Original article

Consumption of energy drinks on cardiovascular and metabolic response and performance. Is there an effect?

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Summary

Over the years, the search for nutritional strategies that promote improved sports performance has increased. Among the available options, energy drinks appear as potential nutritional resources for this purpose, because they offer, in addition to caffeine, substances that act synergistically to improve performance, such as taurine, carbohydrates, amino acids, vitamins and minerals, promoting improved performance for both amateur and professional athletes. The aim of the study was to verify the effects of ingesting energy drinks with (ED1) and without carbohydrates (ED0) containing 2 mg·kg^{-1} of caffeine, and a decaffeinated placebo (PL) on cardiovascular, metabolic and performance parameters during cycling. Twelve male cyclists (age = 24.4 ± 6.6 years old) volunteered to participate in this study. The protocol consisted of three experimental sessions of 60 min of continuous cycling (65-75% of VO_{2maxE}) followed by time-trial 6 km. The subjects ingested ED1, ED0 or a placebo drink (PL) 40 min before beginning the exercise. The heart rate (HR), blood pressure (BP), plasma glucose and lactate concentrations, and the time taken to complete the 6 km time-trial were evaluated. The time taken to complete the time-trial was significantly higher ($p < 0.05$) in the PL group than in the groups ED1 and ED0. This time significantly decreased after the ED1 consumption relative to that for the ED0 consumption. Heart rate, systolic and diastolic arterial pressure and in the plasma glucose and lactate concentrations were similar in all the considered groups. These results demonstrate that ED1 consumption appears to be more effective at maximizing performance during the last 6 km.

Key words:
Caffeine. Taurine. Sport drinks. Sports performance. Cycling

Consumo de bebidas energéticas sobre la respuesta cardiovascular, metabólica y rendimiento. ¿Hay efecto?

Resumen

Con el paso de los años, se ha incrementado la búsqueda de estrategias nutricionales que promuevan un mejor rendimiento deportivo. Entre las opciones disponibles, las bebidas energéticas aparecen como potenciales recursos nutricionales para este fin, pues ofrecen, además de la cafeína, sustancias que actúan sinérgicamente para mejorar el rendimiento, como taurina, carbohidratos, aminoácidos, vitaminas y minerales, promoviendo un mejor rendimiento para atletas tanto aficionados como profesionales. El objetivo del estudio fue verificar los efectos de la ingestión de bebidas energéticas con (ED1) y sin carbohidratos (ED0) que contienen 2 mg · kg^{-1} de cafeína y un placebo descafeinado (PL) sobre los parámetros cardiovasculares, metabólicos y de rendimiento durante el ciclismo. Doce ciclistas varones (edad = 24,4 ± 6,6 años) participaron voluntariamente en este estudio. El protocolo consistió en tres sesiones experimentales de 60 min de ciclismo continuo (65-75% del VO_{2max}) seguidas de una prueba contrarreloj de 6 km. Los sujetos ingirieron ED1, ED0 o una bebida placebo (PL) 40 minutos antes de comenzar el ejercicio. Se registró la frecuencia cardíaca (FC), la presión arterial (PA), las concentraciones plasmáticas de glucosa y lactato y el tiempo necesario para completar la prueba contrarreloj de 6 km. El tiempo necesario para completar la contrarreloj en el grupo PL fue significativamente mayor ($p < 0{,}05$) que en los grupos ED1 y ED0. Este tiempo disminuyó significativamente después del consumo de ED1 en relación con el consumo de ED0. La frecuencia cardíaca, la presión arterial sistólica y diastólica y las concentraciones plasmáticas de glucosa y lactato fueron similares en todos los grupos. Estos resultados demuestran que el consumo de ED1 parece ser más eficaz para maximizar el rendimiento durante los últimos 6 km.

Palabras clave:
Cafeína. Taurina. Bebidas deportivas. Rendimiento deportivo. Ciclismo

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Introduction

In the last decade, the consumption of energy drinks (EDs) has become popular especially among athletes[1] due to the possibility of an ergogenic effect[2] during competitions.

Most EDs contain caffeine, taurine, carbohydrates and vitamins[3]. Caffeine has often been used as an acute ergogenic substance before performing physical exercise to postpone fatigue and consequently to improve performance[4]. In addition, some studies have also shown the positive effect of an acute ingestion of taurine on physical performance in humans[5,6].

