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RESEARCH ARTICLE

Effects of Carbohydrate and Caffeine-Based Energy Gel Ingestion on Blood Glucose, Blood Lactate and Performance During Prolonged Cycling

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Abstract
The aim of this study was to investigate the effects of carbohydrate and caffeine-based energy gels on blood glucose, blood lactate, heart rate, rating of perceived exertion (RPE), power output, cadence during prolonged cycling exercise.
This research was an experimental study in which 15 competitor cyclists were tested in 3 different conditions. 3 experimental trials in a randomized order, no gel intake and water only use (T1), gel intake every 30 minutes (T2), 1 gel intake 15 minutes before exercise, and gel intake every 45 minutes after first gel intake and 1 carbohydrate + caffeine gel at 75 min (T3). Water use was released within 3 trials. Each exercise trial included 2 hours of cycling followed by 15 min TT. Measurements were made at the beginning, every 30 min, and at the end of the exercise. This research found that energy gels increased blood glucose levels and time trial (TT) performance compared to trials without consuming something. A more frequent gel intake improved blood glucose levels and TT distance. In the TT, blood lactate concentration increased significantly in T3 compared to T1 ($p<0.05$). Heart rate and RPE did not make a statistical difference ($p>0.05$). Even though cadence, power output, and TT distance in T3 were not statistically significant, the differences that occur are important in terms of cycling. The research also found no correlation between energy gel feedings and water intake ($p>0.05$). The results were important for cyclists with the positive effect on endurance performance when energy gels are used in long-term cycling exercises.

Keywords
Cycling, Energy Gel, Caffeine, Blood Glucose, Blood Lactate

INTRODUCTION

Endurance athletes use carbohydrate supplementation (CHO) during exercise to improve performance. It has been investigated for many years that carbohydrate supplementation during exercise may be associated with performance. The first studies on this subject were investigated during the 1924 Boston Marathon and it was seen that carbohydrate supplementation helped maintain blood sugar concentration and increase running performance (Kozlowski et al., 2021). In recent times, there has been a notable diversification in the market for carbohydrate (CHO) supplements, with a shift from mostly including drinks to the emergence of extremely concentrated energy gels. Energy gels are highly concentrated sources of carbohydrates that have been specifically designed to be ingested either on their own or in combination with water. Gels are considered by athletes as a convenient way to carry energy easily during movement. Although there is much research supporting the ingestion of CHO drinks, few studies have analyzed the effects of energy gels and how often they should be ingested (Juekendrup, 2008; Pöchmüller et al., 2016).

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Few investigations on the effects of gel-based carbohydrate supplements on performance (Cermak, N. M., & van Loon, 2013). Performance improvements have been demonstrated in relation to Carbohydrate intake in endurance sports during a 3-hour workout at 70% VO_2max versus an artificially sweetened placebo after banana consumption (Murdoch et al., 1993). Based on many studies, it has been observed that the manner in which carbohydrate (CHO) intake is consumed, whether in solid, liquid, or gel form, does not seem to have an impact on its capacity to enhance performance during exercise(Juekendrup, 2004). In addition, the metabolic rates of a CHO fluid and gel gave similar results on cyclists when they cycled for 3 hours at a VO_2max intensity of 59% (Pfeiffer et al., 2010).

Considerable study is now being conducted on the optimal form of carbohydrate (CHO) for consumption, irrespective of its specific composition. Several studies have shown that the consumption of 60-90 grams of carbohydrates per hour may be necessary to get optimal performance outcomes during extended periods of endurance exercise (Stellingwerff & Cox, 2014; Juekendrup, 2004). On the other hand, several contemporary energy gel producers advocate for a much reduced carbohydrate (CHO) consumption, proposing a regimen that yields an intake rate of about 35-50 g CHO/hr. This approach aligns with the prevailing standards set out by the American College of Sports Medicine, which advocate for a carbohydrate intake range of 30-60 grams per hour for physical activities lasting longer than one hour (Rodriguez et al., 2009; Sawka et al., 2007).

While studies indicate that caffeine may contribute significantly to performance enhancement, some studies cannot provide clear evidence. Despite the widespread involvement of individuals in competitive endurance sports, there exists a dearth of knowledge about the potential impacts of carbohydrate (CHO) and caffeine consumption during prolonged exercise of this kind (Davis & Green, 2009).

Studies show that low muscle glycogen can lead to early fatigue and subsequent decreased skill level. For this reason, the preservation of muscle glycogen stores can be an important condition for endurance sports (Ali et al., 2007). Blood lactate concentration is one of the most frequently measured parameters during both clinical exercise tests and performance tests of athletes. An elevated blood lactate concentration may be indicative of ischemia or hypoxemia, while it may also be a "normal" physiological response to exertion. In response to "total" maximal effort lasting 30-120 seconds, peaks of ≈15–25 mM can be observed 3-8 minutes after exercise. It has a nature that increases gradually in response to progressive, incremental exercise, and then more rapidly as exercise becomes more intense. The rate at which blood lactate concentration increases exponentially [lactate threshold] is a better indicator of performance than VO_2max. It is also a better indicator of exercise intensity than heart rate. For this reason, control can be important for endurance athletes (Goodwin et al., 2007)

The experimental framework used in this research was specifically formulated to evaluate the impact of carbohydrate (CHO) and caffeine consumption on performance during physical exercise or engagement in similar activities. The ingestion of energy gels among endurance athletes has gained significant appeal. This investigation has one objective and three outcome variables. The objective of this research was to assess the impact of carbohydrate and caffeine energy gel consumption regimens on (a) blood glucose, (b) blood lactate, (c) heart rate and RPE, and (d) 15-minute TT performance after 2 hours of stable cycling exercise.

