SHORT REPORT

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Effects of Caffeine-Containing Energy Drinks on Endurance Performance and Side Effects: A Randomized Cross-Over Study

Auswirkungen von koffeinhaltigen Energydrinks auf Ausdauerleistung und Nebenwirkungen: Eine randomisierte Cross-Over-Studie

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Summary

- **Introduction:** After caffeine consumption of 3-6 mg/kg, significant increases in endurance performance have been observed in studies, with various side effects occurring. The aim of this study is to analyse whether caffeine intake of 2 mg/kg increases endurance performance while avoiding side effects.
- **Methods:** In two sessions, 13 women and 19 men between 20 and 30 years (24.5±1.9 years) took 2mg caffeine/kg in the form of an energy drink or a placebo. After 60 minutes, participants started with an incremental test on a treadmill to exhaustion. Heart rate and oxygen uptake were measured and immediately afterwards they indicated received perceived exertion (RPE). The morning after, the subjects fill out a questionnaire with 24 items (GBB-24) to analyse their health and symptoms.
- **Results:** In comparison to placebo drink, the ingestion of energy drink with 2 mg caffeine/kg increased running time (7:23±1:03 vs. 7:16±1:03 min; $p<0.05$) and $\dot{V}O_2max$ (47.24±6.5 vs. 45.72±6.2 ml O_2/min/kg; $p\leq0.05$). The heart rates during running as well as the RPE and answering the questionnaire items did not provide any statistical differences between energy drink and placebo group.
- **Conclusion:** Thus the ingestion of the energy drink with a dose of 2mg of caffeine/kg did not affect the prevalence of negative side effects but might be an effective ergogenic aid to improve endurance performance.

Zusammenfassung

- **Einleitung:** Nach Koffeinkonsum von 3-6 mg/kg wurden in Studien signifikante Steigerungen der Ausdauerleistung beobachtet, wobei häufig verschiedene Nebenwirkungen auftraten. Ziel dieser Studie ist es zu analysieren, ob ein Koffeinkonsum von 2 mg/kg die Ausdauerleistung steigert und gleichzeitig Nebenwirkungen vermeidet.
- **Methoden:** In zwei verschiedenen Sitzungen nahmen 13 Frauen und 19 Männer im Alter zwischen 20 und 30 (24,5±1,9 Jahre) 2mg Koffein/kg in Form eines Energydrinks oder ein Placebos ein. Nach 60 Minuten starteten die Teilnehmer mit einem Stufentest auf einem Laufband bis zur Erschöpfung. Dabei wurden Herzfrequenz und Sauerstoffaufnahme gemessen und unmittelbar danach gaben die Probanden den Grad der empfundenen Anstrengung (RPE) an. Am Morgen des Folgetages füllten die Probanden einen Fragebogen mit 24 Items (GBB-24) aus, um das Gesundheitsempfinden und die Beschwerden zu analysieren.
- **Ergebnisse:** Im Vergleich zum Placebo-Getränk verlängerte die Einnahme von Energy-Drinks mit 2 mg Koffein/kg die Laufzeit (7:23±1:03 vs. 7:16±1:03 min; $p<0,05$) und die $\dot{V}O_2max$ (47,24±6,5 vs 45,72±6.2 ml O_2/min/kg, $p\leq0,05$). Die Herzfrequenzen beim Laufen sowie der RPE und die Beantwortung der Fragebogen-Items ergaben keine statistischen Unterschiede zwischen Energy-Drink- und Placebo-Gruppe.
- **Schlussfolgerung:** Somit hatte die Einnahme des Energy Drinks mit einer Dosis von 2mg Koffein/kg keinen Einfluss auf die Prävalenz negativer Nebenwirkungen, konnte aber ein wirksames ergogenes Hilfsmittel zur Verbesserung der Ausdauerleistung sein.