The presence of carbohydrates in EDs appears to be essential for aerobic events, particularly those that are longer than one hour. Carbohydrates decrease the need to consume muscle glycogen and consequently delay the onset of muscle fatigue[7]. Some studies have shown positive results of a possible enhancement in the ergogenic effect during physical exercise after addition of carbohydrates in caffeinated drinks[8,9], in contrast, other studies did not observe any effect[10].

It is becoming quite popular to consume EDs without carbohydrates (sugar free) before physical activity[11]. However, the benefits of these beverages on physical performance are not clear. Some studies with divergent results [12,13] have evaluated performance after the ingestion of this type of EDs. One study reported an increase in the number of sprints during a soccer game[13] and others did not find improvement in the exercise time to exhaustion[12].

Only the studies by Reis *et al.*,[14] and Reis *et al.*[9] verified and compared the impacts of energy drinks ingestion with and without carbohydrates, confirming that the consumption of these drinks does not affect the hydro-electrolyte balance and promotes an improvement in the performance of runners.

Considering both the scarcity of studies that compare the effects of EDs with and without carbohydrates on physical performance and the increased consumption of both types of drink before sport practice, identifying which drink has greater ergogenic benefits is important. Therefore, the aim of this study was to investigate the effects of pre-exercise ingestion of EDs with and without carbohydrates on cardiovascular and metabolic parameters and on performance on a cycle ergometer during an aerobic effort.

Material and method

Participants

Twelve male cyclists (age = 24.4 ± 6.6 years, body mass = 72.7 ± 7.2 kg, estimated VO_{2max} (VO_{2maxE}) = 54.5 ± 4.8 $ml.kg^{-1}.min^{-1}$), volunteered to participate in this study. Participants were amateurs who were participating to regional competitions, and trained at least three times per week for a minimal duration of 2 hours, for at least two years.

All subjects were considered healthy, as assessed by the PAR-Q questionnaire[15]. The participants were non-smokers, did not consume any alcohol or drugs that could affect food intake and energy metabolism, and did not have a previous history of hypertension, heart disease or diabetes mellitus. The daily caffeine intake of the volunteers was also low (<200 mg/day), as determined from their response to a food frequency questionnaire that was adapted for caffeine intake[16].

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and approved by local Institutional Review Board for Human Subject Protection (no. 154/2011).

The sample size was calculated on the basis of the formulas proposed by Mera *et al*.[17]. The time taken to complete time-trial (in seconds) was considered the main variable, with a statistic strength of 95%. Standard Deviations values were applied in these calculations, adopting a difference of 15% for the average value of time-trial based on the study realized by Rankin *et al*.[18]. The women were not included in the sample due to hormonal alterations resulting from the menstrual cycle, because the luteal phase can promote alterations in the metabolism of caffeine[18] which could affect the results.

Preliminary test

The exercise protocol to determine the maximal consumption of oxygen (VO_{2max}) was composed of 3 minutes of warm-up with a charge proportional to the body weight (BW) of each participant in the cycle ergometer (SCIFIT ISSO 1000, Oklahoma, USA). Once finalized, 30 W were added each minute until 85% of heart rate (HR) was reached, which had been calculated through the THR equation (training heart rate = % (HR_{max} – HR_{rest}) + HR_{rest})[19], where HRmax is calculated with the equation validated for exercise on cycle ergometer*: HR_{max} = 202 - 0,72 x (age)[19].

The VO_{2max} was estimated on the basis of recommendations of Marsh[20] using the um submaximal cycle ergometer test, aiming to preserve the safety of the subjects. According to this method, individual equations to estimate the VO_{2max} were formulated by linear regression using the HR (bpm) and the consumption of oxygen (VO_2) ($ml.kg.min^{-1}$) values obtained during exercise through the analysis of respiratory gas exchange.

The metabolic gas analyzer (Medical Graphics Corporation®, VO2000) was used to evaluate VO_2, the cardiac monitor (Polar® RS800cx) was utilized to evaluate the HR, and a software (SigmaPlot®, 11.0) was used to determine the linear regressions. The charge corresponding to the range of 65 a 75% of the VO_{2max} was also determined by the software in order to use it in the main part of the experimental protocol.

