Impact of MCT Oil and Caffeine on Substrate Metabolism during Submaximal Exercise

Original Research

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Abstract

Introduction: Recent research has suggested that medium-chain triglyceride (MCT) supplementation may increase fat oxidation (FatOx) during aerobic exercise, sparing muscle glycogen and, perhaps, enhancing performance. As both MCT and caffeine (CAF) are theorized to elicit these effects, this pilot study's purpose was to compare the physiological responses of their combined supplementation during submaximal cycling exercise.

Methods: Eight aerobically trained males (mean±SD; age 23.6±4.4 years; body mass 82.3±15.8 kg; height 180.9±8.7 cm) completed one aerobic capacity (VO_2peak) test and three 45-min exercise trials at 60% VO_2peak. Blinded and counterbalanced, one-hour prior to each trial, participants consumed: MCT+CAF (20 mL + 100 mg), long-chain triglycerides (LCT)+CAF (40 mL + 100 mg), or CAF (100 mg). Oxygen consumption (VO_2), carbon dioxide output (VCO_2), and minute ventilation (VE) were measured, subsequently calculating respiratory exchange ratio (RER), energy expenditure (EE), carbohydrate oxidation (CarbOx), and FatOx.

Results: No significant differences between conditions were observed for average VO_2 (p=0.474; η^2=0.101), VE (p=0.323; η^2=0.149), (RER (p=0.323; η^2=0.149), EE (p=0.474; η^2=0.101), CarbOx (p=0.274; η^2=0.169), or FatOx (p=0.478; η^2=0.100) or for total EE (p=0.474; η^2=0.101), CarbOx (p=0.274; η^2=0.169), or FatOx (p=0.478; η^2=0.100).

Conclusions: Co-ingestion of MCT+CAF didn't produce any significantly different physiological responses compared to co-ingestion of LCT+CAF or the CAF control.

Key Words: fat oxidation, carbohydrate oxidation, medium-chain triglyceride oil

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Introduction

Excessive intake of dietary fat, particularly saturated fat, is traditionally blamed for weight gain and the subsequent increased risk of obesity. However, not all fats are equal, and all respond differently in the body. For example, medium-chain triglycerides (MCT), specifically caprylic acid (C8:0) and capric acid (C10:0), may facilitate weight loss and even counteract fat deposition through increased energy expenditure and lipid oxidation [1,2]. These findings have led to investigations on MCT potential as both a weight loss tool and ergogenic aid, particularly for endurance athletes [3–5].

In general, fats are slower to digest than carbohydrates. However, saturated fats have been shown to differ in their rate of digestion depending on the length of their aliphatic hydrocarbon chain [1,6]. For instance, long-chain triglycerides (LCT), the most frequently consumed saturated fat, must be re-esterified in the small intestine and incorporated into chylomicrons to be transported via the lymphatic

system, which can take hours, before they can be oxidized for energy or stored in adipocytes [6]. MCT, on the other hand, are cleaved into glycerol and medium-chain fatty acids (six to 12 carbons in length) in the gut lumen, and then, due to their smaller size and solubility, passed directly into the hepatic portal vein to the liver where they (i.e., C8:0 and C10:0) are rapidly metabolized as a fuel substrate through β-oxidation, typically within 30 minutes [1,2,6]. The metabolism of MCT results in the production of β-hydroxybutyrate, acetoacetate, and acetone, three major ketones that, along with any MC fatty acids that escape metabolism, are then released into the blood where they can be taken up by the muscle and brain [2,7]. What is important about these MC fatty acids is their ability to be transported across the mitochondrial membrane without carnitine, making them more easily degraded than LCT via β-oxidation [8,9]. Therefore, it has been speculated that MCT supplementation may be beneficial as both an ergogenic aid and nutritional strategy for maximizing fat oxidation with exercise.

The brunt of the research on acute, pre-exercise supplementation of MCT has focused on sports or exercise performance rather than fat oxidation, indicating MCT consumption prior to, or during, exercise in trained cyclists had no significant impact on performance [3,10,11]. The limited number of studies that have examined the effects of MCT supplementation on substrate oxidation have yielded differing results, with some reporting increased fat oxidation while others reported no change in both physically active adults and trained cyclists [1,9,11]. With that said, more recent and short-term (i.e., ~2 weeks) studies have produced more favorable outcomes. In sedentary individuals, MCT consumption (6 g per day) increased fat oxidation during aerobic exercise when compared to carbohydrates, though the effects appeared to vary depending on biological sex and the composition of the MCT [12]. This makes sense, as C8:0 has been shown to produce three times as many ketones as C10:0 and six times as many as lauric acid (C12:0) 30 minutes to three hours post-ingestion [13]. Another short-term study found that MCT ingestion (2 g per day) increased fat burning during daily, low-intensity physical activity in sedentary and overweight individuals when compared to LCT controls [14]. In recreational athletes, MCT supplementation (6 g per day) significantly increased cycling time to exhaustion while displaying consistently higher fat oxidation rates, though not significant [5]. Overall, these studies reveal the potential of MCT supplementation to induce an increase in fat oxidation in laypersons but also those that are active or athletes, but further research is needed to validate its efficacy.

