Gerlach S, Pettitt R, & Morton H. Caffeinated beverages can benefit anaerobic work capacity and critical power measured in a 3 minute all-out test
J Sport Human Perf 2018; 6(1):1-9.

JSHP
JOURNAL OF SPORT AND HUMAN PERFORMANCE

ORIGINAL RESEARCH **OPEN ACCESS**

CAFFEINATED BEVERAGES CAN BENEFIT ANAEROBIC WORK CAPACITY AND CRITICAL POWER MEASURED IN A 3 MINUTE ALL-OUT TEST

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ABSTRACT

The effect of different caffeinated beverages on high-intensity performance, using a cycling 3-minute all-out exercise test (3MT) was assessed. Twenty-four subjects with low risk stratification completed four 3MTs over a period of 3 weeks. The subjects included males and females with the following demographics: age 22±2 yr; height 175±6.1 cm; weight 78.8±16 kg. One hour before the start of each 3MT, subjects consumed either 250 ml of water, Coca Cola® (Cola), Red Bull® (RB), or Coca Cola® with added dry caffeine (Cola+). The RB and Cola+ beverages had the same caffeine content. Critical power (CP), anaerobic work capacity (W'), oxygen uptake (O_2peak) and rating of perceived exertion (RPE) were measured during 3MTs. Most subjects had the highest W' after the consumption of Cola (41%) compared to 25% each for water and RB, and 8% for Cola+. Anaerobic work capacity was significantly higher after Cola consumption compared to Cola+. Cola consumption produced the highest CP in 11 of 24 subjects. The mean and standard deviation of CP for water, Cola, RB, Cola+ consumption were 192±45 W, 201±45 W, 201±50.5W, 198±42W, respectively ($p<0.05$). O_2peak increased significantly with the amount of caffeine ingested. No differences in RPE were found between beverages. Based on these data, we recommend consuming a standard Coca Cola to increase performance during short high-intensity exercise, as Cola provoked an increase in CP and W' for most subjects during the 3MT.

Keywords: all-out exercise, energy drink, performance

INTRODUCTION

Caffeine is one of the most consumed secondary ingredients in beverages worldwide. Over 90% of American adults consume caffeine on a daily basis (4). The availability of energy drinks containing caffeine is rising continuously with up to 500 new products worldwide each year since the introduction of Red Bull® in 1997. Over 51% of American college students drink energy drinks at least once a month during a semester (25). Caffeine can also be found in sodas, with Coca Cola (Cola) being one of the most consumed worldwide.

Caffeine has been shown to enhance daily work performance, sports performance and improve mental focus (8, 34). Caffeine can increase concentration and alertness, as well as enhances lipolysis, which can be important during exercise as more fat storage is used for energy production (1). Energy from fat storage can become especially important in endurance sports, like marathons or triathlons. For sports performance, aerobic improvements have been shown with caffeine use for a variety of sports. These enhancements include faster completion time of a cycling time trial and reduction in rating of perceived exertion (RPE), the results with anaerobic exercise capacity, on the other hand, are limited and controversial (18, 21). Caffeine generated no difference in peak power, maximal power, or minimum power in repeated Wingate test performances subsequent to caffeine or placebo ingestion (29); therefore, the ergogenic effects of caffeine may be limited in very short (< 60 seconds) high-intensity, exercise bouts.

The 3 minute all-out test (3MT) is a relatively new test performed on a cycle ergometer, that has become a reliable established test in the sport and exercise fields (13, 34). The 3MT is used to determine critical power (CP) and anaerobic capacity (W'). Critical power is the aerobic capacity an individual can sustain for extended periods of time (27). Individuals could complete a marathon when running just below CP. Anaerobic capacity denotes the amount of work that can be completed above CP and is depleted within the initial 150 s of all-out exercise (30). Once W' is depleted during all-out exercise, the subject sustains a power output equivalent to CP. This is similar to the CP determined from the regression of a series of three or more exhaustive bouts at different severe exercise intensities (31). The 3MT is a reliable measure of CP, and provides a constant estimate of the power-duration relationship (23). Anaerobic work capacity is not consistent in each test because it can change daily due to fatigue, nutrition, sleep, and other factors.

It takes 45-minutes to 1-hour for the body to absorb caffeine after ingestion, which has a half-life of 3-4 hours (10, 21). Therefore, someone should wait one hour after caffeine ingestion before exercising if they wish to increase performance (9, 17). Caffeine can improve oxygen uptake at a given power output, increase catecholamine release, and increase metabolic rate (19, 21). The recommended dose for caffeine ingestion prior to exercise varies between 2-9 mg * kg (6).