After the preliminary test, the volunteers were instructed to refrain from consuming caffeine or alcohol or performing physical activity for 48 hours before their visit to the laboratory to perform the test.

Experimental protocol

For the double-blind, randomized crossover design, each subject performed three experimental tests that were separated by at least 2 days. The participants arrived at the laboratory between 6:00 and 9:00 AM after fasting for 10 to 13 hours, and the volunteers then consumed a breakfast (including grape juice, sliced white bread, mozzarella cheese and an apple). The breakfast was based on the recommendations of the Institute of Medicine[21] and provided 15% of the estimated energy requirements (EER), which were calculated for the nutritional needs of each participant. The variables used in this calculation were: age, weight, height and level of physical activity.

The volunteers were instructed to standardize their meals on the previous day and for the remaining days between the three tests. The actual consumption was monitored by a 24-hour dietary recall, which was collected before each experimental protocol.

One hour after breakfast, the subjects consumed their drinks. The EDs differed only in the presence (ED1) or absence (ED0) of carbohydrates, and the placebo solution (PL) was prepared with lemon juice (absence of sugar) dissolved in 500 ml of carbonated water. Table 1 shows the nutritional composition of each drink.

Considering that the flavor placebo was not identical to other energy drinks, the subjects were informed that all drinks had ergogenic substances mixed in their composition.

The beverages were ingested 40 minutes before starting the experimental tests; thus, the caffeine peaks in the bloodstream occur within 30 to 60 minutes of ingestion[22]. The drinks were supplied in opaque plastic bottles to prevent identification.

The amount of liquid consumed (454.7 ± 44.2 ml) was calculated for each individual to provide a dose of 2 mg caffeine/kg of BW. The dosage was selected based on previous studies[23,24] that showed improved physical performance in populations that were similar to the volunteers of the present study.

The exercise consisted of an initial 5-minute warm-up at 45 - 55% of VO_{2maxE} and the main exercise for 60 min at continuous speed and 65 - 75% of VO_{2maxE}. All subjects maintained the spinning/cycling rate between 65 to 75 rpm during the 60 minutes of continued exercise. Immediately after the 60 minutes of exercise, subjects realized 6 km time-trial with the same charge carried in the entire test. The verbal encouragement was given to all participants during time-trial, where speed was selected self- selected.

The hydratation procedure adopted during experimental sessions were exclusively realized with water, which corresponds to an individual calculation of 3ml/kg of PC, before exercise and every 15 minutes during exercise, as well as after the time-trial. At those times, the blood pressure (BP) was measured using a Tycos® sphygmomanometer. Additionally, the HR was monitored using a Polar® RS800cx (Polar Electro Ltd., Kempelen, Finland) with recordings every 15 seconds, and the value was averaged every 5 minutes.

Every 15 minutes during continued exercised and after the time-trial, participants were asked to provide the index of perceived exertion (IPE) which variants from 6 to 20[25].

For each experimental test, blood samples were collected before breakfast (fasting), before the drink ingestion, immediately before the beginning of the exercise, every 20 minutes during the continuous exercise and at the end of the time-trial. After each blood collection, the catheter was filled with 0.9% saline solution to prevent blood coagulation and preserve access for subsequent collections. From each blood sample, 1 ml was removed and immediately transferred to an eppendorf tubes. An automatic pipette was used to select 100 µL of this blood, which was injected into a single-use disposable cartridge and analyzed "in situ" by a portable blood analysis system for glucose measurements (i-STAT, Abbott®, Illinois, United States). A drop of blood was collected from the eppendorfs and placed into a portable lactate analyzer (Accutrend®, Roche, Mannheim, Germany) to determine the value of this metabolic variable.

All experimental tests were performed under similar ambient conditions of temperature and relative humidity (23.2 ± 0.91ºC and 69.5 ± 5.56%; $p > 0.05$), as measured by a Hygro Thermometer®.

Table 1. Nutritional composition (per 250 ml) of the beverages used in experimental trials.