Caffeine is one of the most common stimulants included in pre-workout supplements, with numerous randomized trials indicating its effectiveness as an ergogenic aid for aerobic exercise [15]. While originally theorized to increase fat oxidation and spare muscle glycogen directly [16–18], recent research suggests that the ergogenic benefits of caffeine may be due to other factors [19–21]. Specifically, caffeine may stimulate the sympathetic nervous system to increase epinephrine secretion and other satellite effects [15,22], which, of course, will stimulate both lipolysis and fatty acid oxidation. If MCT supplementation is indeed an effective strategy for increasing fat utilization during aerobic exercise, co-ingesting it with caffeine, which is already known to provide these benefits, would theoretically provide an enhanced ergogenic benefit on fat oxidation, facilitating greater weight loss and aerobic performance.

To our knowledge, no research has been performed examining the effects of acutely co-ingesting MCT oil and caffeine prior to steady state exercise and little research has been done comparing the effects of pre-exercise MCT and LCT supplementation. Thus, the purpose of this experiment was to compare the physiological responses between co-ingestion of 20 mL MCT oil and 100 mg of anhydrous caffeine powder (MCT+CAF) and co-ingestion of 40 mL of heavy cream, which naturally contains predominantly LCT, and CAF (LCT+CAF), with ingestion of a CAF control, 60 minutes prior to submaximal exercise on a cycle ergometer. The primary outcome measure for this pilot investigation was substrate unitarization (i.e., fat and carbohydrate oxidation). It was hypothesized that MCT+CAF would result in greater fat oxidation and lower carbohydrate oxidation compared to LCT+CAF and the CAF control.

Methods

Participants

As this study was exploratory in nature, or a pilot study, we did not conduct an ad hoc power analysis. Healthy, aerobically trained (i.e., self-reported), males between the ages of 18 and 35 years were recruited for the study through email advertisement and word of mouth from the Skidmore College community. After providing written informed consent, participants' health history was screened using the Physical Activity Readiness Questionnaire (PAR-Q) and a medical history questionnaire. Participants were excluded if they had a recent surgery, had previous injuries that would prevent completion of exercise trials, or presented any preexisting metabolic, cardiovascular, or pulmonary diseases. All experimental procedures were approved by the Institutional Review Board of Skidmore College (protocol code #1801-693).

Protocol

Test Beverages: The three isovolumetric, flavor matched, beverages CAF (40 kcal), LCT+CAF (173 kcal), and MCT+CAF (207 kcal) were provided in bottles labeled inconspicuously as "A", "B", and "C", respectively. The CAF beverage (i.e., control) contained 240 mL of water, 11 g of a sugar free chocolate milk powder (Nesquik, Nestle, Vevey, Vaud, Switzerland), and 100 mg of anhydrous caffeine powder (Caffeine, Nutricost, Vineyard, Utah, USA). The MCT+CAF beverage contained 220 mL of water, 11 g of a sugar free chocolate milk powder (Nesquik, Nestle, Vevey, Switzerland), 100 mg of anhydrous caffeine powder (Caffeine, Nutricost, Vineyard, Utah, USA), and 20 mL of coconut derived MCT oil (Organic MCT Oil, Sports Research, San Pedro, California, USA) comprising of 18.4 g of fatty acids (i.e., 37.8% C8:0, 30.7% C10:0, and 31.5% C12:0). The MCT oil supplement was selected because it is sourced from a certified GMP manufacturer that has their products 3rd party tested, ensuring product integrity. Dosage of MCT oil was chosen based on a meta-analysis of MCT oil studies, which found that acute dosages of MCT oil tended to cause gastrointestinal distress once they exceeded 30 mL [10]. The LCT+CAF beverage contained 200 mL of water, 11 g of a sugar free chocolate milk powder (Nesquik, Nestle, Vevey, Switzerland), 100 mg of anhydrous caffeine powder (Caffeine, Nutricost, Vineyard, Utah, USA), and 40 mL of heavy cream (Pics, Price Chopper, Schenectady, New York, USA) comprising of 13.3 g of fat (i.e., 9.3 g of saturated fat). The caffeine supplement was selected because it is sourced from a certified GMP manufacturer that has their products 3rd party tested, ensuring product integrity. Caffeine amount was selected as it was proportional to a typical cup of coffee [23]. On average the relative caffeine dose was 1.2 mg/kg body mass.

