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The effects of acute carbohydrate and caffeine feeding strategies on cycling efficiency.

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The effects of acute carbohydrate and caffeine feeding strategies on cycling efficiency.

Abstract

Many research studies report and monitor cycling efficiency yet few report that nutritional intake was controlled across the period of assessment. To assess the effect of carbohydrate and caffeine on gross efficiency (GE), 14 cyclists ($\dot{V}O_{2\max}$ $57.6 \pm 6.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) completed 4 x 2-hour tests at a submaximal exercise intensity (60% Maximal Minute Power). Using a randomized, counter-balanced crossover design, participants consumed a standardised diet in the 3-days preceding each test and subsequently ingested either caffeine (CAF), carbohydrate (CHO), caffeine+carbohydrate (CAF+CHO) or water (W) during exercise whilst GE and plasma glucose were assessed at regular intervals (~30mins) and heart rate was measured at 5 second intervals throughout the test. GE progressively decreased in the W condition but, whilst caffeine had no effect, this -was significantly attenuated in both trials that involved carbohydrate feedings (W = $-1.78 \pm 0.31\%$; CHO = $-0.70 \pm 0.25\%$, $p=0.008$; CAF+CHO = $-0.63 \pm 0.27\%$, $p=0.023$; CAF = $-1.12 \pm 0.24\%$, $p=0.077$). Mean blood glucose levels were significantly higher in both carbohydrate ingestion conditions (CHO = $4.79 \pm 0.67 \text{ mmol} \cdot \text{L}^{-1}$, $p<0.001$; CAF+CHO = $5.05 \pm 0.81 \text{ mmol} \cdot \text{L}^{-1}$, $p<0.001$; CAF = $4.46 \pm 0.75 \text{ mmol} \cdot \text{L}^{-1}$; W = $4.20 \pm 0.53 \text{ mmol} \cdot \text{L}^{-1}$). Whilst heart rate increased in all conditions ($p<0.001$), this was not influenced by acute supplementation ($p>0.05$). In conclusion, carbohydrate ingestion has a small but significant effect on exercise-induced reductions in gross efficiency, indicating that cyclists' feeding strategy should be carefully monitored prior to and during assessment. exercise induced reductions in gross efficiency are attenuated when

~~carbohydrate is ingested. This suggests that when measuring gross efficiency, cyclists' feeding strategy should be controlled and monitored to ensure the validity of the results obtained.~~

Introduction

Carbohydrate ingestion during exercise has frequently been found to have a positive effect on endurance performance (Below, Mora-Rodriguez, Gonzalez-Alonso & Coyle, 1995; El-Sayed, Balmer & Rattu, 1997; Jeukendrup, Brouns, Wagenmakers & Saris, 1997). During prolonged (>90-min) moderate intensity (~65%VO_{2max}) exercise there is evidence to suggest that the improvement in performance may be due to the preservation of high carbohydrate oxidation rates, thus delaying the onset of fatigue (Coyle, Coggan, Hemmert & Ivy, 1986). However it is currently unknown whether carbohydrate intake during exercise influences gross efficiency and subsequent performance during prolonged cycling. Indeed, it has been calculated that a 1% improvement in gross efficiency could lead to significant enhancements in performance (Jeukendrup & Martin, 2001).

~~The laboratory measurement of gross efficiency during cycling is an area of increasing interest and has been purported as key factor in endurance cycling performance (Joyner & Coyle, 2008). Whilst the study of this is not particularly new, very little research has assessed the impact of nutritional intake during exercise on the measurement of gross efficiency.~~

Previously we have demonstrated that consumption of a short-term high carbohydrate diet prior to exercise can lead to improvements in gross efficiency under steady-state laboratory conditions (Cole, Coleman, Hopker & Wiles, 2014). Whilst these results demonstrate the influence of pre-exercise dietary interventions,

