The Effects of Caffeine on Performance of Trained Cycling Athletes

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Abstract

With many methods being used in cycling to gain an edge on the competition, researchers wanted to find the effects of caffeine on performance of trained cycling athletes. While most researchers realize that caffeine has an impact, further determining what ergogenic effects caffeine has, the process of caffeine methods, and comparing methods to other options lead to various studies on purpose of this study. Fifteen articles were found to be delimited enough to gain access to a vast amount of knowledge on types of caffeine cycling studies. Results showed that caffeine had a significant positive impact on time and power output performance. Throughout this, caffeine supplements were concluded as the most consistent option, especially when taken an hour before the trial. Still, other methods like caffeinated gum, and a study that focused on caffeine withdrawal were also important foci for furthering caffeine's impact and future research.

Chapter I: Introduction

Lance Armstrong once said, “I believe that the mind powers the body, and once the mind says we want to do it, then the body will follow” (CNN, 2008). Cycling is an intense sport that can physically drain the most endurance trained athlete. From blood doping to other forms of drugs, cyclists often take any means necessary to gain superiority in competition (Lundby et al., 2012, p. 1306). With caffeine being one of the few legal options available to athletes, it is important to review and research the effects that caffeine can have on the cyclists’ performances.

Cycling has a high aerobic demand due to the extensive length of races and the changes in altitude. Some altitudes can be as high as 2000 meters in many nationally recognized cycling races including Bogota and Mexico City (Hahn, Gore, 2001, p. 534). The average road race day for cyclists is 150 miles, and can often times be more. Professional cycling is unique compared to other sports because the most notable competitions, like the Tour de France, are three weeks long; where cyclists bike over 2000 miles (Purdum). As a result, cyclists are interested in any type of training and advantage they can receive to help with: power output, energy expenditure, and oxygen intake as they increase in altitudes and distance for the race. This created issues in the sport as many cyclists were blood doping, or taking substances like pseudoephedrine (PSE). This gave athletes a significant enough advantage that it created unfair racing competitions (Lundby et al., 2012, p. 1306). This shows why caffeine, a legal substance with enhancing benefits, is a top consideration for cyclers.

Caffeine is a common stimulant that is used as a performance enhancing drug in many aspects of sports (Paton et al., 2015, p. 1076). There are variant ways for researchers to study caffeine, due to differences in: the dosage given, the time allowed for the caffeine to be implemented in the body before activity, and the types of ingestion of caffeine. Most often, caffeine is given around an hour before the activity, through a supplement that is in between three to ten milligrams per kilogram of body weight (Paton et al., 2015, p. 1076). The researchers apply this dosage method, despite the varying intake per person because it allows for a consistent percentage of each participant’s body intake throughout. Depending on the study, the types of caffeine delivery include basic supplements or tablets, chewing gum, energy drinks, and mouth rinse. There are varying studies that focus on delivery methods in order to understand which methods achieve the quickest caffeine absorption into the bloodstream. (Paton et al., 2015, p. 1076).

Caffeine can have an impact on performance because of the influence it has on the central nervous system. Caffeine has been shown to increase alertness, as well as having a role in “decreasing fatigue and perceptual effort via its effect as an antagonist on the adenosine receptors (Spence et al., 2013, p. 507). There have been widespread reports of caffeine having an impact on athletes. However, more studies in cycling are explored to see if caffeine affects those who are professional cyclists, and how much more effective caffeine is compared to placebos and other drugs that are banned.

Statement of the Problem

Many cyclists are trying to find any way they can to get an edge on the competition. Caffeine is one legal option that can have an impact on those cyclists who take it before racing. Still, with so many differences in dosages, types, and time the caffeine is taken, figuring out what produces the greatest result could change how many competitors perform.

Every article that discusses the relationship of caffeine and cycling has slightly different styles. The goal is always to see how caffeine affects performance for those cyclists, but the process can be different. For example, Smolka and Kumstat (2014, p. 131) use a gel supplement of caffeine that equals 2 milligrams per kilogram of body weight, which is less caffeine than a cup of coffee; comparing the effects on sub-elite versus elite athletes. In another article, Spence (et al., 2013, p. 507) compared 200 milligrams of caffeine for all participants, versus 180 milligrams of PSE, which is a banned substance for competitions. Between the two, both options yielded similar results.

It is important to see what areas caffeine can improve cycling as well. With power, speed, and endurance being a factor in all races, caffeine may give these cyclists the boost they need if they use it efficiently. It is also significant to find out if there are inconsistencies in how useful caffeine might be, even compared to other options. Supplements versus placebos are the biggest comparison for most studies. Mindset alone could be the biggest factor, as Lance mentioned. Still, one interesting difference in a type of caffeine intake for two studies looks into how caffeinated chewing gum or caffeinated mouth rinses can be a faster, yet effective way to get caffeine into your bloodstream (Pataky et al., 2016, p. 613). Ultimately, with several slightly different procedures for caffeine intake for cyclists, one may wonder how valuable caffeine is for cyclists and athletes overall.

Purpose of the Study

The purpose of this synthesis project is to review the literature on the effects of caffeine on performance of trained cycling athletes.

Operational Definitions

1. Caffeine: a chemical, found for example in tea and coffee, that is a stimulant (something that makes people more active) (Merriam Webster, 2020)

2. VO2 max: maximal oxygen consumption, refers to the maximum amount of oxygen that an individual can utilize during intense or maximal exercise (UVA, 2020)
3. Sub-elite cyclists: cyclists with a VO2 max average of 56.9 ml/kg and training volume of 5000-7000 kilometers per year (Smolka, Kumstat, 2014, p. 134).
4. Elite cyclists: cyclists with a VO2 max average of 66.4 ml/kg and training volume of 18,000 to 20,000 kilometers per year (Smolka, Kumstat, 2014, p. 134).
5. Ergogenic: intended to enhance physical performance, stamina, or recovery. (Oxford, 2020)

Research Questions

1. What are the effects of caffeine on the performance of trained cyclists?
2. Does the dosage amount of caffeine affect cyclists differently?
3. Do different methods of caffeine intake affect cyclist performance?

Delimitations

1. Participants in the review of literature are all well trained cyclists with an average age of 30 years old.
2. Participants included 174 men and 34 women total, with only four of fifteen including women.
3. Articles used in this research synthesis were full articles that were in peer and published journals between 2010-2020.

Chapter II: Methods

The purpose of this chapter is to review the methods and procedures used to determine the effects of caffeine on performance of trained cyclists. The studies collected for this synthesis were located using the EBSCO database from SUNY Brockport's Drake Library. Within the EBSCO database the following databases were searched: SPORTDiscus with Full Text and Academic Search Complete.

Within the databases, there were 38 articles that resulted from the most delimited search possible. These were ultimately considered for inclusion in the literature review. For the articles to meet the criteria for the research study, it must have been published between 2010 and 2020. This allows for the most current research available. The next delimitation made sure the articles were all peer-reviewed and scholarly with access to full pdf text, and can be appropriately cited in the reference section. Using peer-reviewed articles allows for the most valid and legitimate research for the synthesis. Any other articles included were used as context and background information to complete the review.