Overview of Laboratory Assessments: This study was conducted in a randomized, single-blind, counterbalanced, and crossover manner. The assessments for this study were conducted by trained research assistants during four separate sessions at the Skidmore College Human Performance Laboratory (Figure 1). The first visit (V1) to the laboratory consisted of a baseline peak aerobic capacity (VO_2peak) test on a cycle ergometer to establish workloads for the subsequent experimental trials (i.e., visits 2-4; V2-V4). All visits were conducted between 08:30 and mid-afternoon, depending on the availability of the participants. Participants were asked to wear comfortable shorts and a T-shirt for all visits. One-hour prior to each experimental trial, participants were instructed to consume one of the three isovolumetric beverages that was delivered to them by the researchers the night before. Beverage consumption one-hour prior was based on expected bioavailability and practical application for training (i.e., ecological validity). They were asked to abstain from alcohol, caffeine, and strenuous exercise 24 hours prior to each experimental trial, and to be fasted for at least eight hours to prevent any extraneous foods or beverages from affecting the measured physiological variables, aside from the designed intervention. Empty shaker cups were returned on the day of each experimental trial to ensure beverage consumption compliance. The three experimental trials were counterbalanced and separated by a three-day minimum washout period. All trials were completed within three weeks.

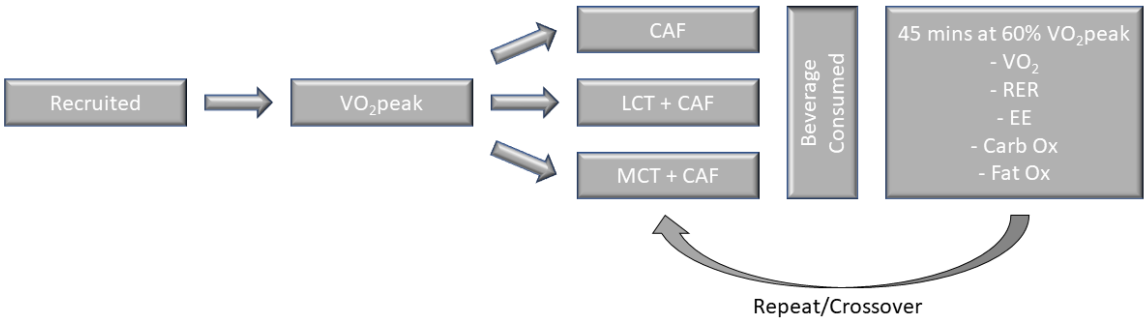

Figure 1. Overview of experimental paradigm. Abbreviations: CAF, caffeine; LCT, long-chain triglycerides; MCT, medium-chain triglycerides; RER, respiratory exchange ratio; EE, energy expenditure; Carb Ox, carbohydrate oxidation; Fat Ox, fat oxidation; VO_2, oxygen consumption.

Preliminary Visit (V1): Each participant had their height, body mass, and body composition measured using a stadiometer (Seca, Hamburg, Germany) and Bod Pod (CosMed, Chicago, IL, USA), respectively [24]. Participants wore tight fitting compression shorts and a swim cap during Bod Pod testing. A VO_2peak test was then conducted to determine the absolute workloads for each participant during the experimental trials. Heart rate (HR) was monitored via a heart rate sensor (H7, Polar Electro Oy, Kempele, Finland) which was worn at the level of the xiphoid process

and connected to a mobile device via Bluetooth. Rating of perceived exertion (RPE) was measured using the Borg CR-10 scale [25]. Each participant was seated on the Monark cycle ergometer with the seat adjusted to the comfort of the participant and fit with a Hans-Rudolph valve body and mouthpiece (one-way, non-rebreather) and corresponding headgear, which were connected to a metabolic cart (TrueOne 2400, ParvoMedics, Salt Lake City, Utah, US) to measure oxygen consumption (VO_2), carbon dioxide output (VCO_2) and respiratory exchange ratio (RER) [26]. The participant warmed up on the cycle ergometer at a self-selected pace. After the warmup, the participant cycled at a pace of 60-70 revolutions per minute (RPM) at a workload of 0.5-1.0 kp, depending on participant comfortability. The workload was then increased by 0.5 kp every minute until one or more of the following end criteria was reached: 1) RER > 1.15, 2) HR ± 10 bpm of age predicted HR max (i.e., 220 - age), 3) plateau in VO_2 consumption, 4) a RPE of 9-10, 5) failure to maintain workload/cadence, or 6) volitional exhaustion. After test termination, the participant was allowed to cooldown at a self-selected pace. Peak was defined as the highest 15-sec average seen during the trial.

