

The effects of pre-exercise co-ingestion of caffeinated gum and carbohydrate gel on functional threshold power and physiological-perceptual responses in youth road cyclists

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Abstract

Aim. Caffeine is frequently used in many team or individual sports worldwide, either before or during exercise. However, despite being a widely researched ergogenic aid, its interaction with Functional Threshold Power (FTP) remains unclear. The aim of the current study was to investigate the acute effects of caffeinated chewing gum and carbohydrate gel supplementation on FTP and physiological-perceptual responses. **Methods.** Thirteen highly trained male youth cyclists participated in a double-blind, placebo-controlled, counterbalanced crossover trial. Participants consumed four supplements—placebo (PLA), caffeine (CAF), carbohydrate gel (CHO), and CAF+CHO—at 48-hour intervals. Supplements were ingested 5 minutes prior to the protocol consisting of a 15-minute warm-up, a 20-minute FTP test, and a cool-down. Post-exercise assessments included rating of perceived exertion (RPE), visual analog scale (VAS), gastrointestinal symptom rating scale (GSRS), and balance, whereas hydration was determined via pre- and post-test saliva analysis. **Results.** A significant difference was observed for average power output ($p<0.007$), with post hoc analyses indicating significant differences between PLA and CAF+CHO ($p<0.008$) and between CHO and CAF+CHO ($p<0.006$). Similarly, significant differences were found for FTP (W) ($p<0.007$) and FTP (W/kg) ($p<0.007$), with both measures showing significant pairwise differences between PLA and CAF+CHO, and CHO and CAF+CHO ($p<0.01$). No statistically significant differences were detected for speed ($p<0.123$), heart rate (HR) ($p<0.638$), cadence ($p<0.550$), or distance ($p<0.100$). Hydration status and gastrointestinal symptoms varied between groups. **Conclusions.** CAF and CAF+CHO appear effective for performance enhancement, though individual tolerance must be considered. The use of CAF and CAF+CHO supplementation may be recommended to improve performance in youth cyclists, provided individual tolerance is considered.

Keywords: Cyclists, Ergogenic Aids, Caffeinated Gum, Carbohydrate Gel, Performance, Training

Introduction

Cycling is an endurance sport regarded as one of the most challenging disciplines, requiring that cyclists perform at various exercise intensities, which demand different physical capacities (Valino-Marques et al., 2024). The optimal balance between training load and recovery is a lasting endeavour for both cyclists and coaches, as cyclists are frequently subjected to high levels of training load (Lamberts et al., 2024). Although the aerobic energy system is dominant in cycling, the anaerobic system also plays an important role during climbs, attacks, and sprint finishes (Norte et al., 2024). The Functional Threshold Power test (FTP) was developed to identify training intensity zones and monitor performance variations during the training period of competitive cyclists (Allen and Coggan, 2010). FTP is defined as “the maximum average power maintained without fatigue for approximately 1 hour, which is estimated through 8- or 20-minute self-paced cycling protocols by subtracting 10% or 5% of the average power achieved after each respective cycling test” (Denham et al., 2020). FTP is an important performance attribute for competitive cyclists because there is a strong relationship between maximum sustained cycling power output and endurance cycling performance (Acker-Hewitt et al., 2012; Jeffries et al., 2021; Jeukendrup et al., 2000; MacInnis et al., 2019). Therefore, the FTP test is commonly utilized by athletes to estimate various training loads and exercise intensities, including Training Stress Score, average power output, and intensity factor (Allen and Coggan, 2010; Mackey and Horner, 2021).

The effect of pre-test ergogenic supplements on FTP test results has become a research topic due to the increasing use of the FTP test. This is because athletes might train at higher intensities if pre-test ergogenic supplements increase power output and decrease the rating of perceived exertion (RPE). This type of training, especially over a prolonged period, could increase the likelihood that athletes might be better prepared for competitions. Notably, as exercise intensity increases in high-intensity training programs, a threshold point is 2600-----

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reached at which a maximal metabolic steady state is achieved; beyond this point, perceived exertion tends to increase, and physiological deterioration accelerates (Jones et al., 2019). These physical and physiological impairments are associated with peripheral fatigue mechanisms that ultimately result in task failure (Hureau et al., 2018).