MATERIALS AND METHODS

Participants

This research is an experimental model in which the sample participant group (elite and master cyclists) is tested in three different situations. The sample of the study was determined by using the convenient sampling method. Buyukozturk et al. (2018) defined the convenient sampling method as a sampling method in which easily and quickly accessible units are preferred due to basic limitations such as labor force and time. Accordingly, it was planned to include 15 male road cyclists actively competing in the Turkish Cycling Federation races in the elite and master categories of the study on a voluntary basis. This study wasapproved by the Fenerbahçe University Non-Interventional Clinical Research Ethics Committee; 13.04.2022/15.2022fbu. Written informed consent was obtained from all participants.

Study Design and Data Collection

After anthropometric measurements and Vo_2max determination, each participant underwent three experimental exercise sessions in a randomized and counter-balanced way. These trials consisted of two ingesting trials and one fasting trial. Each trial day was applied as follows;

T1; Free to use water.

T2; 1 carbohydrate gel* every 30 minutes. Free to use water.

T3; 1 gel intake 15 minutes before exercise, and gel intake every 45 minutes after first gel intakeand 1 carbohydrate + caffeine gel (150mg caffeine) at the 75th minute, different from A1. Free to use water.

For each exercise trials, blood glucose, blood lactate, watt output, cadence, heart rateand Borg rating of perceived exertion (Williams, 2017) data was monitored at the beginning, every 30 minutes and at the end.

Research variables

The dependent variable

- VO_2Max, Blood Lactate, Blood Glucose, Performance test against time (TT).

Independent variable

Consumption of Carbohydrate Gel, Caffeine gel.

Inclusion Criteria

- To participate in federation races,
- To be 16 years of age or older,
- Athletes must have trained for 2 hours or more at least 4 days a week in the last 3 months.

Exclusion Criteria

- Athletes must not have any joint and/or ligament injuries in the last three years.
- BMI, 25 and below
- Not signing the informed consent form

Personal (age, body weight, etc.) data obtained from laboratory tests were recorded in a single data collection form created by the researcher.

Working Process

After obtaining permission from Fenerbahçe University Non-Interventional Clinical Research Ethics Committee; The working process has started by obtaining the necessary permissions from the participants and Fenerbahçe University Sports Research Application and Research Center.

After the measurement methods to be applied were explained to the participants, the measurement devices were optimized, and the measurement environment and the athletes were prepared. First, the participants; Anthropometric measurements (height and body weight) were taken. After the participants had a routine warm-up on the bike, the VO_2Max test was applied. Heart rate and power output were recorded during all tests.

Exercise trials were conducted with a Tacx (Garmin ltd, USA) brand smart trainer so that the cyclists could better adapt to the exercise. All 3 exercises trials were performed the same, with different nutrition protocolsin in a randomized order. The maximum watt output obtained during the VO2max analysis was determined. With 70% of this value, an endurance ride lasting 120 minutes was made. Then, a 15-minute time trial was performed.

The gel supplement used in our research was Bigjoy on the Go Progel, manufactured by Farmatek Iç ve Dış. Tic. A.Ş in Turkey. This particular product is well recognized and often employed by triathletes and endurance athletes. A single unit of Progel is composed of 96 calories, 24 grams of carbohydrates in the form of maltodextrin, and also includes electrolytes. The caffeine gel used in the research contains 150 mg of caffeine, unlike the standard gel.

Participants were asked to participate in all tests with equipment suitable for cycling competition conditions (cycling jersey and tights, cycling shoes). Participants were asked not to do high-intensity exercise, not to consume alcohol or high-caffeine-containing foods and foods within 48 hours before coming to the test. It was paid attention that the athletes who will participate in the study had their last meal between 09:00 and 17:00 on weekdays and 3 hours before the measurements, and they were included in the study at the normal satiety level.

Height and Body Weight Measurement

The height and length measurements of the volunteer athletes were measured with a stadiometer (Holtain Ltd, UK) fixed to the wall with an accuracy of ±0.1mm. Body weights were measured with an electronic laboratory scale (Seca, Vogel & Halke, Hamburg) with an accuracy of ±0.1 kg.

The subjects did not wear thick clothes and socks so that the appropriate body position could be given during the measurements. Measurements were taken with the heads of the subjects in the "Frankfort Horizontal Plan" position, the arms on the side of the body and the palms facing the legs, of the subjects whose body weight was evenly distributed on both legs. When the heels touch each other, the angle on the inside of the feet is approximately 60°. All height measurements were taken with the heels, hips and scapula touching the platform in a vertical position and subjects in an upright position. Body weights were calculated by Lohman et al. (1988) suggested.