The effect of caffeine on CP and W' in the 3MT has yet to be examined. The purpose of this study is to determine if popular caffeinated beverages influence CP or W' during the 3MT. We hypothesize that caffeine ingestion will result in both an improvement in anaerobic capacity and an increase in CP.

METHODS

Experimental Approach to the Problem

The study used a randomized design where beverages were consumed in random order. Subjects were asked to visit the laboratory on 4 separate occasions with at least 48-hours in between. All tests were performed at a similar time of day. All tests were completed in a 3-week period. Subjects completed a 5-minute warm-up at 50 Watts at the subject's preferred cadence at the beginning of each test on a Lode cycle ergometer (Excalibur, Groningen, The

Netherlands). The warm-up was followed by 5-minutes of rest before starting the 3MT. During the first visit, subjects completed the 3MT after drinking 250ml of water followed by one hour of passive rest. During the test, subjects maintained the highest cadence possible. After three minutes of active rest, where subjects cycled at 50W for three minutes, subjects performed a square wave bout (an exercise bout at a constant workload of which was determined from the 3MT (CP + 10%), until subject fatigue to measure maximal oxygen uptake (14). The workload was adjusted by increasing the workload on the cycle ergometer in manual mode. Visits two, three and four had a counterbalanced design.

Upon arrival for each visit, subjects received either one 250 ml serving of Red Bull® (RB) containing 80mg of caffeine and 27g sugar, a 250 ml serving of CocaCola® (Cola) containing 24mg of caffeine and 28g sugar, or a 250 ml serving of CocaCola® (Cola+), where 56mg dry caffeine was added. Ingredients of the Cola and RB can be found in table one. Subjects were blinded for which CocaCola® beverage they received. Subjects had 10 minutes to consume the beverage. A one-hour rest period was started once the beverage was completely consumed. After one hour of rest, subjects performed a warm-up and the 3MT all-out test.

Table 1. Nutritional fact of 250ml Coca Cola and Red Bull®

Ingredients	Cola	Red Bull®
Calories	100	110
Total Fat (g)	0	0
Sodium (mg)	35	105
Total Carbs (g)	28	28
Sugar (g)	28	27
Protein (g)	0	<1
Caffeine (mg)	24	80

Volunteers

Twenty-four college students, 5 females and 19 males, participated in the experiment (mean age 22 ± 2yr; height 175 ± 6.1cm; weight 78.8±16kg). Volunteers reported participating consistently in at least 150min·wk-1 of moderate intensity physical activity. All subjects completed a risk stratification questionnaire and were deemed to be at low risk for exercise testing (2). All testing was approved by the Minnesota State University, Mankato, Institutional Review Board. Written informed consent was obtained before the start of the study using a form approved by the Minnesota State University, Mankato, Institutional Review Board. Participants were asked to follow a similar diet each day of testing and refrain from alcohol as well as high intensity exercise 24-hours prior to testing. Participants reported consumption of between one and four caffeinated beverages weekly, and had consumed an energy drink in the past. Volunteers were asked to abstain from additional caffeine for at least 3-hours prior to testing based of the half-life of caffeine (10, 21). Researchers watched for any mental and physical distress due to the caffeine throughout testing. The calculation, including the subject's information and physical activity rating, to determine the resistance for the 3MT can be found elsewhere (17).

Procedures

Volunteers completed a 5-minute warm-up at 50 Watts at their preferred cadence, followed by 5-minutes passive rest before the 3MT (14). Subjects were asked to pedal as fast as possible in the initial 5-seconds of the test before the calculated resistance loaded (14). Participants continued to maintain the highest cadence possible throughout the entire 3-minute duration. Data were collected for a total of 185-seconds to ensure that 3 complete minutes were recorded (14). Volunteers were verbally encouraged throughout the test, but were not informed of elapsed time to discourage pacing. The raw data of all 3-minute tests were filtered at 6 Hz to a Microsoft® Excel® spreadsheet and then run through a Butterworth filter (14). Critical power was estimated using the last 30-seconds of data. The formula: $W' = 150sec * (P_{150} - CP)$ was used to estimate W' (14). The power at 150 seconds is noted as P150. Each test was followed by 3-minutes of active recovery at the subjects preferred cadence and a workload of 50 Watts.