In high-intensity, short-duration activities, especially during sprints, insufficient recovery may negatively affect the muscle's energy production capacity. Insufficient recovery hinders the reactivation of anaerobic energy sources, including the phosphocreatine system and glycolysis. ATP synthesis is reduced, resulting in the accumulation of lactate and hydrogen ions, which induces acidosis. This limits skeletal muscle contraction and power generation, thereby impairing sprint performance (Smith et al., 2023). Similarly, it is well-established that athletes who engage in high-intensity endurance exercise at their maximum capacity need to optimize their carbohydrate stores both before and during the exercise to achieve performance. Endurance athletes need to prioritize strategies for the supercompensation of glycogen stores and the management of pre-competition carbohydrate intake. In addition, the consumption of carbohydrates during exercise, as a source of energy for events lasting over 90 minutes, is a valuable dietary strategy for improving endurance exercise performance (Moore, 2015). Carbohydrate ingestion has frequently been shown to reduce deterioration in next-day performance through reduced metabolic stress and fatigue (Clauss et al., 2023) development, to improve gross efficiency under steady-state laboratory conditions (Cole et al., 2014) and to increase glucose and insulin concentrations (Rustad et al., 2016). Moreover, the combined use of caffeine with carbohydrates during exercise enhances glucose availability. A study indicated that, compared to glucose alone, the co-ingestion of caffeine (5 mg/kg body mass) with carbohydrates enhanced muscle glucose oxidation during prolonged submaximal cycling (Yeo et al., 2005). Additionally, a study reported that the co-ingestion of caffeine with carbohydrates after strenuous exercise led to a significantly greater accumulation of muscle glycogen after 4 hours of recovery compared to the consumption of carbohydrates alone (Pedersen et al., 2008). Collectively, this implies that nutrition strategies (such as caffeine or carbohydrates) are needed to maintain and improve performance in athletes. Strong evidence supports that caffeine and carbohydrate significantly influences sport-specific performance factors, including power (Glaister et al., 2019), endurance (Melo et al., 2021; Ruiz-Moreno et al., 2020), RPE (Kumar et al., 2019), and time trial (TT) performance (Acker-Hewitt et al., 2012; Ryan et al., 2013b) in cyclists. Moreover, other research has suggested that caffeine and carbohydrate co-ingestion yields a greater improvement in performance compared to the intake of each ergogenic supplements alone (Hulston and Jeukendrup, 2008a; Mitchell and Podczerwinski, 2017; Slivka et al., 2008). However, CHO ingestion immediately before exercise resulted in a significant difference in repeated sprint exercise (RSE) performance on the cycle ergometer, whereas CAF+CHO showed no significant effect (Lee et al., 2014). Furthermore, in two sets of 12x4 short sprints, caffeine alone produced a significant ergogenic effect not in the 20-s, but in 90-s active recovery intervals in the intermittent sprint cycling test (ISCT) (Lee et al., 2012). Likewise, Paton et al. (2010) showed that 300 mg of CAF via chewing gum during high-intensity cycling exercise improved power output by 5.4%. Power profiling in cycling is commonly defined as the assessment of field-derived power, i.e., values obtained during training and racing (Leo et al., 2020). Power profiling can be utilized to monitor long-term changes in cycling performance and race analysis (Leo et al., 2022). However, to our knowledge, despite the widespread use of the FTP test, no published studies have directly addressed the effects of ergogenic supplements on the FTP test in youth cyclists. Hence, the aim of the current study was to investigate the effects of caffeinated gum and carbohydrate gel intake on body hydration status, FTP test results, dynamic balance, heart rate, cadence, average power, speed, distance, RPE, VAS, and gastrointestinal symptoms in youth cyclists. We hypothesized that (a) CAF+CHO combined use would result in a greater enhancement in FTP performance compared to CAF or CHO alone, (b) CAF or CHO, whether administered alone or in combination, would not significantly alter body hydration status, and (c) CAF or CAF+CHO would decrease the rating of perceived exertion (RPE) but would not significantly change heart rate (HR) and VAS scores.

Materials and methods

Participants

Participants: Ten highly trained male youth cyclists (age: 13.37 ± 1.18 years, height: 156.56 ± 8.40 cm, weight: 47.90 ± 9.37 kg, body mass index [BMI]: 19.37 ± 2.06 kg/m², training age: 2.12 ± 0.35 years, and habitual CAF intake: 69.75 ± 68.83 mg/day) participated in this study. The required sample size was estimated using GPower software (Heinrich-Heine-University Düsseldorf, version 3.1.9.2, Düsseldorf, Germany), and a sample size of 10 participants was determined to be sufficient (effect size = 0.50, power $[1 - \beta] = 0.95$, α error probability = 0.05). All participants competed in regional competitions. The inclusion criteria were as follows: No chronic or acute illnesses, no serious sports injuries in the last 6 months, regular cycling training at least 5 days per week (10 h per week), and at least 2 years of cycling training experience. The exclusion criteria were as follows: Diagnosis of any cardiovascular, metabolic, or respiratory disease (diabetes, heart disease, asthma, etc.), regular use of caffeine, carbohydrate gels, or similar sports supplements in the last 3 months, or the presence of a psychological or physical condition that could prevent active participation in the study. The study was carried

out during the cyclists' competition preparation period. All cyclists were informed of the objectives and risks related to their participation before providing their written informed consent.

Table 1. Descriptive Statistics

Variables	X	SD
Age (yr)	13.37	1.18
Height (cm)	156.56	8.40
Weight (kg)	47.90	9.37
BMI (kg/m ²)	19.37	2.06
Training age (yr)	2.12	.35
Habitual consumption of caffeine (mg/day)	69.75	68.83

X = Mean; SD = Standard deviation

Experimental Design

The study followed a double-blind, placebo-controlled, and counterbalanced crossover trial design. The participants visited the laboratory on five separate occasions. On the first visit, a familiarization session was conducted one week before the experimental measurements to determine all athletes' Functional Threshold Power (FTP) values and to set their training intensity levels accordingly. On this visit, anthropometric measurements, including weight, height, and BMI, were taken, and caffeine consumption was determined using a standardized questionnaire (Goncalves et al., 2017). Identical tests were conducted on the athletes using four different supplements, including placebo (PLA), caffeinated gum (CAF), carbohydrate gel (CHO), and a combination of caffeinated gum and carbohydrate gel (CAF+CHO), at 48-hour intervals. The study was conducted on athletes participating in the same training program to ensure reliability, given the potential effects of different training methods and levels. During the test days, participants were instructed to refrain from eating for a minimum of three hours prior to each trial and to avoid alcohol and caffeinated beverages throughout the four-day period. On supplementation days, participants were instructed to chew the gum for five minutes and then spit it out. Each piece of gum (military gum) contained 100 mg of CAF, and it has been reported that 85% of the dose is released and absorbed during the first five minutes of chewing. (Tarnopolsky, 2008a). Athletes were allowed to consume water ad libitum. On test days 1, 2, 3, and 4, participants consumed placebo gum (sugar-free gum), caffeinated gum (military gum, 2 × 100 mg), carbohydrate gel (Torq CHO gel, 21.1 g), and a combination of caffeinated gum (2 × 100 mg) and carbohydrate gel (21.1 g), respectively. Supplements were provided to the athletes five minutes prior to the test, after which they performed the test (Bazzucchi et al., 2011; Behrens et al., 2015b; Ryan et al., 2013a; Ryan et al., 2013b). On each testing day, cyclists performed a 15-minute warm-up, followed by 20 minutes of cycling at maximal threshold, and then completed the protocol with a cool-down ride. Cyclists were encouraged to achieve maximal average power during the 20-minute test; however, no specific pacing strategy was recommended. Participants were allowed to adjust their gears during the test to maintain their preferred pace. Saliva samples were obtained before and after each test to assess athletes' hydration status. Heart rate (HR) was continuously monitored, and RPE was recorded at the end of each test. Following each test, the athletes' balance was measured. Upon completion of the test, the Borg Scale (0–10) was employed to assess the rating of perceived exertion (RPE) (Borg, 1998). Delayed-onset muscle soreness was evaluated using the Visual Analog Scale (VAS) one day after each test. The Gastrointestinal Symptom Rating Scale (GSRS) was used to determine any discomfort reported by the participants due to the supplements.