To get the best articles for the purpose of the study, specific keywords and phrases were used when searching for the articles. I began by using the library's KSSPE resource database search engine that allowed me to search "effects of caffeine on cyclists" for both SPORTDiscus with Full Text, and Academic Search Complete simultaneously, without duplicates. This first search, combined with the advanced search setting of peer-reviewed articles ranging between 2010-2020, resulted in 97 articles. To further delimit the study, I kept "effects of caffeine on cyclists", but added "time performance" in the second search bar. This was added to find more articles that researched how caffeine affects performance and time for the cyclists, which is closest to my purpose statement. This resulted in 38 articles for review. Other search words were considered but ultimately delimited the study too much.

To find appropriate articles for the synthesis study, I reviewed each articles' methods, process, and results. First, I wanted to find articles that specifically used caffeine without any other additives. Some articles compared caffeine to other drugs or options; these were included. Next, I wanted to make sure that the articles produced results where the end goal was to see that caffeine affected performance in some way. Under these two parameters of review, I found seventeen articles that possibly fit for the synthesis. To further delimit the study, I examined the participants of each of the seventeen articles to see if there were differences, and I found that fifteen of them had well trained participants, while two had just recreational cyclists. Therefore, fifteen articles were found that best fit the purpose statement of the effects of caffeine on performance of trained cycling athletes.

The articles all came from a variety of journal sources. Three articles were sourced from the Journal of Sports Sciences. Two articles came from the International Journal of Sport Nutrition & Exercise Metabolism. Two articles were sourced from PLoS ONE. One article, for a total of eight, was sourced from each of the following journals: *Medicine & Science in Sports & Exercise, International Journal of Sports Physiology & Performance, Journal of Science & Medicine in Sport, European Journal of Applied Physiology, Journal of the International Society of Sports Nutrition, Journal of Strength & Conditioning Research, Annales Kinesiologiae,* and *Applied Physiology, Nutrition & Metabolism*.

The critical mass throughout the fifteen articles is 210, for an average of about fourteen per study. The studies participants included 176 men and 34 women who were competitively trained cyclists. Most often, the articles only included men in the study (eleven of fifteen).

Therefore, four of the fifteen included women, mostly at an equal rate to men in the study. The studies were single or double blind, randomized, placebo-controlled, and crossover experimental trials that focused on the implementation of the caffeine or other placebo or drug. The dosage amount ranged from 2-6mg/kg of the participants body weight. Here, the researchers would have the participants take the supplement or placebo at a certain time, ranging from 40 to 90 minutes, before the trial. Some researchers used caffeinated gum or caffeinated beverages instead of the caffeine supplement, but the goal was the same. Ultimately, the cyclists would perform cycling trials at a certain duration or distance and evaluate the performance data. Throughout the studies, the participants would perform multiple trials with different intakes to compare the data across different tests.

Chapter 3: Review of Literature

The purpose of this chapter is to present a review of literature on the effects of caffeine on the performance of trained cycling athletes. The focus of the review will be on: the type of caffeine taken, the time the participants took the caffeine before the trial, the ergogenic impacts of caffeine, and the effects of caffeine on both males and females. It is widely known that the majority of authors in studies similar to these conclude that caffeine has a positive impact on athletes. However, the review of the literature on these different elements can key in on what process can be of most use for cyclists.

Types of Caffeine

Throughout the fifteen studies, there were several different types of caffeine ingestion that the researchers focused on. In many studies, like Ferreira et al. (2020), participants ingested a caffeine supplement before they performed their trial. This trial of nine endurance trained athletes, with an average age of 30, were studied to find the effects of caffeine ingestions on power output and performance. Participants took six mg/kg of their body weight (BW) of caffeine, (the most commonly used caffeine amount in the studies), or a placebo, 60 minutes before the four-kilometer stationary bike time trial. Every study included a placebo control for comparison. The results showed that a caffeine supplement can have a positive effect on cyclists, with an eight percent power output increase.

Similarly, a study done by Desbrow et al. (2012) focused on caffeine supplementation. However, the purpose of this study was to investigate the effects of two different doses of caffeine on endurance cycle time trial performance in male athletes. In this study, well-trained male cyclists with a mean age of 32 years ingested a 3mg/kg BW caffeine supplement, 6mg/kg

BW caffeine supplement, or a placebo 90 minutes before the trial (longer than most periods). Then, cyclists biked on a stationary bike at 75% power for 60 minutes.

The results concluded that exercise performance improved by 4.2% with 3mg/kg of caffeine and 2.9% with 6mg/kg of caffeine, though the difference between the two caffeine supplements was not considered to be statistically significant. Heart rate increased significantly with caffeine compared to the placebo. Caffeine amounts across all studies range from about 3mg/kg BW to 6mg/kg BW. In this case, both caffeine supplements gave cyclists more performance success than the placebo. However, the higher dose of caffeine did not have any more of an impact than the lower dose.

Alternatively, other studies wanted to see if different methods than caffeine alone had a bigger impact on cycling performance. Spence et al. (2013) compared the impact of caffeine versus a banned substance known as pseudoephedrine (PSE). Pseudoephedrine is a nasal decongestant that cyclists could use to clear their sinuses and breathe easier during a race. In this study, ten well-trained cyclists participated in a 40 km time trial on a stationary bike, analyzed by a bike ergometer. 60 minutes before the trial, participants were administered 200 mg of caffeine, 180 mg of PSE, or the placebo. The results showed that the total time between caffeine and PSE trials were not significantly different.

However, caffeine alone had the biggest impact in this study, showing an average time of almost a minute faster than both the PSE and placebo trials. The results even showed that PSE did not have any more of an impact than the placebo. Therefore, the authors concluded that caffeine, which is legal, had more of an impact on the cyclists' power and time performance than PSE or the placebo. This is especially true in the second half of the race. More studies should be done to show if PSE does have a true effect, and if it should continue to be banned.

Similarly, another unique research study by Lane et al. (2014) investigated different methods by focusing on the independent and combined effects of caffeine gum and beetroot juice supplements. The purpose of this project was to investigate the independent and combined effects of caffeine and NO3 − supplementation on the performance of a cycling task simulating the physical challenges of the London 2012 Olympic Games road cycling time trial. 12 male (mean age 31) and 12 female (mean age 28) competitive cyclists began to chew a caffeinated gum (3 mg/kg BW) 40 minutes before TT, a concentrated beetroot juice supplement 2 hours before TT, a caffeine and beetroot juice supplement, or a placebo. Males completed a 43.83km course and females completed a 29.35km course on a Velotron cycle ergometer as quickly as possible.

Males with caffeine showed the most improvement in time (50 seconds faster) and power (11W) compared to the placebo. Females has similar improvements with caffeine in time (50 seconds) and power (9W) compared to the control. Both had no significant ergogenic changes with beetroot juice alone compared to the placebo. Beetroot juice also did not add to any more improvement when taken with caffeine, compared to when cyclists just took caffeine alone. Nitrates, like in beetroot juice, have been shown in other studies to improve cardiovascular health and enhance high intensity activities. Though beetroot juice increased the cyclists nitrate levels, the authors concluded that it did not improve the cyclist's ability to perform the trial, nor did it give an added benefit with caffeine. One other interesting aspect was that the gum effects were fast acting, where caffeine was shown within twenty minutes of chewing the gum.

