink in improving rugby union physical performance. The outcomes of caffeine ingestion on team sports performance have been the subject of several previous investigations. In some, the research protocol included sets of sprint bouts interspersed with recovery periods. With this methodology, Carr et al. (2008) found that 6 mg·kg^{-1} of anhydrous caffeine increased sprint speed when team sports players performed 5 sets of 6 × 20 m. Similarly, Glaister et al. (2008) found that physically active men increased their sprint speed after the ingestion of 5 mg·kg^{-1} of caffeine during a 12 × 30-m test. Conversely, the use of an energy drink with a caffeine dose equivalent to 1.3 mg·kg^{-1} (Astorino et al. 2011) did not produce benefits during a 24 × 20-m sprint test. Thus, it seems that the caffeine amount ingested is a key factor in producing ergogenic effects on sprint performance.

Other authors have used team-specific tests that included repeated sprint actions interspersed with walking, jogging, or resting periods, with these actions maintained during long periods of time. This methodological approximation attempts to better replicate real team sports actions, because sprint bouts are repeated for a time period similar to that of a match. Stuart et al. (2005) found that 6 mg·kg^{-1} of caffeine increased sprinting speed in a group of rugby players during a 2 × 40-min test that included repeated sprint actions. Gant et al. (2010) found that the addition of 3.7 mg·kg^{-1} of caffeine to a carbohydrate–electrolyte solution improved sprinting performance during a 2 × 15-min test that included running sprints. Similarly, Roberts et al. (2010) found that 4 mg·kg^{-1} of caffeine combined with carbohydrate increased running speed during 2 × 21-min blocks that included sprint bouts.

More recently, the use of GPS technology has allowed investigators to assess sprint performance and movement patterns during real or simulated match actions by team sports players. These GPS devices allow continuous measurement and storage of the velocity of movements while their size and placement (usually on the back) do not hinder movements during real game actions. With this methodology, in soccer players, we found previously that 3 mg·kg^{-1} of caffeine in the form of an energy drink increased the running distance covered at sprint speed and the number of sprint bouts performed during a 2 × 40-min soccer match (Del Coso et al. 2012*a*). The current investigation confirms the effectiveness of caffeine-containing energy drinks in improving sprint performance during a team sport, because the energy drink increased sprint running distance (Fig. 1) and the number of sprint bouts in rugby union players. All these investigations indicate that caffeine, no matter the form of administration (via pills or energy drinks), could be an effective nutraceutical substance for the improvement of performance in team sports. In addition, 3 mg·kg^{-1} seems to be the minimal dose necessary to obtain favorable effects on performance from caffeine administration (Del Coso et al. 2012*a*).

The movement patterns of rugby players during a competitive match have been analyzed recently. Cunniffe et al. (2009) found that rugby players covered an average distance of 6953 m during a team-selection match. Likewise, Coughlan et al. (2011) measured an average distance of 6715 m during an international rugby match. McLellan et al. (2011) found during 5 regular seasons of rugby that players covered an average of between 4982 and 5573 m. In the current investigation, running distance during the simulated match was 4749 ± 589 m for the placebo trial and 5139 ± 475 m for the energy drink trial. The lower running distance measured in our study is mostly due to the reduced time periods used in the investigation (2 × 30 min vs 2 × 40 min used in official games). When the running distance covered during the match is divided by minute of play in all the cited investigations, the running pace of rugby players during official games is between 62 and 84 m·min^{-1}. These running paces are consistent with the movement rate measured in the placebo trial (79 m·min^{-1}). However, the ingestion of caffeine increased the running pace to 86 m·min^{-1} during the simulated match ($p < 0.05$). Because rugby players' movements are motivated by offensive and defensive actions, these data may indicate that caffeine produces a higher game involvement of players during a match.

For the current study, we categorized the total running distance into 6 intensity zones, from standing and walking to sprinting. Previous studies describing movement patterns found in rugby have found that players spent the major part of the match walking and running at low intensity, whereas medium- and high-intensity running activities are less frequent (Coughlan et al. 2011; McLellan et al. 2011). Categorization of movements during play is important because the capacity to run at high intensity or to sprint is the movement variable most related to playing at a higher competitive level in team sports (Rampinini et al. 2007; Bishop et al. 2011). The prematch ingestion of the caffeine-containing energy drink significantly increased the running distance covered in zones 2, 3, 4, 5, and 6 (Fig. 1), whereas it did not affect the distance covered in zone 1. The positive effects of the caffeine-containing energy drink on the distance covered in zone 5 (107 ± 70 vs 143 ± 86 m, $p < 0.05$) and in zone 6 (184 ± 38 vs 208 ± 38 m, $p < 0.05$) are probably the most important for rugby physical performance. Thus, although caffeine exerts no effect on the distance covered by walking (zone 1), its ingestion increases the capacity to run at high intensity and sprint during a simulated match.

The physical and physiological demands of rugby have been typically examined only using data from players' movement patterns. However, rugby is a sport involving heavy contact, including continuous collisions of various intensities, tackles, and scrums that are not directly related to movement patterns (McLellan et al. 2010). In the current investigation, rugby players wore a built-in accelerometer (included together with the GPS device) that measured and stored body accelerations during the match. The pre-exercise use of the caffeine-containing energy drink significantly increased the number of impacts produced during the match (481 ± 352 vs 641 ± 366, $p < 0.05$). The accelerometer assessed the number of accelerations during the match but also the intensity provided in "*g*" forces. Similarly to movements, accelerations were classified into 6 intensities zones, according to their *g* value (Cunniffe et al. 2009). The caffeine-containing energy drink increased the number of impacts in zones 1, 4, and 5. A larger number of body accelerations during a rugby match may suggest that the energy drink improved the number of changes of directions, the quantity of tackles (produced or received), and the players' involvement during scrums.

