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Comparison of the Effect of Caffeine Ingestion on Time to Exhaustion between Endurance Trained and Untrained Men

Steven Porterfield, Jon Linderman, Lloyd Laubach, Corinne Daprano

University of Dayton, Dayton, Ohio, USA

ABSTRACT

Porterfield S, Linderman J, Laubach L, Daprano C. Comparison of the Effect of Caffeine Ingestion on Time to Exhaustion between Endurance Trained and Untrained Men. **JEPonline** 2013;16(5):90-98. This study compared the ergogenic effects of caffeine on men who were endurance trained to those who were untrained. The study was a double-blind, placebo-controlled crossover experimental design. Ten endurance trained men (mean age 24.4 ± 2.0 yrs, weight 79.4 ± 8.5 kg, predicted VO_2 max 46.3 ± 1.8 mL·kg⁻¹·min⁻¹) and 10 untrained men (mean age 22.8 ± 1.9 yrs, weight 88.9 ± 9.9 kg, predicted VO_2 max 37.6 ± 2.7 mL·kg⁻¹·min⁻¹) completed two cycle ergometer trials to exhaustion at 80% of their predicted workload max 30 min after ingesting either 5 mg·kg⁻¹ of body weight of caffeine or a placebo. Neither group displayed significant increases in time to exhaustion (Trained Group: 786.4 ± 251.5 sec for the placebo trial and 810.7 ± 209.4 sec for the caffeine trial and the Untrained Group: 514.6 ± 107.8 sec for the placebo trial and 567.3 ± 140.5 sec for the caffeine trial) after ingesting caffeine. When compared statistically between groups, the difference was not significant. When the groups were combined, the difference was caffeine and the placebo was not significant. The findings indicate that there was no ergogenic effect of caffeine on time to exhaustion in either endurance trained or untrained men.

Key Words: Ergogenic Aid, Cycle Ergometry, YMCA Protocol, Predicted VO_2 max, Predicted Workload Max

INTRODUCTION

The use of ergogenic aids has become increasingly popular in the past several decades (3,10,17). One aid of particular interest to athletes is caffeine. It is most commonly seen in beverages such as cola, coffee, tea, and energy drinks. It is easily accessible to just about anyone, and is very widely accepted by most social groups (11). Caffeine works as an ergogenic aid by stimulating the release of catecholamines in the cardiovascular, muscular, and central nervous systems (13). It is also reported that caffeine stimulates the secretion of adrenaline and increases fat utilization during exercise (12). As a result, Jenkins et al. (11) concluded that since the 1970s caffeine has been considered as an ergogenic aid (especially during aerobic exercise to exhaustion).

Because of its known ergogenic effect in high doses, caffeine has been banned by the National Collegiate Athletic Association (NCAA), United States Olympic Committee, and at one time the International Olympic Committee (IOC). In order to produce a positive test, urine concentration levels must be $\geq 15 \mu\text{g}\cdot\text{mL}^{-1}$ (12). While an average person is likely to require about 800 mg before competition or around $10 \text{ mg}\cdot\text{kg}^{-1}$ of body weight to produce a positive test, numerous research studies (2,8,9,14,19) indicate that the most effective dose as an ergogenic aid is $\sim 5 \text{ mg}\cdot\text{kg}^{-1}$ of body weight (Table 1). However, it is important to point out that the ergogenic effects have been seen in as little as 1 to $2 \text{ mg}\cdot\text{kg}^{-1}$ of body weight (2,3,5,12).

According to Desbrow and Leveritt (4), who administered a questionnaire to 140 (105 male and 35 female) athletes at the 2005 Ironman Triathlon World Championships, 89% of the athletes planned to use caffeinated substance prior to or throughout the race. Athletes understand that essentially every person in endurance sports is likely to use caffeine to harness its ergogenic effects. While there are individual differences, in general, upon entering the body caffeine reduces the loss of glycogen during endurance sports by increasing the use of fat as the primary fuel source.

Bell and McLellan (2) examined how caffeine versus a placebo affected the time to exhaustion in 9 men while riding a cycle ergometer (Table 1). With the ingestion of $5 \text{ mg}\cdot\text{kg}^{-1}$ of body weight of caffeine, the subjects rode 38.3% longer (24.9 min vs. 18.0 min) than when they ingested a placebo and 23.2% longer (21.8 min vs. 17.7 min) when they ingested $2.5 \text{ mg}\cdot\text{kg}^{-1}$ of body weight of caffeine. Hoffman et al. (8) examined the effect of caffeinated versus decaffeinated coffee on cycle ergometer time to exhaustion. During the caffeine trials, the subjects ingested 450 mg of caffeine. The subjects' time to exhaustion was significantly longer during the caffeinated coffee trial (35.3 min) than during the decaffeinated coffee trial (27.3 min). Hogervorst et al. (9) found similar results with a lower dose (100 mg) of caffeine (27.8 min vs. 21.9 min) (refer to Table 1).

