The Effects of a Recommended Dose of a Pre-Workout Supplement on Anaerobic Performance

Alyssa Labrosse and Jessica Luder
Department of Sport Science, Douglas College, New Westminster, British Columbia.

Introduction

Pre-workout supplements have been gaining popularity amongst young athletes and fitness enthusiasts, due to their flavours that mimic candy and other treats, as well as the performance enhancements that are said to follow ingestion (Shoshan & Post, 2021). Pre-workout has also seen a spike in use more recently due to the growing population of young athletes wanting to increase their performance quickly and succeed with less difficulty (Çetin et al., 2018). More specifically, multi ingredient pre-workout supplements are seen more and more, containing ingredients like creatine, amino acids, caffeine, and many more (Harty et al., 2018). When combined, these ingredients are meant to complement each other to enhance the body's ergogenic performance during exercise (Harty et al., 2018). Multi-ingredient pre-workouts are said to enhance sympathetic response, substrate availability, and muscle contraction during exercise (Figueiredo et al., 2020). Many pre-workout supplements promise positive effects like extreme energy, increased focus, increased endurance and more. The question is, are the benefits that pre-workout supplements pose really worth their cost? In this study we will be observing the effects of a recommended dose of C4 (a popular multi ingredient pre-workout supplement) on anaerobic performance.

Literature Review

What is pre workout? How does it affect the body?

Multi-ingredient pre-workout supplements are a type of sport nutrition product that elevate the body's physiological and psychological performance during exercise (Fye et al., 2021). Pre-workout significantly improves focus, alertness, and perceived energy when taken 20 minutes before a workout (Spradley et al., 2012). A study by Leutholtz et al., found that a multi-ingredient pre-workout called NO-Shotgun increased muscle strength as well as mass,

and the protein content at the myofibril level when used for 28 days alongside resistance exercise training (2009). However, changes to body composition in a study done by Outlaw et al., found that pre-workout had no significant acute effects on body composition (2014).

Many multi-ingredient pre-workouts contain ingredients like caffeine, amino acids, nitric oxide agents, creatine, and other botanical enhancers (Figueiredo et al., 2020). There are many factors that influence what ingredients and how much of each ingredient are used in a supplement, a few examples being; physiological rationale, cost, formula patents, ingredient availability, and taste (Jagim et al., 2019b). Due to the caffeine in pre-workout, the cardiovascular system experiences an increase in blood pressure and heart rate (Benjamim et al., 2021). Caffeine is thought to be the main performance impactor as it has ergogenic effects which include increased myofibrillar calcium availability, enhanced metabolism and substrate availability, and the increased stimulation of the central nervous system (Guest et al., 2021). A potential downfall of caffeine in the supplement is that it is a diuretic, which can increase the rate of dehydration if proper water consumption is not attained during exercise (Benjamim et al., 2021). Branch chain amino acids are often added to the multi-ingredient pre-workout supplements because it helps to increase the rate of protein synthesis in the muscles, reducing the time it takes to heal damage done to muscle tissues during a workout (Harty et al., 2018). The amino acid creatine is naturally occurring in the body and has the main metabolic role to combine with phosphorus to create the enzyme creatine kinase, which is important in energy production (Kreider et al., 2017). Nitric oxide agents promote vasodilation and increase blood flow to the muscles during exercise (Domínguez et al., 2018). A study by Dominguez et al., found that when consuming doses of 300mg or greater of dietary nitrate, acute endurance and high intensity exercise performance were increased (2018).

Pre-workout supplements have many dangerous side effects including hemorrhagic stroke and cardiac arrest (Wang, 2020). These conditions could be due to different dangerous pharmacological ingredients such as stimulants like DMAA (1,3 Dimethylamylamine) and DMBA, which is 1,3-dimethylbutylamine that are usually present in multi-ingredient pre-workout supplements (Wang, 2020). Acute consumption also showed no impact on human growth hormone (Schwarz & McKinley-Bernard, 2020). However, another study found that one third of their participants who consumed multi-ingredient pre-workout along with other caffeinated products on a regular basis for a long period of time did have some negative side effects, which is why it is suggested that more research is done on the long term use of pre-workout (Jagim et al., 2019a). For short term use in active females, after consuming a multi-ingredient pre-workout for 28 days, there were no changes seen in haematological chemistry, metabolic markers, or resting vital signs (Vogel et al., 2015). No negative effects are seen with resting blood pressure, blood lipid levels, and resting heart rate in females (Nelson et al., 2019). An 8 week study with healthy males also found that there were no significant side effects from the consumption of pre-workout (Jung et al., 2017). A study looking at the influence of pre-workout on androgen receptors and glucocorticoid activation following resistance exercise found that the supplementation very minimally influenced an early recovery response, and had no influence on cortisol and testosterone levels (Nicoll, Fry & Mosier, 2021).