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2
3 many cyclists also utilise feeding strategies during competition and so the current
4
5 study will aim to understand if these also have an influence on gross efficiency.
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8 Additionally, many studies have reported improvements in endurance performance
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10 following caffeine ingestion (Bell & McLellan, 2002; Ivy et al., 2009; Pasman, Van
11
12 Baak, Jeukendrup & De Haan, 1995). The use of caffeine as an ergogenic aid is
13
14 increasingly popular among athletes, particularly since its removal from the World
15
16 Anti-Doping Agency's list of prohibited substances in 2004 (Lawrence, Wallman &
17
18 Guelfi, 2012). Whilst several mechanisms, principally focussing on influences in the
19
20 central nervous system (Tarnopolsky, 2008), have been purported towards this
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22 enhancement, little is known regarding the influence of caffeine ingestion on gross
23
24 efficiency. If, as suggested, caffeine increases neuromuscular function during
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28 exercise then one might also expect a resultant increase in gross efficiency. Some
29
30 ~~researchers have purported an increase in lipolytic activity, and thus suppression, or~~
31
32 ~~sparing, of the carbohydrate stores as the primary mechanism for the ergogenic~~
33
34 ~~effects of caffeine on endurance performance (Ivy, Costill, Fink & Lower, 1978;~~
35
36 ~~Schubert et al., 2014). Whilst this theory is disputed within the literature, if true, this~~
37
38 ~~mechanism would have important implications for the calculation of gross efficiency~~
39
40 ~~as it would appear that caffeine might lead to greater substrate availability from fat~~
41
42 ~~sources, in the opposite manner to that of carbohydrate ingestion.~~ It would be of
43
44 interest to understand whether this is in fact the case.
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48 Furthermore, some studies have also reported greater performance improvements
49
50 when both carbohydrate and caffeine are co-ingested than either independently
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52 (Cureton et al., 2007), possibly due to caffeine increasing the rate at which
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54 carbohydrate can be absorbed (Yeo, Jentjens, Wallis & Jeukendrup, 2005).
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3 Despite widespread literature assessing carbohydrate and caffeine feedings during
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5 exercise, there are a limited number of studies that present efficiency data, or the
6
7 complete data set required to calculate efficiency from indirect calorimetry during
8
9 steady state conditions (work rate, $\dot{V}O_2$ and respiratory exchange ratio). Of those
10
11 from which we have been able to calculate gross efficiency, or in the very least been
12
13 able to determine energy expenditure, it appears that consumption of either
14
15 carbohydrate or caffeine, immediately prior to or during exercise, reduces gross
16
17 efficiency or increases energy expenditure in comparison to that of a placebo
18
19 (Coggan & Coyle, 1989; Dumke et al., 2007; Febbraio et al., 1996; Fletcher &
20
21 Bishop, 2011; Ivy et al., 1983; Jenkins et al., 2008; McConnell, Kloot & Hargreaves,
22
23 1996; Neufer et al., 1987; Nikolopoulos, Arkinstall & Hawley, 2004; Schubert et al.,
24
25 2014). However, it is difficult to quantify the practical value of the above findings
26
27 as many of the studies mentioned did not involve fixed work intensity and so this
28
29 complicates the interpretation of gross efficiency which is highly susceptible to
30
31 alterations in work rate (Gaesser & Brooks, 1975). Therefore, this investigation will
32
33 aim to clarify these results by specifically assessing the influence of acute
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35 carbohydrate and caffeine feeding strategies on gross efficiency during 2 hour
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37 steady-state submaximal cycling.
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45 **Methods**