Experimental Trials (V2-V4): Upon arrival to the laboratory, participants were fitted with a HR monitor, connected to the metabolic cart with the mouthpiece and corresponding headgear, and then seated on the cycle ergometer while pre-exercise trial data was collected. After pre-exercise measurements, exercise was completed at 60% VO_2peak and titrated to stay within 5% during the first experimental session. The corresponding absolute workload was then used for subsequent sessions. This intensity was chosen because the regulation and utilization of fatty acids is best at intensities between 45% and 65% VO_2max, allowing for maximum fat oxidation [27]. Participants cycled at that workload for 45 minutes while HR, VO_2, VCO_2, and RER were measured every one-minute and RPE was measured every five minutes until the end of the trial. After the 45 minutes of cycling was completed, participants completed a five-minute cooldown at a self-selected pace with the mouth and headpieces removed. Indirect calorimetry measurements of VO_2 and VCO_2 provided estimates on the relative substrate utilization (i.e., carbohydrate and fat) within the body using the Frayn calculations [28]. Energy expenditure (EE) was calculated by using the caloric equivalent for oxygen to determine the amount of kcal burned for every liter of oxygen consumed, and then used to determine absolute levels of carbohydrate and fat oxidation (Carb Ox & Fat Ox, respectively).

Statistical Analysis

All indirect calorimetry data was exported in 15-sec intervals to Microsoft Excel and then separated into pre-exercise trial and experimental trial data. All 15-sec pre-exercise intervals were averaged together, while the 15-sec experimental trial intervals were averaged into 1-minute intervals to represent data over time for entire the 45-minute experimental trial. From this, the exercise data was examined on an individual basis for the peak-exercise responses, average-exercise responses, total exercise EE, and 5-min exercise interval.

Separate one-way (condition: CAF, LCT+CAF, MCT+CAF) repeated measures analysis of variance (ANOVA) was run for pre-exercise, peak-exercise, average-exercise (i.e., VO_2, VE, EE, RER, Carb Ox, and Fat Ox), and total exercise EE (i.e., total EE, Carb Ox, and Fat Ox) data. To determine the presence of any order effects due to the counterbalancing design of the study, a between-subject variable (i.e., condition sequence) was included in the analysis peak-, average- and total exercise data. To examine the data (i.e., VO_2, VE, RER, EE, Carb Ox, and Fat Ox) between conditions (CAF, LCT+CAF, MCT+CAF) over time (i.e., 5-min intervals), separate two-way repeated measures analysis of variance was conducted. Per tradition, an alpha level of $p < 0.05$ was used to determine statistical significance. If a significant effect was found, estimated marginal means with LSD corrections were run to compare conditions. Estimates of effect size are included to complement p-values, namely partial eta squared (η^2), and values of 0.01, 0.06, and 0.14 correspond to small, medium, and large effects, respectively [29]. All data was expressed as means ± standard deviation (SD) or means with 95% confidence interval (CI). All statistical analyses were conducted using SPSS 28 software (IBM Corp. Armonk, NY, US).

Results

Participant Characteristics: A total of nine male participants were recruited, and eight completed the entire study. During the study, one participant dropped out due to personal reasons. Due to this smaller sample size, our experiment was left underpowered and should be viewed as a pilot investigation. Participant characteristics, expressed as mean ± standard deviation, were age (years) 23.6 ± 4.4, height (cm) 180.9 ± 8.7, body mass (kg) 82.3 ± 15.8, fat mass (kg) 12.4 ± 7.6, fat free mass (kg) 69.9 ± 10.8, and VO_2peak (ml/kg/min) 47.0 ± 7.8.

Effect of MCT+CAF vs LCT+CAF vs CAF on Pre-Exercise Metabolism: A significant difference was observed for pre-exercise Carb Ox between conditions ($p = 0.035$; $\eta^2 = 0.382$). Pairwise comparisons indicated that CAF had

significantly greater Carb Ox compared to LCT+CAF ($p = 0.023$) before exercise (Table 1). No significant differences between conditions were observed for pre-exercise VO_2, VE, EE, RER, or Fat Ox (all $p > 0.05$).

Table 1. Pre-exercise physiological responses for each experimental trial

Variable	MCT+CAF	LCT+CAF	CAF	*p*-value	η^2
VO_2 (L/min)	0.40 [0.28, 0.52]	0.37 [0.30, 0.44]	0.46 [0.35, 0.57]	0.219	0.195
VE (L/min	14.28 [11.62, 16.94]	14.53 [12.60, 16.46]	17.11 [13.19, 21.03]	0.072	0.313
RER (a.u.)	0.91 [0.84, 0.98]	0.92 [0.82, 1.02]	0.93 [0.86, 1.00]	0.951	0.007
EE (kcal/min)	2.02 [1.41, 2.63]	1.83 [1.49, 2.17]	2.29 [1.77, 2.81]	0.219	0.195
Carb Ox (kcal/min)	1.30 [0.79, 1.30]	1.16 [0.74, 1.58]	1.72 [0.94, 2.50]	0.035	0.382
Fat Ox (kcal/min)	0.72 [0.36, 1.08]	0.66 [0.19, 1.13]	0.56 [0.23, 0.89]	0.758	0.039

Data expressed as mean [CI]. Abbreviations: CAF, caffeine; LCT, long-chain triglycerides; MCT, medium-chain triglycerides; RER, respiratory exchange ratio; EE, energy expenditure; Carb Ox, carbohydrate oxidation; Fat Ox, fat oxidation; VO_2, oxygen consumption; VE, minute ventilation.