McLellan and Bell (14) examined whether the prior consumption of coffee (COF) would decrease the ergogenic effect of a subsequent ingestion of anhydrous caffeine (CAF). Thirteen subjects performed 6 rides to exhaustion at 80% of VO_2 max 1.5 hrs after ingesting combinations of COF, decaffeinated coffee (DECOF), CAF, or placebo. The conditions were: (a) DECOF + placebo; (b) DECOF + CAF ($5 \text{ mg}\cdot\text{kg}^{-1}$); (c) COF ($1.1 \text{ mg}\cdot\text{kg}^{-1}$ caffeine) + CAF ($5 \text{ mg}\cdot\text{kg}^{-1}$); (d) COF + CAF ($3 \text{ mg}\cdot\text{kg}^{-1}$); (e) COF + CAF ($7 \text{ mg}\cdot\text{kg}^{-1}$); and (f) and colored water + CAF ($5 \text{ mg}\cdot\text{kg}^{-1}$). The subjects' times to exhaustion were significantly greater for all trials with CAF versus the placebo (trial "a"). Exercise times (in minutes) were: 21.7 ± 8.1 , 29.0 ± 7.4 , 27.8 ± 10.8 , 25.1 ± 7.9 , 26.4 ± 8.0 and 26.8 ± 8.1 for trials "a" through "f" respectively. They concluded that the prior consumption of COF did not decrease the ergogenic effect of the subsequent ingestion of anhydrous CAF (i.e., the dry powder form of caffeine) (see Table 1).

Table 1. Brief Overview of the Current Literature.

Reference	Sample Size	Age (yrs)	Fitness Level (mL·kg ⁻¹ ·min ⁻¹)	Dose	Intensity (VO ₂ max)	Time to Exhaustion (min)		%Δ
						CAF	Placebo	
Bell & McLellan	9	33.0 ± 7.0	52.0 ± 9.0	2.5 mg·kg ⁻¹	80%	21.8	18.0	↑23.2
				5.0 mg·kg ⁻¹		24.9	17.7	↑38.3
Hoffman et al.	10	20.9 ± 1.7	51.9 ± 8.7	450 mg	75%	35.3	27.3	↑29.3
Hogervorst et al.	24	23.0 ± 5.0	56.6 ± 4.7	100 mg	75%	27.8	21.9	↑27.0
McLellan & Bell	13	34.0 ± 8.0	52.0 ± 4.0 (m)	4.1 mg·kg ⁻¹	80%	25.1	21.7	↑15.7
			40.0 ± 3.0 (f)	5.0 mg·kg ⁻¹		29.0	↑33.6	
			6.1 mg·kg ⁻¹	27.8		↑28.1		
			8.1 mg·kg ⁻¹	26.4		↑21.7		
Wong et al.	9	25.4 ± 6.9	51.0 ± 8.2	5.0 mg·kg ⁻¹	70%	110.1	83.6	↑31.7

What is still unclear is the effect of caffeine on untrained subjects (i.e., individuals with predicted VO₂ max values in the bottom 40th percentile). Due to the lack of research with untrained subjects, given that all the subjects in Table 1 fall into the trained group, it is difficult to compare the effect of caffeine ingestion on aerobic exercise between trained and untrained individuals. If it should be determined that caffeine does in fact show more of an ergogenic effect in one group versus the other, then future research studies may show stronger results if only one group is studied. Thus, the purpose of this study was to determine if caffeine has more of an ergogenic effect on endurance trained subjects than non-endurance trained subjects.

METHODS

Subjects

The participants consisted of 20 male subjects who were placed into one of two groups (10 in each group) based on their predicted VO₂ max values. Males with predicted VO₂ max values in the top 40th percentile (≥ 44.2 mL·kg⁻¹·min⁻¹) were placed in the Trained Group while males with predicted VO₂ max levels in the bottom 40th percentile (≤ 41.0 mL·kg⁻¹·min⁻¹) were placed in the Untrained Group. The percentiles were determined by following the American College of Sports Medicine's guidelines for exercise testing and prescription. Refer to Table 2 for the subjects' mean age, body weight, body mass index (BMI), and predicted VO₂ max in the Trained Group and the Untrained Group. Prior to testing, the subjects were required to complete a health history questionnaire. None of the subjects took any medication or performance enhancing supplements that might influence the outcome of the tests. Prior to testing, each subject consented to participate in the study based on the University of Dayton's Institutional Review Board policies. This study was approved by the University of Dayton Institutional Review Board (Table 2).