The outcomes of caffeine ingestion on physical performance have been tested mainly by using pure anhydrous caffeine supplied to experimental subjects in pills (Doherty and Smith 2004; Burke 2008; Del Coso et al. 2008, 2009). However, the current use of caffeine in sports mainly comes from the ingestion of commercially available energy drinks (Hoffman 2010). These beverages have become the most popular supplements in the sports population, with a prevalence of 73% in American college athletes (Froiland et al. 2004), 75% in Canadian varsity athletes (Kristiansen et al. 2005), and 42% in British elite athletes (Hoffman 2010). In an attempt to improve the applicability of the results of this study to the sports population, we used a lyophilized energy drink with a caffeine content of 100 mg·g^{-1} of product and a placebo drink that differed from the experimental drink only in the amount of caffeine. Although the influence of caffeine contained in the energy drinks has been the topic of the current investigation, more information is required to elucidate any effects of the remaining components of the energy drinks (taurine, glucuronolactone, and B-group vitamins, etc.) on sports performance.

Because of the systematic abuse of caffeine during competition in the 1980s (Delbeke and Debackere 1984), caffeine use in sports, only during competitions, was limited from 1984 to 2004. Antidoping authorities considered caffeine to be doping when postcompetition caffeine concentration in urine exceeded 12 μg·mL^{-1} (World Antidoping Web Site 2012). However, during the period of caffeine limitation, there was an open debate about the effectiveness of this urinary threshold in controlling the abuse of caffeine in sports. Several investigations demonstrated that anhydrous caffeine ingestion was ergogenic even when the urine caffeine concentration was below 12 μg·mL^{-1} (Pasman et al. 1995; Bruce et al. 2000; Cox et al. 2002) and thus, it is believed that athletes benefited from caffeine without being penalized by antidoping authorities. In 2004, caffeine was eliminated from the prohibited list of the World Anti-Doping Agency (WADA) and at present it is on the WADA Monitoring Program to track the trends of its use and to assess its future reinclusion on the prohibited list.

Between 2004 and 2008 (just after caffeine was removed from the prohibited list), the Spanish Anti-Doping Agency analyzed 20 686 urine samples obtained after national and international competitions (Del Coso et al. 2011). In that investigation, it was found that approximately 3 out of 4 urine samples contained caffeine, indicating the high prevalence of the use of this substance after its removal from the prohibited list. In addition, 10% of the urine samples contained considerable amounts of caffeine (>4 μg·mL^{-1}), especially the samples from endurance sports. Data on postexercise urine caffeine concentration derived from energy drink consumption are scarce. Recently, it has been found that the ingestion of a caffeine-containing energy drink (e.g., 3 mg·kg^{-1}) significantly increased soccer performance even though the postexercise urine caffeine concentration was only 4.1 ± 1.0 μg·mL^{-1} (Del Coso et al. 2012*a*). In the current study with rugby players, the ingestion of 3 mg·kg^{-1} of caffeine in the form of an energy drink produced a postmatch urinary caffeine concentration of 2.4 ± 1.0 μg·mL^{-1}. These data corroborate the opinion that the previous urinary threshold for caffeine doping was not sensitive enough to restrain the use of this performance-enhancing substance. The use of caffeine-containing energy drinks, similar to anhydrous caffeine drinks, is ergogenic even when urinary caffeine concentration is much lower than 12 μg·mL⁻¹.

In the human body, caffeine is converted mostly into paraxanthine (80%), theobromine (11%), and theophylline (5%), whereas the remaining 4% of caffeine is eliminated in urine without transformation (Lelo et al. 1986). Consequently, the urinary concentrations of paraxanthine and (or) theobromine can be used to estimate the amount of caffeine ingested in the sport setting. However, the prematch to postmatch increase in urinary paraxanthine concentration after the ingestion of energy drinks was lower than that of urine caffeine concentration. In contrast, the urinary theobromine concentration tended to be reduced (Table 1) after the match. The half-life for elimination of caffeine ranges from 2.5 to 10 h in humans, and the duration of the simulated rugby match was not long enough to produce the transformation of caffeine into its metabolites. Thus, the assessment of postcompetition urine caffeine concentration remains the better marker to assess caffeine intake, at least in sports events shorter than 2.5 h.

In summary, the pre-exercise ingestion of a caffeinated energy drink (3 mg·kg⁻¹ of caffeine) increased the total running distance, the distance covered at high intensity, and the number of body accelerations during a 2 × 30-min simulated rugby union match. The improvement in satisfying the physical demands of rugby indicates that the ingestion of an energy drink in the correct dosage may be a potent ergogenic aid for rugby players. In addition, the postexercise urinary caffeine concentration was well below the former WADA threshold. These outcomes, which included performance assessment in real sports situations and the determination of urinary indices for caffeine excretion, may be helpful to the antidoping authorities when making a decision about reintroducing caffeine to the list of banned substances.

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