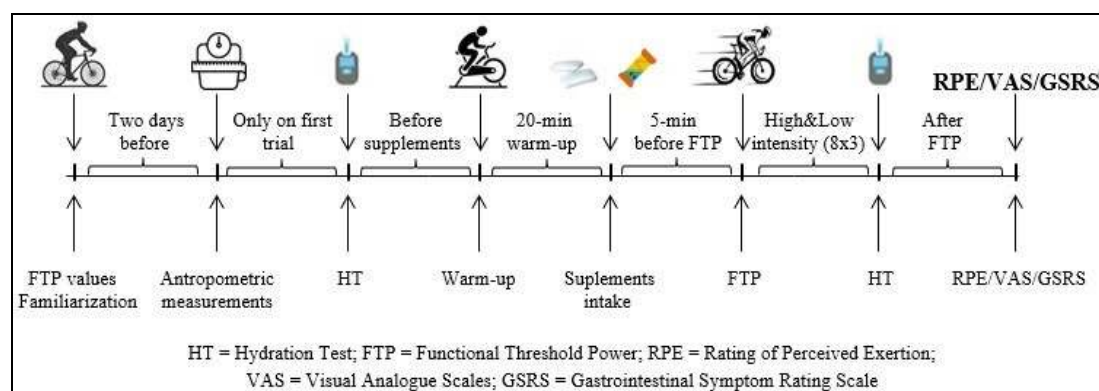


Figure 1. A schematic illustration of the experimental design

Preliminary Familiarization Session and Anthropometric Assessments

All body composition and anthropometric assessments were performed during the initial familiarization session. On the familiarization day, athletes completed a short familiarization session involving

the practice of adjusting seat height, changing the resistance and other bike dimensions, and practicing maintaining a constant “challenging” workload (Denham et al., 2020). Body mass was measured in kilograms using bioelectrical impedance analysis equipment (BIA; InBody 120, InBody Co., Ltd., Seoul, Republic of Korea), and height was measured in cm using a portable stadiometer (Seca 213, Hamburg, Germany). BMI was computed by dividing body mass in kilograms by the square of height in meters (kg/m^2), based on recorded height and weight measurements.

Supplement Administration Protocol

Participants chewed placebo gum (sugar-free gum), caffeinated gum (military gum, 2 x 100 mg), carbohydrate gel (Torq CHO gel, 21.1 g), and a combination of caffeinated gum (2 x 100 mg) and carbohydrate gel (21.1 g) on the first, second, third, and fourth days, respectively. Supplements were provided to athletes 5 minutes prior to the test, and then they performed the test (Bazzucchi et al., 2011; Behrens et al., 2015b; Ryan et al., 2013a).

Functional Threshold Power Test

This study adopted the FTP test protocol previously described by Denham et al. All athletes were informed about the purpose and details of the study prior to the tests (Denham et al., 2020). All athletes had prior experience with the FTP test and were familiar with the prescribed procedures. Before the test, each athlete adjusted seat height and other cycle dimensions to suit their comfort and riding style. The preferred adjustments were saved, and athletes used their own settings for all tests. All FTP tests were conducted in an air-conditioned room at 22 °C. The test was performed using a pedal (Garmin, Rally XC 100, Olathe, Kansas, USA) attached to a trainer (Elite, Direto XR-T Interactive Trainer, Fontaniva, Italy). The athletes' data were transferred to a cycling computer (Garmin 530 Bundle, Olathe, Kansas, USA) integrated with the trainer, pedal, and chest strap, and the athletes monitored their metrics on the device screen during the test. Athletes visited the laboratory on four occasions and performed four FTP tests. Athletes completed a 20-minute warm-up before each FTP test. Following the warm-up, each athlete was instructed to strive for the highest wattage possible during the 20-minute period and to complete the 20-minute FTP test. The researchers provided verbal encouragement to the athletes every five minutes during the test. Athletes completed a 15-minute cool-down after each test. At the completion of the test, 95% of the average power output was recorded as the athletes' FTP value. This value was divided by the athlete's body mass to calculate power per kilogram (W/kg).

Balance Test

The portable balance device Togu Challenge Disc 2.0 (Prien am Chiemsee, Germany) was used to measure athletes' balance. It is a movable platform that provides an unstable surface, with a maximum tilt of 12°. The Challenge Disc was connected to a tablet via Bluetooth and used a three-dimensional motion sensor to record the athlete's movements on the platform. The stability index was categorized into ranges from 1 to 5 (1 = very good, 2 = good, 3 = normal, 4 = weak, and 5 = very weak). Athletes stood barefoot on the platform to prevent potential effects of different types of footwear on the results. During the test, the tablet was placed at eye level in front of the athlete, who performed the test for 20 s after 10 s of preparation, including a 5 s countdown, without touching the ground. Athletes were asked to remain steady without moving the platform during the test, keeping the point within the circle on the tablet as centered and stable as possible. The test was conducted twice with a three-minute passive rest period, and the higher score was used as the dynamic balance test score (Cole et al., 2018b).