Table 2. The Trained and Untrained Subjects' Descriptive Data.

	Descriptive Statistics								
	Mean		Standard Deviation		Minimum		Maximum		Sig
	Trained	Untrained	Trained	Untrained	Trained	Untrained	Trained	Untrained	
Age (yrs)	24.40	22.80	± 1.96	± 1.87	21.00	20.00	27.0	25.00	0.078
Height (m)	1.79	1.77	± 0.05	± 0.06	1.73	1.68	1.91	1.88	0.627
Weight (kg)	79.43	88.86	± 8.52	± 9.93	71.66	77.57	101.15	104.30	0.035*
BMI (kg·m⁻²)	24.83	28.24	± 1.36	± 2.68	23.40	23.80	27.70	32.60	0.002*
Predicted VO₂ Max (mL·kg⁻¹·min⁻¹)	46.30	37.60	± 1.59	± 2.70	44.30	32.60	48.90	40.80	0.047*

*Statistically significant at the P≤0.05 level.

Procedures

A double-blind, placebo-controlled crossover experimental design was used in this study. Prior to beginning any testing, the subjects were required to abstain from any caffeine ingestion for 1 wk to allow for a full caffeine “washout.” The subjects were also required to refrain from performing any strenuous exercise for 48 hrs prior to any testing. All testing was performed in the morning and at the same time for each individual's sessions.

After a minimum of 48 hrs to recover from the YMCA protocol, the subjects completed two cycle ergometer trials to exhaustion at 80% of their predicted workload max with 48 to 96 hrs between trials. Thirty minutes prior to each trial, the subjects would ingest either 5 mg·kg⁻¹ of caffeine per body weight dissolved in artificially colored and artificially flavored water or a placebo.

Statistical Analyses

Time to exhaustion data were analyzed using a Two-Way analysis of variance in order to determine if significant differences were produced between the placebo and caffeine trials for each Group and also to determine if significant differences were seen in the average change when compared between Groups. Statistical significance was set at the P≤0.05 level.

RESULTS

The predicted VO₂ max for the Trained Group (46.3 mL·kg⁻¹·min⁻¹) was significantly higher than the predicted VO₂ max of the Untrained Group (37.6 mL·kg⁻¹·min⁻¹) (Table 2). This finding indicates that the two groups were significantly different in aerobic capacity. Mean time to exhaustion for the Trained Group was 786.4 ± 251.5 sec for the placebo trial and 810.7 ± 209.4 sec for the caffeine trial. This difference resulted in an average improvement of 3.1% in performance time (Table 3).

Table 3. The Trained Groups' Results during the Placebo and Caffeine Trials.

Trained Group				
	Mean	± SD	Min	Max
Placebo Trial (sec)	786.4	± 251.5	470	1143
Caffeine Trial (sec)	810.7	± 209.4	465	1126

For the Untrained Group, the mean time to exhaustion was 514.6 ± 107.8 sec for the placebo trial and 567.3 ± 140.5 sec for the caffeine trial. This difference resulted in an improvement in performance of 10.2% (Table 4). However, what is important is that, while both the Trained Group and the Untrained Group showed the appearance of an improvement in the caffeine trials compared to the placebo trials, neither was statistically significant (Trained Group, $P=0.676$ and Untrained Group, $P=0.107$). It was also determined that the improvements were not significant when compared between groups ($P=0.225$). When both groups were compared together, caffeine showed an insignificant mean increase of 38.5 sec versus the placebo ($P=0.230$).

Table 4. The Untrained Groups' Results during the Placebo and Caffeine Trials.

Untrained Group				
	Mean	± SD	Min	Max
Placebo Trial (sec)	514.6	± 107.8	382	702
Caffeine Trial (sec)	567.3	± 140.5	375	736

DISCUSSION

It is well known that caffeine stimulates the central nervous system, which has a direct effect on the cardiovascular and muscular systems. It is also understood that caffeine has a glycogen-sparing role during exercise by mobilizing the free-fatty-acid blood concentration as the primary fuel source for muscle contraction during endurance events. While there are other explanations for the role caffeine plays in sports, it was expected that the trained subjects would benefit from the use of caffeine more so than the untrained subjects. Moreover, it seemed reasonable that the untrained subjects would benefit to some degree from consuming a moderate dose of caffeine ($5 \text{ mg}\cdot\text{kg}^{-1}$) as well.