Effect of MCT+CAF vs LCT+CAF vs CAF on Exercise Metabolism: A significant difference across time was observed for 5-minute interval VO_2 ($p < 0.001$; $\eta^2 = 0.699$), VE ($p < 0.001$; $\eta^2 = 0.634$), RER ($p < 0.001$; $\eta^2 = 0.739$), EE ($p < 0.001$; $\eta^2 = 0.646$), Carb Ox ($p = 0.009$; $\eta^2 = 0.294$), and Fat Ox ($p < 0.001$; $\eta^2 = 0.826$) during exercise (Figure 2). For 5-minute interval VO_2, all conditions increased across time (MCT+CAF = 27.3%, LCT+CAF = 34.4%, and CAF = 20.6%) with MCT+CAF trending below all other conditions (Figure 2A). For 5-minute interval VE, all increased across time (MCT+CAF = 28.4%, LCT+CAF = 36.9%, CAF = 21.7%) with CAF trending above all conditions during the first 25 minutes and then MCT+CAF trending below all other conditions after 25 minutes (Figure 2B). For 5-minute interval RER, all conditions decreased across time (MCT+CAF = 4.6%, LCT+CAF = 4.1%, CAF = 8.0%) with CAF trending above all conditions during the first 25 minutes then sharply decreasing to match all other conditions (Figure 2C). For 5-minute interval EE, all conditions increased across time (MCT+CAF = 27.3%, LCT+CAF = 24.3%, CAF = 20.6%) with CAF trending higher and LCT+CAF trending lower than all other conditions (Figure 2D). For 5-minute interval Carb Ox, MCT+CAF & LCT+CAF increased across time (6.0% and 10.9% respectively) while CAF decreased across time (8.3%) with MCT+CAF trending below all other conditions and CAF trending above all other conditions during the first 25 minutes then sharply decreasing to match LCT+CAF (Figure 2E). For 5-minute interval Fat Ox, all conditions increased across time (MCT+CAF = 119.6%, LCT+CAF = 141.3%, CAF = 318.8%) with LCT+CAF trending above all other conditions after 15 minutes and CAF trending below all other conditions during the first 25 minutes then sharply rising to match MCT+CAF (Figure 2F). A significant interaction effect was observed between condition and time for 5-minute interval RER ($p = 0.035$; $\eta^2 = 0.208$), but not VO_2 ($p = 0.406$; $\eta^2 = 0.131$), VE ($p = 0.443$; $\eta^2 = 0.127$), EE ($p = 0.607$; $\eta^2 = 0.110$), Carb Ox ($p = 0.336$; $\eta^2 =0.139$), or Fat Ox ($p = 0.247$; $\eta^2 = 0.151$) during exercise. No significant differences between conditions were observed for 5-minute interval VO_2, VE, RER, EE, Carb Ox, or Fat Ox during exercise (all, $p > 0.050$).

No significant difference between conditions nor significant interaction between conditions and condition sequence was observed for peak-exercise VO_2, VE, RER, EE, Carb Ox, or Fat Ox (Table 2, all $p > 0.05$). For peak VO_2, MCT was 6.0% less than LCT and 8.1% less than CAF. For peak VE, MCT was 8.6% greater than LCT and 11.2% greater than CAF. For peak RER, MCT was 4.1% less than CAF and equivalent to LCT. For peak EE, MCT was 6.0% less than LCT and 8.4% less than CAF. For peak Carb Ox, MCT 6.6% less than LCT and 16.2% less than CAF. For Fat Ox, MCT was 11.9% less than LCT and 11.0% less than CAF.

Table 2. Peak physiological responses for each experimental trial

Variable	MCT+CAF	LCT+CAF	CAF	*p* (t)	η^2	*p* (int)	η^2
VO_2 (L/min)	2.34 [1.89, 2.79]	2.48 [1.99, 2.97]	2.53 [2.15, 2.91]	0.348	0.910	0.616	0.521
VE (L/min)	61.30 [47.70, 74.90]	63.15 [45.82, 80.48]	68.60 [56.79, 80.41]	0.532	0.190	0.559	0.550
RER (a.u.)	0.98 [0.94, 1.02]	0.98 [0.95, 1.01]	1.02 [0.97, 1.07]	0.454	0.197	0.449	0.622
EE (kcal/min)	11.68 [9.42, 13.94]	12.38 [9.93, 12.38]	12.66 [10.78, 14.54]	0.750	0.091	0.616	0.521
Carb Ox (kcal/min)	9.25 [6.74, 11.76]	9.86 [7.37, 12.35]	10.75 [9.06, 12.44]	0.693	0.115	0.686	0.484
Fat Ox (kcal/min)	4.62 [3.57, 5.67]	5.17 [3.68, 6.66]	5.12 [4.10, 6.14]	0.739	0.096	0.799	0.415

Data expressed as mean [CI]. Abbreviations: CAF, caffeine; LCT, long-chain triglycerides; MCT, medium-chain triglycerides; RER, respiratory exchange ratio; EE, energy expenditure; Carb Ox, carbohydrate oxidation; Fat Ox, fat oxidation; VO_2, oxygen consumption; VE, minute ventilation.

