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Article

Caffeine: Does Drinking Coffee Alter Performance and RPE Levels of a Teenage Athlete in both Aerobic and Anaerobic Exercises?

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SUMMARY

The purpose of the study is to determine if ingesting caffeine in the form of coffee prior to workouts can enhance performance and alter Borg Rating of Perceived Exertion (RPE) of teenage athletes for both endurance (aerobic) and strength (anaerobic) exercises. Our hypotheses are that caffeine lowers RPE for both endurance and strength exercises and that it enhances performance in endurance, but not strength, exercises.To answer this question, we analyzed a 16-year-old high school athlete (myself) for a total of 12 days: 3 days consuming a cup of coffee prior to running, 3 days consuming a cup of coffee 1 hour prior to performing strength exercises, and 3 days without consuming a cup of coffee prior to exercise for each exercise type. For the endurance test, the athlete ran two miles as fast as they could. Average heart rate and total time of the run were analyzed for three days with coffee and three days without, as well as RPE levels. For the strength test, the athlete performed as many push-ups as possible in a one-minute time frame. The results showed that caffeine ingestion prior to exercise enhanced endurance, but had no impact on strength. Additionally, though RPE was lower for the endurance test, RPE remained unchanged for the strength test. Thus, the effect of drinking coffee in aerobic and anaerobic exercises were evaluated through several measures in this study, providing support that caffeine has an effect on aerobic exercises as opposed to anaerobic exercises.

INTRODUCTION

Caffeine, a substance commonly found in coffee, sports drinks, soft beverages, and energy supplements, is a stimulant. This is the world's most consumed psychoactive drug and it is legal for consumption. Caffeine stimulates the central nervous system as it is a part of the methylxanthine class (2). Many athletes consume cups of coffee prior to workouts, races, or games. Recent research has shown that caffeine can compete with adenosine for adenosine receptors in the brain to specifically affect endurance performance. Due to this mechanism, caffeine can modulate perceived exertion, pain, and other levels of vigor and exhaustion. Additionally, caffeine may have a greater impact on endurance, as caffeine may have more significant neural effects than muscular effects due to the ability to cross nerve cell membranes (4). Studies have supported an increase in endurance performances with caffeine as there is an increase in secretion of β-endorphins after caffeine consumption (4). For example, research has shown that in two groups of cyclists, the one that ingested caffeine had an increase in plasma β-endorphins during a two-hour period of cycling as opposed to the placebo group. An increase in these endorphins is highly significant in that it leads to a decrease in pain perception, thus being a vital force in improving endurance(5). Studies have shown that caffeine improves performance in endurance exercises since a majority of the energy is produced through aerobic pathways. Conversely, in short-term exercise at a high intensity, energy is produced through anaerobic pathways. After about three minutes of exercise, most energy is produced through aerobic pathways, and thus, becomes classified as endurance exercise. When energy is produced through aerobic pathways, for example, during the runs, it is independent of exercise mode. Aerobic performance is most likely enhanced far more than anaerobic performance as studies have noted, through increased fat oxidation and muscle glycogen sparing. Additionally, as previously mentioned by other studies, central nervous system stimulation through adenosine antagonism is also a mechanism for enhanced aerobic performance (6–8). Although studies involving caffeine have been performed, these studies were done on adults and athletes who were professionally trained. There are few studies done on teenagers, specifically, the teenage athlete.

RPE is the Borg Rating of Perceived Exertion and a way of measuring physical activity intensity level. RPE is primarily based on how the individual feels during the exercise, through analysis of heart rate, breathing, perspiration, and muscle fatigue. The scale goes from a 6 with no exertion at all, to 20, being maximum exertion. Furthermore, by using RPE levels, one's heart rate during the exercise can be estimated by multiplying the level by ten (3). Research about caffeine's competition with adenosine was done to see if RPE levels decreased only in aerobic activities. The antagonism at the adenosine receptors leads to several mechanisms which are crucial in caffeine's more significant effect on aerobic exercise. Caffeine increases energy metabolism throughout the brain and activates noradrenaline neurons, affecting the local release of dopamine. This release of dopamine increases adrenaline, leading to an overall better mood and increased energy (11).