Pre-Workout on Power and Endurance

The intake of multi ingredient pre-workout has shown to increase performance during exercise to exhaustion, explosive power, anaerobic power, and maximum strength (Figueiredo et al., 2020). Not only has it been shown to improve physical functioning, it also improves cognitive function and the athletes perceived readiness to perform (Figueiredo et al., 2020). A study done by Figueiredo et al., found that consuming multi-ingredient

pre-workout supplements had a major increase in the effectiveness of the oxidative energy system by 23.8% and the ATP-CP energy system by 28.4% (Figueiredo et al., 2020). Gonzalez et al., observed the effect of a pre-workout energy supplement on multi-joint resistance exercises in which participants chose either to do the barbell back squat exercise or the barbell bench press exercise (2011). Results indicated that after acute ingestion of the pre-workout supplement, the number of repetitions performed in either resistance exercise (whether it was the barbell back squat or the barbell bench press) increased, leading to greater peak and mean power performance (Gonzalez et al., 2011).

Cameron et al., conducted a study to determine if there are any acute effects of a multi-ingredient pre-workout supplement on resting energy expenditure and exercise performance in active females (2018). There were acute elevations in resting energy expenditure as well as a positive increase in upper body muscular endurance, which over time may lead to individuals working with greater training volumes, and therefore enhancing training adaptations (Cameron et al., 2018). Effects of a pre-workout energy drink supplement on upper body muscular endurance was observed among healthy males and females (Magrini et al., 2016). Results show that there is improved performance in muscular endurance over multiple push-up sets to fatigue (Magrini et al., 2016). Concentric contraction forces were impacted by the consumption of a multi-ingredient pre-workout, and consumption of caffeinated and non-caffeinated supplements increased minimally concentric force production in males, but not in females (Tinsley et al., 2017). To conclude, most studies observed an improvement in performance for muscular endurance and resting energy expenditure.

A study was conducted to determine if a pre-exercise energy drink has any positive effects on multiple aspects of fitness (Campbell, Richmond, & Dawes, 2016). A vertical jump test, upper body muscular endurance test (YMCA bench press), and trunk muscular

endurance (curl-up test) were tested and re-tested to see if a pre-exercise energy drink had any influence on performance (Campbell et al., 2016). Results showed that the vertical jump test improved slightly, which was an improvement of 1.0%, following consumption of the pre-exercise energy drink compared to the placebo treatment (Campbell et al., 2016). The curl-up test improved after consumption of the pre-exercise energy drink compared to the placebo treatment as well. Furthermore the curl-up performance increased by 21% in individuals who consumed the energy drink, while it decreased by 15% in the placebo treatment. Lastly, the YMCA bench press also saw an increase in performance in the pre-exercise energy drink consumers over the placebo treatment (Campbell et al., 2016).

A vertical jump test to observe lower body power was conducted on women after consumption of a pre-workout supplement and results showed no significant improvement in performance (Lane et al., 2019). Upper body power was also observed by doing a bench press exercise before and after consumption of the pre-workout supplement, as well as a high intensity cycle test to observe maximum and peak power output (Lane et al., 2019). The bench press test and high intensity cycle test also did not show any significant improvements after participants took the pre-workout supplement (Lane et al., 2019). A study done by Collins et al., (2017) found that a ready-to-drink pre-workout supplement has some impact on individuals' recovery time for the 1-RM bench press and leg press and there was improvement in recovery of muscular endurance after acute and short-term ingestion of this ready-to-drink pre-workout supplement. There wasn't, however, an increase in these individuals' 1-RM leg press or bench press weight (Collins et al., 2017). A study done to observe the effects of a pre-workout supplement on upper and lower body power and upper body strength in an active population found that there was no significant benefit of ingestion of the pre-workout prior to execution of the fitness tests of power and strength (Martinez et al., 2016).

Pre-Workout on Training After Multiple Weeks

Multiple studies have been done to determine if pre-workout supplements have an effect on fitness training over a period of multiple weeks. The effects of a multi-ingredient pre-workout supplement was observed over a four week training period in young, active men and results showed that greater increases in strength, specifically with the bench press exercise and total weight lifted, was present compared to the placebo group (Kreipke et al., 2015). The effects of a multi-ingredient pre-workout supplement was done over an eight week training program in a different study and results suggested that the multi-ingredient pre-workout supplement contributed to an increase in thickness of the quadriceps muscle compared to the placebo group (Lowery et al., 2013). Lean body mass also increased significantly more in the pre-workout supplementation group than the placebo group (Lowery et al., 2013). Lastly, there was more of an increase in bench press strength in the pre-workout group compared to the placebo group (Lowery et al., 2013). A 28 day resistance exercise program while consuming both pre- and post- workout supplements was conducted to determine if this kind of supplementation had an influence on body composition, muscular strength, muscle mass, and markers of protein synthesis (Spillane et al, 2011). Results indicated that both pre- and post- supplementation had a positive influence on fat-free mass and upper and lower body muscular strength (Spillane et al., 2011).