Additionally, Hodgson, Randell, and Jeukendrup (2013) investigated whether acute intake of coffee (5 mg CAF/kg BW) and anhydrous caffeine (5 mg CAF/kg BW) are ergogenic to cycling performance compared to decaffeinated coffee or placebo beverages when using a validated 45-minute time trial performance test. With coffee being the most readily available caffeine method available, the researchers wanted to establish if it had the same effects as a caffeine supplement drink. Eight trained male cyclists, with a mean age of 41 years, completed a 30-minute steady-state cycle at 55% VO2 max followed by a 45-minute time trial at 70% power. One hour prior to exercise, each athlete consumed a drink consisting of either just caffeine (5 mg CAF/kg BW), instant coffee (5 mg CAF/kg BW), instant decaffeinated coffee or a placebo drink.

With the participants blood being drawn, the researchers found that caffeine alone had a higher peak than coffee, yet finish times were within seconds of each other with both options. Both caffeine and coffee had significant improvements in time at over 4% compared to both decaf coffee and placebo trials. The authors can conclude that coffee is a reliable source of caffeine for cyclists, as it had very similar results.

Another different caffeine method used was in Doering et al. (2014) where the purpose was to investigate if acute caffeine exposure via mouth-rinse improved endurance cycling time-trial performance in well-trained cyclists. In this study, ten well-trained male cyclists with a mean age of 32 completed two experimental time trials where they cycled at 75% of peak power for 60 minutes. Cyclists were given 25ml mouth rinses for 10 seconds with either 35mg of caffeine eight times throughout the trial, or a placebo each of those times. This methodology is different in many ways, with the mouth rinse itself being taken throughout the trial, without any time for caffeine to set in beforehand like the majority of studies.

Unlike the majority of caffeine studies, results showed that there was not any significant improvement for the well-trained cyclists when taking mouth rinse throughout the trial. Their caffeine blood levels also did not elevate during the trial. Studies like this that use mouth rinse, or others that use gum, suggest that caffeine can be ingested in the mouth through the buccal cavity more quickly than other methods. While gum showed positive improvements in other studies, the mouth rinse did not.

Lastly, Quinlivan et al. (2015) investigated the effects of a popular energy drink, Red Bull, containing a moderate dose of caffeine (3 mg/kg BM) or an equivalent dose of anhydrous caffeine in a CHO-matched beverage in comparison with a noncaffeinated control beverage on endurance-cycling time trial performance in trained participants. Eleven trained male cyclists with a mean age of 31 years were given Red Bull or a caffeine capsule both containing 3mg/kg BW of caffeine. The study also included a placebo. All ingestion methods were taken by liquid, and 90 minutes before the 75% power for 60 minutes time trial. In this study, researchers analyzed the participants time, power output, heartrate, rate of perceived exertion (RPE), quadriceps muscle pain postexercise, and blood glucose.

After analysis, researchers found that the caffeine supplement gave cyclists an improved time by 120 seconds, while the Red Bull drink improved their time by 109 seconds compared to the placebo. RPE, power output, heart rate, and quadricep muscle fatigue had no statistically significant changes. Other aspects of Red Bull like taurine, glucuronolactone, and B-complex vitamins showed no additional benefits to caffeine alone. Interestingly, gastric discomfort was described as having an effect on three different participants, including one (a twelfth participant) who withdrew from the study after experiencing severe stomach pains after drinking Red Bull. Overall, researchers could conclude that even though caffeine supplements and Red Bull had similar results, taking caffeine alone can be more beneficial because of no major side effects.

The Impact of Time

While most studies examined whether or not the type of caffeine had a direct result in the outcomes of the studies, some articles had an interesting look into how important time withdrawal before the trial can be for the athletes' performances. The first article investigating this was by Irwin et. al (2011) where the researchers investigated the effect of an acute moderate caffeine dose (3mg/kg BW) on time trial performance following a four-day controlled withdrawal period, in habitual caffeine consumers. While the majority of studies had participants go without caffeine for two days, this study is unique because of the four-day withdrawal period before the trial. Twelve well-trained male cyclists, with a mean age of 28 years, participated.

Four experimental trials occurred. Athletes were given two supplements each day of the trial, either placebo and caffeine supplement, or both in the same day. This allowed for all four possibilities to occur, with one in the morning, and one 90 minutes before the trial. Cyclists cycled one hour at 75% peak power for as far as they could get. Results showed that implementing caffeine before the trial, especially when implemented earlier in the day as well, showed an increase of power output by 14W and decreased time taken for the trial by an average of two minutes and twenty seconds. The authors concluded that the four-day period without caffeine desensitized habitual caffeine drinkers, allowing for a greater impact of caffeine for the trial.

Alternatively, a different study by Skinner et al. (2013) had an interest of when caffeine levels peaked for the cyclists, before they would let them perform the time trial. The primary purpose of the study was to determine whether coinciding the onset of endurance exercise with peak serum caffeine concentration, following a pre-exercise meal, would result in further improvement. Fourteen male competitively trained cyclists, with a mean age of 31 years participated. Participants fasted overnight, ate a pre-exercise meal 20 minutes before ingesting 6mg/kg BW of a caffeine supplement or a placebo. Trials began based on peak caffeine serum levels, or after 60 minutes of a base caffeine supplementation, where they performed a 40km time trial.

Knowing when to take caffeine seems like an important aspect of a cyclist's process. Overall, the study concluded that ingesting caffeine resulted in faster time trial performances in both caffeine type trials. However, when cyclists consumed the caffeine supplement one hour before the trial, cyclists had more success than the ones who began the trial at their peak caffeine serum rate. Almost every article has a different caffeine intake amount and time, so more studies need to be done to see the total picture on this concept.

Ergogenic Impact

While each research study had various foci, all of the studies used ergogenic analysis to establish the effects of the caffeine methods and time taken before the trial. Ergogenic is defined by Oxford Dictionary as, "intended to enhance physical performance, stamina, or recovery." Ergogenic effects are well documented across all studies. However, studies focus on different areas including power output, time performance, heart rate, and even as specific as quadricep fatigue in Quinlivan et al. (2015).

One unique research study was done by Paton, Costa, and Guglielmo (2015) investigated the effects of caffeine, delivered via chewing gum, on measures of endurance and sprint power performance in trained cyclists. Twenty trained cyclists (ten males, ten females) ages 20-40 years performed a thirty-kilometer (three, ten-kilometer laps) computer simulated course on a stationary bike, with a sprint in the last .2 km on each lap. Caffeine gum (3-4mg/kg of body weight of caffeine) or placebo gum was given after the first ten kilometers of the trial. A small increase in power output overall, especially during the final sprint of the trial, of caffeine taking athletes was shown. A time decrease was found in the first lap (1,056 seconds for placebo and 1,049 seconds for caffeine) and the final lap (1,126 to 1,105 seconds for placebo and caffeine). With the unique chewing gum method, ergogenic effects like power and time performance were improved overall, even slightly.

Alternatively, a study performed by Smolka and Kumstat (2014) focused on the influence of caffeine on maximal power output during endurance performance, while comparing sub-elite to elite athletes. In the study, ten male sub-elite and eight elite male cyclists were chosen based on their biking metrics. Three different supplements were administered: a 2 mg/kg BW caffeine supplement, a 7 mg/kg BW caffeine supplement and a placebo, all given 45 minutes before trial. Cyclists performed a 60-minute drive at 70% of their VO2 max on a software-controlled bike ergometer.