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47 **Participants:** Fourteen healthy trained male cyclists gave their written informed
48
49 consent to participate in the investigation. All potential participants completed a
50
51 general health questionnaire. The participants had an age of 42.6 ± 8.4 years, mass
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53 of 76.7 ± 6.7 kg, height of 180 ± 5.9 cm and maximal oxygen uptake ($\dot{V}O_{2max}$) of
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3 57.6 ± 6.3 ml·kg⁻¹·min⁻¹ (mean ± SD). The study was approved by the Canterbury
4
5 Christ Church University Ethics Committee prior to commencement.
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9
10 **Study Design:** In a randomised, counter-balanced, cross-over design, each
11
12 participant attended the laboratory on five separate occasions in an environment
13
14 maintained at 19.6 ± 3.4 °C, 754 ± 8 mmHg and 54.1 ± 5.2 % humidity throughout.
15
16 Visit 1 comprised of an incremental exercise test to exhaustion to determine maximal
17
18 minute power (MMP), defined as the highest 60 second power output during the test,
19
20 and maximum oxygen uptake ($\dot{V}O_{2max}$). Visit 1 also acted as a familiarisation trial in
21
22 which the participants were made fully aware of the testing procedure and also
23
24 ensured that they could complete the desired level of exercise. Visits 2-5 were
25
26 experimental trials involving completion of a set duration of exercise (2 hours) at
27
28 constant exercise intensity (60% MMP) following a single-blind supplementation
29
30 protocol. Exactly 1 h prior to each experimental trial-visits 2-5, participants were
31
32 required to consume 250ml water and on two of those occasions, were also given
33
34 5mg·kg⁻¹ body mass of caffeine (Blackburn Distributions, Blackburn, UK) to
35
36 consume. This timing and dosage has been shown to enhance endurance
37
38 performance (Bell & McLellan, 2002; Pasman et al., 1995). During the all four 2
39
40 hour exercise tests, participants were provided with an equal volume (300 ml) of
41
42 water every 30 min (total of 1.2 L over 2 hours) to ensure that they did not
43
44 become >2 % body mass dehydrated. During two of the four experimental trials, 18
45
46 g of maltodextrin (Blackburn Distributions, Blackburn, UK) was added to each 300
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48 ml of water to make 6 % carbohydrate solution. On one of the visits, to act as a
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50 ‘control’ neither caffeine nor carbohydrate was consumed. Thus, the design of the 4
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52 experimental trials is outlined in **Table 1**:
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5 ****INSERT TABLE 1 NEAR HERE****
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10 Prior to visit 2 participants consumed and recorded a diet for 3 days and this diet was
11 then replicated for the 3 days preceding subsequent experimental trials. In addition to
12 following their individual standardised diet (which was verbally confirmed by
13 participants on arrival at the laboratory for each visit), participants were asked to
14 refrain from vigorous exercise and caffeine and tobacco ingestion during the 3 days
15 prior to each visit.
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25 **$\dot{V}O_{2max}$ determination and familiarisation:** All exercise tests were undertaken on
26 an electronically braked cycle ergometer (Schoberer Radmesstechnik, Julich,
27 Germany). Participants performed an incremental exercise test to volitional fatigue.
28 This comprised of an initial intensity of 100 W with a gradual increase in the
29 exercise intensity (5 W every 15 sec). The test was terminated when cadence
30 dropped below 50 rpm despite standardised verbal encouragement. Ventilation,
31 oxygen uptake ($\dot{V}O_2$), and carbon dioxide production ($\dot{V}CO_2$) were measured
32 throughout the exercise test (Oxycon Pro, Jaeger, Germany). In addition, heart rate
33 was monitored continuously via telemetry (Polar S725X, Polar Electro Oy, Finland).
34 In order to establish if the participant had reached $\dot{V}O_{2max}$, two of the following three
35 criteria had to be satisfied. 1) The cyclist's heart rate had to be within ± 2 beats \cdot min⁻¹
36 of the age-calculated theoretical maximal heart rate, determined as 220 minus age.
37 2) The participants RER had to be greater than 1.1. 3) A plateau in the cyclist's $\dot{V}O_2$
38 (increase in $\dot{V}O_2 < 0.05$ L \cdot min⁻¹) in the last 30 seconds of the test. Following a period
39 of rest, participants then completed a familiarisation of the protocol for Visits 2-5,
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3 during which each cyclist's habitual cycling position was recorded and standardised
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5 for all subsequent trials in order to minimise the influence of different riding position
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7 efficiency as reported by Faria (1992).
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11 **Experimental trials:** Participants arrived at the laboratory post-prandial following
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13 ingestion of a meal ~4 h prior to the visit. The experimental trials were performed at
14
15 the same time of day to avoid any circadian variance. On arrival at the laboratory
16
17 the participants were fitted with a heart transmitter and their body mass was
18
19 recorded. After a brief warm-up (2 min at each of the following intensities: 20%,
20
21 30%, 40%, 50% & 60% MMP), participants began the exercise test. The cycle
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23 ergometer was set to maintain the resistance of the fly wheel to elicit 60% of the
24
25 participants MMP. Participants viewed pedal cadence throughout the trials and
26
27 maintained a constant self-selected cadence throughout the tests (± 1 rpm). A fan
28
29 was placed 1 m in front of the participant to provide some cooling and air flow
30
31 during the exercise. Heart rate, speed and power output were recorded continuously
32
33 throughout the entire protocol although this information was blinded to the
34
35 participants. At set intervals during the trial (every 30 min of the trial completed)
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37 participants' respiration was recorded for a period of 10 minutes via breath-by-breath
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39 analysis (Oxycon Pro, Jaeger, Germany). 20 μ l finger-prick blood samples were also
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41 collected (~30 min intervals) to assess plasma glucose and lactate concentrations
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43 (Biosen X030, EKF Industrie, Elektronik GmbH, Barleben, Germany). Participants
44
45 received no performance-related feedback (distance covered, average speed, $\dot{V}O_2$ or
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47 heart rate) during the trials and no results were given until completion of the entire
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49 study.
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3 **Determination of Gross Efficiency:** The calculation of gross efficiency divides the
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5 work accomplished by the total energy cost required to do the work:
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7 **Gross Efficiency % = (Work Done/Energy Expenditure)*100** (Gaesser & Brooks,
8
9 1975)
10