The major finding in this study is that there was no significant difference between the Trained Group and the Untrained Group. However, although it was not the purpose of this study to prove a particular point of view, it is likely that the results would have been different if the sample size in each Group

had been larger. What is important is that, while both the Trained Group and the Untrained Group showed the appearance of an improvement in the caffeine trials compared to the placebo trials, neither was statistically significant (Trained Group, $P=0.676$ and Untrained Group, $P=0.107$). It is also worth pointing out that the mean differences were not significant when compared between groups ($P=0.225$). Lastly, when both groups were compared together, caffeine showed a non-significant mean increase versus the placebo ($P=0.230$).

Had the p-value for the different conditions tested in this study been 0.05, there would still have been a 5% chance that the subjects in both group experienced a caffeine stimulating effect on the cardiovascular and muscular systems just by chance. However, since the p-value for all comparisons was >0.05 , the result is considered statistically non-significant and, therefore, it is justified in concluding that caffeine is not correlated with time to exhaustion in either the endurance trained subjects or the untrained subjects. This does not mean that caffeine did not help the subjects in both groups, but that it has not been proven to help.

Although not significant, the Untrained Group did show a slightly higher improvement than the Trained Group (10.2% compared to 3.1%, respectively) from placebo to caffeine. This may have occurred for two reasons. First, the Untrained Groups' placebo trial time to exhaustion was lower than the Trained Group, so there was more room for improvement in the caffeine trial. Second, since it is likely that the subjects in the Trained Group exercised more regularly than the subjects in the Untrained Group, it is assumed that they would better expect what a time trail to exhaustion would physically feel like. Although it is not considered ergogenic, one theory as to how caffeine provides a positive effect during aerobic exercise is the reduction in the subjects' perceived pain. The Untrained Group may have felt the effect of the caffeine in the reduction of perceived exertion while the Trained Group may have reacted to the exertion that they expected to feel, which minimized the effect (Figure 1).

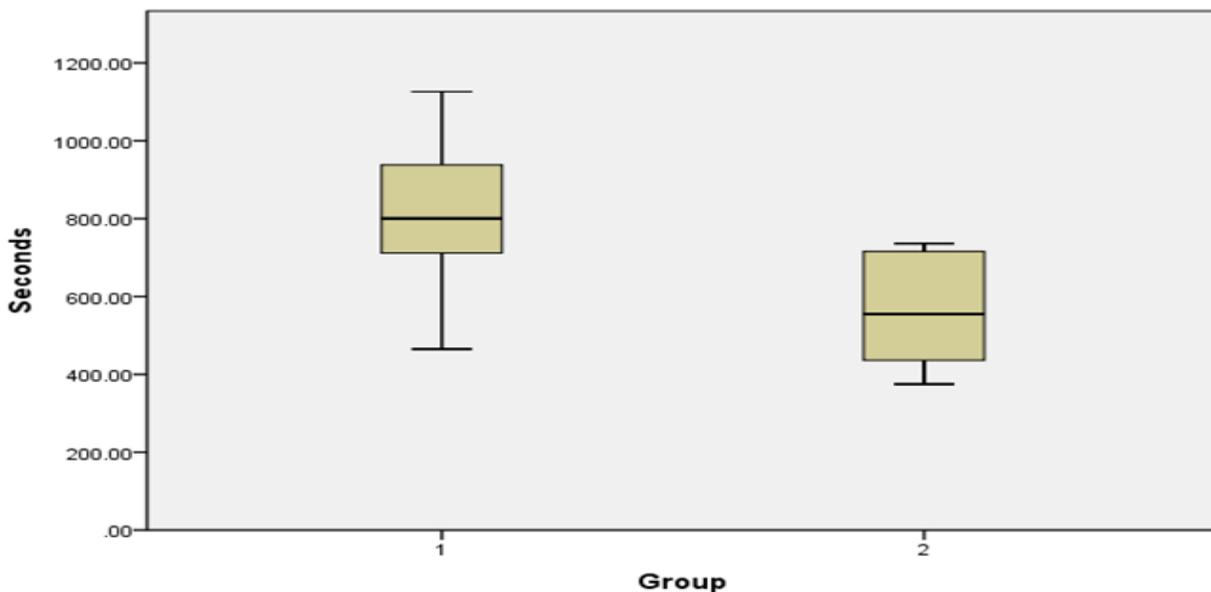


Figure 1 - Mean CAF trial time to exhaustion.