In this study, the effects of caffeine on teenage athletic performance and RPE were investigated. We hypothesized that caffeine would lower RPE for both endurance and strength exercises. We also hypothesized that caffeine would enhance performance in endurance exercise but not strength

Variables Analyzed	Measurements
Endurance HR with Caffeine	144 bpm
Endurance HR without Caffeine	147 bpm
Strength HR without caffeine	106 bpm
Strength HR with caffeine	106 bpm
Number of Push-ups performed with Caffeine	13
Number of Push-ups performed without Caffeine	14
Total Time With Caffeine	12.27 minutes (12:16)
Total Time Without Caffeine	12.80 minutes (12:48)
Strength RPE Without Caffeine	12
Strength RPE With Caffeine	12
Endurance RPE With Caffeine	13
Endurance RPE Without Caffeine	17

Table 1. Average values for each variable measured during experimentation. (*Right*) List of conditions measured in each experiment. (*Left*) Average values for each condition (3 trials). The variables included heart rate during the endurance and strength exercises, RPE levels for strength and endurance exercises, and the performance being analyzed (total time and number of push-ups). Each variable was analyzed with and without caffeine consumption and the averages of all data analyzed show the general differences with and without caffeine intake.

Percent Decrease	Measurements-Aerobic Test Only
4%	Total Time
16%	HR
23.5%	RPE Levels

Table 2. Percent decrease for each variable significantly affected by caffeine consumption. (*Right*) Percent decrease of the conditions that were measured and affected by caffeine intake (endurance test only). (*Left*) List of the conditions analyzed. The variables include the aerobic test only-- heart rate, RPE levels, and performance being analyzed (total time). This indicates by what percent each variable was affected by caffeine consumption in the endurance test only.

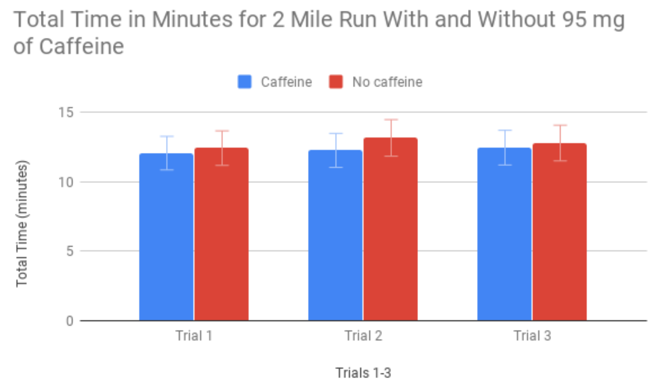

Figure 1. Lower total run time in the presence of caffeine. The total run time in the presence (blue) or absence (red) of 95 mg of caffeine was measured after a 2-mile run (*n*=3)

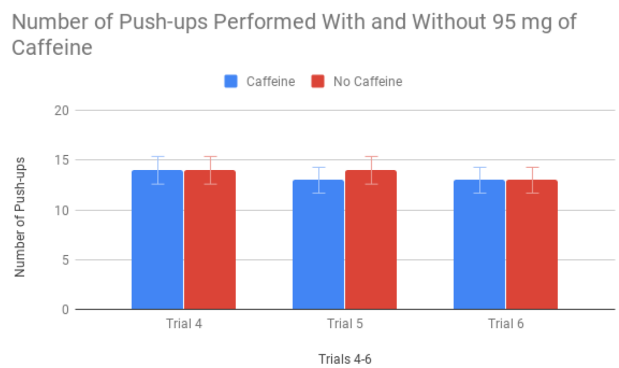

Figure 2. No observable differences in number of push-ups performed in the presence or absence of caffeine . The number of push-ups performed in the presence (blue) or absence(red) of 95 mg of caffeine was measured in one minute (*n*=3)

exercises. To test the hypotheses, a teenage athlete (myself) was analyzed for a total of 12 days. During the first three days, aerobic endurance exercise (2-mile run) was performed one hour after caffeine consumption. The next three days consisted of strength exercises performed one hour after caffeine consumption.