Pre-workout supplements with the ingredient synephrine (a substance found in some plants and animals that aids in digestion and circulation) and pre-workout supplements without synephrine were tested on resistance-trained males over a span of 8 weeks to see if there was an effect on training adaptation. Some evidence showed that there was an increase in 1-RM strength gains in the pre-workout supplement groups versus the placebo group after the 8 week training program (Jung et al., 2017). Evidence also showed that there was an increase in peak power, mean power, and total work during an aerobic capacity sprint test in

the pre-workout supplement group compared to the placebo group (Jung et al., 2017). There were, however, no significant benefits of the pre-workout supplement with synephrine compared to the pre-workout supplement without synephrine (Jung et al., 2017). Therefore, in this study synephrine did not improve the pre-workout supplement's effects.

Body composition, anabolic hormones, strength, and power were measured to determine if pre-workout supplements had an influence on these factors after six weeks of consumption (Ormsbee et al., 2012). Results showed significant improvements in lean mass and anaerobic power using the Wingate test (Ormsbee et al., 2012). In another study, after six weeks of supplementation of a pre-workout supplement complemented with a heavy resistance training program, higher feelings of energy and lower feelings of fatigue were present among participants (Kedia et al., 2014).

Although the study Ormsbee et al. (2014) conducted showed improvements in lean mass and anaerobic power, there were no significant benefits observed for muscular strength for the pre-workout supplement group compared to the placebo group. While Kedia et al. (2014) discovered lower feelings of fatigue and high feelings of energy after six weeks of pre-workout supplementation and a heavy resistance training program, there was no improvement in markers of muscular performance such as upper and lower body power, muscular endurance, and strength.

Pre-Workout on Aerobic Performance

A study done on NCAA cross country athletes by Fye et al., found that the use of multi-ingredient pre-workout supplements increased athletes' time to fatigue and post exercise blood lactate levels (2021). This means that athletes who consumed pre-workout were able to handle higher levels of blood lactate circulating in their bodies before reaching exhaustion (Fye et al., 2020). These particular NCAA cross country athletes experienced physical improvements when it came to consumption of a pre-workout supplement.

Although some studies have found that pre-workout supplements have had a positive effect on performance, for college basketball players, an aerobic test called the Yo-Yo Intermittent Recovery Test 1 was used to determine if a pre-workout supplement had an influence on each athletes' results, and it was found that there was no positive effect on these basketball players' aerobic performance (Çetin et al., 2018). Multiple female subjects participated in a research study to determine if there was an effect of one versus two doses of a multi-ingredient supplement on metabolic factors and perceived exertion during moderate-intensity running (Erickson, et al., 2020). Results showed that the multi-ingredient pre-workout supplement had no effect on metabolic factors or perceived exertion during the submaximal 30 minute treadmill run, however, there was an increase in systolic blood pressure and diastolic blood pressure in the one and two dose supplement group as opposed to the placebo group (Erickson et al., 2020). To conclude, there are mixed results as to whether pre-workout supplements have a positive influence on aerobic performance.

Pre-Workout on Anaerobic Performance

Anaerobic performance using the Wingate test was conducted on resistance-trained men after supplementation of pre-workout (Kaczka et al., 2020). The pre-workout supplement that was used had a positive effect on improving resistance and high intensity performance (Kaczka et al., 2020). This particular supplement showed that its effects could improve strength and overall delay or fatigue (Kaczka et al., 2020). There has been observed improvement in mean power output during an anaerobic capacity sprint test after consuming one serving of a multi ingredient pre-workout (Jagim et al., 2016). In a study done on college basketball players, anaerobic performance tests including the running-based anaerobic sprint test and the countermovement vertical jump test were influenced positively by the consumption of a pre-workout supplement (Çetin et al., 2018). Using the Wingate test researchers determined that acute ingestion of a pre-workout supplement can notably improve

anaerobic peak power and mean power in active males (Martinez et al., 2016). Another article suggests that acute ingestion of a pre-exercise supplement may enhance running performance over a 3-week period when combined with high intensity interval training (Kendall et al., 2010).

Using repeated 30 second Wingate tests, Herbe et al. found that peak power and mean power were not affected by the multi ingredient pre-workout supplement they used (2019). Power decline, acknowledged as a percentage, was also not affected after repeated Wingate tests were performed (Herbe et al., 2018). Examination of a pre-exercise supplement on exercise performance showed that reaction time, self-perceived feelings of energy, and focus significantly increased, however, there was no significant improvement of anaerobic power performance (Hoffman et al., 2009).

From these studies, it is clear that there are conflicting results about the effectiveness of multi-ingredient pre-workout supplements on physical performance. Even though it is still unclear on how great of a significance pre-workout can improve performance, there is evidence to suggest that it does impact the body in some way. This study aims to provide more insight specifically on how pre-workout affects short duration high intensity exercise.

Methods

Study Design

For this study a blind, within-subject study design was used. Each participant performed both testing conditions. One of the conditions being the wingate test with the consumption of a placebo (2ml of "ZAZ Fruit Punch Liquid Water Enhancer") 30 minutes before the test. The second condition being another wingate test thirty minutes after consumption of the pre-workout supplement. The recommended dose (1scoop/6.5grams) of pre-workout "C-4: Original Pre Workout Powder" was kept the same for each participant.

This study was given approval from the Douglas College ethics board before it was conducted.