When analyzing the power through the ergometer software, the maximal power output for elite athletes stayed consistent throughout each supplement. The sub-elite athletes displayed increased maximal power with the more caffeine they took (mean: 361W placebo, 365W 2mg/kg BW, 372W 7mg/kg BW). Comparing different levels of athletes allowed for further analysis on how impactful caffeine can be. Ultimately, those with less training had a larger increase in performance with caffeine.

Similarly, Bortolotti et al. (2014) analyzed the effect of caffeine ingestion on the performance and physiological variables associated with fatigue in 20-km cycling time trials. In this study, 13 male cyclists with an average age of 26 years received 6mg/kg BW caffeine capsules or placebos 60 minutes before performing a 20km time trial. No caffeine was ingested by the participants 48 hours before. Power, speed and cadence had an insignificant increase with the caffeine intake versus the placebo. Physiological performance stayed consistent as well. The authors concluded that caffeine did not have a significant ergogenic effect on the cyclists in the sprint trial.

In addition, another study by Anderson et al. (2020) investigated the influence of the placebo effect of caffeine on anaerobic power and the overall influence of caffeine on cycling power in trained sprint cyclists using the Wingate Anaerobic Test. In this study, ten competitively trained cyclists (nine males, one female) were given highly caffeinated coffee (280mg), low caffeinated coffee (140mg), or a placebo 45 minutes before the trial. While power was the main analysis, one other interesting aspect was that participants were asked to guess what they took after, to see the physiological factors that could take away from the placebo effect.

The analysis included peak power, time to peak power, average power, power drop, and the question of what they thought they took. The results concluded that time to peak power was significantly shorter for the trial in which subjects incorrectly guessed they had consumed caffeine when given the placebo compared with placebo trial. Power drop was significantly higher for the trial in which subjects incorrectly guessed they had consumed caffeine when given the placebo compared with placebo trial (524 6 37 vs. 433 6 35 W). There seems to be a placebo effect of caffeine on anaerobic performance. The authors concluded that caffeine had more of a positive ergogenic impact if the athletes did not figure out that they consumed caffeine.

Lastly, Roelands et al. (2011) had a unique ergogenic analysis study to determine the effects of caffeine supplements before the start of prolonged exercise on performance, thermoregulation and hormonal variables in high ambient temperature (30℃). In this study, eight trained mild caffeine consuming males with a mean age of 23 years, that were not accustomed to warm environments, participated. Cyclists took 6 mg/kg BW of caffeine or the placebo one hour before exercise. Cyclists cycled for 60 minutes at 55% max power. Urine samples, heart rate, blood samples, and core temperature were analyzed before and after each trial. Caffeine administration did not significantly influence time trial time. Core temperatures increased more combined with caffeine than with placebo. The researchers concluded that environmental factors may have an impact on how effective caffeine is on performance.

Males and Females

The majority of the studies on the effects of caffeine on cyclists only focus on males. Participants throughout all fifteen articles included 174 men and 34 women total, with only four of fifteen including women. Therefore, it is important that the research of Skinner et al. (2019) aimed to determine whether: consumption of caffeine improves endurance cycling performance in women and if sex differences exist in the magnitude of the ergogenic and plasma responses to caffeine supplementation. In this study, 27 participants of 11 women (mean age 29 years) and 16 men (mean age 32 years) completed a 75% power output for a “set amount of work” never specified. 90 minutes before the trials, the cyclists took a 3 mg/kg BW caffeine capsule or a placebo.

Time, heart rate, and blood were analyzed for values that are most affected by caffeine. The results concluded that time improved by about 169 seconds for both males and females with caffeine instead of a placebo. No significant differences were found between males and females in time performance difference. Caffeine concentration in the females’ plasma were significantly greater in women after exercise. The authors concluded that the range of caffeine of 3-6mg/kg BW that is often used in studies can be just as effective for women as men. With females having a concentration of caffeine after the trial ended, this suggests there could be more studies done to see if longer trials could have a different effect between males and females.

Summary

There is much research to conclude that caffeine has a positive impact on cycling performance. The types of caffeine versus other substances, the time it takes for caffeine to make an impact, the ergogenic factors, and the effects of males and females were more specific foci to review because changing any process might impact the end result. Throughout the review of literature, one could see that certain processes had a bigger impact on the cyclists than others.

Caffeine supplements are the most common method for the studies to implement caffeine easily and to have a placebo that is not easily detectable. Across the majority of the studies, caffeine supplements ranging from 3 mg/kg BW to 6 mg/kg BW improved the cyclists' power and decreased their time. However, investigating if other caffeine options like coffee, gum, mouth rinse, and red bull, or other methods like PSE or beetroot juice are effective can allow for authors to further conclude if caffeine is effective. Ultimately, caffeine supplements alone had the best or similar impact compared to the other options. The time the researchers allowed for caffeine withdrawal, or waiting for caffeine to set in, also had an impact on the cyclists' performance.

Cycling is a difficult sport, often spreading over long distance and requiring athletes to need any edge they can get to perform better. The review of literature concluded that caffeine has a positive effect on cyclists, even over some banned substances, and that it works best with allowing time for it to peak in the bloodstream. Caffeine has a positive effect on power and time performance, and it has similar effects between males and females. Further research can be done to examine the benefits of further withdrawal from caffeine from studies, and to see how long caffeine is effective in the system.

Chapter 4

Results, Discussion, and Recommendations for Future Research

The purpose of this chapter is to present the results of the review of literature on the effects of caffeine on the performance of trained cycling athletes and how these results align with the purported research questions which guided this synthesis project. In addition, recommendations for future research as it relates to the impact of caffeine on trained cyclist performances are presented.

The results of this review of literature revealed the following: caffeine has a positive ergogenic effect on time, power output, and performance overall. There were several different ways researchers implemented caffeine (supplement, gum, mouth rinse, Red Bull, and coffee). While all methods seemed to have a positive impact, the supplements had the most consistent positive effect on the performance of cyclists, even when compared to other known ergogenic substances like PSE and beetroot juice. Caffeine seems to have a similar positive effect on both male and female cyclists. However, the number of female cyclists in the articles overall was minimal.

Discussion

Interpretations

As part of the literature review, several research questions were posed. The first research question examined was, what are the effects of caffeine on the performance of trained cyclists? The results in many of the research studies concluded that caffeine had an ergogenic effect on cycling athletes. For example, in Smolka and Kumstat (2014), they found that the more caffeine the cyclists took resulted in a higher power output during the time trials (mean: 361W placebo, 365W 2mg/kg BW, 372W 7mg/kg BW). In line with this, Anderson et al. (2020), concluded that peak power and power drop were best when cyclists consuming the coffee at both caffeine concentrations. However, this study also had interest in the cyclist's ability to determine if they had ingested caffeine or the placebo. They then concluded that those who believed they had ingested caffeine when they been given the placebo resulted in the biggest impact on power output. Therefore, there seems to be a psychological factor that coincides with caffeine intake.

Only 16% of all participants throughout the studies were female. Therefore, to see how caffeine effects all cyclists, it was important to find the ergogenic effects of caffeine in women as well. When Skinner et al (2019) compared the effects of caffeine on female and male participants, they found that the impact was significantly similar between the two. Time improved by about 169 seconds for both males and females in the time trial. Interestingly, caffeine concentration in the females' plasma was greater than the males though. Overall, the authors concluded that the range of caffeine of 3-6mg/kg BW that is often used in studies can be just as effective for women as men.