Group 1 = trained
Group 2 = untrained

In the present study, exhaustion occurred in ~12 min when the subjects in the Trained Group exercised at 80% of their predicted maximal exercise capacity while the untrained subjects exercised ~8 min. Since it is likely that greater improvements are seen when subjects exercise for 20 min or more, the intensity of exercise may have been greater than 80% of predicted VO_2 max. Also, while the $5 \text{ mg}\cdot\text{kg}^{-1}$ does has been shown to be effective in increasing high intensity exercise tolerance, it was ineffective when the bout of exercise was considerably shorter in duration (Figure 2).

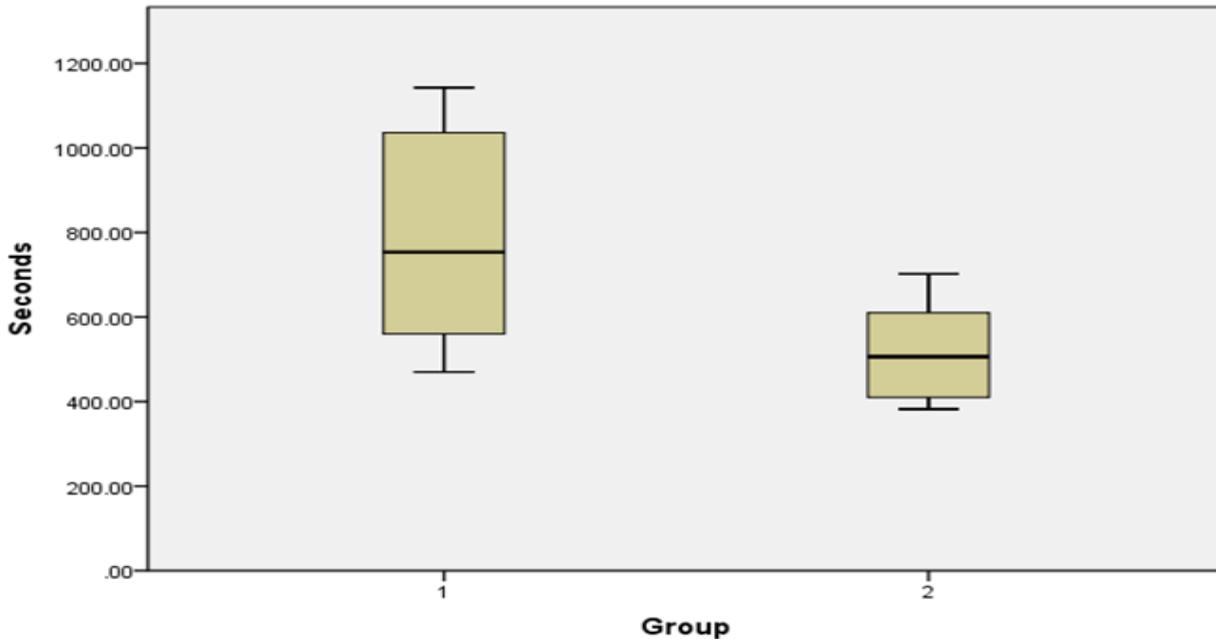


Figure 2 - Mean placebo trial time to exhaustion.

Group 1 = trained
Group 2 = untrained

After a review of the literature, it would appear that longer duration exercise would help caffeine to produce a stronger ergogenic effect. For example, in this study, TTE with placebo was highest with the trained group at ~13 min but showed only a 3.1% improvement with caffeine. Previous research indicates that the magnitude of improvement from caffeine ingestion increases with the duration of exercise trial. For instance, Bell and McLellan (2) studied two groups of subjects and found that doses of $5 \text{ mg}\cdot\text{kg}^{-1}$ of body weight of caffeine produced an improvement in performance of ~35%. Both of those groups originally averaged around 18 to 20 min for a cycle ergometer trial to exhaustion at 80% VO_2 max. Since there is apparently a lack of research on the topic, observing the effects of caffeine as an ergogenic aid on cycle ergometer exercise to exhaustion on subjects whose TTE is considered shorter (10 to 20 min) should be a major focus of future studies.

CONCLUSION

The findings indicate that there was no ergogenic effect of caffeine on time to exhaustion in either endurance trained subjects or the untrained subjects. Because the Untrained Group failed to produce an improvement during the caffeine trials, continuation of the study of the ergogenic effects of caffeine on untrained men should be considered. Lastly, future investigations should consider the effects of caffeine as function of exercise time in both trained and untrained subjects.

Address for correspondence: Jon K. Linderman, PhD, Department of Health and Sport Science, University of Dayton, 300 College Park, Dayton, OH 45469. Email: jlinderman1@udayton.edu

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