Participants

Nine Douglas College students were chosen via convenient random sampling. Snowball sampling also occurred as some participants told other people they knew would be interested in participating. Participants contacted the researchers if they were interested and willing to participate. Participants with a history of heart disease, extreme caffeine sensitivity, or severe food allergies were not allowed to participate. All participants read the description of the study including the possible risks, and had the opportunity to ask any questions. Once having received all information if they agreed to participate they signed a written consent form. Once consent had been attained, participants were given a time to come into the Douglas College New Westminster campus sport science lab. Participants were asked to be available for two one hour time windows on different days.

Equipment

To conduct this research, a laboratory testing room was needed containing a Velotron. A weighing scale to measure participants weight before the test was needed. Height was also measured for the purposes of the test. Three blood lactate measuring strips were used for each participant. A pulse oximeter was used to measure heart rate. 6.5 grams of pre-workout "C-4: Original Pre Workout Powder" mixed in 1 cup of water were needed for each person. This dose of pre-workout was used because it is the recommended dose by the brand on the packaging. And the single serve dose (2ml) of "ZAZ Fruit Punch Liquid Water Enhancer" was mixed in 1 cup of water for the placebo. "ZAZ Fruit Punch Liquid Water Enhancer" was chosen because it is sugar free, thus minimising the effects that the placebo could cause on the participant, it also had a very similar taste and colour to the pre-workout supplement which can be seen in Figure 1. A food scale was used to measure out the proper dosage of the

supplements. Disposable cups were used to administer the pre workout powder and water drink mix to each participant.

Figure 1

Final Preparation Image of C4 Supplement and Placebo

Note. The liquid in the left cup is the prepared C4 pre-workout supplement, and the right cup is the prepared placebo.

Experimental Design/Procedure

Participants were asked to come into the lab on two separate occasions to perform two Wingate tests. Prior to coming into the lab participants were asked to not consume any caffeine at least four hours before the test. Participants also needed to not consume any food for up to two hours before the test. Participants were asked to come wearing light weighted clothing of a t-shirt or tank top, pants they could move comfortably in, and runners or cycling footwear. Before the wingate test could begin, the participants' body mass in kilograms was obtained by having them remove any accessories/shoes and then stepping onto a physician scale. Their height was measured at the same time in centimetres.

For both days the participants came in, the same protocol was used. However, one day the participant drank the pre-workout supplement, and the other day they drank the placebo solution. When participants arrived, they were to sit quietly for five minutes. Following this,

heart rate was taken.. This was to give a baseline of the participants heart rate before exercise and the supplements. The participants were then given a dose of 6.5 grams of "C-4: Original Pre Workout Powder" mixed with 250ml of water or a single serve dose (2ml) of "ZAZ Fruit Punch Liquid Water Enhancer" was mixed in 250ml of water for the placebo . The 6.5 gram dose of pre-workout contained 150mg of caffeine which is within a safe consumption amount. After consumption of the supplement or placebo participants then waited for 30 minutes, sitting quietly for the last 5 minutes. A 30 minute wait time was chosen due to caffeine being the most effective when consumed 30-60 minutes before exercise (Vogel et al., 2015). After the 30 minutes, heart rate was taken again as well as the first blood lactate sample. The participant then performed a three and a half minute warmup at 75 W on the bike (Bonetti de Poli et al., 2021). Once the three and a half minutes were up the administrator counted down "3-2-1-GO", and on "go" the calculated test weight was added, and participants began cycling at a maximal level for the 30 seconds (Maciejewska-Skrendo et al., 2019). The administrator counted down from 3 again ending with a "stop" to let the participant know once the test was over. Blood lactate and heart rate were taken immediately after cessation of the test. Participants were encouraged to cycle lightly or get off the bike and walk around the room to prevent venous pooling and delayed onset muscle soreness. Two minutes after the test was complete, the participants' blood lactate was taken one last time. The data collected from the ergometer during the test was min, mean, and peak Watts and RPM, anaerobic power, anaerobic capacity, as well as fatigue index. Before participants left they were recommended to not drink any more caffeine for the rest of the day, and encouraged to drink a lot of water and stay hydrated.

Results

Using Microsoft Excel Analysis ToolPak a series of single factor ANOVAS were run. All graphs and tables were also created using Microsoft Excel. Table 1 (below) shows a list

of all the ANOVAS run, the significance (p-value), along with the differences between the averages from the placebo and C4 supplement group. The ANOVA looking at the fatigue index between the placebo and C4 group had a p-value of 0.18, degrees of freedom (df) of 17, and an f-value of 1.98. From figure 2, the average fatigue index for the placebo group (in green) was 16.09W/s, and the average fatigue index for the C4 supplement group (in blue) was 11.99W/s.

Post wingate blood lactate was taken 2 minutes after completion of the wingate test. The ANOVA done for post blood lactate had a p-value of 0.88, df of 17, with a f-value of 0.02. Figure 3 shows the average post wingate test blood lactate levels for the placebo group (in green) at 12.10mmol/L, and the supplement group (in blue) at 11.78mmol/L.