Contrary to most studies, two studies found that there were no significant differences between caffeine and the placebo in ergogenic effects. Roelands et al. (2011) concluded that caffeine administration of 6 mg/kg BW did not influence time trial time compared to the placebo in a 60-minute trial. The study did find that caffeine increased the cyclist's core temperature, which could be important for races in certain conditions. Similarly, Bortolotti et al. (2014) investigated the ergogenic effects of caffeine on a 20-kilometer trial. They concluded that despite most studies showing positive impacts of caffeine, power, speed, and cadence has an insignificant increase between the caffeine intake and the placebo.

The second research question asked, does the dosage amount of caffeine affect cyclists differently? Most studies have an average caffeine dosage range of 3-6 mg/kg. However, as mentioned earlier, Smolka and Kumstat (2014) compared a low dose of 2 mg/kg BW to a higher dose of 7 mg/kg BW. They concluded that the higher dose of caffeine correlated with higher maximal power output. Therefore, there could be a higher performance impact with a higher amount of caffeine. In another case, Desbrow et al. (2012) specifically investigated the effects of two different doses of caffeine on endurance time trial performance. The researchers focused on the two most common caffeine doses: 3 mg/kg BW and 6 mg/kg BW. Results showed that exercise performance improved by 4.2% with 3mg/kg of caffeine and 2.9% with 6mg/kg of caffeine, though the difference between the two caffeine doses was not considered to be statistically significant. While both caffeine supplements gave cyclists more performance success than the placebo, the higher dose of caffeine did not have any more of an impact than the lower dose.

The last research question asked, do different methods of caffeine intake affect cyclists' performances? Throughout the articles, the two things that varied the most were: the amount of time before the trial that the caffeine was consumed, and the varying types of caffeine. First, time was an important method focus because cyclists should know when the caffeine will have its biggest impact. Irwin et al. (2011) focused on investigating the effects of 3 mg/kg BW of caffeine after a four-day withdrawal. Most studies that mentioned any caffeine withdrawal before the trials had them go two days without caffeine. Results showed that implementing caffeine before the trial, especially when implemented earlier in the day as well, showed an increase of power output by 14W and decreased time taken for the trial by an average of two minutes and twenty seconds. The authors concluded that the four-day period without caffeine desensitized habitual caffeine drinkers, allowing for a greater impact of caffeine for the trial.

Other studies focused on the specific types of caffeine and compared them to other ergogenic methods. For example, Spence et al. (2013) found that despite pseudoephedrine being a banned substance in cycling, when compared to the effects of caffeine and the placebo, caffeine was the only one that had a performance impact. Caffeine supplement consumption correlated with a time that was a minute faster than both the PSE and placebo trials. Similarly, Lane et al. (2014) compared caffeinated chewing gum, which is unique alone, to a beetroot juice supplement and a placebo. Cyclists in the study that chewed the caffeinated gum performed an average of 50 seconds faster in their time trial and had an average power output that was highest as well, compared to the beetroot juice and placebo supplements.

In Hodgson, Randell, and Jeukendrup (2013), they concluded that coffee and caffeine supplementation had very similar effects on the cyclists when they have the same caffeine content. This shows that caffeine supplementation is not always the best primary option. Another different method of caffeine was researched by Quinlivan et al. (2015), where Red Bull was compared to a caffeine capsule and a placebo. No significant differences were found in time performance between Red Bull and caffeine capsule trials. However, several participants stated that they had stomach pains after drinking Red Bull, including making one participant have to leave the study due to those stomach pains. While the caffeine effects between the two were similar, caffeine supplements alone seem to be the better option. Lastly, the effects of caffeinated mouth rinse were investigated by Doering et al. (2014). Unlike most studies, researchers concluded that there was not a significant difference between the mouth rinse and placebo trials. Therefore, not all caffeine methods have a positive impact on cycling performance.

Implications

When it comes to earlier research done on the effects of caffeine on cycling performance, most researchers concluded that, at a base, caffeine has a positive impact on cyclists. All but a few trials that used any type of caffeine ingestion found a higher ergogenic effect in caffeine than a placebo and also compared to other supposed ergogenic methods. The authors also found that other than mouth rinse, many different methods of caffeine consumption can be effective in decreasing total time and increasing power output. Also, the idea that different levels of caffeine could have different effects was an important focus throughout the studies. However, it seems as though the range of 3 mg/kg BW to 6 mg/kg BW of caffeine have significantly similar effects throughout the trials.

While many researchers found that caffeine has a positive effect, the methods and foci were different in most. For example, Irwin et al. (2011) had their participants withdrawal from caffeine for four days straight. This is important because most studies had their participants only withdrawal from caffeine for two days. Here, researchers concluded that four days of withdrawal from caffeine may further desensitize caffeine drinkers, which would allow for more of a positive impact when caffeine is ultimately ingested. Another study that was unique was one that focused primarily on both females and males and their performance with caffeine. Skinner et al. (2019) found that females and males had significantly similar time performance improvements when taking caffeine supplements. This is important, because the majority of all studies do not include women as participants.

There are many implications of the effect of caffeine on trained cyclists. First, there are many different methods of caffeine that people use on a daily basis. However, athletes that know the methods that allow for the best result will then have an edge in their cycling races. For example, Paton, Costa, and Guglielmo (2015) concluded that caffeinated gum had a positive impact on the cyclists' power output and time performance, even though the gum was not consumed until after the first ten kilometers of the thirty-kilometer race. This is important because other studies with different methods of caffeine had their participants ingest the caffeine at an average of an hour before the trial. Therefore, one can conclude that ingesting caffeinated gum allows for a quicker method to obtain the effects of caffeine.

Another practical implication is the result of caffeine supplements having the most consistent positive impact over other methods, including a banned substance called PSE (Spence et al., 2013). In that study, though PSE is banned, it had very similar effects to the placebo, while caffeine had a larger impact on their performance. Studies also found that caffeine and Red Bull can be effective methods of caffeine consumption, though caffeine supplement had the least amount of side effects. Red Bull, while effective, created stomach issues for several participants that could lead to issues in the cyclist's performance alone. Overall, it is practical for athletes to use caffeine supplements for their races about an hour before, or caffeine gum during the race for the most positive impacts.

Recommendations for Future Research

In reviewing the data base on the effects of caffeine on the performance of trained cyclists, the following limitations were noted regarding the studies under review: the lack of female participants across all studies, lack of knowledge of participants truthfulness of caffeine withdrawal before trials, lack of amount of participants per study to make a significant conclusion, limited amount of studies focusing on different methods of caffeine other than supplements, and the variance in habituation of caffeine across all participants.

Based on these limitations and other insights related to the literature, the following recommendations for future research should be considered:

1. Further research in different caffeine methods (mouth rinse, gum, coffee, Red Bull)
2. Research on the effects of a controlled four day or longer caffeine withdrawal before the trial.
3. Further research on the effects of caffeine on both male and female cyclists.
4. More research into the effects of caffeine of habitual drinkers versus non-habitual drinkers.

Summary

The purpose of this literature review was to determine the effects of caffeine on the performance of trained cycling athletes. Delimiting variables were used to do an exhaustive data-based search which yielded fifteen articles. These articles were then systematically used to determine the effects of caffeine on the performance of trained cycling athletes.