Hydration Analysis

Hydration status was assessed using a portable hydration test device (MX3 Diagnostics LAB Pro, Melbourne, Australia), as previously described (Cole et al., 2018b). The device determined hydration status via saliva collected directly from the tongue using a hydration test strip. Sterilization procedures were followed during saliva sampling, and the test strip was replaced after each saliva collection. The saliva sample was collected and evaluated immediately using a hydration test strip fixed to the device, without additional procedures. The values and their corresponding hydration status were defined as ≤ 65 = hydrated, 65–100 = mildly dehydrated, 101–150 = moderately dehydrated, and >150 = severely dehydrated.

Borg scale (rating of perceived exertion [RPE])

The Rating of Perceived Exertion (RPE) is a method used to assess athletes' perceived exertion during physical activity. In the scale developed by Borg, the highest value is 10, and the lowest value is 0 at rest. An increasing score between 0 and 10 corresponds to an increasing level of exertion experienced during the test (Borg, 1998). After each measurement, athletes were asked to rate their perceived exertion using a numerical value, which was then recorded.

Visual Analogue Scale (VAS)

The Visual Analogue Scale (VAS), developed by Albersnagel (1988), is a measurement tool that allows the assessment of perceived pain or fatigue on a 10 cm horizontal line divided into equal intervals. The scale ranges from “no pain” to “worst imaginable pain” (Albersnagel, 1988). In this study, the VAS was used to numerically evaluate athletes' levels of fatigue.

Gastrointestinal Symptom Rating Scale The Gastrointestinal Symptom Rating Scale (GSRS) was developed by Revicki et al., (1997) to assess the severity of symptoms commonly associated with gastrointestinal disorders.

The Gastrointestinal Symptom Rating Scale (GSRS) consists of 15 items and is structured as a 7-point Likert-type scale, with response options ranging from “no discomfort” to “very severe discomfort.” Based on factor analysis, the 15 items of the GSRS are grouped into five subcategories: abdominal pain, reflux, diarrhoea, indigestion, and constipation. Items 1, 4, and 5 of the scale assess abdominal pain; items 2 and 3 assess reflux; items 11, 12, and 14 assess diarrhoea; items 6, 7, 8, and 9 assess indigestion; and items 10, 13, and 15 assess constipation. Evaluation is carried out accordingly. The total score obtained from the responses ranges from 15 to 105. Higher scores on the scale indicate more severe gastrointestinal symptoms (Revicki et al., 1997).

Statistical Analysis

The Shapiro–Wilk test was employed to assess the normality of the data. Differences between conditions were analyzed using repeated-measures ANOVA. Mauchly’s test of sphericity was applied to test the assumption of sphericity. When the assumption of sphericity was not met, the Greenhouse–Geisser correction was applied if the epsilon value was lower than 0.75, whereas the Huynh–Feldt correction was applied if the epsilon value was greater than 0.75. Post hoc pairwise comparisons were adjusted using the Bonferroni correction. Pairwise comparisons were analyzed using paired-samples t-tests. The effect size index was calculated using eta squared values, and effect size magnitude was interpreted as 0.01 = small, 0.06 = medium, 0.14 = large, and 0.20 = very large (Alpar, 2010). Data are presented as mean $\pm$ SD, and statistical significance was set at $p < 0.05$. All data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA).

Results

Performance Measures and Subject Characteristics

All data were checked for normality before statistical analyses. Group comparisons showed significant differences between supplementation conditions (Table 2). Specifically, a significant main effect and a large effect size were observed for average power output ($F = 5.359$, $p = 0.007$, $\eta^2 = 0.43$), with post hoc analyses indicating significant differences between PLA and CAF+CHO ($p = 0.008$) and between CHO and CAF+CHO ($p = 0.006$). Similarly, significant differences were found for FTP (W) ($F = 5.359$, $p = 0.007$, $\eta^2 = 0.43$) and FTP (W/kg) ($F = 5.271$, $p = 0.007$, $\eta^2 = 0.43$), with both measures showing significant pairwise differences between PLA and CAF+CHO and between CHO and CAF+CHO ($p < 0.01$). Furthermore, balance performance demonstrated significant group differences ($F = 7.440$, $p = 0.001$, $\eta^2 = 0.52$), with PLA differing from CAF ($p = 0.001$) and CHO ($p = 0.039$), CAF differing from CAF+CHO ($p = 0.003$), and CHO differing from CAF+CHO ($p = 0.018$). RPE values were also significantly different between groups ($F = 7.377$, $p = 0.001$, $\eta^2 = 0.51$), with significant differences observed between PLA and CAF ($p = 0.050$), PLA and CHO ($p = 0.024$), PLA and CAF+CHO ($p = 0.010$), and CAF and CAF+CHO ($p = 0.050$). No statistically significant differences were detected for speed ($F = 2.160$, $p = 0.123$, $\eta^2 = 0.24$), heart rate ($F = 0.308$, $p = 0.638$, $\eta^2 = 0.04$), cadence ($F = 0.721$, $p = 0.550$, $\eta^2 = 0.09$), distance ($F = 2.369$, $p = 0.100$, $\eta^2 = 0.25$), or VAS scores ($F = 1.060$, $p = 0.387$, $\eta^2 = 0.13$).

Table 2. Performance Measures and Subject Characteristics

Groups				
Variables (X $\pm$ SD)	PLA	CAF	CHO	CAF+CHO
Heart Rate	190.75 $\pm$ 9.33	192.12 $\pm$ 9.14	190.12 $\pm$ 6.95	189.75 $\pm$ 6.73
Cadence	92.87 $\pm$ 5.69	95.50 $\pm$ 5.68	95.87 $\pm$ 5.33	93.87 $\pm$ 5.08
Average Power (W)	174.00 $\pm$ 36.26†	178.25 $\pm$ 35.13	173.12 $\pm$ 36.99†	183.62 $\pm$ 38.13*‡
FTP (W)	156.60 $\pm$ 32.64†	160.42 $\pm$ 31.62	155.81 $\pm$ 33.29†	165.26 $\pm$ 34.32*‡
FTP (W/kg)	3.29 $\pm$.45†	3.37 $\pm$.37	3.27 $\pm$.43†	3.47 $\pm$.41*‡
Speed	25.06 $\pm$ 2.37	25.41 $\pm$ 2.49	25.24 $\pm$ 2.28	25.66 $\pm$ 2.43
Distance (km)	3.35 $\pm$.31	3.39 $\pm$.33	3.37 $\pm$.30	3.43 $\pm$.32
Balance	3.51 $\pm$.31*‡	2.93 $\pm$.49*†	2.91 $\pm$.58*†	3.57 $\pm$.30##
RPE	7.62 $\pm$ 1.40##†	8.62 $\pm$ 1.06*†	9.25 $\pm$.88*	9.62 $\pm$.74*##
VAS	2.62 $\pm$ 2.26	3.00 $\pm$ 3.38	3.00 $\pm$ 2.77	1.62 $\pm$ 2.06