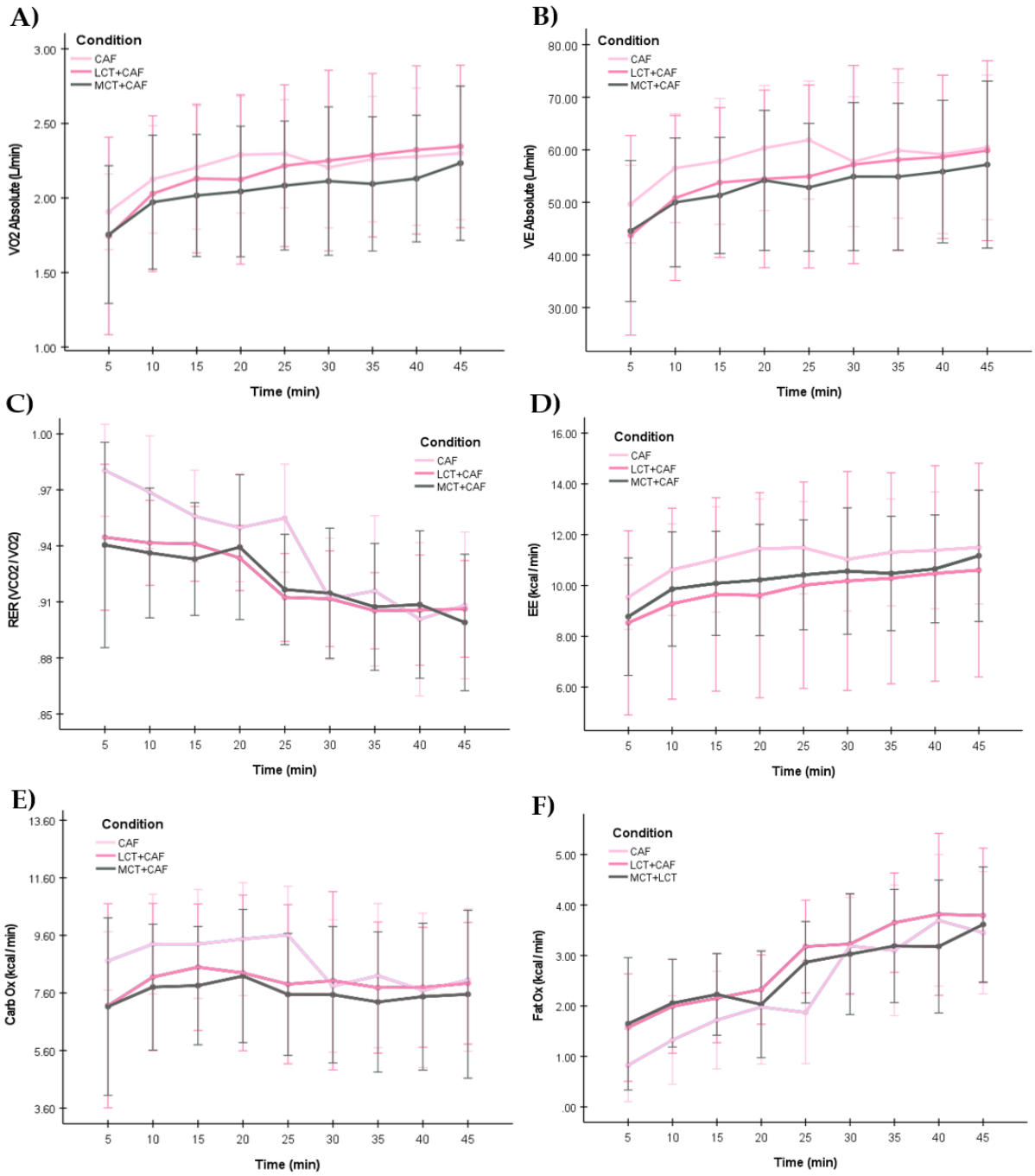

Figure 2. Acute changes between conditions during submaximal cycling exercise in young healthy males (n=8) supplemented with caffeine (CAF), long-chain triglycerides (LCT)+CAF, or medium chain triglycerides (MCT)+CAF. **A)** Absolute oxygen consumption (VO_2) condition x time effect $p = 0.406$, condition effect $p = 0.447$, and time effect $p < 0.001$. **B)** Absolute minute ventilation (VE) condition x time effect $p = 0.443$, condition effect $p = 0.327$, and time effect $p < 0.001$. **C)** Respiratory exchange ratio (RER) condition x time effect $p = 0.035$, condition effect $p = 0.310$, and time effect $p < 0.001$. **D)** Energy expenditure (EE) condition x time effect $p = 0.607$, condition effect $p = 0.566$, and time effect $p < 0.001$. **E)** Carbohydrate oxidation (Carb Ox) condition x time effect $p = 0.336$, condition effect $p = 0.232$, and time effect $p = 0.009$. **F)** Fat oxidation (Fat Ox) condition x time effect $p = 0.247$, condition effect $p = 0.434$, and time effect $p < 0.001$.