Research revealed that caffeine has a positive impact on the cyclists' power input and time performance of time trials. Caffeine supplements were concluded as the most consistent option for cyclists, though coffee and caffeinated gum showed similar positive impacts as well. Caffeine also had a larger influence on cyclists than PSE, which is a banned substance, and beetroot juice, that is also known for its ergogenic effects. Furthermore, researchers that had the participants ingest caffeine an hour before the trial averaged the best results. Lastly, both males and females had similar increases in performance with caffeine consumption during their trials.

Even with overall positive results, further research into varying caffeine methods, larger participant pools that include more women, and caffeine withdrawal can lead to a clearer understanding of how effective caffeine can be for cyclists. When trained cyclists can increase their knowledge of the ergogenic effects of caffeine, and the processes of ingesting it, it can result in further success in the highly competitive sports of cycling.

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Appendix A

Author	Title	Source	Purpose	Methods & Procedures	Analysis	Findings	Discussion/ Recommendations Research Notes Commonalities/Differences
Spence, A., Sim, M., Landers, G., & Peeling, P. 2013	A Comparison of Caffeine Versus Pseudoephedrine on Cycling Time-Trial Performance	International Journal of Sport Nutrition & Exercise Metabolism	The purpose of the study was to determine if similar ergogenic effects could be obtained through the use of caffeine in comparison with PSE (Pseudoephedrine, a banned substance) during a 40 km cycling time trial.	10 well-trained male cyclists participated in a 40 km time trial on a stationary bike, analyzed by a bike ergometer. 60 minutes before the trial, participants were administered 200 mg of caffeine, 180 mg of PSE, or the placebo.	Time, power, heart Rate (HR), mean power output, blood, and rate of perceived effort (RPE) were analyzed.	Total time between caffeine and PSE trials were not significantly different. Although caffeine alone had the biggest impact, showing an average time of almost a minute faster than both the PSE and placebo trials. Therefore, PSE also did not have any more of an impact than a placebo. The back half of the trial of caffeine was significantly better in time and	PSE is a banned substance due to its supposed performance enhancing qualities. However, caffeine, which is legal, had more of an impact on the cyclists' power and time performance, especially in the second half of the race. PSE did not have more of an impact than a placebo. More studies should be done to show if PSE does have a true

						power than the PSE and placebo trials, showing that caffeine does have the superior effect for the second half of the race.	effect, and if it should continue to be banned.
Ferreira-Viana, B., Trajano, G. S. Ugrinowitsch, C. Olivera-Pires, F. 2020	Caffeine increases motor output entropy and performance in 4 km cycling time trial.	PLoS ONE	The purpose of the study is to verify if caffeine ingestion increases power output complexity and performance.	Nine endurance trained male athlete of ages ranging from 25 to 39. All were non-smokers, with low-to-moderate caffeine intake per day (<50mg). Cyclists performed a baseline 4km trial, then a 4km trial with 6mg/kg of caffeine taken 60 minutes before, 4km trial with a placebo.	Researchers used equipment on a bike that could test power output as the cyclists pedaled. Cyclists would rate their perceived exertion for the researchers every .5km. Researchers used both to motor output entropy.	Ingestion of caffeine resulted in an 8% increase in mean power output compared to the placebo. Rates of perceived exertion (RPE) were comparable with both supplements.	Results show that caffeine has an effect on power output, which would increase time trial performance. This also showed that perceived exertion is the same with caffeine as it is with a placebo, showing that you are performing better with caffeine without realizing. This article focuses more on power output and simple caffeine

							supplementation of 6mg/kg of body weight, while others focus on time and other factors, as well as implement different supplementations of caffeine.
Smolka, O., Kumstat, M. 2014	Caffeine Intake Enhances Endurance Performance in Sub-elite But Not in Elite Athletes	Annales Kinesiologiae	The purpose of the study was to evaluate the influence of caffeine ingestion on maximal power output during endurance performance.	Ten male sub-elite and eight elite male cyclists were chosen based on their biking metrics. Three different supplements were 2 mg/kg BW caffeine supplement, 7 mg/kg BW caffeine supplement and a placebo, all given 45 minutes before trial. Cyclists performed a 60-minute drive at 70% of their VO2	Power was analyzed through the bike software, as researchers compared that to the cyclists RPE	The maximal power output for elite athletes stayed consistent throughout each supplement. The sub-elite athletes displayed increased maximal power with the more caffeine they took (mean: 361W placebo, 365W 2mg/kg BW, 372W 7mg/kg BW	Caffeine has shown an effect in power output in most studies. However, it showed here that elite cyclists do not have much of a change in maximal power with caffeine vs placebos. However, sub-elite athletes gain a maximal power output with more caffeine intake. This also shows that higher doses of caffeine

				max on a software-controlled bike ergometer.			may have more of an impact. Still, the maximal power output was still significantly lower for sub-elite athletes than elite athletes through all experiments, with a max of 421W for sub-elite and 500W for elite. Therefore, preparedness overall has the largest impact, over caffeine itself for athletes.
Irwin, C., Desbrow, B., Ellis, A., O'Keeffe, B., Grant, G., Leveritt, M. 2011	Caffeine withdrawal and high-intensity endurance cycling performance.	Journal of Sports Sciences	The purpose of the study was to investigate the effect of an acute moderate caffeine dose (3mg/kg BW) on time trial performance following a 4-day controlled withdrawal	Twelve well-trained male cyclists with a mean age of 28 who ingested around 240mg of caffeine a day and were within specific VO2 max standards participated	Plasma caffeine, heart rate, and RPE were analyzed alongside the time.	Results show that placebos throughout the day provided the least amount of power output, and took them the longest to complete the trial. However, implementing caffeine before the	Caffeine withdrawal is significant to the impact that caffeine can have on athletes, as this study showed that when you have a time period of withdrawal, it shows

			period, in habitual caffeine consumers.	. Four experimental trials occurred, athletes were given two supplements each day of the trial, either placebo and caffeine supplement, or both in the same day, allowing for all four possibilities to occur, with one in the morning, and one 90 minutes before the trial. Cyclists would cycle one hour at 75% peak power for as far as they could get.		trial, especially when implemented earlier in the day as well, showed an increase of power output by 14W and decreased time taken for the trial by an average of two minutes and twenty seconds. RPE stayed consistent	that the cyclists are being especially impacted by caffeine after. 4 days may desensitize habitual caffeine drinkers to have the impact more thoroughly. Therefore, the amount of caffeine you intake habitually has an effect on how much of an impact caffeine will have on your cycling performance.
Skinner, T. L., Jenkins, D. G., Taaffe, D. R., Leveritt, M. D., Coombes, J. S. 2013	Coinciding exercise with peak serum caffeine does not improve cycling performance	Journal of Science & Medicine in Sport	The purpose of the study was to determine whether coinciding the onset of endurance exercise with peak serum	14 male competitively trained cyclists with a mean age of 31 participated. Participants would fast overnight,	Blood sampling, food diaries, HR, RPE, speed, and power were analyzed. Food diaries were important	Results showed that caffeine levels peaked at 120-150 minutes. Time decreased with caffeine	Knowing when to take caffeine seems like an important aspect of a cyclist's process. While the study