Oxygen Consumption Test

Oxygen consumption values of the participants will be measured with a PNOE (Palo Alto, CA, USA) brand metabolic analyzer. The analyzer consists of a cordless, lightweight and easily portable unit (120 × 110 × 45 mm, height, width, length, respectively) developed for measuring gas exchange rates. The device can be put on the participant with a vest and can be kept on during the tests. At the same time, the participant wears a mask of suitable size and passes through the flow sensor while breathing with it. Before and after each measurement, the device was calibrated in accordance with the manufacturer's instructions. An antibacterial filter is attached to the end of the mask and all parts, including the mask, are disinfected after each measurement. There will be only participant and two researchers in the measurement environment, while the tests were going on, entrance and exit to the laboratory could not be made. After a 10-minute warm-up, the participants will start the test by pedaling with a 200-watt load at their preferred pedal speed. During the first 6-minute period, the load will be increased by 50 watts every 2 minutes, then 25 watts every 2 minutes, and the test will continue. The test will be terminated at the point where the participant is exhausted (Harnish et al., 2001; Beam & Adams, 2013). In addition, a Garmin brand (Garmin ltd, USA) chest strap will be used to control the participants' heart rate.

Blood Glucose, Blood Lactate, Power Output, Cadance and Heart Rate Measurements

Blood Glucose measurements were made using On Call brand glucometer and sticks. Measurements were taken before the test, immediately after the test, and every 30 minutes.

Blood lactic acid measurement was made using a blood lactate analyzer (Lactate Scout) and sticks. The blood taken from the fingertip for measurement was immediately analyzed using the lactate oxide technique on the blood lactate analyzer lactate Scout measuring device by dripping onto the test strips. Blood lactic acid measurements were taken before the test, immediately after the test, and every 30 minutes.

Power output and cadence measurements were made by Tacx Smart Trainer (Garmin ltd, USA) Laboratory tests carried out within the scope of the study were carried out in Fenerbahçe University, Sports Research Application and Research Center in May – July 2022.

Statistical Analysis

For all variables, descriptive statistics (means ±SD) were computed. After examining the data visually and checking for kurtosis and skew, it was discovered that they were regularly distributed. Blood glucose, lactate, RPE, and Heart Rate within-subject differences across the 3 trials were examined using a 2-way (time point 3 ingestion schedule) analysis of variance (ANOVA) with repeated measurements. Simple effects for time were investigated when there were significant interaction effects, and main effects were evaluated when there were no significant interaction effects. The TT distance covered during the course of the three trials was compared using an ANOVA with repeated measurements. F-ratios for a main effect were shown to be significant using a Bonferroni post hoc test. A post-hoc statistical power calculation was performed to find changes in TT performance between three trials. All statistics were performed in SPSS 24 for Windows (SPSS, Inc., Chicago, IL).

RESULTS

Table 1 shows the demographic characteristics of the participants. Age, body weight, body height, BMI and body fat percentage of the athletes were determined.

An interaction effect was found between 3 measurements in blood glucose values (Table 2). There was no significant difference in blood glucose values between the 3 measurements at baseline (Figure 1). During T1, blood glucose dropped at 30 minutes and remained almost stable until the end of TT and did not rise again. During T2, blood glucose dropped similarly to T1 at 30 minutes but rose again at 60 minutes and remained almost stable until the end of TT. During T3, blood glucose dropped at 30 minutes but rose again at 60 minutes and gradually decreased until the end of 120 minutes, rising to peak at the end of TT. At the end of TT, blood glucose was statisticallysignificantly higher at T2 than at T1 (p

= 0.026) and at the end of TT, blood glucose was statistically significantly higher at T3 than at T1 (p = 0.001). There were significant differences in the effect of time on blood glucose in the 3 measurements (Table 2). Post Hoc analyses showed that during T1, blood glucose decreased significantly at 120 minutes (p = 0.008) and at the end of TT (p = 0.001) compared to baseline. During T3, blood glucose at the end of TT was statistically significantly higher than blood glucose at 30 minutes (p = 0.010) and 120 minutes (p = 0.003).

Table 1. Demographic characteristics of the participants (n=15)

	Mean (±SD)	Minimum	Maximum
Age (yr)	32.33 (9.58)	18	44
Body mass (kg)	74.33 (7.76)	62	89
Height (cm)	175.87 (6.70)	161	187
BMI ($kg·m^{-2}$)	21.11 (1.86)	19.02	24.72
$\dot{V}O_2$ max ($mlO_2·kg^{-1}·min^{-1}$)	60.77 (5.83)	52.00	72.40

BMI= Body Mass Index

Dependent measures across all time points and all 3 trials are presented in Table 2.

Table 2: Dependent variables across all time point and trials.