KEY WORDS:
Endurance Exercise, Incremental Test, Sports Nutrition, Beverages

SCHLÜSSELWÖRTER:
Ausdauerbelastung, Stufentest, Sporternährung, Sportgetränke

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Introduction

In the first years on the market energy drinks became known as " 'speed in a can', 'liquid cocaine' and a 'legal drug' " (15). They are advertised as fashion drinks for energy increasing, avoiding fatigue and improving mental awareness (4, 11). On the other hand, the effects are associated with insomnia, nervousness, headache, rapid heartbeat and increased blood pressure (1). In addition to the health-damaging effects of energy drinks, they are also known for their energy-providing effects. Doherty and Smith analysed studies on caffeine consumption for endurance performance in their meta-analysis. In these studies caffeine doses were taken between 3-13 mg/kg body weight. Compared to placebo, performance after caffeine consumption improved by 12.3% with a standard deviation of 13.8% (7). Other

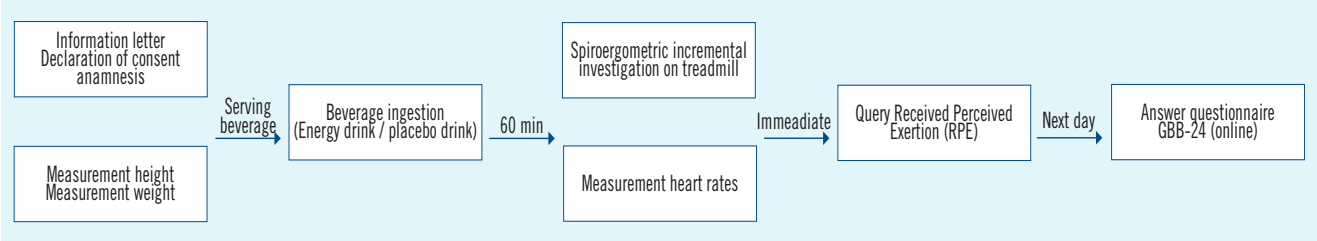

Figure 1

Experimental Protocol.

meta-analyses also showed significant increases in endurance performance after caffeine consumption of 3-6 mg/kg (17, 18). In addition, it was observed that caffeine consumption of more than 3 mg/kg could include side effects like tachycardia, nervousness, activeness, insomnia, headache and gastrointestinal problems (5, 6, 14).

Due to the performance-enhancing effects of caffeine at 3-6 mg/kg body weight as an ingredient in energy drinks, in particular on endurance performance and the reported side effects, the effects of lower dosages should be investigated (8). Therefore, this study investigated whether ingestion of 2 mg/kg caffeine one hour before exercise in an ergometer incremental test increased endurance performance in comparison to a placebo drink. Furthermore, it should be shown whether and which kind of side effects are associated with the intake of the energy drink.

Methods

Totally 35 participants between 20 and 30 years volunteered to take part in this study. The results of three participants were excluded of this study because of missing criteria of complete exhaustion, too low run-time or caffeine-intake before the testing so that thirty-two databases (19 male, 13 female) are included in the analysis. Subjects had a mean±SD age of 24.5±1.9 years, height of 179.0±10.1 cm and body mass of 74.2±11.8 kg before placebo energy drink ingestion and 74.0±12.1 kg before energy drink ingestion. Before each testing the participants were asked to fill out anamnesis questionnaires. Following these anamnesis of each participant they did not receive medical treatment, had neither acute or chronical diseases and were sporty fully resilient. All participants were asked to refrain from vigorous exercise, do not consume caffeine 24 hours before testing and to have a light meal two hours before the test. Participants were informed of any risks associated with the experiments before giving their written consent to participate. The study was carried out in accordance with the Declaration of Helsinki.

A placebo-controlled and randomized crossover design was used. Each participant performed two different experimental trials under the same conditions. On one occasion, participants ingested an amount of fluid of a commercially available, caffeine-containing energy drink (ROCKSTAR®) with 2 mg caffeine/kg body mass (2 mg/kg), 750 mg sugar/kg body mass and other ingredients. On other occasion, participants ingested the same amount of fluid with the same sugar content but without caffeine and the other ingredients (placebo; 0 mg/kg). The experimental trials were separated by at least of 48 hours to allow complete caffeine washout.

The drinks were distributed double-blind after the participants had previously been randomized, so that 18 subjects received the energy drink and 14 subjects received the placebo drink at the first time of the test. Thus, subjects started an incremental test on the treadmill (pulsar™, h/p/cosmos, Germany) 60 minutes after consuming the energy drink. The subjects should run on the treadmill as long as they were able to achieve their subjective exertion. The test started at a speed of 7.2 km/h (2 m/s) and every minute the speed increased by 1.8 km/h (0.5 m/s). The incline angle of the treadmill was 1% throughout the test. Oxygen uptake and heart rate were measured by a mobile spirometry system (MetaMax 3b™, Cortex, Germany) and the total running time was determined. Immediately after the end of the test, the subjects indicated received perception of exertion (RPE) at the last speed level. The subjects were encouraged not to consume any caffeinated foods until the next day. The next morning after testing, the subjects filled out a questionnaire with 24 items, called Giessen Subjective Complaints List (GBB-24) (3). ›