No significant difference between conditions nor significant interaction between conditions and condition sequence was observed for average VO_2, VE, RER, EE, Carb Ox, or Fat Ox during exercise (Table 3, all $p > 0.05$). For average VO_2, MCT was 5.2% less than LCT and 6.9% less than CAF. For average VE, MCT was 6.4% greater than LCT and 9.8% greater than CAF. For average RER, MCT was 2.1% less than CAF and equivalent to LCT. For average EE, MCT was 5.2% less than LCT and 7.5% less than CAF. For average Carb Ox, MCT 3.9% less than LCT and 13.6% less than CAF. For average Fat Ox, MCT was 9.9% less than LCT and 10.0% greater than CAF.

Finally, no significant difference between conditions nor significant interaction between conditions and condition sequence was observed for the total EE, Carb Ox, or Fat Ox during the whole exercise bout (Table 4, all $p > 0.05$). For peak EE, MCT was 5.3% less than LCT and 7.5% less than CAF. For peak Carb Ox, MCT 3.9% less than LCT and 13.6% less than CAF. For Fat Ox, MCT was 9.3% less than LCT and 10.3% greater than CAF.

Table 3. Average physiological responses for each experimental trial

Variable	MCT+CAF	LCT+CAF	CAF	p (t)	η^2	p (int)	η^2
VO_2 (L/min)	2.02 [1.60, 2.44]	2.13 [1.64, 2.62]	2.17 [1.85, 2.49]	0.900	0.034	0.672	0.492
VE (L/min)	52.01 [39.89, 64.13]	53.67 [38.74, 68.60]	57.11 [47.25, 66.97]	0.661	0.129	0.580	0.539
RER (a.u.)	0.92 [0.89, 0.95]	0.92 [0.90, 0.94]	0.94 ± [0.91, 0.97]	0.424	0.249	0.098	0.801
EE (kcal/min)	10.11 [8.02, 12.20]	10.64 [8.18, 13.10]	10.87 [9.24, 12.50]	0.900	0.034	0.672	0.492
Carb Ox (kcal/min)	7.48 [5.22, 9.74]	7.77 [5.49, 10.05]	8.50 [6.81, 10.19]	0.590	0.161	0.315	0.669
Fat Ox (kcal/min)	2.62 [1.79, 3.45]	2.88 [1.99, 3.77]	2.37 [1.48, 3.26]	0.556	0.177	0.134	0.774

Data expressed as mean [CI]. Abbreviations: CAF, caffeine; LCT, long-chain triglycerides; MCT, medium-chain triglycerides; RER, respiratory exchange ratio; EE, energy expenditure; Carb Ox, carbohydrate oxidation; Fat Ox, fat oxidation; VO_2, oxygen consumption; VE, minute ventilation

Table 4. Total energy expenditure for each experimental trial

Variable	MCT+CAF	LCT+CAF	CAF	p (t)	η^2	p (int)	η^2
EE (kcal/min)	455 [361, 549]	479 [368, 590]	489 [416, 562]	0.900	0.034	0.672	0.492
Carb Ox (kcal/min)	337 [235, 439]	350 [248, 452]	383 [307, 459]	0.590	0.161	0.315	0.669
Fat Ox (kcal/min)	118 [80, 156]	129 [89, 169]	107 [67, 147]	0.556	0.177	0.134	0.774

Data expressed as mean [CI]. Abbreviations: CAF, caffeine; LCT, long-chain triglycerides; MCT, medium-chain triglycerides; EE, energy expenditure; Carb Ox, carbohydrate oxidation; Fat Ox, fat oxidation.

Discussion

The purpose of this pilot investigation was to compare the physiological responses of MCT+CAF, LCT+CAF, and CAF during 45 minutes of cycling at 60% VO_2peak. While significant time effects were found, this experiment indicates that the consumption of MCT+CAF 60 minutes prior to submaximal exercise does not result in any significant change in VO_2, RER, EE, Carb Ox, or Fat Ox when compared to LCT+CAF or CAF. Thus, the authors reject their hypothesis that MCT+CAF would result in greater Fat Ox and lower Carb Ox compared to LCT+CAF and CAF.