Peak oxygen consumption ($\dot{V}O_2$ peak) was recorded during all four visits. Metabolic data were collected and analyzed using 15-second-averages via a metabolic analyzer (Parvo-medics, TrueOne, Logan, UT, USA). A 2-way non-rebreathing valve mouthpiece (Hans Rudolph, Inc., Shawnee, KS, USA) and nose clip were used to collect expired air. The metabolic cart was calibrated according to manufacturer's guidelines. Filters and tubes were changed after each test. Heart rate was recorded each minute (Polar Electro Inc., Lake Success, NY, USA).

Statistical Analyses

Reliability of the test was determined using an intraclass correlation coefficient (ICC = 0.92). A within subjects' ANOVA was used to determine the effect of caffeine on W', CP and oxygen consumption. The sample size of 24 subjects corresponds to a statistical power of 0.8 with $p = 0.05$. Using the Bonferroni adjustment, differences between means were measured with a significant F test. Paired t-tests were used to measure differences between each beverage. The alpha level was set a priori at $p < 0.05$. The data were analyzed with the statistical package SPSS v22.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Cola, Cola+ and RB showed higher CP values than water. The lowest CP was measured with water ingestion (192 ± 45W) compared to Cola+ (198 ± 42W), RB (201 ± 50W) and Cola ((201± 45W), $F = 2.432$; $P = 0.09$). Critical power after the ingestion of Cola was significantly higher compared to the consumption of water ($p = 0.01$). Critical power was higher for the high caffeine beverages compared to water. Eleven subjects achieved their highest CP results after the ingestion of Cola and nine subjects after the ingestion of RB. Critical power was similar after the consumption of Cola and RB. Only 3 of 24 subjects recorded the highest CP after the Cola+ ingestion.

Anaerobic work capacity was greater, though not significantly, with the ingestion of Cola, Cola+ and RB compared to water. After water and RB consumption, W' stayed constant (6583 ± 2694 and 6596 ± 2646 J, respectively), decreased after Cola+ (6061± 3120 J), but increased after Cola (6974 ± 3173 J). The differences in W' were not significant for any caffeinated beverage compared to water. W' was significantly greater after Cola compared to Cola+ ($p = 0.033$). For Cola+ and RB, W' was higher only after the ingestion of RB. Forty-one percent of subjects achieved their highest W' after the ingestion of Cola (25%, 25% and 8% for RB, Water and Cola+, respectively).

Table 2. Mean ± SD for different beverages for 3 minute all-out test.

	W' (Joules)		CP (Watts)		$\dot{V}O_2$peak (ml * kg * min $^{-1}$)		RPE	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Water	6582.6	± 2693.8	191.9	± 44.9 Ϯ	46.5	± 8.3 *	17.7	± 1.0
Cola	6974.2	± 3173.8	201.4	± 44.7	47.8	± 8.3	17.8	± 1.3
RB	6596.5	± 2646.6	201.0	± 50.5	49.1	± 8.8	17.8	± 1.2
Cola+	6061.7	± 3210.9 Ϯ	197.9	± 42.0	48.3	± 8.8	17.6	± 1.7

*Significantly different from Cola with added caffeine (Cola+) and Red Bull (RB);
Ϯ Significantly different from Cola

$\dot{V}O_2$peak increased significantly as the amount of caffeine consumed increased. Peak oxygen consumption for Water, Cola, RB, Cola+ were 46.5, 47.8, 49.1 and 48.3 ml * kg * min^{-1}, respectively ($F = 7.35$; $p = 0.02$). The average standard deviation between trials for $\dot{V}O_2$peak was 8.51 ml * kg * min^{-1}. Seventy-one percent of subjects achieved their highest $\dot{V}O_2$peak after the ingestion of a beverage with high caffeine content (11 after RB, 6 after Cola+). An increase in oxygen uptake did not lead to an increase in work performed. No significant differences were found for RPE within/between subjects.

DISCUSSION

The purpose of the study was to measure the effect of low dosages (1-2ml * kg) of caffeine, found in popular caffeinated beverages, on the 3MT. Energy drinks and their effect on endurance and short exercise bouts have been widely investigated (1, 5, 10, 19, 20, 22, 26, 29, 33). While the effect of > 3 mg * kg of caffeine has been shown to be ergogenic in endurance-type exercise, the results are quite mixed for short exercise bouts of 2 minutes and less. In a study by Forbes et al., no effect of 2 mg * kg caffeine consumed by drinking RB could be found in repeated Wingate test performance (20). Another study measuring the influence of RB on the Wingate, also found no significant effect (26). Mueller et al. (26) instructed subjects to complete the Wingate test 15-minutes after ingestion of RB, which did not allow for optimal caffeine uptake by the gastrointestinal tract (26). Davis and Green (15) suggest that caffeine might be ergogenic in exercise lasting 60-120 seconds; however, not in the case of the Wingate test, because of the shorter duration of 30 seconds. Another study by Astorino et al. did not show any ergogenic benefit of RB on repeated sprint performance in women soccer players (5). Wiles et al. measured an increase in anaerobic power after the ingestion of 5 mg * kg caffeine in a 1km time trial that lasted roughly 60-seconds (33). Their study was one of the few that found a positive effect of caffeine on anaerobic work capacity; however, the amount of caffeine consumed is above the quantity normally ingested by individuals with one drink. In the present study, the caffeine content is lower than in most previous studies. No effect on W' during the 3MT could be found