*Mean = arithmetic mean; SD = standard deviation; FTP = functional threshold power; PLA = placebo; CAF = caffeine; CHO = carbohydrate; CAF+CHO = caffeine + carbohydrate; Significant difference compared with PLA; #Significant difference compared with CAF; ‡ Significant difference compared with CHO; †Significant difference compared with CAF+CHO

Hydration Status

Hydration status showed no significant differences at baseline (pre-test) among the four supplementation conditions in between-group comparisons ($F = 2.229$, $p = 0.115$, $\eta^2 = 0.24$). However, significant differences were observed at post-test following the intervention ($F = 4.628$, $p = 0.012$, $\eta^2 = 0.40$).

Post hoc analyses indicated that PLA (75.75 ± 29.19) had significantly higher hydration values than CAF+CHO (103.37 ± 37.19 ; $p = 0.034$). In addition, CAF (63.12 ± 31.33) demonstrated significantly higher hydration status than both CHO (105.75 ± 40.45 ; $p = 0.037$) and CAF+CHO (103.37 ± 37.19 ; $p = 0.013$) at post-test (Figure 2).

Table 3. Gastrointestinal Symptom Rating Scale

Variables (X $\pm$ SD)	Groups			
	PLA	CAF	CHO	CAF+CHO
Abdominal Pain	1.00 $\pm$.00#	1.92 $\pm$.75*	1.33 $\pm$.53	1.42 $\pm$.58
Reflux	1.25 $\pm$.46	1.88 $\pm$.83†	1.13 $\pm$.35	1.00 $\pm$.00#
Diarrhea	1.00 $\pm$.00	1.38 $\pm$ 1.06	1.25 $\pm$.46	1.00 $\pm$.00
Indigestion	1.03 $\pm$.08	1.22 $\pm$.41	1.13 $\pm$.18	1.03 $\pm$.08
Constipation	1.00 $\pm$.00	1.00 $\pm$.00	1.00 $\pm$.00	1.00 $\pm$.00
GSRS	1.04 $\pm$.06#	1.43 $\pm$.38*	1.17 $\pm$.19	1.09 $\pm$.12

*Mean = arithmetic mean; SD = standard deviation; GSRS = gastrointestinal symptom rating scale; PLA = placebo; CAF = caffeine; CHO = carbohydrate; CAF+CHO = caffeine + carbohydrate; Significant difference compared with PLA; #Significant difference compared with CAF; † Significant difference compared with CHO; ‡Significant difference compared with CAF+CHO

In the PLA condition, a significant change in hydration status was detected from pre-test (49.12 ± 16.52) to post-test (75.75 ± 29.19 ; $p = 0.041$). In contrast, the CAF condition showed an improvement in hydration status from pre-test (77.25 ± 27.60) to post-test (63.12 ± 31.33), although this change was not statistically significant ($p = 0.381$). The CHO condition exhibited a worsening in hydration status from pre-test (76.25 ± 33.65) to post-test (105.75 ± 40.45); however, this difference did not reach statistical significance ($p = 0.207$). Similarly, in the CAF+CHO condition, hydration status worsened from pre-test (76.50 ± 24.68) to post-test (103.37 ± 37.19); this change was also not statistically significant ($p = 0.089$) (Figure 3).

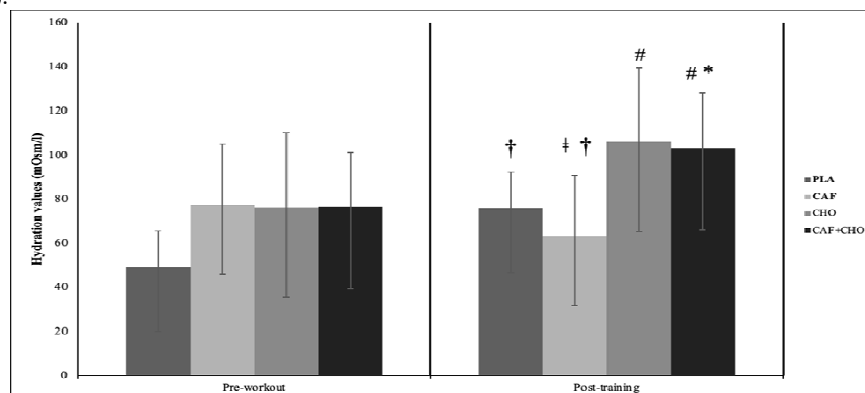


Figure 2. *Mean = arithmetic mean; SD = standard deviation; Significant difference compared with PLA; #Significant difference compared with CAF; ‡Significant difference compared with CHO; †Significant difference compared with CAF+CHO.