Ingredients	Energy Drink (ED1)	Energy Drink sugar free (ED0)	Placebo Drink (PL)
Calories (kcal)	110	10	6.37
Carbohydrates (g)	28	3	0
Protein (g)	0	0	0
Fat (g)	0	0	0
Caffeine (mg)	80	80	0
Taurine (mg)	1000	1000	0
Other ingredients	Glucuronolactone, inositol, sodium, water, and vitamins of group B	Glucuronolactone, inositol, sodium, water, and vitamins of group B	Sodium

ED1: Energy Drink in the presence of carbohydrates. ED0: Energy Drink in the absence of carbohydrates. PL: Placebo solution, prepared with lemon juice (absence of sugar) dissolved in 500 ml of carbonated water.

Statistical analysis

All results are reported as the mean and standard deviation. The Shapiro-Wilk test was used to verify the normality. To compare the time-trial duration between the different treatments, a one-way ANOVA test for repeated measures with a post-hoc Tukey HSD test was used. To verify the interaction between the treatments over time, a two-way ANOVA test for repeated measures (split-plot ANOVA test) was used while applying a Mauchly test and a Greenhouse-Geisser correction when the assumption of sphericity was violated. Significant p-values were identified for interaction effects (time x treatment); simple analyses were performed when an influence from the energy drinks was found. Significant values for certain moments were investigated using paired comparisons with Bonferroni-adjusted confidence intervals. The statistical analysis was performed using SPSS (v17.0, USA) and assuming $p<0.05$ as the significance level.

Results

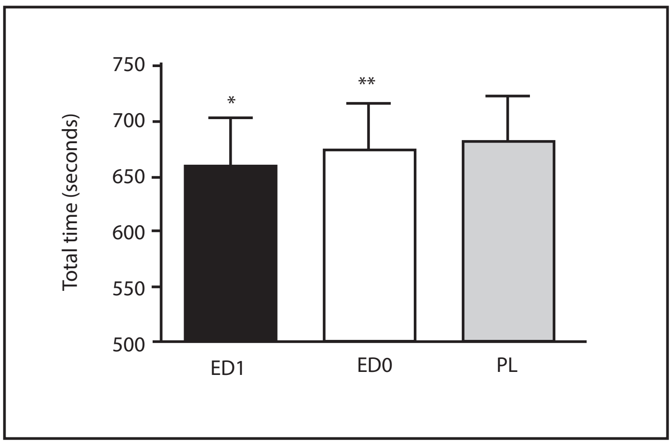
Evaluation of physical performance

The time required to complete the 6 km time-trial was significantly higher for the PL group than for the groups that the consumed energy drinks, ED1 ($p<0.001$) and ED0 ($p<0.01$) (see Figure 1). The time-trial time after consuming ED1 was significantly lower ($p<0.001$) than the time after consuming ED0. The mean performance time for the last 6 km was 2.01% and 2.78% faster after ingesting ED1 than after ingesting ED0 and PL, respectively.

Cardiovascular parameters

The cardiovascular responses are shown in Table 2. For all treatment groups, there was a significant increase (p<0.001) in the HR and systolic arterial pressure (SAP) during the time-trial relative to the values during the continuous exercise. The diastolic arterial pressure (DAP) remained stable throughout the exercise at 65-75% of VO_{2maxE} (p<0.05) and increased significantly (p<0.001) during the time-trial for all treatments. No differences were observed in HR, SAP and DAP between the treatments either at rest, during the 60 minutes of continuous exercise, or during the time-trial.

Figure 1. Sprint duration for the three treatments.