A week later, the same exercises were performed in the three-day periods, except no coffee/caffeine drinks were consumed an hour before, only water. The teenage athlete in this study trains 15 hours a week, and is more physically fit than most teenagers, however, not to the level of a professional athlete. This study analyzed a teenage athlete to see if the similar benefits of a professional athlete or adult can be reciprocated in both endurance and strength fields despite being younger and not as highly trained. Additionally, few studies have been done on caffeine's impact on strength exercises. The exercises performed in this experiment vary from traditional ones, as the athlete is not running to "exhaustion" as other studies have done and the athlete is performing push-ups as a form of anaerobic activity, not lifting weights (9–10). By running to exhaustion, it would be difficult to gauge caffeine's effect clearly as there is no clear data for comparison. By performing a timed trial, data is more effective to compare. Finally, we directly compared and contrasted both aerobic and anaerobic activity's changes after caffeine consumption which has a lack of evidence. Little research has been done analyzing a single trained teenage athlete for a long period of time, 12 days in this case, and this study seeks to see if by performing this experiment for a longer duration, caffeine's effect may change. Previous research led us to hypothesize that there could be lower RPE levels in both strength and endurance training, however, no performance advantage in strength workouts. The findings supported the hypothesis that caffeine enhanced aerobic performance and lowered aerobic RPE levels. The findings also supported the hypothesis that caffeine did not enhance anaerobic performance. However, the findings did not support the hypothesis that RPE levels were lowered in anaerobic

Variables Analyzed	Standard Deviation
Endurance HR with Caffeine	5.86 bpm
Endurance HR Without Caffeine	3.06 bpm
Strength HR With Caffeine	5.69 bpm
Strength HR Without Caffeine	3.21bpm
Number of Push-ups Performed With Caffeine	0.56 push-ups
Number of Push-ups Performed Without Caffeine	0.58 push-ups
Total Time With Caffeine	0.20 minutes
Total Time Without Caffeine	.37 minutes
Strength RPE With Caffeine	0.00
Strength RPE Without Caffeine	0.00
Endurance RPE With Caffeine	.58
Endurance RPE Without Caffeine	1.00

Table 3. Standard Deviations for each variable measured during experimentation. (*Right*) List of conditions measured in each experiment. (*Left*) standard deviations for each condition (3 trials). Each variable was analyzed with and without caffeine consumption and the standard deviations of all data analyzed show general differences in the data spread with and without caffeine intake.

Variables Analyzed	Coefficient of Variation
Endurance HR with Caffeine	0.04
Endurance HR Without Caffeine	0.02
Strength HR With Caffeine	0.05
Strength HR Without Caffeine	0.03
Number of Push-ups Performed With Caffeine	0.04
Number of Push-ups Performed Without Caffeine	0.04
Total Time With Caffeine	0.02
Total Time Without Caffeine	0.03
Strength RPE With Caffeine	0.00
Strength RPE Without Caffeine	0.00
Endurance RPE With Caffeine	0.04
Endurance RPE Without Caffeine	0.06

Table 4. Coefficient of variation for each variable measured during experimentation. (*Right*) List of conditions measured in each experiment. (*Left*) coefficient of variations for each condition (3 trials). Each variable was analyzed with and without caffeine consumption and the coefficient of variations of all data analyzed show general differences in the data spread with and without caffeine intake.

exercises. There could be broader implications that caffeine may be more beneficial to an endurance athlete as opposed to a strength athlete based on the evidence of this study only, but much further research needs to be done.

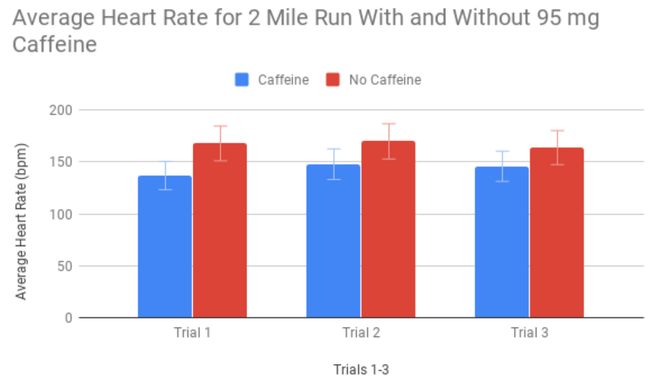

Figure 3. Lower average heart rate for 2-mile run in the presence of caffeine in the presence of caffeine. The average heart rate for the 2-mile run in the presence (blue) or absence (red) of 95 mg of caffeine was measured (*n*=3)