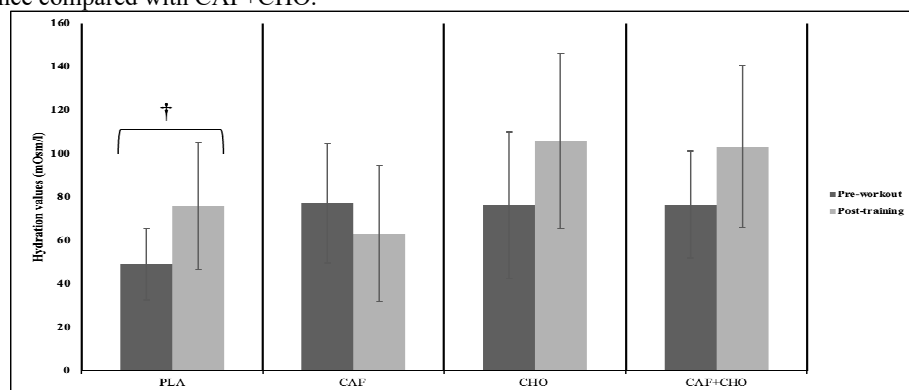


Figure 3. Mean = arithmetic mean; SD = standard deviation; PLA = placebo; CAF = caffeine; CHO = carbohydrate; CAF+CHO = caffeine + carbohydrate; †Significant within-group difference between pre-test and post-test.

Gastrointestinal Symptom Rating Scale

Between-group comparisons revealed significant differences in several gastrointestinal symptoms following supplementation (Table 3). Abdominal pain scores were significantly higher in CAF (1.92 ± 0.75) compared with PLA (1.00 ± 0.00 ; $p = 0.011$; $F = 3.945$; $\eta^2 = 0.36$). Similarly, reflux symptoms differed significantly between groups ($F = 4.319$; $p = 0.016$; $\eta^2 = 0.38$), with CAF (1.88 ± 0.83) reporting higher scores than CAF+CHO (1.00 ± 0.00 ; $p = 0.021$). No significant between-group differences were observed for diarrhoea ($F = 0.797$; $p = 0.424$; $\eta^2 = 0.10$) or indigestion ($F = 1.102$; $p = 0.370$; $\eta^2 = 0.13$). Constipation scores were identical across all groups, precluding statistical analysis. Regarding overall gastrointestinal symptoms, assessed using the GSRS total score, a significant group effect was found ($F = 4.496$; $p = 0.014$; $\eta^2 = 0.39$), with CAF (1.43 ± 0.38) showing significantly higher GSRS scores compared with PLA (1.04 ± 0.06 ; $p = 0.026$).

Discussion

This study aimed to investigate the effects of acute caffeinated gum and carbohydrate gel intake on body hydration status, FTP, dynamic balance, heart rate, cadence, average power, speed, distance, RPE, VAS, and gastrointestinal symptoms in youth cyclists. The existing literature includes a number of studies that have investigated the effects of caffeine and carbohydrate intake on cyclists (Hulston and Jeukendrup, 2008b; Mitchell and Podczerwinski, 2017; Slivka et al., 2008). However, the present study is the first to examine the acute effects of these supplements, both separately and in combination, on selected physical, physiological, and performance parameters in youth cyclists. The main findings of this study were the positive effects of caffeinated gum and carbohydrate gel supplements, administered separately and in combination, on several performance parameters in youth cyclists. In the present study, supplementation caused significant differences in post-test body hydration status and resulted in changes in gastrointestinal symptoms. Moreover, no between-group differences were observed for heart rate, cadence, speed, distance, or VAS. These findings partially align with our hypothesis that moderate doses of caffeine and carbohydrate supplementation would improve performance in youth cyclists.

In this study, placebo gum (sugar-free gum), caffeinated gum (military gum, 2×100 mg), carbohydrate gel (Torq CHO gel, 21.1 g), and a combination of caffeinated gum (2×100 mg) and carbohydrate gel (21.1 g) were administered to the cyclists before the FTP test on different test days. Caffeine and carbohydrate supplements enhanced several performance parameters in cyclists when administered separately and in combination. However, no differences were found in heart rate values or VAS scores, whereas significant differences were observed in RPE between groups. Regarding RPE, the PLA group showed lower scores overall. This may be related to the fact that the PLA condition was administered on the first test day. Although the cyclists did not report any physical problems on subsequent test days, they may have experienced mental fatigue due to the strenuous exertion demanded by the test protocol. Therefore, the increase in RPE values in the CAF, CHO, and CAF+CHO conditions may have been related to the 48-hour intervals between consecutive testing sessions.

The current literature contains numerous studies investigating the effects of caffeine and carbohydrate intake on athletic performance (Lopez-Seoane et al., 2024). While some of these studies report findings that align with the present study, others report inconsistent results (Acker-Hewitt et al., 2012; Cole et al., 2018b; Hulston and Jeukendrup, 2008a; Slivka et al., 2008). The primary finding of this study was that caffeinated gum significantly increased average power and FTP when consumed in combination with carbohydrate gel. Performance in the CAF+CHO condition was significantly higher than in the PLA and CHO conditions. The greater ergogenic effect observed with combined supplementation was not evident following the administration of caffeine alone. The findings of the present study extend previous observations and indicate that caffeine supplementation exerts an ergogenic effect on average power and FTP. The positive effect of caffeine on these performance outcomes may be attributed to adenosine receptor antagonism, which has been shown to enhance neurotransmission (Tarnopolsky, 2008b), promote motor unit recruitment (Bazzucchi et al., 2011) and augment muscle activation (Behrens et al., 2015a). Another mechanism underlying the greater effect observed in the CAF+CHO condition is that carbohydrates prevent energy deficiency, increase fuel supply to skeletal muscle, and help maintain blood glucose levels, thereby attenuating muscle glycogen depletion (Bourdass et al., 2021). Accordingly, Acker-Hewitt et al. (2012) reported that the combined intake of caffeine and carbohydrates improved cycling time-trial (TT) performance, whereas no such effect was observed when the supplements were consumed alone. The study also demonstrated that combined supplementation did not differentially affect heart rate or RPE compared with caffeine or carbohydrate alone. Similarly, co-ingestion of caffeine and carbohydrates has been reported to increase fat oxidation and reduce reliance on non-muscle glycogen carbohydrate use compared with carbohydrate alone, thereby enhancing cycling performance. In line with the present findings, heart rate values were similar, whereas RPE showed a significant difference in a previous study (Slivka et al., 2008). Likewise, Walker et al. reported no differences in heart rate during exercise. However, in contrast to the present findings, they observed that RPE values in the CAF+CHO condition were significantly lower. (Walker et al., 2007). In another study, researchers showed that co-ingestion of CAF and CHO during exercise increased cycling time-trial (TT) performance compared with placebo and carbohydrate alone. Furthermore, unlike the