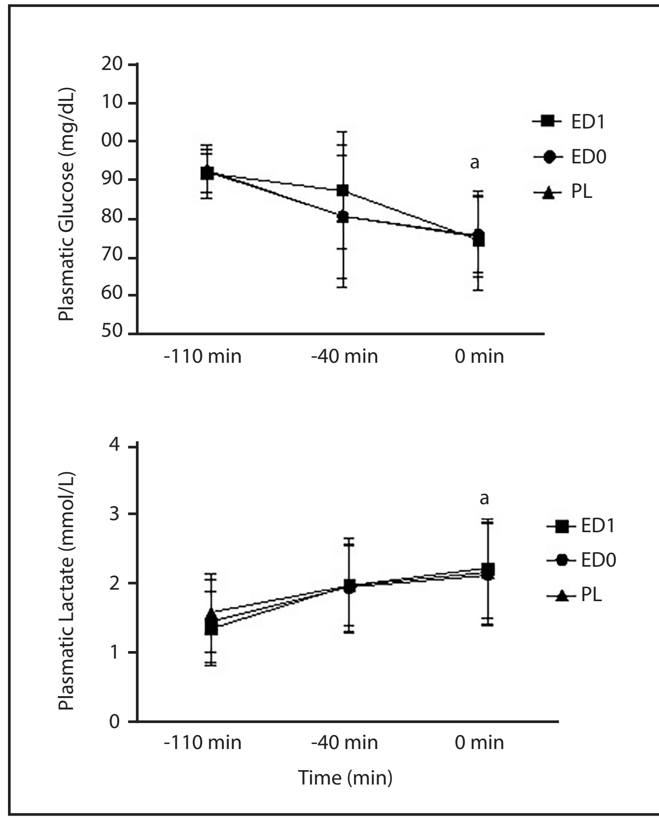
* Significant difference compared with ED0 (p<0.001) and PL (p<0.001). ** Significant difference compared with ED1 (p<0.001) and PL (p<0.01).

Table 2. Average ± Standard deviation values of the cardiovascular responses at rest, during exercise 65-75% of the VO_{2maxE} and sprint.

Condition	Type of Treatment ED1	ED0	PL
SAP			
Resting	114.50 ± 9.65	113.00 ± 9.04	115.30 ± 6.51
Exercise	147.50 ± 14.04*	148.00 ± 16.06*	150.54 ± 14.51*
Sprint	197.33 ± 19.22[§]	198.50 ± 19.13[§]	200.00 ± 17.06[§]
DAP			
Resting	70.83 ± 7.93	74.83 ± 9.96	75.16 ± 6.68
Exercise	73.95 ± 5.58	71.62 ± 9.11	77.29 ± 9.38
Sprint	90.83 ± 13.11[§]	90.83 ± 16.21[§]	93.45 ± 19.23[§]
HR (beats/min)			
Resting	55.75 ± 7.16	55.08 ± 7.77	56.75 ± 9.38
Exercise	145.82 ± 8.93*	148.06 ± 7.77*	146.44 ± 12.17*
Sprint	173.71 ± 7.37[§]	171.57 ± 7.05[§]	173.27 ± 9.86[§]

* Significant differences compared to resting and sprint (p<0.001). [§] Significant differences compared to resting and exercise (p<0.001).
SAP = Systolic arterial pressure; DAP = Diastolic arterial pressure; HR = Heart rate.

Figure 2. Average ± standard deviation of the plasma glucose and lactate levels during fasting (-110 min), before the drink intake (-40 min) and immediately before the beginning of the exercise (0 min).



Plasma metabolites

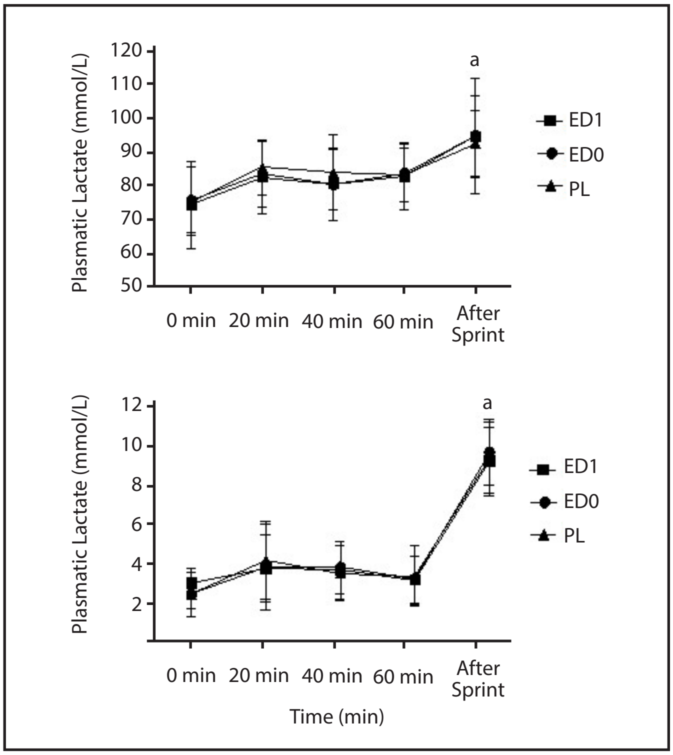
The plasma concentrations of glucose and lactate before breakfast (fasting), before the drink intake and immediately before the beginning of the exercise are shown in Figure 2. No significant differences (p>0.05) were observed between the treatments, indicating that the subjects started the exercise under similar metabolic conditions.