11 In order to establish the 'Work Done', the last 5 min of each 10 min respiratory
12
13 collection was averaged to ascertain mean $\dot{V}O_2$ and Respiratory Exchange Ratio
14
15 (RER). The calorific equivalent of O_2 was then determined from the corresponding
16
17 RER according to the table of Zuntz (1901).
18
19

20 Thus, '**Work Done**' ($\text{kcal}\cdot\text{min}^{-1}$) = $\dot{V}O_2$ ($\text{L}\cdot\text{min}^{-1}$) x $\text{kcal}\cdot\text{L}^{-1}$ of O_2
21
22

23 In order to establish the 'Energy Expenditure', the mean power for the last 5-mins of
24
25 each 10-min respiratory collection was determined and converted into $\text{kcal}\cdot\text{min}^{-1}$ via
26
27 the following equation:
28

29 '**Energy Expenditure**' ($\text{kcal}\cdot\text{min}^{-1}$) = Power (W) x 0.01433 (Astrand & Rodahl,
30
31 1988)
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36 **Statistical Analysis:** Statistical Analysis was carried out using the SPSS computer
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38 software, version 14.0 (SPSS Inc., USA). For all physiological parameters, specific
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40 differences between the four trials were determined using a repeated measures
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42 ANOVA (four measures of supplement by four repeats of time) with specific
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44 differences determined using a Bonferroni correction *post hoc*. The level of
45
46 probability for rejecting the null hypothesis in all cases was set at $p < 0.05$. Where
47
48 significant differences were obtained, effect sizes were subsequently determined via
49
50 the method of Cohen (1992). Data are reported as mean and standard error (mean \pm
51
52 SEM), unless otherwise stated.
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7.3 Results

Gross Efficiency: Mean GE data are reported in **Table 2**. During the W+W trial, mean GE was significantly greater than in both W+CHO ($p=0.010$) & CAF+W ($p=0.030$) conditions. ~~There was a significant main effect of condition where mean GE in the W+W condition was significantly greater than both W+CHO & CAF+W conditions ($p<0.05$).~~

****INSERT TABLE 2 NEAR HERE****

Additionally, **Figure 1**. demonstrates a significant decrease in ~~main effect of time where~~ mean GE with time in all conditions ($p<0.0015$). Significant differences between trials can be observed at the 20-30 minute time point only, with W+W having higher GE measures than both W+CHO ($p=0.002$) & CAF+W ($p=0.038$) conditions ($p<0.05$).

****INSERT FIGURE 1 NEAR HERE****

When analysing the percentage decrease in efficiency from the 20-30 min measurement to that at the end of the test, it was determined that the decrease was significantly attenuated in both trials involving carbohydrate feedings when compared with the water-only condition ($W = -1.78 \pm 0.31$ %; $CHO = -0.70 \pm 0.25$ %, $p=0.008$, Cohen's $d = 1.15$; $CAF+CHO = -0.63 \pm 0.27$ %, $p=0.023$, Cohen's $d = 1.14$; $CAF+W = -1.12 \pm 0.24$ %, $p=0.077$, Cohen's $d = 0.64$, **Figure 2**).

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****INSERT FIGURE 2 NEAR HERE****

Heart Rate: Mean heart rate increased with time. There was a main effect of time in all conditions ($p < 0.001$) but this was not influenced by supplementation (W+W = 144 ± 3 bpm; W+CHO = 145 ± 3 bpm, $p = 0.079$; CAF+W = 144 ± 3 bpm, $p = 0.938$; CAF+CHO = 143 ± 3 bpm, $p = 0.281$).

Plasma Glucose & Lactate: Mean blood glucose levels were significantly higher in both carbohydrate feeding conditions vs. the water-only trial (W+W = 4.20 ± 0.53 mmol·L⁻¹; W+CHO = 4.79 ± 0.67 mmol·L⁻¹, ($p < 0.001$, Cohen's $d = 0.365$); CAF+CHO = 5.05 ± 0.81 mmol·L⁻¹ ($p < 0.001$, Cohen's $d = 0.469$); CAF+W = 4.46 ± 0.75 mmol·L⁻¹) and this increase appeared to be primarily as a result of significant decreases in plasma glucose concentration differences beyond the 40 min time point in both the W+W & CAF+W trials (Figure 3). There was no main effect of condition ($p = 0.412$) or time ($p = 0.065$) on blood lactate levels.