present study, the CAF+CHO group had lower RPE values than the PLA and CHO groups, and significant differences were observed in heart rate levels between conditions (Hulston and Jeukendrup, 2008a). Collectively, these studies are partially consistent with the findings of the present study. In contrast, Cole et al. (2018a) reported that, unlike caffeine, carbohydrate improved cycling performance. The researchers also observed that supplementation had no effect on heart rate, which is congruent with the present findings. In another study involving caffeine ingestion on two separate days, caffeine significantly increased cycling performance and power output in both trials relative to placebo; however, no significant differences were observed in RPE or heart rate, although heart rate was numerically higher with caffeine (Astorino et al., 2012).

The FTP test includes a maximal, self-paced 20-minute cycling time trial (TT), in which average power output is scaled to 95%. Conceptually, it defines the maximum average power that can be sustained for approximately 1 h without fatigue and serves as a predictor of maximal aerobic potential prior to an exponential increase in blood lactate (Jeffries et al., 2021). In the present study, combined supplementation with caffeinated gum and carbohydrate gel was found to improve FTP. Similarly, Ruiz-Moreno et al. found that acute caffeine consumption improved peak aerobic performance and increased peak pulmonary ventilation (Ruiz-Moreno et al., 2020). In a placebo-controlled study, Ryan et al. (2012) administered 200 mg of caffeinated gum or placebo gum to participants at different times (35, 15, and 5 min prior to the test), after which participants performed an aerobic-based cycling test (~30–35 min) at 85% of $\text{VO}_{2\text{max}}$. The findings indicated that low doses of caffeinated gum administered at different times did not improve endurance performance. In addition, the same researchers conducted a 15-minute cycling test at 75% of $\text{VO}_{2\text{max}}$ after administering either caffeinated gum (300 mg) or placebo to trained cyclists at different times (5, 60, and 120 min) before the test. Only caffeinated gum ingested 5 min before the test was reported to improve cycling performance (Ryan et al., 2013b). Furthermore, caffeine ergogenicity via caffeine mouth rinse has recently been reported to increase endurance performance and RPE and to decrease muscle activity during moderate-intensity exercise (Melo et al., 2021). In accordance with current research findings, caffeine exerts performance-enhancing effects via two primary mechanisms. The antagonistic action of caffeine on adenosine receptors (A1 and A2A) in the central nervous system leads to increased neurotransmitter release and potentiation of Na^+/K^+ pump activity in skeletal muscle. This may, in turn, enhance excitation-contraction coupling (Guest et al., 2021).

Heart rate and VAS showed no differences in the present study, whereas the CAF condition exhibited lower RPE values than the CHO and CAF+CHO conditions. Another finding of the study was that balance scores were higher following caffeine or carbohydrate supplementation alone. Caffeine has an adenosine-like structure and binds to adenosine receptors in the brain, thereby increasing neurotransmitter levels (Fredholm et al., 1999). Caffeine also acts as a central nervous system stimulant by blocking adenosine receptors and increasing neurotransmitters such as norepinephrine, dopamine, acetylcholine, and serotonin (De Kivit et al., 2013). Lei et al. (2023) reported that a moderate dose of caffeine enhances aerobic metabolism and increases performance during high-intensity endurance exercise. Likewise, Melo et al. (2021) suggested that caffeine mouth rinse had no effect on heart rate, and that RPE values were higher in the CAF group than in the PLA group, similar to the present study. Additionally, a previous study showed that heart rate was higher while RPE values were lower in the caffeine group than in the placebo group (Smirmaul et al., 2017). With respect to RPE, caffeine has been suggested to act as an ergogenic agent by antagonizing adenosine receptors, thereby reducing pain and lowering RPE (Guest et al., 2021). In addition, its chemical structure allows caffeine to cross the blood-brain barrier and act on adenosine receptors (A1 and A2), thereby blocking receptors involved in pain perception. This is another factor that may have influenced RPE levels in the present study (Ferre, 2008). Caffeine has been shown to induce a significant increase in maximal power output and to delay neuromuscular fatigue in the quadriceps femoris muscles. In addition, heart rate was significantly higher in the caffeine group compared with placebo, while no difference was observed in RPE (Morse et al., 2016). Interestingly, cyclists reported no significant differences in performance, heart rate, or RPE with caffeine mouth rinse (Doering et al., 2014). In contrast, another study demonstrated that caffeine increases exercise performance and heart rate during cycling exercise compared with placebo, whereas RPE remained similar (Astorino et al., 2012). In a study involving participants similar to those in the present study, low, mild, and moderate doses of caffeine (1, 3, and 5 $\text{mg}\cdot\text{kg}^{-1}$) · doses of caffeine do not generate a graded response on physiological responses to exercise in young, healthy children. It did not generate a graded physiological response to exercise in young, healthy children. Additionally, these doses did not affect metabolic or respiratory responses to exercise, although supplementation caused an increase in blood pressure and a decrease in heart rate. However, a moderate dose of caffeine (5 $\text{mg}\cdot\text{kg}^{-1}$) significantly decreased RPE compared with placebo (Turley et al., 2008). Accordingly, moderate doses of caffeine did not influence metabolism in young children during low-to-moderate intensity exercise, but resulted in significantly lower heart rate and higher blood pressure in both male and female children (Turley and Gerst, 2006).