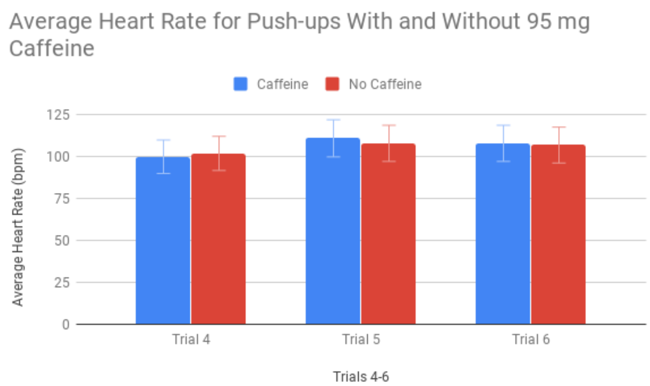

Figure 4. No observable differences in the average heart rate in presence or absence of caffeine for push-ups. The average heart rate in the presence (blue) or absence (red) of 95 mg of caffeine was measured during the push-ups performed in one minute (*n*=3).

RESULTS

This experiment examines the effect of caffeine in performance enhancing and RPE levels for both aerobic and anaerobic exercises for the teenage athlete First, to investigate the effects of caffeine on the athlete's performance during aerobic exercise, the athlete performed a 2-mile run 1 hour after caffeine (95 mg) or water consumption. In three separate trials, performance was measured, in total time in minutes of the run. After caffeine consumption, the athlete's total run time was 4% lower on days. (**Table 2**, **Figure 1**). Conversely, caffeine had no observable effects on the athlete's performance in an anaerobic test – performing as many push-ups as possible in a minute (**Table 1**, **Figure 2**).

The effects of caffeine on average heart rate during aerobic exercises and anaerobic exercises were also investigated in the same experiments. In three separate trials, average heart rate was measured during a 2-mile run. After caffeine consumption, the athlete's average heart rate was 16% lower (**Table 2**, **Figure 3**). Meanwhile, caffeine had no observable effects on the athlete's average heart rate when performing push-ups (**Table 1**, **Figure 4**).

To investigate the effects of caffeine on average RPE levels during aerobic exercise, the athlete performed a 2-mile run 1 hour after caffeine (95 mg) or water consumption. In three separate trials, RPE levels were recorded during the 2-mile run. We observed that the RPE levels were 23.5% lower on average after caffeine consumption (**Table 2**, **Figure 5**). Again, caffeine had no observable effects on the athlete's RPE levels when performing push-ups (**Table 1**, **Figure 6**).

Lastly, for all of the variables analyzed, the standard deviations show a lack of a large spread in data (**Table 3**). The results varied little, especially shown through the coefficients of variation, which were all low – under 0.1 – for all data collected (**Table 4**).

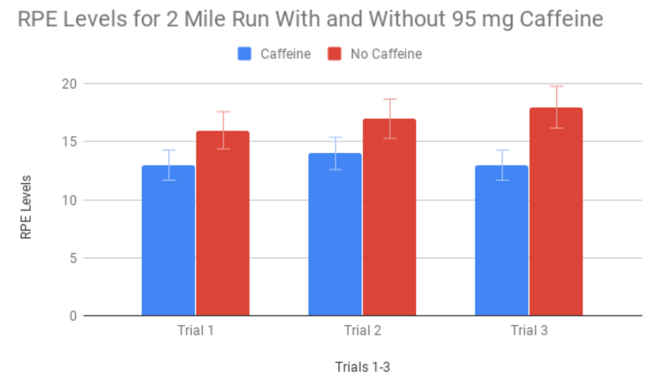

Figure 5. Lower RPE levels for a 2-mile run in the presence of caffeine. The RPE levels in the presence (blue) or absence(red) of 95 mg of caffeine was measured during the 2-mile run (*n*=3).