ANOVAS for anaerobic capacity and anaerobic power were also run. For anaerobic capacity the p-value was 0.35, df was 17, and f-value was 0.92. Anaerobic power results had a p-value of 0.68, df of 17, and an f-value of 0.18. Figure 4 shows the averages for both anaerobic capacity and anaerobic power for both the placebo and C4 supplement trials. The placebo trials had an anaerobic capacity average of 6.99W/s and an anaerobic power average of 9.81W/s. The C4 trials had an anaerobic capacity average of 7.92W/s, and an anaerobic power average of 10.14W/s.

Heart rate was the next data that was analysed. Resting heart rate was taken 30 minutes after consumption of the placebo and the C4 supplement. The ANOVA for resting heart rate had a p-value of 0.48, df of 17, and a f-value of 0.52. Figure 5 shows the average resting heart rate for both the placebo and C4 trials. The average resting heart rate for the placebo group (in green) was 75bpm, and the average resting heart rate for the C4 group was 72bpm. The ANOVA for post wingate heart rate (which was taken immediately following cessation of the test) had a p-value of 0.67, df of 17, and a f-value of 0.18. In figure 5, the

average post test heart rate for the placebo trials (in green) was 158bpm, and the average post test heart rate for the C4 supplement trials was 163bpm.

Lastly, ANOVAS for both mean and peak Watts were done. For mean Watts there was a p-value of 0.21, df of 17, and an f-value of 1.68. In figure 6, the average mean Watts for the placebo trials was 571.67W, and for the C4 trials was 491.33W. Peak Watts had a p-value of 0.20, df of 17, and an f-value of 1.81. In figure 6, the average peak Watts for the placebo trials was 819.89W, and the average for the C4 trials was 671.11W.

Table 1

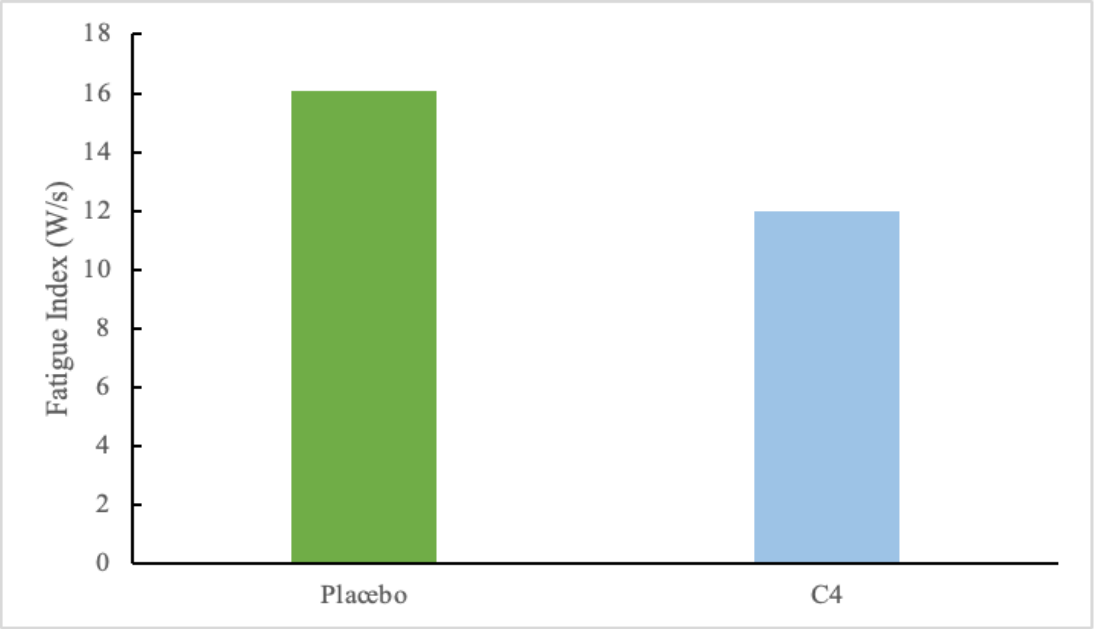
Data Averages of C4 Supplement Compared to Placebo

Variable	Placebo Average	C4 Average	Difference	p-value
Fatigue Index (W/s)	16.09	11.99	-4.10	0.18
Post Blood Lactate (mmol/L)	12.10	11.78	-0.32	0.88
Anaerobic Capacity (W/kg)	6.99	7.92	0.93	0.35
Anaerobic Power (W/kg)	9.81	10.14	0.33	0.68
Resting Heart Rate (bpm)	75	72	-2.89	0.48
Post Test Heart Rate (bpm)	158	163	4.78	0.67
Mean Watts	571.67	491.33	-80.33	0.21
Peak Watts	819.89	671.11	-148.78	0.20

Note. Placebo averages and C4 supplement averages are listed as well as the differences between them. The significance (p-value) from the ANOVAS is listed in the last column.