The plasma concentrations of glucose and lactate at rest (0 min), during exercise at 65-75% of VO_{2maxE} and after the time-trial are shown in Figure 3. For all treatments, the plasma concentrations of glucose and lactate were significantly higher (p<0.001) after the time-trial than those at rest and during the continuous exercise. No significant differences were observed in the plasma levels of glucose and lactate between the treatments at rest, during the continuous exercise and after the time-trial.

Index of perceived exertion (IPE)

The IPE remained stable throughout continued exercise (13.41 ± 0.59 for ED1, 13.41 ± 0.44 for ED0 and 13.48 ± 0.65 for PL) and increased significantly (p<0.001) after time-trial in all treatments (18.25 ± 1.35 for ED1, 18.5 ± 1.62 for ED0 and 19.15 ± 1.07 for PL). The IPE value at the end of the time-trial was higher in the treatment with PL compared to ED1 (p=0.012) and to ED0 (p=0.022).

Figure 3. Average ± standard deviation of the plasma glucose and lactate concentrations during the experimental protocol. (a) Significant difference (p<0.001) compared with the other conditions (0-60 min) for all treatments.



Discussion

The aim of this study was to verify the effects of pre-exercise ingestion of an ED with and without carbohydrates on cardiovascular, metabolic and performance parameters during an aerobic effort on a cycle ergometer.

The main finding of this study was that the use of EDs with and without carbohydrates decreased the time to complete a 6 km time-trial after 60 minutes of aerobic training relative to the PL time-trial time (Figure 1). This improvement in performance after the ED ingestion is consistent with other previous studies[8].

The mechanisms by which EDs improve performance are not fully understood. Some authors believe that caffeine is the main active ingredient of EDs and is responsible for the ergogenic effects on physical performance[12]. Several mechanisms may be involved in these effects. These mechanisms include the following: action on the sarcoplasmic reticulum by increasing the availability of calcium to potentiate muscle contraction[26] an antagonist effect on adenosine receptors, leading to increased activation of the central nervous system and plasma epinephrine[26]; and changes in potassium concentrations that assist in the maintenance of the membrane excitability of contractile muscle during exercise[27].

Although caffeine is considered the main active ingredient in energy drinks, taurine may also contribute to the ergogenic effect on exercise[28]. Some studies reported that taurine supplementation can increase the ability to prolong exercise[5,6], possibly by stabilizing the phospholipids of the membrane and increasing the availability of calcium in the muscle[29].

The combination of the ingestion of caffeine and taurine in the same formulation showed significant improvements in the ventricular function, increasing the stroke volume[6] compared to drinks only containing caffeine. This way, these components can act synergistically and improve the performance in training as well as in competitions.

ED1 seems appears to increase performance more effectively because it reduced the 6 km time-trial time by 2.01% relative to the time for ED0. The results corroborate those of other studies indicating that the combination of caffeine and carbohydrates can improve the ergogenic effect during exercise[30]. Caffeine has also been linked with increased intestinal glucose absorption and utilization of exogenous carbohydrates[31] thus minimizing the depletion of muscle glycogen and delaying the onset of fatigue during aerobic exercise.

The HR values gradually increased during the 60 minutes of continued exercise and during time-trial, although no significant difference was observed between the treatments (Table 2). Caffeine inducts the liberation of adrenaline during exercise, higher HR values were expected in treatment with energy drinks. However, some studies reported a decrease in HR during submaximal exercise after the ingestion of an ED containing taurine[32] suggesting that taurine could alter cardiovascular physiology.