Dependent variable	Condition	Time (min) 0	30	60	90	120	TT	F	p
Blood glucose ($mg·dl^{-1}$) mean (±SD)	T1	110.07 (6.18)	102.60 (9.67)	100.53 (11.07)	101.00 (8.13)	98.67 (4.17)µ	96.07 (10.05)¥	3.963	0.001§
	T2	111.60 (8.66)	102.13 (8.99)	110.73 (9.00)	110.33 (7.32)	107.27 (6.61)	109.07 (10.43)¶		
	T3	114.13 (11.60)	107.93 (6.53)	113.73 (8.74)	110.87 (7.61)	107.00 (12.97)	119.13 (12.50)‖¤ɸ		
Blood lactate ($mmol·L^{-1}$) mean(±SD)	T1	1.87 (0.87)	3.62 (1.44)Ϫ	3.89 (1.71)Ϫ	4.36 (2.49)Ϫ	5.29 (2.43)¥Ϫ	10.97 (2.38)¥	2.732	0.004¦
	T2	1.54 (0.58)	3.93 (1.35)Ϫ	4.47 (2.74)ʉϪ	3.61 (2.43)Ϫ	3.86 (1.31)Ϫ	12.95 (5.18)¥		
	T3	1.40 (0.59)	3.47 (1.84)Ϫ	3.56 (2.21)Ϫ	3.36 (2.11)Ϫ	4.09 (2.85)Ϫ	14.19 (2.68)¥¶		
Heart Rate (bpm) mean (±SD)	T1	64.33 (8.69)	144.73 (14.90)¥Ϫ	146.47 (16.10)¥Ϫ	150.53 (14.61)¥Ϫ	152.93 (14.04)¥Ϫ	182.73 (9.40)¥	0.887	0.546
	T2	64.33 (11.49)	146.80 (14.15)¥Ϫ	147.13 (12.43)¥Ϫ	150.00 (13.00)¥Ϫ	151.60 (14.28)¥Ϫ	184.60 (9.46)¥		
	T3	63.20 (10.02)	141.93 (12.17)¥Ϫ	142.07 (12.12)¥Ϫ	145.53 (12.01)¥Ϫ	149.87 (12.22)¥Ϫ	186.93 (7.94)¥		
RPE mean (±SD)	T1	-	4.67 (1.18)	5.67 (1.11)‖	6.40 (1.24)ϴ	7.33 (1.29)ϴЂ	-	0.541	0.776
	T2	-	4.87 (1.13)	5.53 (1.06)	6.07 (1.10)ρ	7.07 (1.16)ϴЂЊ	-		
	T3	-	3.93 (1.28)	4.93 (1.34)‖	5.33 (1.35)ϴ	6.20 (1.15)ϴЂ	-		

*TT = end of the time trial measurement; RPE = ratings of perceived exertion.

§ Significant interaction effect p<0.001

¦ Significant interaction effect p<0.01

‖ A significant difference from 30 minutes during the same trial p<0.05

ρ A significant difference from 30 minutes during the same trial p<0.01

ϴ A significant difference from 30 minutes during the same trial p<0.001

Ђ A significant difference from 60 minutes during the same trial p<0.001

Њ A significant difference from 90 minutes during the same trial p<0.05

ϫ A significant difference from TT during the same trial p<0.001

¤ A significant difference from 120 minutes during the same trial p<0.01

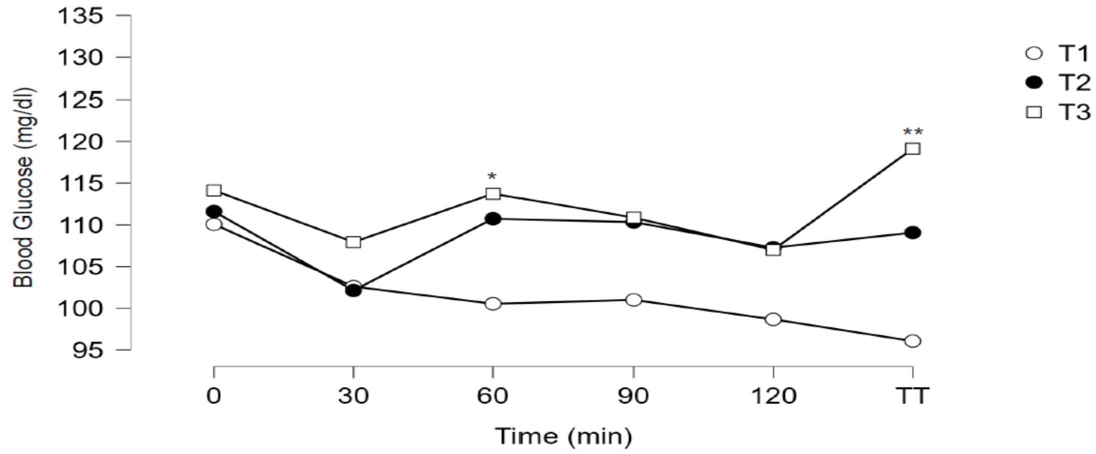
¶ A Significantly different from T1 at the same time p<0.05