			caffeine concentration following a pre-exercise meal would result in further improvement.	eat a pre-exercise meal 20 minutes before ingesting 6mg/kg BW of a caffeine supplement or placebo. Trials would begin based on peak caffeine serum levels, while also doing one at one hour. Cyclists performed a 40km time trial.	to find correlations between different participants with the effects of the pre-trial meal in mind.	intake versus the placebo, by an average of a minute or more with the caffeine trials versus placebo. Peak caffeine concentration did not have significant effects compared to just taking caffeine one hour before the trial.	showed that caffeine decreases time taken for the trial, the one hour before supplement had more success than the one taken at the cyclists' peak caffeine serum rate. About every article has a different caffeine intake amount, so more studies need to be done to see the total picture on this concept.
Paton, C., Costa, V., Guglielmo, L. 2015	Effects of caffeine chewing on race performance and physiology in male and female cyclists	Journal of Sports Sciences	The purpose of this study was to investigate the effects of caffeine, delivered via chewing gum, on measures of endurance and sprint performanc	20 trained cyclists (10 males, 10 females) ages 20-40 performed a 30 km (3 10km laps) computer simulated course on a stationary bike, with a sprint in the last .2 km od each lap.	Oxygen consumption and heart rate were measured at the end of each lap. Blood lactate and measures of perceived exertion were obtained every 5 km. Means of	A small increase in power output overall and during the final sprint of the trial of caffeine taking athletes was shown. A time decrease was found in the first lap (1056	Caffeine is shown to decrease time and increase power output, even minimally, where every second counts. This all again with the same rate of

			e in trained cyclists.	Caffeine or a placebo gum (3-4mg/kg of body weight of caffeine) was given after the first 10km.	all were made into a spreadsheet.	seconds for placebo and 1049 seconds for caffeine) and the final lap (1126 to 1105 seconds for placebo and caffeine)	perceived exertion. Caffeine intake was less than many others (3-4mg/kg of body weight) Chewing gum has an effect just like caffeine supplements. Caffeine effects were fast acting, within 20 minutes of ingestion.
Roelands, B., Buyse, L., Pauwels, F., Delbeke, F., Deventer, L., Meeusen, R. 2011	No effect of caffeine on exercise performance in high ambient temperature.	European Journal of Applied Physiology	The purpose of the study is to determine the effects of caffeine supplements before the start of prolonged exercise on performance, thermoregulation and hormonal variables in high ambient temperature (30°C)	Eight trained mild caffeine consuming males with a mean age of 23 that were not accustomed to warm environments participated. Cyclists took 6 mg/kg BW of caffeine or the placebo one hour before exercise.	Urine samples, heart rate, blood samples, and core temperature were analyzed before and after each trial.	Caffeine administration did not significantly influence time trial time. Core temperatures increased more combined with caffeine than with placebo.	Caffeine may not have affected time significantly, but their core body temperature increased with caffeine. Therefore, environmental factors may have an impact on how effective caffeine is on performance.

				Cyclists cycled for 60 minutes at 55% max power.			
Bortolotti, H., Altimari, L. R., Vitor-Costa, M., Cyrino, E. S. 2014	Performance during a 20-km cycling time-trial after caffeine ingestion.	Journal of the International Society of Sports Nutrition	The purpose of the study was to analyze the effect of caffeine ingestion on the performance and physiological variables associated with fatigue in 20-km cycling time trials.	13 male cyclists with an average age of 26 received 6mg/kg BW caffeine capsules or placebos 60 minutes before performing a 20km time trial. No caffeine was ingested by the participants 48 hours before.	Distance, speed, power, rpm, rating of perceived exertion (RPE), electromyography (EMG) of the quadriceps muscles and heart rate (HR) were continuously measured during the tests. Participants also took a BRUMS questionnaire before and after tests to establish their mood.	Power, speed and cadence had an insignificant increase with the caffeine intake versus the placebo.	Caffeine abstinence for a longer period of time may lead to a bigger impact. Caffeine may not have as much of a factor in a shorter distance than other trials have done.
Anderson, D. E., German, R. E., Harrison, M. E., Bourassa, K. N., Taylor, C. E. 2020	Real and Perceived Effects of Caffeine on Sprint Cycling in Experienced Cyclists.	Journal of Strength & Conditioning Research	The purpose of this study was to determine the influence of the placebo effect of caffeine on anaerobic power and the overall influence	10 competitively trained cyclists (9 males, one female) were given highly caffeinated coffee (280mg), low caffeinated coffee (140mg),	Power was the main analysis: peak power, time to peak power, average power, power drop. After each trial, participants were asked	Time to peak power was significantly shorter for the trial in which subjects incorrectly guessed they had consumed caffeine when given the placebo	Different cycling races use groups or individuals. Knowing how caffeine affects sprints can lead to future success for certain

			of caffeine on cycling power in trained sprint cyclists using the Wingate Anaerobic Test	or a placebo 45 minutes before the trial.	to guess what caffeine they took.	compared with placebo trial. Power drop was significantly higher for the trial in which subjects incorrectly guessed they had consumed caffeine when given the placebo compared with placebo trial (524 6 37 vs. 433 6 35 W). There seems to be a placebo effect of caffeine on anaerobic performance.	areas of races. Coffee is a unique source of caffeine compared to other studies. Knowing you are taking caffeine may take away from how effective of an impact it has. The cyclists positive and negative expectations based on whether or not they had caffeine impacted their performance.
Lane, S. C., Hawley, J. A., Desbrow, B., Jones, A. M., Blackwell, J. R., Ross, M. L., Zemski, A. J., Burke, L. M. 2014	Single and combined effects of beetroot juice and caffeine supplementation on cycling time trial performance	Applied Physiology, Nutrition & Metabolism	The purpose of this project was to investigate the independent and combined effects of caffeine and NO3 − supplementation on the performanc	12 male (mean 31) and 12 female (mean 28) competitive cyclists took a caffeinated gum (3 mg/kg BW) 40 minutes before TT, a concentrate	8ml of whole blood was taken throughout the trial, before beginning, during the warmup, right after the warmup, and after the trial.	Males with caffeine showed the most improvement in time (50 seconds faster) and power (11W) compared to the placebo. Females has similar	It is important to see if certain additives with caffeine can enhance the effect, or alone those different supplements have an effect

			e of a cycling task simulating the physical challenges of the London 2012 Olympic Games road cycling time trial	d beetroot juice supplement 2 hours before TT, a caffeine and beetroot juice supplement, or placebo. Males completed a 43.83km course and females completed a 29.35km course on a Velotron cycle ergometer as quickly as possible.	The blood was analyzed for caffeine, NO3, and nitrate concentrations. With the ergometer, they analyzed time and power, while also testing their heart rate and their RPE.	improvements with caffeine in time (50 seconds) and power (9W) compared to the control. Both had no significant ergogenic changes with beetroot juice alone compared to the placebo. Beetroot juice also did not add to any more improvement when taken with caffeine, compared to when cyclists just took caffeine.	similar to caffeine. Nitrates have been shown in other studies to improve cardiovascular health and enhance high intensity activities. Though beetroot juice increased the cyclists nitrate levels, the results showed it did not improve their ability to perform the trial, nor did it give an added benefit with caffeine. Different cyclists had different trials, may have ingested different foods across their time in the study that could affect the trials.