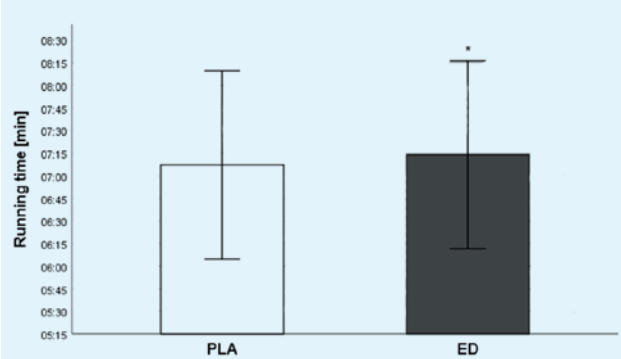

Figure 2

Running time on treadmill until exhaustion after ingestion of a caffeinated energy drink (ED) with 2 mg caffeine/kg body weight or a placebo energy drink (PLA). Data are means±SD (n = 32). *=(P<0.05).

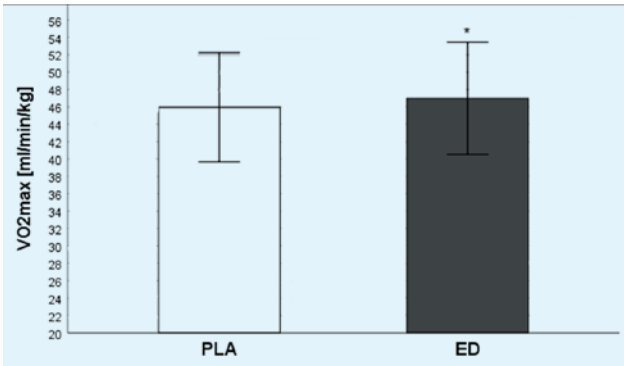

Figure 3

Maximum oxygen consumption on treadmill until exhaustion after ingestion of a caffeinated energy drink (ED) with 2 mg caffeine/kg body weight or a placebo energy drink (PLA). Data are means ± SD (n = 25). *(P ≤ 0.05).

Table 1

Energy drink ingredients.

INGREDIENT	AMOUNT (PER KG BODY MASS)
Sugar	0.75 g/kg
Caffeine	2 mg/kg
Taurine	25 mg/kg
Glucuronolactone	1.5 mg/kg
Niacin	0.2 mg/kg
Pantothenic acid	0.075 mg/kg
Vitamin B6	0.0175 mg/kg
Vitamin B12	0.03125 µg/kg
Guarana Seed Extract	0.625 mg/kg
Ginseng Root Extract	0.625 mg/kg
Inositol	0.625 mg/kg

Differences of total running time, $\dot{V}O_2$max and heart rates were analysed by paired t tests.

The prerequisites of the normal distribution by using the Shapiro-Wilk test for carrying out the tests were fulfilled. Difference in RPE and items of the questionnaire GBB-24 were analysed using the Wilcoxon signed-rank test. Data were analysed with the statistical package SPSS V25 (SPSS Inc., Chicago, IL, USA). The significance level was set at $p \leq 0.05$.

Results

In comparison to the placebo, the pre-exercise ingestion of the caffeinated energy drink significantly increased total running time (7:23±1:03 vs. 7:16±1:03 min; $p < 0.05$; d=0.38) and $\dot{V}O_2$max (47.24±6.5 vs. 45.72±6.2 ml O_2/min/kg; $p \leq 0.05$; d=0.41). According to the latter, oxygen uptake data from six participants had to be excluded from the analyses due technical problems.

In addition, in both groups the RPE after exhaustion had an average of 18 (p=0.12). The heart rates during the investigation were unaffected by the caffeine ingestion at all velocity levels, for 7.2 km/h (140±14 vs. 139±16 bpm; p=0.652), 9.0 km/h (152±12 vs. 151±13 bpm; p=0.808), 10.8 km/h (163±12 vs. 162±12 bpm; p=0.434), 12.6 km/h (172±11 vs. 171±11 bpm; p=0.507), 14.4 km/h (179±10 vs. 178±9 bpm; p=0.223), 16.2 km/h (182±8 vs. 183±6 bpm; p=0.969), 18.0 km/h (185±8 vs. 185±7 bpm; p=0.645), 19.8 km/h (184±6 vs. 184±6 bpm; p=0.5) and HRmax (188±7 vs. 188±6 bpm; p=0.846). The items of the questionnaire were also unaffected by caffeine ingestion, with p-values ranging from p=0.059 to p=1.0.