ɸ A Significantly different from T1 at the same time p<0.001

ʉ A Significant difference from baseline measures from the same trial p<0.05

µ A Significant difference from baseline measures from the same trial p<0.01

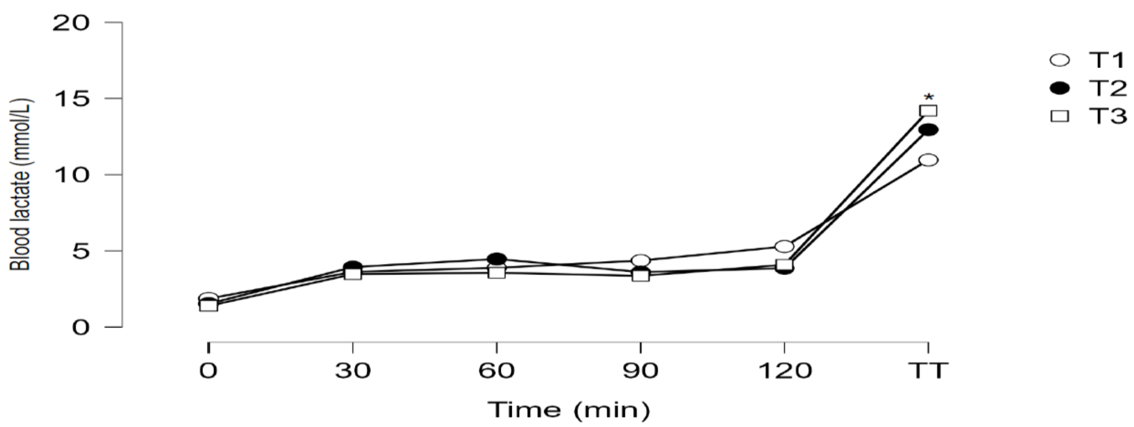
¥ A Significant difference from baseline measures from the same trial p<0.001



*T3 is significantly different than T1 (p<0.05). **T2 is significantly different than T1 (p<0.05); T3 is significantly different than T1 (p<0.001).

Figure 1. Mean blood glucose measures across all trials.

An interaction effect was found between 3 measurements in blood lactate concentration values (Table 2). There was no significant difference in blood lactate concentration values between the 3 measurements at baseline (Figure 2). Similarly in all 3 measurements; blood lactate concentration increased slightly at 30 minutes and remained almost stable until the end of 120 minutes, and blood lactate concentration increased similarly in all 3 measurements at the end of TT. At the end of TT, blood lactate concentration was statistically significantly higher at T3 than at T1 (p = 0.026). There were significant differences in the effect of time on blood lactate concentration in the 3 measurements (Table 2). In all 3 measurements, blood lactate concentration values at the end of TT were statistically significantly higher than baseline (p = 0.001). During T1, blood lactate concentration at 120 minutes was significantly higher compared with baseline (p = 0.001). During T2, the blood lactate concentration at 60 minutes was significantly higher compared to baseline (p = 0.019). In all 3 measurements, the blood lactate concentration at the end of TT was significantly higher than at 30, 60, 90 and 120 minutes (p = 0.001).



*T3 is significantly different than T1 (p<0.05).

Figure 2. Mean blood lactate concentrations across all trials.

No interaction effect was found between the 3 measurements in heart rate values (Table 2). There was no significant difference in heart rate values between the 3 measurements at baseline (Figure 3). Similarly in all 3 measurements; heart rate data increased at 30 minutes, progressed almost stably until the end of 120 minutes, and increased again similarly at the end of TT. There were significant differences in the effect of time on heart rate in the 3 measurements (Table 2). In all 3 measurements, heart rate data were statistically significantly higher at 30,60,90,120 minutes and at the end of TT compared to baseline (p 0 0.001). Heart rate data in all 3 measurements; the value at the end of TT was statistically significantly higher than the values at 30,60,90 and 120 minutes (0.001).

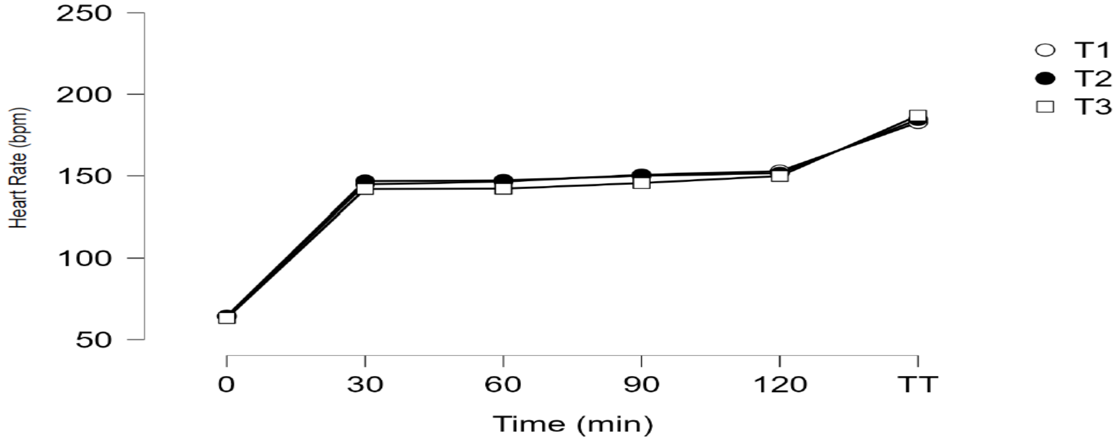


Figure 3. Mean heart rate datas across all trials

There was no interaction effect between the 3 measurements in the perceived degree of difficulty values (Table 2). There was no significant difference in perceived difficulty between the 3 measurements at baseline (Figure 4). Perceived degree of difficulty data increased gradually in all 3 measurements. There were significant differences in the effect of time on perceived difficulty in the 3 measurements (Table 2). The perceived difficulty at 90 and 120 minutes during T1 was statistically significantly higher than at 30 minutes ($p = 0.001$). The perceived degree of difficulty value at 60 minutes during T1 was statistically significantly higher than at 30 minutes ($p = 0.05$). The perceived degree of difficulty value at 120 minutes during T1 was statistically significantly higher than at 60 minutes ($p = 0.001$). The perceived degree of difficulty value at 90 minutes during T2 was statistically significantly higher than at 30 minutes ($p = 0.01$). Perceived difficulty at 120 minutes during T2 was significantly higher than at 30 minutes ($p = 0.001$), 60 minutes ($p = 0.001$) and 90 minutes ($p = 0.05$). Perceived difficulty at 60 minutes during T3 was significantly higher than at 30 minutes ($p = 0.05$). Perceived degree of difficulty values at 90 and 120 minutes during T3 were significantly higher than at 30 minutes ($p = 0.001$). The perceived degree of difficulty value at 120 minutes during T3 was statistically significantly higher than at 60 minutes ($p = 0.001$).