Doering, T. M., Fell, J. W., Leveritt, M. D., Desbrow, B., Shing, C. M. 2014	The Effect of a Caffeinated Mouth-Rinse on Endurance Cycling Time-Trial Performance.	International Journal of Sport Nutrition & Exercise Metabolism	The purpose of this study was to investigate if acute caffeine exposure via mouth-rinse improved endurance cycling time-trial performance in well-trained cyclists.	Ten well-trained male cyclists with a mean age of 32 completed two experimental time trials where they cycled at 75% of peak power for 60 minutes. Cyclists were given 25ml mouth rinses for 10 seconds with either 35mg of caffeine eight times throughout the trial, or a placebo each of those times.	Blood was taken before and after the trial to analyze caffeine concentration. RPE and heart rate were also taken.	Results show that there was not any significant improvement for the well-trained cyclists when taking mouth rinse throughout the trial. Their caffeine blood levels also did not elevate during the trial. The mouth rinse also did not affect physiological or perceptions during the trial.	Studies like this that use mouth rinse or others that use gum suggest that caffeine can be ingested in the mouth through the buccal cavity more quickly than other methods. While gum showed positive improvements in other studies, the mouth rinse did not. Maybe giving it to them earlier will allow more time for the caffeine to be ingested and implemented into the bloodstream. However, this also raises the question to whether or not mouth rinse is actually effective since the trial was an

							hour long. Another possibility is that the lower doses of caffeine throughout do not have the same effect as one larger dose of caffeine. Since this is the first study of mouth rinse effectiveness, more accounts of this should be researched.
Desbrow, B., Biddulph, C., Devlin, B., Grant, G., Anoopkumar-Dukie, S., Leveritt, M. 2012	The effects of different doses of caffeine on endurance cycling time trial performance	Journal of Sports Sciences	The purpose of the study was to investigate the effects of two different doses of caffeine on endurance cycle time trial performance in male athletes.	16 well-trained male cyclists of a mean age of 32 ingested a 3mg/kg BW caffeine supplement, 6mg/kg BW caffeine supplement, or a placebo 90 minutes before the trial. Cyclists biked on a stationary bike at 75% power for 60 minutes.	Blood, heart rate, RPE, and ergogenic data were analyzed in the study for caffeine concentration,	Exercise performance improved by 4.2% with 3mg/kg of caffeine and 2.9% with 6mg/kg of caffeine, though the difference between the two caffeine was not considered to be statistically significant. Heart rate increased significantly with caffeine compared	Heart rate had not had a significant difference in most studies, but this study showed that caffeine increased it. Both caffeine supplements gave cyclists more performance success than the placebo, but the higher dose of caffeine

						to the placebo.	did not have any more of an impact than the lower dose.
Quinlivan, A., Irwin, C., Grant, G., Anoopkumar-Dukie, S., Leveritt, M., Desbrow, B. 2015	The Effects of Red Bull Energy Drink Compared with Caffeine on Cycling Time-Trial Performance.	International Journal of Sports Physiology & Performance	The purpose of the study to compare the effects of a popular energy drink (Red Bull) containing a moderate dose of caffeine (3 mg/kg BM) or an equivalent dose of anhydrous caffeine in a CHO-matched beverage in comparison with a noncaffeinated control beverage on endurance-cycling TT performance in trained participants.	Eleven trained male cyclists with a mean age of 31 were given Red Bull or a caffeine capsule both containing 3mg/kg BW of caffeine. The study also included a placebo. All ingestion methods were taken by liquid, and 90 minutes before the 75% power for 60 minutes time trial.	Time, power output, heartrate, RPE, quadriceps muscle pain postexercise, and blood glucose were analyzed throughout the trial.	The caffeine supplement gave cyclists an improved time by 120 seconds, while the red bull drink improved their time by 109 seconds compared to the placebo. Both power outputs of the non-placebo beverages had improved similarly. RPE, heart rate, and quadricep muscle fatigue had no statistically significant changes. Other aspects of Red Bull like taurine, glucuronolactone, and B-complex	Red Bull showed to have a positive impact on athletes' performances, similarly to caffeine alone. However, gastric issues effected 25% of the participants, enough to make one withdrawal from the study. Therefore, even though there are benefits to Red Bull, caffeine has the same effect without any major side effects.

						vitamins showed no additional benefits to caffeine alone. Interestingly, gastric discomfort was described as having an effect on three different participants, including one (a twelfth participant) who withdrew from the study after experiencing severe stomach pains after drinking Red Bull.	
Hodgson, A. B., Randell, R. K., Jeukendrup, A. E. 2013	The Metabolic and Performance Effects of Caffeine Compared to Coffee during Endurance Exercise.	PLoS ONE.	The purpose of the study was to investigate whether acute intake of coffee (5 mg CAF/kg BW) and anhydrous caffeine (5 mg CAF/kg BW) are ergogenic to cycling performance compared to	Eight trained male cyclists with a mean age of 41 completed a 30-minute steady-state cycle at 55% VO2 max followed by a 45-minute time trial at 70% power. One	Blood, heart rate, and time were analyzed throughout the trials. This led to an understanding of different caffeine concentrations and how that affected the time differences	Caffeine concentration peaked at the beginning of the trial, 60 minutes after drinking caffeine or coffee. Caffeine alone had a higher peak than coffee, yet finish times were within seconds of each other	Coffee was analyzed in another study, yet this one is different because the participants were not asked about what they perceived was coffee and not coffee. In this study, unlike the other one, coffee alone

			decaffeinated coffee or placebo beverages when using a validated 45-minute time trial performance test.	hour prior to exercise, each athlete drank drinks consisting of either just caffeine (5 mg CAF/kg BW), instant coffee (5 mg CAF/kg BW), instant decaffeinated coffee or placebo		with both options. Both caffeine and coffee had significant improvements in time at over 4% compared to both decaf and placebo trials.	showed to have a positive effect on time performance. However, caffeine had a very similar effect, showing that coffee isn't more effective. Still, coffee can be a reliable source for caffeine, especially when athletes know that peak caffeine levels were shown at one hour after consumption.
Skinner, T. L., Desbrow, B., Arapova, J., Schaumberg, M. A., Osborne, J., Grant, G. D., Anoopkumar-Dukie, S., Leveritt, M. 2019	Women Experience the Same Ergogenic Response to Caffeine as Men.	Medicine & Science in Sports & Exercise	This study aimed to determine whether 1) consumption of caffeine improves endurance cycling performance in women and 2) sex differences exist in the magnitude of the	27 participants of 11 women (mean 29) and 16 men (mean 32) completed a 75% power output for a "set amount of work" never specified. 90 minutes	RPE, time, HR, and blood were analyzed for values that are most affected by caffeine.	Time improved by about 169 seconds for both males and females with caffeine instead of a placebo. No significant differences were found between	Hardly any studies have females as participants, and this one has a focus on them and compares the impact to males. The study did not specify the distance

			ergogenic and plasma responses to caffeine supplementation.	before the trials, the cyclists took a 3 mg/kg BW caffeine capsule or a placebo.		males and females in time performance difference. Caffeine concentration in the females' plasma were significantly greater in women after exercise.	they traveled, though the trial was done in a little over 60 minutes. Women and men both were enhanced by caffeine compared to placebos. Shows that the range of caffeine of 3-6mg/kg BW that is often used in studies can be just as effective for women as men. Women had higher concentrations of caffeine after the trial ended, which suggests there could be more studies done to see if longer trials could have a different effect between males and females.