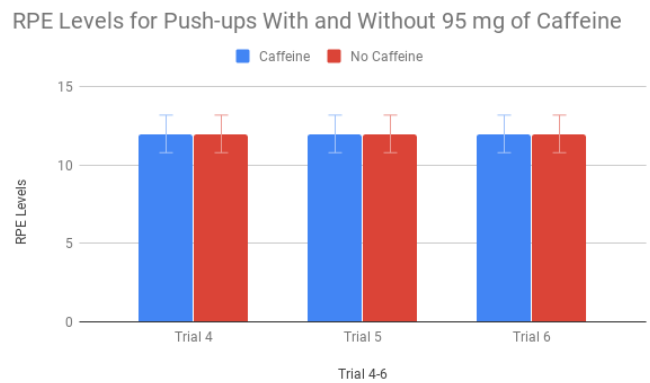

Figure 6. No observable differences in RPE levels for push-ups exercises in the presence of caffeine. The RPE levels in the presence (blue) or absence(red) of 95 mg of caffeine was measured during the push-ups performed in one minute (*n*=3).

DISCUSSION

The 12 days of the experiment – 3 days of running with caffeine, 3 days of running without caffeine, 3 days of push-ups with caffeine, 3 days of push-ups without caffeine – supported evidence that caffeine had a greater impact on endurance exercises than on strength exercises. The results support the hypothesis stating that caffeine would lower RPE, heart rate, and increase performance for endurance exercises Additionally, the hypothesis that caffeine would not enhance performance for the strength exercises was also supported. However, the hypothesis that caffeine would lower RPE levels and heart rate for the push-up test was not supported by the study. This is perhaps because caffeine's competition with adenosine receptors is most directly associated with aerobic activity. The increase in adrenaline created a decrease in RPE levels as the athlete felt as if they had more energy during the run.

Moreover, the accuracy of using the Borg Rating of Perceived Exertion seems to be fairly accurate as based on the rating, one can multiply the levels by 10 to estimate average heart rate during the period. Obviously, these are just estimations, not extremely accurate representations. However, these estimations seem to coincide with the data and rating the athlete gave themselves in this experiment. For example, the rating of 13 during the running portion with caffeine should lead to a heart rate of 130. This is comparable to a heartrate of 144 bpm. The rating of 17 given on the day of running with caffeine should lead to an estimated heart rate of 170 bpm. This is again comparable to a heartrate of 167 bpm. Thus, the RPE is a reliable indicator of exertion levels.

There are several limitations in this experiment. Firstly, this experiment analyzed one highly trained high school athlete over the course of 12 days. Perhaps if multiple athletes, such as 10 or more, were analyzed, there would be a much wider and varying set of results. People might have differing responses to caffeine, especially in teens, so these results cannot be a standard for every person. Additionally, coffee was used as the source of caffeine here. The coffee also had full fat milk and sugar in it, so it was not drunk as black coffee. The milk and sugar could also play into the factors analyzed for this athlete, so it is a limitation as it is unclear if the milk and sugar could have enhanced performance along with the caffeine as well. Perhaps caffeine pills or other gels may have different results, but for the sake of this experiment being performed on a teenager and not an adult, coffee was resorted to for safety.

Another note is that this experiment could have an element of bias to it. The experiment has no placebo and the athlete was not blinded, so they knew that they were ingesting caffeine prior to the runs. Perhaps, the athlete would have expected to feel energized, affecting the results, especially in a subjective indicator like RPE levels. As a follow-up to this study, it would be effective to use a decaf coffee in a blinded experiment to compare this with the effect of a caffeinated coffee which tastes the same. This way, there could be a greater elimination of bias that could alter perception of effort, and to see if those results are similar to the ones found in this study. Additionally, as a follow-up, it would be effective to perform this on a group of 10 people around the same age and same athletic capacity. It would be important to test people who are also runners/endurance athletes predominantly to see if the results are the same, and perhaps do another trial with those who are predominantly strength athletes, such as lifters, to see if the results are similar or different. By incorporating a decaf coffee in a blinded experiment on the same three-day rotation along with a caffeinated coffee, the results may vary, and this could provide much larger implications than the ones studied here.