Figure 4

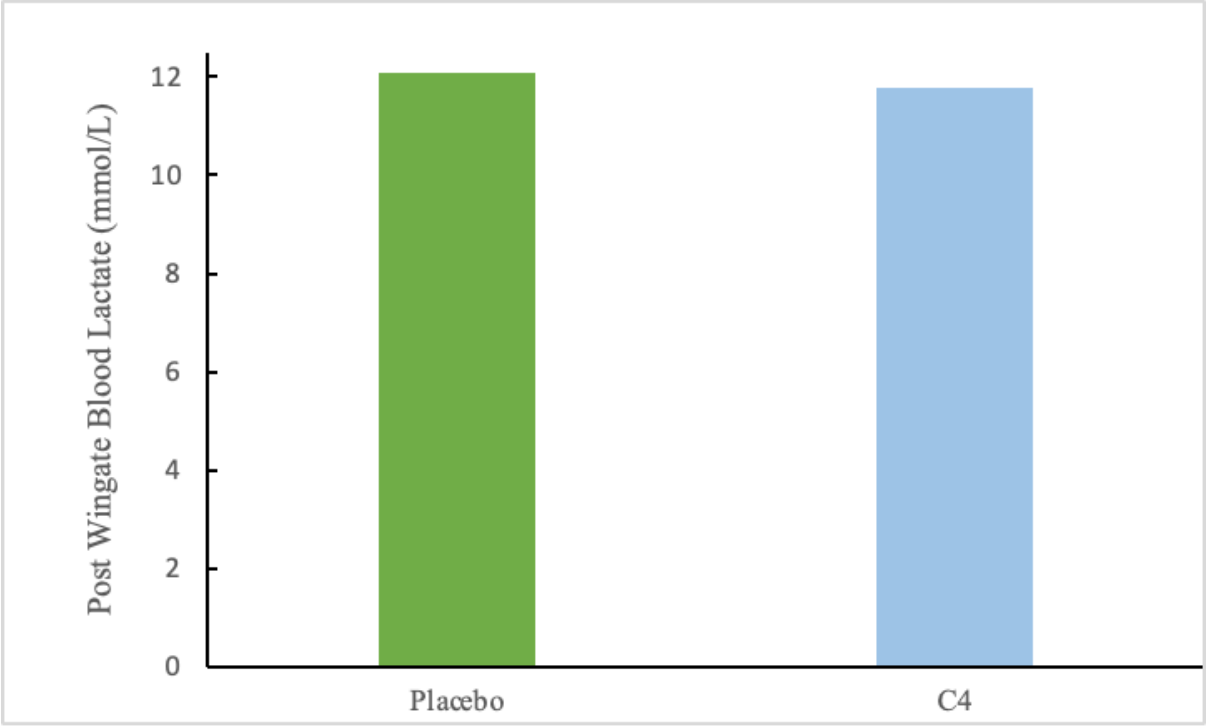
Average Fatigue Index of Placebo Group and C4 Supplement Group Post Wingate



Note. Fatigue index for the placebo group's results can be seen on the left in green with an average fatigue index of 16.09W/s, while the C4 supplement group's results can be seen on the right in blue with an average fatigue index of 11.99W/s.

Figure 5

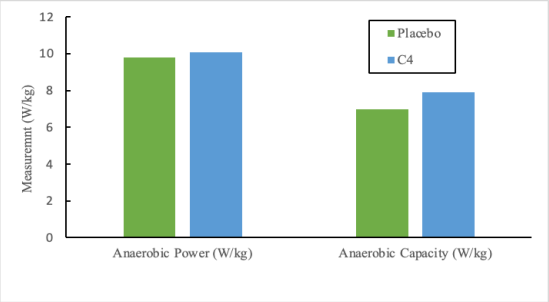
Average Post Wingate Blood Lactate Levels for Placebo and C4Supplement Groups



Note. Average post-Wingate blood lactate levels can be seen with the placebo group having an average of 12.10mmol/L, while the C4 pre-workout supplement had an average post-Wingate blood lactate of 11.78mmol/L.