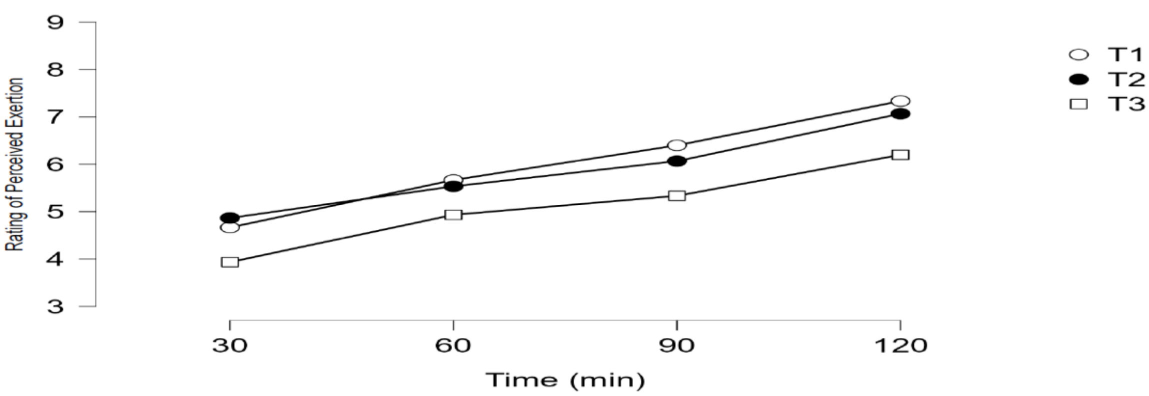


Figure 4. Mean ratings of perceived exertion across all trials.

Table 3. Shows the data of the time trials (15 minutes) and hydration

Dependent variable	Condition	Mean (±SD)	F	p
	T1	246.87 (55.06)		
Mean power output TT (watt)	T2	241.80 (55.02)	0.130	0.879
	T3	252.13 (56.51)		
	T1	93.00 (6.89)		
Cadance TT (rpm)	T2	94.47 (6.26)	1.269	0.292
	T3	96.67 (5.85)		
	T1	9.87 (0.83)		
Distance covered during TT (km)	T2	9.89 (0.85)	0.537	0.589
	T3	10.15 (0.78)		
	T1	1.97 (0.49)		
Hydration (Liter)	T2	1.98 (0.53)	0.284	0.754
	T3	1.87 (0.37)		

*rpm = revolutions per minute

No significant difference was found in mean power output, cadence, the distance covered and hydration values (p>0.05). When the distance traveled (figure 5) and average power output (figure 6) values were analyzed; it was seen that the values in T3 are higher, although there is no significant difference between the trials.

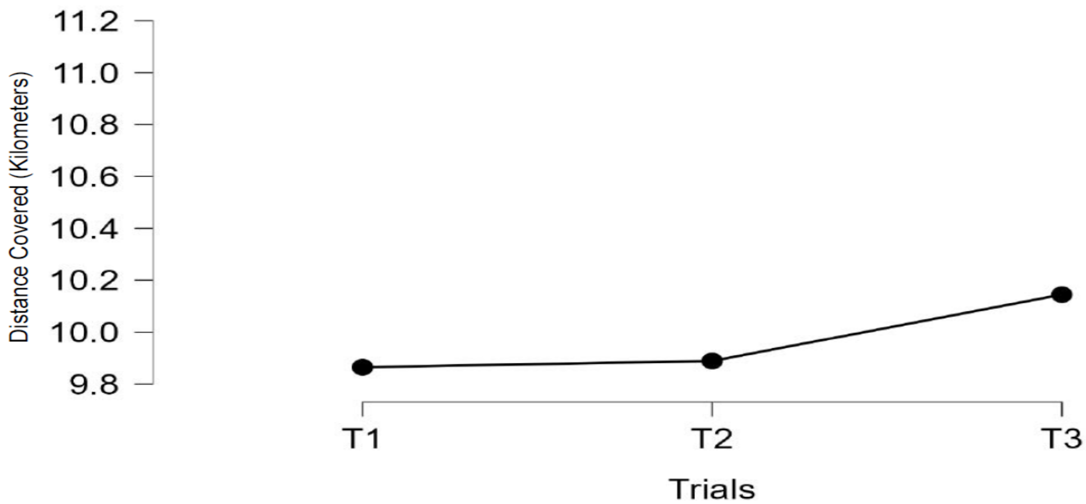


Figure 5. Distance in kilometers covered during the 15-minute time trial.