Effects of CAF, LCT, and MCT on Exercise Metabolism: Previous findings on the effects of lipid consumption prior to aerobic exercise has conclusively demonstrated since the 1970's that both chronic and acute consumption of lipids prior to aerobic exercise can elicit increased fat utilization along with decreased carbohydrate and glycogen utilization [30–33]. However, it appears that the predominant length of triglyceride molecules in lipid source, MCT or LCT, did not have any significant effect on measured metabolic parameters in the aerobically trained males of this investigation, nor did the inclusion of CAF appear to enhance these effects. As MCT consumption prior to exercise should lead to greater Fat Ox due to their rapid delivery into the liver and subsequent metabolism and ketone production [1,2,6–8], it is possible that our results were offset by the consumption of CAF.

It has also been noted that lower doses (e.g., 6 g per day) with longer supplementation periods (e.g., 14 days), as well as the composition of the MCT fatty acids, play a role in their bioavailability and subsequent effect on Fat Ox [5,12]. For example, 6 g of 75% C8:0 and 25% C10:0 (C8R) MC fatty acids induced greater Fat Ox in males during aerobic exercise whereas 6 g of 30% C8:0 and 70% C10:0 (C10R) MC fatty acids induced greater Carb Ox and oxygen uptake in females during aerobic exercise [12]. After pooling the data, both C8R and C10R increased Fat Ox in males and females during aerobic exercise [12]. These results suggest that the hydrocarbon chain length of the MC fatty acids may lead to differences in Fat Ox during aerobic exercise. In this study, the composition of the MCT oil consisted of relatively

similar percentages of C8:0 (37.8%), C10:0 (30.7%), and C12:0 (31.5%) which could have influenced the subsequent rate of metabolism as C8:0 is metabolized markedly faster than C10:0 and especially C12:0 [13].

Effects of CAF, LCT, and MCT on Exercise Economy: Previous research has observed no significant differences in intra-exercise VO_2 between MCT and LCT conditions and between MCT and carbohydrate conditions, respectively [3,5]. Our investigation was no exception. We believed that the truncated metabolic pathway associated with digesting MCT may make it less energetically taxing to make fatty acids available for utilization during exercise and therefore decrease relative oxygen demand at a constant workload. However, this was not observed in our study.

A prior study indicated that chronic MCT consumption may have ergogenic benefits related to the potential sparing of muscle glycogen for later stages of exercise leading to improved exercise performance [5], but the trends in our study are negligible, especially as exercise duration continued, and had no significant effect on exercise performance like previous studies [3,11,34–37]. Further research with a larger sample size, extended exercise duration, varied MC fatty acid composition and dosage, and better controlled pre-exercise trial diet is needed to elucidate any potential glycogen sparing and exercise economy benefits of MCT+CAF or any significant differences in fuel substrate utilization associated with pre-exercise MCT+CAF and LCT+CAF consumption during moderate-intensity aerobic exercise.

Limitations: The first noticeable limitation was the utilization of isovolumetric, but not isocaloric, beverages in this experiment. While the 34-kcal difference in calories may have been negligible, we do not know whether this discrepancy in energy intake between MCT and LCT may have had a significant impact on the metabolic parameters measured in this study. Secondly, the researchers used self-report to monitor compliance with the dietary restrictions (i.e., no alcohol or caffeine 24 hours prior) and additional procedures outlined in the informed consent, including adherence to fasting protocol and experimental beverage consumption. Thirdly, this study did not fully control diet in the day(s) prior to each experimental trial, nor account for the habitual total caffeine consumption of the participants, which would have likely affected substrate oxidation. While dietary control is important and beneficial, it is not always feasible for practical application in athletes or recreationally active persons who are not always following a controlled diet. The authors believe if the ergogenic effects of these beverages were strong, some sort of enhanced physiological response would have been observed regardless. Fourthly, participants self-reported their training status (i.e., aerobically trained). Further analysis of the mean VO_2peak for the participants (i.e., 47 ml/kg/min) indicated that they were between the 50th and 60th percentile for age and sex specific values and thus above average [38]. Next, scheduling conflicts made it difficult to ensure all participant exercise trials were completed at the same time of day which may have influenced substrate utilization and fasting duration. Including a placebo control (i.e., no CAF) could have enhanced the study design to provide a more complete picture of each condition's effects. Our intent was to explore a theorized "enhanced" ergogenic benefit from co-ingestion of CAF with MCT or LCT compared to CAF alone, while simultaneously minimizing participant burden. Measurements of MC fatty acids, total fatty acids, triglycerides, and ketone body concentrations in plasma after ingestion or during exercise could have also improved interpretation of the data. Lastly, an increased sample size could potentially show stronger effects between experimental conditions and the variables measured in this study, but the effect sizes reported herein may be fruitful in planning future studies.

Conclusions

The ingestion of MCT+CAF, LCT+CAF, and CAF did not result in any significantly different physiological responses during a 45-minute exercise bout on a cycle ergometer at 60% VO_2peak in aerobically trained males.

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