Figure 6

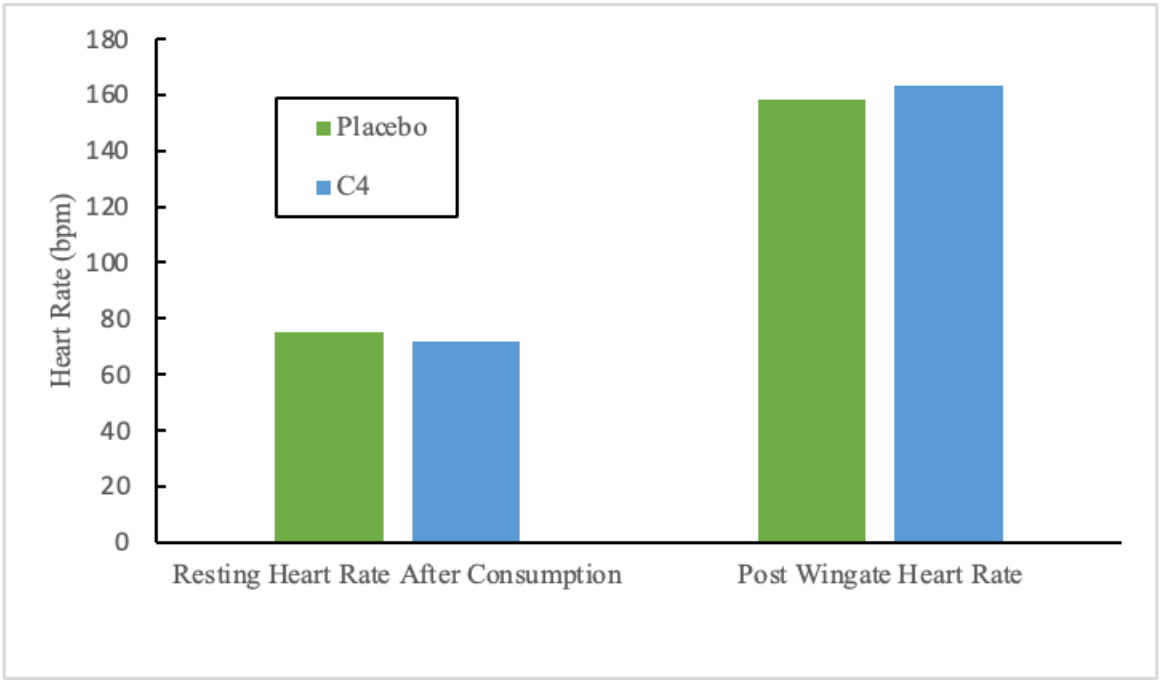
Average Anaerobic Power and Capacity for Placebo and C4 Supplement Groups



Note. Average anaerobic power is on the left with the placebo group represented in green, and the C4 supplement represented in blue. Anaerobic capacity is on the right, again with the placebo group in green, and the C4 supplement in blue. The average anaerobic power for the placebo group was 9.81W/kg, while the C4 supplement group was 10.14W/kg. The average anaerobic capacity for the placebo group was 6.99W/kg while the C4 supplement group was 7.92W/kg.

Figure 7

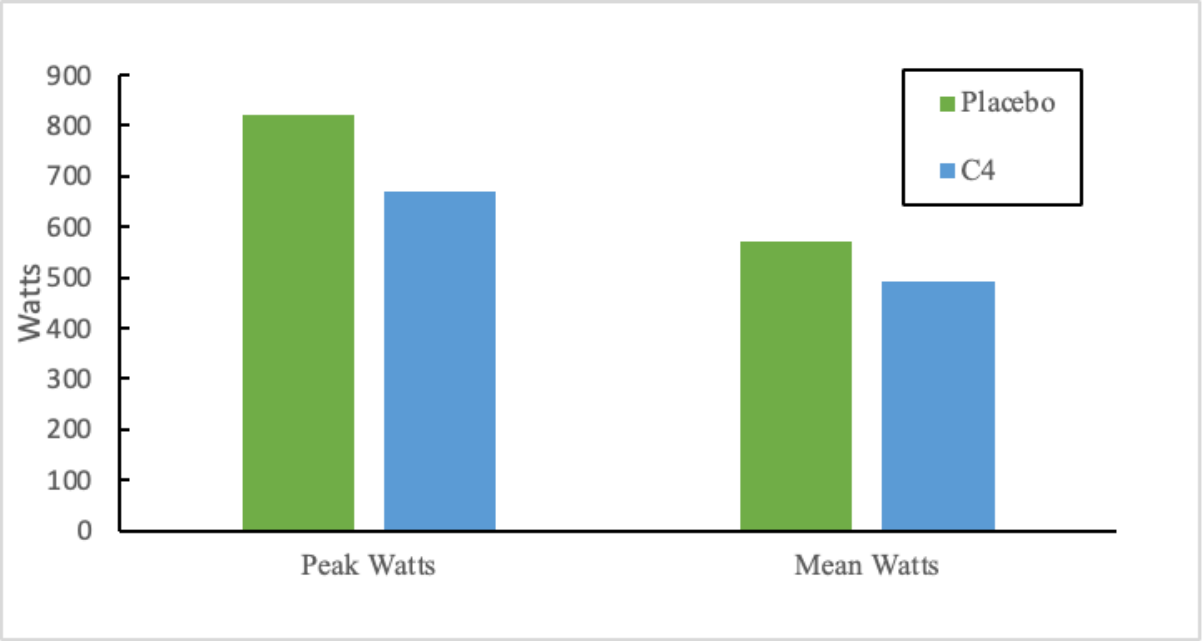
Average Heart Rates of Placebo and C4 Supplement Groups Pre and Post Wingate Test



Note. Average resting heart rate and average post Wingate heart rate is represented above for both the placebo and the C4 supplement group. Average resting for the placebo group was 75bpm while the average for the C4 supplement group was 72bpm. Average post heart rate for the placebo group was 158bpm while the C4 supplement group's average was 163bpm.

Figure 8

Average Peak and Mean Watts for Placebo and C4 Supplement Groups for Wingate Test



Note. Average peak and mean Watts are represented for both the placebo and C4 supplement groups. For peak Watts, the placebo group had an average of 819.89 Watts while the C4 supplement group had an average of 671.11 Watts. For mean Watts, the placebo group had an average of 571.67 Watts while the C4 supplement group had an average of 491.33 Watts.