DISCUSSION

The aim of this study was to investigate the effects of carbohydrate gel use, which is frequently used by cyclists, on the performance of a 2-hour endurance exercise followed by a 15-minute TT. In the tests performed in 3 different conditions, blood glucose, blood lactate, heart rate, watt output, cycling cadence, RPE and TT were primarily analyzed. Our study showed that the use of carbohydrate-based energy gel created a significant difference compared to the tests performed with only water and maintained the blood glucose level. While no significant change was observed in blood lactate levels during the 120-minute exercise period for all three trials, a statistically significant increase in T3 compared to T1 occurred during the 15-minute TT performance. Heart rate and RPE values did not change significantly for a total of 135 minutes in all 3 trial types. However, although there is no significant difference in terms of cadence, watt output and distance covered during TT, the difference may be important in terms of cycling. There was no significant relationship between energy gel and water consumption.

In a similar study by Kozlowski et al. (2021) found that carbohydrate gel feeding maintained blood sugar level, did not cause a change in blood lactate level, and increased performance in the TT cycling test during a 2-hour exercise. They mentioned the positive effect on performance of using a gel every 30 minutes, not at intervals of 45-60 minutes. One of the main findings in the research pertains to the role of energy gel consumption in maintaining blood glucose levels, while also demonstrating a favorable impact on the rating of perceived exertion (RPE) with repeated usage. Limited research has been conducted to assess the impact of energy gel consumption on glucose levels and physical performance during exercise. A research was conducted to examine the effects of pre-exercise carbohydrate gel consumption on athletes' blood glucose concentrations and other performance indicators during extra time in a simulated football match. The findings revealed that the carbohydrate gel intake resulted in higher blood glucose concentrations and improved dribbling performance among the athletes. However, no significant improvements were seen in other performance indicators such as sprinting or jumping (Harper et al., 2016). Another research found that the use of isotonic carbohydrate gel during high-intensity shuttle running resulted in a significant delay in the onset of tiredness and a notable enhancement in running capacity by 45% when compared to the group presented with a placebo. The feature of this study is the positive effect of carbohydrate supplementation on endurance capacity, consistent with previous research. In addition, it is the first study to investigate carbohydrates in gel form and to report its positive effects (Patterson & Gray, 2007). There is a positive trend in studies on carbohydrate supplements. According to a research, the consumption of a 6.9% carbohydrate (CHO) beverage immediately before to and during a 75-minute high-intensity shuttle run resulted in a notable 33% improvement in endurance capacity when compared to a placebo (Nicholas et al., 1995). An additional investigation revealed that the absence of a 4-second recuperation time subsequent to each sprint resulted in a 32% enhancement in high-intensity running performance when carbohydrate (CHO) intake in the form of a 6% solution was administered prior to and throughout exercise, as compared to a placebo (Davis et al., 2000). In a study conducted by Wels et al. (2002), it was discovered that the consumption of a 6% carbohydrate (CHO) drink before to the beginning of each 15-minute exercise session had a notable impact, while taking an 18% CHO fluid halfway through a 60-minute interval jog, extended the interval time to fatigue by 37%.

Although there are positive studies on carbohydrate intake, some studies with carbohydrate gels did not have the same positive effect. In one of the conducted instances, participants performed in a 5.2-kilometer training run, after which they ingested a 70-gram sachet of isotonic carbohydrate (CHO) gel, comprising 25 grams of carbohydrates. Following the administration of carbohydrate (CHO), the participants engaged in a 5 kilometer running experiment. Brooks et al. (2002) did not provide any performance data in their study. However, they did find that carbohydrate consumption had a substantial impact on blood glucose concentration, causing a lesser decrease in blood volume compared to the control or water conditions. The study conducted by Burke et al. (2005) is the second research endeavor aimed at examining the impact of carbohydrate gel consumption on performance. According to their research, the observed effect on performance was found to be negligible, as the duration was enhanced by a mere 14 seconds. Given that this investigation was carried out on a cohort of highly skilled athletes, a temporal discrepancy of 14 seconds may be seen as a noteworthy improvement in performance as time progresses.Recent studies in terms of the amount of carbohydrate supplementation during exercise recommend 1.5 g CHO intake per 1 minute. Gel manufacturers have recommendations for 1 packet (almost 35 gr CHO)15 minutes before exercise and 1 packet every 45 minutes.In the study, the use of more frequent energy gels against the recommendations of the gel manufacturers increased the TT performance by 7-12% compared to the non-reinforced condition. In terms of TT performance, the use of gel at 30 minutes and 45 minutes did not make a significant difference, while more frequent use showed a performance increase of 5% (Kozlowski et al., 2021). Similarly, in our study, there was no significant difference in the blood glucose level of the energy gel feeding used every 30 minutes and 45 minutes.