Discussion

The aim of the present investigation was to determinate the effects of a low amount of caffeine ingestion on performance as well as psycho-physiological side effects. The results showed that subjects increased their running time during the incremental test on average for 7.75 seconds or a total of 4:08 minutes when the consumed 2mg caffeine per kg body weight prior to performance. The overall increase in the energy drink condition was 1.78% higher than in the placebo condition. With regard to the individual, 20 athletes stayed on the treadmill longer than the intrapersonal control group after consuming energy drinks. In comparison, the placebo group achieved better or longer times of running, only 12 times compared to the energy drink group. The mean value of the relative maximum oxygen intake from the energy drink group differed significantly from that of the placebo drink group, indicating that consuming the energy drink positively effects aerobic endurance performance (12).

The GBB-24 questionnaire was filled out in the morning after each test date to evaluate whether the consumption of a comparable low dose caffeine causes psychosomatic complaints. It revealed that no significances emerged from the comparison of the individual items after statistical analysis. However, from previous studies, items emerged that can be viewed in a focused manner, which include tachycardia, nervousness, activeness, insomnia, headache and gastrointestinal problems (5, 6, 14). Within the questionnaire used in this study, several items such as "palpitations, chasing, stumbling" (p=0.276), "feeling of pressure or fullness in the abdomen" (p=0.942), "excessive need for sleep" (p=0.490), "regurgitation" (p=0.414), "heartburn or acid regurgitation" (p=0.257), "headache" (p=0.206), "stomach pain" (p=0.317), "feeling of pressure in the head" (p=0.180) addressed the subjective assessment of these complaints, but none of them suggests a negative effect of the caffeine consumption.

It should be noted that a randomized placebo-controlled cross-over study was carried out in the present study. Still, there are several limitations to be mentioned that might affect the results. First, a pre-test, which precedes the first day of the test, could serve to get the subjects used to the spiroergometry on the treadmill. But due to the randomized cross-over design half of the energy drink and the placebo drink group had no prior experience with the measuring system in the first test. At the same time, the study was carried out double-blind, whereby in contrast to a blind design, an improvement in the quality of the study design was brought about, since both the test subject and the test leader did not know about the group membership and thus the drink taken on the test day.

To further ensure a high level of standardization, the subjects were informed in advance of the second day of the test about the requirements of similar nutritional and behavioural patterns, similar sporting activity, the same or similar clothing and footwear as well as about the 24-hour abstinence from caffeine before the test. The drink was consumed 60 minutes before the start of exercise and since like in many other previous studys, because the highest caffeine concentration in the blood plasma is reached within one hour after ingestion (16, 17, 18). With half-lives of one hour for taurine and four to six hours for caffeine, the amounts of caffeine or taurine taken in were rinsed out before the next day of the study (9, 16). However, we did not asked subjects to fill out a food diary to precisely record both the amount and type of food consumed to control the effect of calories or especially carbohydrate intake (14). The energy drink also contained ginseng and guarana to a very low amount (0.01%). As these plant extracts contain low amounts of caffeine, but manufacturers are not obliged to list the caffeine content of these ingredients (15), the actual amount of caffeine in the energy drinks could be slightly higher than stated on the product package.

The daily amount of caffeine ingestion could also have an influence to the results of the study. Consumption of coffee, black tea, coke or energy drinks ranged from none (n=19) to up to three or more cups a day (n=7). By qualitative inspection, these habits did not seem to affect the results, but their influence could not be analysed systematically.

Conclusions

In order to achieve a higher rate of increase in aerobic endurance, however, previous research results show that an energy drink amount of 3-6 mg caffeine/kg body weight should be consumed (8, 17, 18). Since the higher the caffeine consumption increases the probability of side effects, this recommendation should be viewed critically with a simultaneous health perspective. Examples of side effects can include nervousness, headache, restlessness, stomach problems, sleep disorders or rapid heartbeat (10, 13). In summary, it can be concluded from the study carried out that, in contrast to the placebo drink, the energy drink consumed with a caffeine content of 2 mg/kg body weight led to performance-enhancing effects of aerobic endurance and at the same time there were no negative side effects.

Conflict of Interest

The authors have no conflict of interest.

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