ISSN: 2326-6333

after the ingestion of RB, Cola, or Cola+ compared to water.

Effects of caffeine on CP have not been measured previously. Most research on CP has been done on endurance exercise. According to a meta-analysis by Doherty and Smith caffeine as an ergogenic aid was demonstrated only to be advantageous in endurance type exercise (18). For example, in a cycling time-trial equal to 1-hour cycling at 70% maximal workload, subjects improved endurance after the ingestion of 1 big, or 2 regular cans of RB (22). In the 3MT, the subject depletes all anaerobic capacity and keeps cycling at CP, which is the work someone can perform even after depletion of anaerobic energy (30). In the present study, we showed, with the ingestion of caffeine, CP increased compared to no caffeine ingestion prior to exercise. When relating CP to a given speed in cycling on a flat terrain without wind, an individual of 78.8kg would cycle at 13 kilometers per hour (km/h) after the ingestion of water and at 13.3km/h after the consumption of Cola. For exercise over 30-minutes, it appears that the ingestion of relatively small amounts of caffeine can be beneficial for the athlete.

A study conducted in South Korea showed no rise in oxygen uptake with an increase in caffeine ingested (3). This could be due to the low dosages of caffeine (1.25 and 2.5 mg * kg) used. However, in the current study, with the onset of exercise, the peak oxygen consumption increased after caffeine ingestion and was higher when the higher caffeinated beverages were consumed compared to Cola and water. In our study, subjects had lower oxygen uptake levels at all times during the test after water consumption compared Cola+ and RB consumption. $\dot{V}O_2$peak increased with the amount of caffeine ingested in our subjects.

Rating of perceived exertion (RPE) was not significantly different between tests. Only 13 subjects reported that one beverage elicited a lower RPE compared to the other three interventions. Astorino and colleagues (7) showed similar results with no change in RPE in a 10-km cycling time trial after caffeine ingestion. Other studies report lower RPE after caffeine ingestion for exercise over 30-minutes (18, 24). This could be due to the arousal caused by the caffeine and the altered perception of exercise intensity at a given workload.

Cola had the lowest caffeine content of the three caffeinated beverages, nonetheless, the consumption of Cola provided the highest increase in W’ and CP. While subjects consumed on average 0.31 mg * kg caffeine with 250 ml Cola, 1 mg * kg was ingested with the RB and Cola+. As participants consumed caffeine on a regular basis, the effect of caffeine should have been extenuated, especially with a very low dose of 0.31 mg * kg. Even so research indicated that caffeine uptake takes 45-minutes to 1-hour, it could be hypothesized that not a total of 1 mg * kg has been digested after one hour of rest. The absorption of caffeine depends on the physicochemical formulation properties of the caffeine dose (11). Bell and McLellan (9) measured an increased cycling time to exhaustion three hours after caffeine ingestion in caffeine users compared to cycling after one hour post caffeine consumption.

Popular caffeinated beverages are used by many athletes of different fields for various reasons. Popular caffeinated beverages caused higher W’ and CP than water. A low caffeine dosage, found in Cola, resulted in the greatest increase in W’ and CP. We found a slight performance difference between RB and Cola+. Peak oxygen uptake increased with a rise in caffeine consumption. Adding caffeine to a Cola does not provide an enhanced ergogenic effect on short all-out sports performance.

LIMITATIONS

A limitation of the study were the low caffeine dosages in all caffeinated beverages. Accordingly, the average caffeine dose for subjects was 1mg * kg for the higher caffeinated beverages and below 1mg*kg for Cola. Other studies used caffeine ingestions of over 3mg * kg. Because some subjects became sick in previous tests due to the intensity of the 3MT, we decided to keep the amount of fluid relatively low. No subject vomited during or after completion of the 3MT in our study. There could have been subject performance variability between test days. Subjects might be able to perform better on one test day compared to another day due to more sleep, less stress, or lower university workload, among other variables. Even so, a learning curve is likely, no pacing of volunteers was indicated from the performance data.

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