The data we obtained in our study revealed a statistically significant blood lactate value in the TT performance of T3 who started to use gel before exercise, took gel every 45 minutes, and used caffeine gel at 75 minutes. In a similar study, Kozlowski et al. (2021) found blood lactate values to be similarly high in TT performance when fed with carbohydrate gel.The metabolic path used for energy generation during exercise might be influenced by the glucose state inside the body. If there is a substantial rise in glycolytic metabolism, it may lead to an elevation in lactic acid generation if the oxidative cycle is incapable of managing the heightened synthesis of pyruvic acid. The observed elevation in lactate levels at T3, as compared to T1, is plausibly attributed to enhanced glucose accessibility resulting from a higher frequency of gel consumption throughout the time trial. Furthermore, it was observed that the performance distance exhibited a larger disparity in T2 and T3 as compared to T1. This discrepancy may likely be attributed to the heightened availability of substrates during these trials, which can be attributed to the preservation of muscle glycogen. Following the completion of the time trial (TT), participants were instructed to exert their utmost effort in certain topics for the last 15 minutes. Our observations revealed a notable inclination towards increased lactate generation during T2 and T3, particularly when exercise was often accompanied by the consumption of an energy gel. This phenomenon may indicate that the elevation in blood glucose levels is metabolized anaerobically and transformed into lactate while engaging in physical activity at an intensity above 70% of the maximum oxygen consumption (VO_2max). Additionally, the consumed substrate has a role in augmenting both the rate of energy generation and the formation of lactate.

Similarities might be seen in the lactate concentrations throughout various supplementation trials. In accordance with the results of our study, Steiner et al. (2009) reported a lack of statistically significant disparity in lactate levels between the group that received the carbohydrate supplement and the group that received the placebo during the 45-minute cycling session at 70% of maximum oxygen consumption (VO_2 max). A research investigating the effects of long-term exercise observed that the consumption of 58 g of carbs per hour during a self-paced treadmill run covering a distance of 24.14 km did not provide any statistically significant differences in lactate concentrations (Andrews et al., 2003).

Many studies have shown that carbohydrate supplementation is associated with low RPE (Anastasiou et al., 2004). Similarly, studies have found a relationship between carbohydrate supplementation and high RER values. This may indicate that subjects actually oxidized larger amounts of carbohydrates as the frequency of supplementation increased (Anastasiou et al., 2004; Andrews et al., 2003). Nevertheless, our investigation did not provide any statistically significant disparities in the values of perceived exertion (RPE) and heart rate. According to reports, exhaustion might potentially exist due to the breakdown of one or more connections within the pathway connecting the central nervous system (CNS) to the mechanism responsible for muscle contraction (Sahlin,1992). Nybo (2003) the current investigation examined the impact of administering a 6% glucose polymer solution at 15-minute intervals on the voluntary force generation throughout a 3-hour cycle trial, with a workload of 200 W at 90 revolutions per minute. The researchers reported that glucose homeostasis was sustained throughout the glucose study conducted during exercise, but it declined to hypoglycemia levels (~3.0 mmol/L) in the placebo trial. Furthermore, the occurrence of exercise-induced hypoglycemia was shown to result in a decrease in the mean force generated during prolonged maximum muscular contraction.

Existing research has shown that dehydration has the potential to cause an early onset of fatigue in both aerobic endurance events and high-intensity exercise (Davis et al., 2000). The amount of water consumed during the tests was measured in order to analyze the water consumption of the athlete in cases where different gels were used and only water was consumed.In our study, there was no significant difference in water consumption in 3 different feeding types.

Consuming caffeine 4-6 mg/kg before working out. provides energizing effects that are beneficial during high-intensity interval training for improving sprinting ability, muscle growth, and hand-eye coordination (Roberts et al., 2010). As an adenosine antagonist (Fredholm et al., 1999), Caffeine has the ability to easily pass the blood-brain barrier, so promoting its interaction with the main target inside the central nervous system (CNS) (Graham, 2001). The effects include a reduction in the sense of work and discomfort (Roberts et al., 2010), increased central drive (Kalmar & Caffarelli, 1999), and, to a reduced degree, enhanced muscular strength and endurance (Warren et al., 2002). The co-ingestion of caffeine and carbohydrates has been seen to decrease the use of muscle glycogen during the first phases of physical activity, so preserving it for subsequent utilization and delaying the onset of exhaustion (Cox et al., 2002). In our study, carbohydrate gel containing 150 mg of caffeine was used in the T3 feeding type at the 75th minute. There is an expectation among athletes to increase endurance or increase performance, and research supports this expectation. Caffeine can have an effect on peak pace, highest power output, and longest distance, especially during TT.

Conclusion

The findings of this study indicate that the intake of energy gels during trials resulted in higher blood glucose levels and enhanced time trial (TT) performance compared to trials without feeding. Furthermore, an increased frequency of gel administration resulted in improvements in both blood glucose levels and the distance covered during the time trial (TT). The blood lactate concentrations were shown to be elevated after the time trial (TT) performance in all three trialsand a statistically significant increase in T3 compared to T1 occurred during the 15-minute TT. Heart rate and RPE values did not change significantly. In addition, even though cadence, power output and distance covered during TT in T3 were not statistically significant, they made a significant difference in terms of today's sporting expectations. The study also found no association between energy gel feedings and water consumption.

Conflict of interest

No conflict of interest is declared by the authors. In addition, no financial support was received.

Ethics Committee

This study is approved by Fenerbahçe University (FBU) Non-Invasive Clinical Research Ethics Committee (Approval Number: 13.04.2022/15.2022fbu)

Author Contributions

Planned by the author: Study Design, Data Collection, Statistical Analysis, Data Interpretation, Manuscript Preparation, Literature Search. Author have read and agreed to the published version of the manuscript.

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