Corroborating this hypothesis, Baum[6] observed that taurine in combination with caffeine significantly increases the volume of ejection in athletes after endurance exercise. This is due to the greater end diastolic volume and to the decrease of the end systolic volume of the left ventricle, as the fractional shortening increases significantly, and contributes to lower values of HR. If confirmed, these responses in the cardiovascular system can have an important effect after a training session in athletes who train for extended durations, since it acts like a factor of cardioprotection.

As found in a previous study[33], our mean values of SAP were lower, but not significantly, after the consumption of ED1 and ED0 compared with those in the PL group. Besides, no significant differences between treatments were observed in the DAP values.

Ragsdale[34] analyzed the effects of two energy drinks on cardiovascular function during two hours of rest. Those drinks were similar to the drinks used in this study (ED1 and ED0), and those researchers reported that ingesting EDs did not cause a significant difference in BP relative to the BP after ingesting PL.

The lack of studies that has analyzed BP during exercise after the consumption of energy drink brings difficulties in the comparison and the interpretation of the results. Consequently, additional studies are necessary to verify if the consumption of ED effects the pressure values both during rest and exercise, principally when consumed chronically and not as acute in this study.

The IPE significantly increased after the time-trial compared with the values obtained during the continuous exercise. The IPE for the time-trial was significantly higher after PL consumption than after ED1 and ED0 consumption (Table 2). Similar results were observed in the study realized by Hahn *et al.*,[35] after the ingestion of drinks comparable to placebo.

It is believed that caffeine reduces the feeling of pain through its antagonist effect on adenosine[36]. Due to the similarity between the molecular structures of adenosine and caffeine, caffeine occupies some adenosine receptors and minimizes the effect of this neurotransmitter on the body[36]. Thus, dopamine becomes less inhibited, increasing the dopamine concentrations during exercise. Another ergogenic mechanism of caffeine is to decrease the expression of tryptophan hydroxylase (TPH); the degradation of tryptophan modulates the amount of serotonin that crosses the blood-brain barrier[37]. A lower serotonin/dopamine ratio reduces central fatigue and improves performance[38].

Our results show no differences among the treatments in the plasma glucose levels during the continuous exercise and the time-trial (Figure 3). Thus, the energy drinks were equally effective at maintaining plasma glucose levels during the continuous exercise and the time-trial. The maintenance of blood glucose is crucial because hypoglycemia causes fatigue, leading to exhaustion and forcing an individual to stop the exercise[39]. Our results indicate that the presence or absence of carbohydrates in the ED did not affect the plasma glucose kinetics, which were most likely influenced by the breakfast that was consumed before the exercise.

No differences were observed in the plasma lactate concentrations between the treatments (Figure 3). Lactate has an important role in the onset of fatigue during high-intensity exercise[40], as shown for the 6 km time-trial in the present study. The results indicated better performance after ED consumption than after PL consumption but did not show significant differences in lactate concentration. Therefore, it is possible that this improved performance could be linked to specific cellular adaptations.

Consuming an ED can also cause ergolytic effects. The most common problem in these beverages appears to be associated with the high levels of caffeine, rather than the other substances in these drinks. Doses above 6 mg/kg of BW can be toxic to the body, decreasing the stability of the upper limbs and causing insomnia, irritability, anxiety, nausea and gastrointestinal discomfort[41]. Campbell[22] indicated that ingesting a dose of caffeine of 2 mg/kg of BW between 10 and 40 minutes prior to exercise increased performance without ergolytic effects or any risk for the athlete, as was further confirmed in this study.

The limitations of the present study include the absence of either a muscle biopsy to analyze the levels of muscle glycogen or an electromyographic examination that could provide relevant information about the different muscle responses to the work load.

Conclusion

Considering the assessed population group (regular cyclists with a low daily intake of caffeine) and the conditions of the exercises performed in this study, it can be concluded that consuming ED1 (2 mg of caffeine/kg of BW) 40 minutes before 60 minutes of moderate aerobic exercise improved the performance in a 6 km time-trial. Further research that uses other doses and other population groups (such as women and consumers of caffeine) and that measures the effects in other sports should be undertaken to expand upon the scientific evidence presented in this study.

Conflict of interest

The authors do not declare a conflict of interest.

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