In a study conducted by O'Connor et al. (2004) it was reported that caffeine ingestion has a dose-dependent effect on the mitigation of leg muscle pain during exercise. Notably, these effects were observed to be unrelated to potential caffeine-induced increases in systolic blood pressure during exercise. Conversely, Jenkins et al. (2008) found that caffeine did not significantly affect RPE or HR levels but improved

performance during cycling exercise in cyclists. Additionally, similar to our study, the researchers observed no significant effect of caffeine on pain status. However, Motl et al. (2003) reported that high-dose caffeine ingestion significantly mitigated leg muscle soreness following moderate-intensity cycling exercise. Similarly, the researchers reported that caffeine may attenuate delayed-onset muscle soreness (DOMS) since it lowers VAS scores (Maridakis et al., 2007). The ergogenic effect of a moderate dose of caffeine on reducing leg muscle soreness during high-intensity cycling exercise has also been demonstrated in college-age females (Gliottoni and Motl, 2008). A more recent study investigated the effect of caffeine ingestion on DOMS using VAS, suggesting that caffeine reduced pain perception in the days following a challenging resistance training session, and the authors concluded that this would allow individuals to increase the number of training sessions in a specific time frame (Hurley et al., 2013). Few studies have examined the effects of CAF or CAF+CHO on balance performance. Kara et al. (2018) administered 6mg/kg caffeine to physically active males and examined its effects on balance performance. Balance scores were lower in the CAF condition compared with water and/or control conditions, and the authors suggested that caffeine ingestion may enhance balance performance (Kara et al., 2018). However, a recent study reported that ingestion of 6 mg/kg of caffeine did not significantly influence balance performance in athletes (Mor et al., 2024).

Caffeine is generally considered asymptomatic and does not adversely affect the gastrointestinal tract when ingested at low to moderate doses (Antonio et al., 2024; Nehlig, 2022). A study conducted in cyclists revealed that CHO or CAF+CHO supplementation did not cause gastrointestinal symptoms (van Nieuwenhoven et al., 2005). The same researchers also suggested that CHO or CAF+CHO sports drinks did not tend to produce gastrointestinal complaints compared with water (van Nieuwenhoven et al., 2005). The findings of the current study are aligned with these results. The youth athletes experienced gastrointestinal symptoms during the initial days of supplementation; however, this discomfort did not persist in subsequent trials. In the present study, gastrointestinal symptoms were reported only after caffeinated gum ingestion; however, no symptoms appeared on subsequent days, particularly during CAF+CHO supplementation. The gastrointestinal symptoms may be attributed to the youth cyclists being non-habituated to caffeine and receiving caffeine supplementation for the first time. Millard-Stafford et al. (2007) determined that a caffeinated sports drink demonstrated absorption rates comparable to those of a non-caffeinated commercial sports drink and flavored water control. Additionally, the caffeinated sports drink effectively maintained hydration, blood volume, and cardiovascular and thermoregulatory functions during prolonged exercise in warm and humid conditions. Furthermore, the findings suggest that moderate caffeine content in a sports drink does not accelerate fluid appearance in the bloodstream compared with a non-caffeinated carbohydrate drink, indicating that intestinal absorption and gastric emptying rates remain unaffected by caffeine during exercise. Recently, Mor et al. (2024) reported that caffeine supplementation did not alter hydration status in athletes and that body hydration levels remained within normal ranges. Similarly, in the present study, no severe dehydration was observed in the athletes; only mild dehydration, likely related to training, was present, and no dehydration was observed in the caffeine group.

This study had several limitations that should be considered. Firstly, allowing only a 48-hour recovery period between measurements may have increased the risk of incomplete recovery and affected subsequent performance outcomes. Secondly, only the FTP test was utilized, and other important performance measures, such as $\dot{V}O_{2\max}$ or anaerobic power, were not evaluated. Additionally, the potential impact of mental fatigue resulting from the repeated testing protocol may have influenced the results, particularly the rating of perceived exertion. Thirdly, the fact that participants had not previously used caffeine or carbohydrate supplements may have influenced their responses to supplementation. Finally, gastrointestinal symptoms were recorded; however, detailed analyses of their severity and duration were not conducted. The findings of this study have practical implications for coaches and athletes in the design of training and competition strategies to improve performance. The combined use of caffeinated gum and carbohydrate gel significantly increased functional threshold power and average power output. Coaches may consider using this combination before competitions and high-intensity training sessions, as it may enhance energy production, delay muscle fatigue, and improve performance. Similarly, coaches should consider that these supplements may contribute to short-term performance in youth athletes when administered at low to moderate doses (e.g., 200 mg of caffeine and 21.1 g of carbohydrates). These insights may improve training programs, recovery protocols, and performance strategies, potentially resulting in enhanced athletic performance.

Conclusion

In conclusion, this study demonstrates that the use of caffeinated gum and carbohydrate gel, administered separately and in combination, positively influenced various performance parameters in youth cyclists. Notably, co-ingestion of caffeinated gum and carbohydrate gel significantly enhanced average power output during the FTP test. However, no significant between-group differences were observed in heart rate or VAS values. RPE levels were lower in the CAF group compared with the CHO and CAF+CHO groups; however, the lowest levels were observed in the PLA group. Considering balance performance, both caffeinated gum and carbohydrate gel showed beneficial effects. Gastrointestinal symptoms were reported only

in the CAF group. Additionally, no significant alterations were noted in hydration status, and mild dehydration was detected due to training. Future studies should allow for longer recovery periods between tests. The inclusion of various performance and physiological tests, including VO₂max, anaerobic sprint tests, and lactate threshold assessments, would provide additional insights into supplementation effects. In addition, findings from studies conducted in elite youth athletes should be evaluated for their applicability to competitive settings. The effects of different doses and timing of caffeine and carbohydrates should be examined. Additionally, future studies should focus more closely on the severity and duration of gastrointestinal symptoms and assess hydration status using various methods, including urine or blood sampling.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors confirm that no generative artificial intelligence or AI-assisted technologies were used in the preparation, drafting, or editing of this manuscript.

Conflict of interest

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