Discussion

The purpose of this study was to examine the acute effects of the "C-4: Original Pre Workout Powder" on anaerobic performance. Some evidence suggests that the acute effect of caffeine in small doses is effective at increasing peak and mean power during the Wingate test (Lara et al., 2021). As shown in Figure 4, both anaerobic power and anaerobic capacity (measured in Watts/kg) were increased in the pre-workout supplement group compared to the placebo group. The results for anaerobic power, however, produced a P-value of 0.68, which is not statistically significant. In addition, although anaerobic capacity was higher for the pre-workout supplement group, it produced a P-value of 0.35, which is also not statistically significant.

Fatigue index, which is the rate of decline during the Wingate test, is a representation of how much fatigue the individual experiences during the 30 second bout of exercise (Baker

et al., 2011). The higher the fatigue index number, the lower the individual's ability to maintain power throughout the test. As seen in Figure 2, the pre-workout supplement group had a lower fatigue index than the placebo group, suggesting that the pre-workout supplement had a positive influence on the individual's performance regarding fatigue index. The difference between the pre-workout supplement group and the placebo group produced a p-value of 0.18, so although the pre-workout supplement group had a lower fatigue index, this was not statistically significant.

Blood lactate levels were also measured in this study. Blood lactate levels can be used to monitor training intensity by observing the point in time in which blood lactate levels rise/build up during exercise (Gür, 2012). In previous studies, multi-ingredient pre-workout supplements increased individuals' post exercise blood lactate levels (Fye et al., 2020). Looking at Figure 3, however, the placebo trials' average post-Wingate blood lactate levels were higher at 12.10mmol/L, compared to the C4 supplement trials' at 11.78mmol/L. This was not expected because the athletes who consumed the pre-workout supplement were unable to handle higher levels of blood lactate circulating in their bodies before tiring compared to the placebo group, however, the results collected in this study showed no significance with a p-value of 0.88, for the blood lactate levels between the placebo and C4 supplement group.

There is evidence that the caffeine content in pre-workout supplements can cause an increase in heart rate (Benjamim et al., 2021). In Figure 5, a comparison of resting heart rate and post-Wingate heart rate can be seen in the C4 pre-workout supplement group as well as for the placebo group. Resting heart rate, which was taken after consumption of the C4 pre-workout supplement and placebo solution, was lower for the C4 pre-workout group than the placebo group, with the pre-workout group having an average resting heart rate of 72 beats per minute and the placebo group having an average resting heart rate of 75 beats per

minute. The post-Wingate heart rate, however, was on average higher for the C4 pre-workout supplement group than the placebo group, with the pre-workout group having an average post-Wingate heart rate of 163 beats per minute and the placebo group having an average post-Wingate heart rate of 158 beats per minute. These findings, however, produced p-values of 0.48 (average resting heart rate) and 0.67 (post-Wingate heart rate) which are not statistically significant.

During the Wingate test, peak and mean watts were measured for both the placebo and the C4 pre-workout supplement groups. A past study observed an improvement in mean power output during an anaerobic capacity test after consumption of a multi ingredient pre-workout supplement (Jagim et al., 2016). Another study observed an improvement in anaerobic peak power as well as anaerobic mean power using the Wingate test after acute ingestion of a pre-workout supplement (Martinez et al., 2016). In Figure 6, average peak and average mean watts are listed for both the placebo and C4 pre-workout supplement groups. For both peak and mean watts, the placebo group had a higher average output than the C4 pre-workout supplement group. This is the opposite of what other studies have found, however, the results for the peak and mean watts produced p-values of 0.20 and 0.21, which are not statistically significant. This could be due to the small sample population of which this study used, and other factors out of the study's control.

Although the data found in this study was not statistically significant, athletes or other fitness enthusiasts who are interested in increasing their time to fatigue and anaerobic capacity and power may find that pre-workout supplements are beneficial to their needs. A limitation of this study is that it only looked at maximum short bursts of output after consumption of the C4 supplement. The study did not take into consideration the potential impact pre-workout has on sustained long duration exercises as well as mild to moderate intensity exercises. Therefore, even though the data was not statistically significant for

showing an improvement in performance during short duration-high intensity exercise, it could potentially help in different physical settings. Another limitation to the study was the small sample size used to collect data. The small sample size was due to having a limited amount of time for data collection and analysis, however, because the data was so far from being statistically significant, a larger sample may not have changed the results too heavily.

Conclusion

Based on the results from this study, acute ingestion of the C4 pre-workout supplement does not significantly improve anaerobic performance in this population of college students. These results prove that there is more research needed on the impact pre-workout has on anaerobic performance. The question of if pre-workout is really worth the money for short duration, high intensity activities may differ for each individual. If the goal is to improve time to fatigue and anaerobic power and capacity, someone may find it useful to consume it, although, from these results it is showing that there is not enough of a significant impact on performance to make it worthwhile for short duration activity. However, this is not to say it does not have other mental or potential benefits for the individuals consuming it.

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