The order of the experiments could have affected the results as well, but not to a degree as great as the bias element. This is because the athlete was highly trained for years, and the athlete also received a week of complete rest and very easy running between the caffeine and no caffeine sessions. Within the three days of each trial, whether it be strength or endurance, and caffeine or non-caffeine, we observed no significant difference in exertion or difficult levels. Between the caffeine and non-caffeine experiments, we gave a week period of rest so that two continuous weeks of strenuous exercise would not lead to poor performance and skewed results. However, there is a chance that within the three-day periods, the athlete could have felt tired on the third day as opposed to the first, but in this case, we observed no significant difference.

Furthermore, as previous studies have only analyzed caffeine's effect for one or two days, this study analyzed caffeine for a longer period of time. However, the extent of caffeine's impact on aerobic and anaerobic activity did not lessen over the period, indicating that it could potentially be beneficial for an avid, daily, drinker. If this study were performed on someone who does not consider themselves an avid drinker, the results could be different. The effect of the caffeine could perhaps be more potent and lasting as his or her body may not be as accustomed to it, compared to the regular consumer. Another limitation of this study as it was not performed on more people is that each person may have differing reactions to caffeine, with it having a more potent effect on others, so these results can again not be generalized.

Finally, as this study observed an adolescent athlete, there could be differences compared to performing it on adults, as many previous studies have done. This is because adolescents may have a much stronger reaction to coffee or caffeinated substances compared to adults for reasons such as body weight, or that their bodies are still growing (12).There are growing concerns of caffeine overconsumption in teens, as many teens demand busy schedules with social life, school, and extracurriculars, losing sleep. These are indeed addictive substances, and overconsumption in a growing adolescent could lead to damage of their bodies and risks to their health (1). Based on the results in this study, the benefit caffeine seemed to provide may lead to an excuse for overconsumption of teenage athletes; however, since this is just a case of only one athlete, it does not mean the effects are generalizable, but this should be a concern as teenagers could potentially abuse anything that can enhance their performances. As many studies perform studies using caffeine pills or gels, this study used a common household item – coffee. Thus, this study supports evidence that a common household item can have profound effects on an endurance athlete's performance. Thus, the experiment's results are consistent with data from various studies, however, they cannot be the same case for all teenage athletes.

METHODS

The order of the four three-day periods of testing were as follows: three days of running after drinking coffee, three days of strength exercises after drinking coffee, three days of running without coffee and three days of strength exercises without coffee. The experiments performed without coffee happened a week after the experiments that happened with coffee. This was done so that the athlete could have time to recover and reset, so that they would not feel tired or sore, which could affect the results. For the endurance portion of the experiment, the athlete used a Garmin Forerunner 35 watch to monitor heart rate, pace, and distance of runs.

Additionally, the athlete also consumed 95 mg of brewed coffee with 2 tablespoons of full fat milk and 2 teaspoons of sugar exactly 1 hour prior to running. On days when no caffeine was consumed, the athlete consumed no drink besides water 1 hour prior to the run. The time of running was always at the same time each day. The athlete ran at eight in the morning and coffee was consumed at seven in the morning. Similar weather conditions were also picked each day, with close humidity levels and temperatures. This way, the athlete could not feel more tired on a particular day due to higher temperatures or humidity. The athlete ran 2 miles at a tempo pace, or 70% of VO2 max. Thus, the pace should have been in the 6:15-6:25 range ideally for this particular athlete. The pace and average heart rate were recorded during the 2-mile distance.

For the strength portion, the athlete again consumed 95 mg of brewed coffee with 2 tablespoons of full fat milk and 2 teaspoons of sugar exactly 1 hour prior to performing the push-ups test. The athlete also did not consume any drink besides water 1 hour prior to the strength exercises on the days without caffeine. The athlete turned on the watches with a timer for a minute and performed as many pushups as possible during this time period. At the conclusion, heart rate was recorded as well as how many pushups they were able to perform consecutively. Finally, at the conclusion of each session, the athlete recorded their RPE level based on the scale and how they felt based on effort during the session. The Borg Scale used ranged from 6-20.

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