****INSERT FIGURE 3 NEAR HERE****

Respiratory Exchange Ratio (RER): There were no significant differences in the RER between any conditions (W+W = 0.87 ± 0.01 ; W+CHO = 0.87 ± 0.01 , $p = 0.408$; CAF+W = 0.87 ± 0.01 , $p = 0.352$; CAF+CHO = 0.87 ± 0.01 , $p = 0.914$).

Discussion

The aim of this investigation was to assess whether carbohydrate and caffeine feedings either independently, or together, could influence the laboratory assessment of gross efficiency during a 2 hour steady-state cycling trial. ~~These results suggest that if the measurement of gross efficiency is undertaken over short periods (<30 min), ingestion of caffeine or carbohydrate in the 1 hour before and during exercise has significant implications on the gross efficiency observed.~~ In the current study, it was observed that gross efficiency was significantly lower at the 20-30 minute time point for the two conditions involving carbohydrate or caffeine intake in comparison to that of when only water was consumed. **Interestingly when carbohydrate and caffeine were consumed in-combination, there was no significant impact on gross efficiency.**

One explanation for the lower gross efficiency under caffeine conditions might be to suggest increased lipolytic activity as proposed by Ivy and colleagues (1978). If this was the case, one would anticipate a lower RER as evidence of the higher oxygen cost of fat metabolism. However the data from the current investigation do not support this theory as there was no difference in the RER ~~during the 20-30 minute time point for the~~ **between the** caffeine condition vs. **the** water-only condition.

The findings of this study are in agreement with several others which, although they did not report efficiency directly, permit efficiency determination from the data presented (Coggan & Coyle, 1989; Dumke et al., 2007; Febbraio et al., 1996; Fletcher & Bishop, 2011; Ivy et al., 1983; Jenkins et al., 2008; McConnell, Klot & Hargreaves, 1996; Neuffer et al., 1987; Nikolopoulos, Arkinstall & Hawley, 2004;

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2
3 Schubert et al., 2014). All of the reported studies demonstrate a trend for either a
4
5 decrease in efficiency or increase in energy expenditure following ingestion of
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7 carbohydrate and/or caffeine. These observations may be attributed to increased
8
9 energy expenditure as a result of digestion, absorption and the associated thermal
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11 losses (Jequier, 1986). The accumulated energy expenditure of these processes has
12
13 been defined as specific dynamic action (SDA) (Secor, 2009). Interestingly, mean
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15 GE in the CAF+CHO was not significantly lower than the water-only condition,
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17 either across the whole exercise duration or at any given time point. This
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21 ~~might~~would suggest that when ingested in combination, caffeine ~~may~~ augment the
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23 carbohydrate uptake (Yeo et al., 2005) and thus the energy losses of digestion and
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25 absorption were not as great relative to the other conditions.
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30 Nonetheless a difference of >1% in the mean GE measures of different conditions
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32 has important implications for the existing literature. A difference in GE of similar
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34 magnitude has previously been reported across different participant groups (Hopker,
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36 Coleman & Wiles, 2007) or following longitudinal data collection over different
37
38 time periods (Coyle, 2005; Hopker, Coleman & Passfield, 2009; Santalla, Naranjo &
39
40 Terrados, 2009). This data would suggest that some of the reported difference could
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42 be due to alterations in nutrient intake immediately prior to or during assessment.
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45 Whilst it would be expected that these studies undertook rigorous controls, the
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47 results of this investigation reinforce the need for investigators to ensure that
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49 participant's nutritional intake is monitored carefully for the period immediately
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51 prior to and during assessment. This should be in addition to standardisation of 3-
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53 day dietary intake prior to measurement which, as previously demonstrated, also
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55 influences gross efficiency (Cole et al., 2014).
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3 The implications of the outcomes from the current study may be wider than simply
4 providing recommendations for the laboratory assessment of gross efficiency. These
5 data might suggest that for prolonged duration cycling events (≥ 2 hr), some of the
6 observed benefits of carbohydrate feedings on performance (Currell & Jeukendrup,
7 2008; Davis et al., 1988; Wright, Sherman & Dernback, 1991) may be as a result of
8 improvements in gross efficiency. This study demonstrated that whilst mean
9 efficiency over the whole trial not higher overall, at the 2 hour time point the
10 decrease in gross efficiency was significantly attenuated in the two conditions
11 involving carbohydrate feedings. If the exercise was to continue beyond this time, as
12 many tour stages and 1 day races often do, it is reasonable to suggest that if this trend
13 were to continue, these conditions would actually sustain greater gross efficiency for
14 longer.
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32 An interesting paradox is presented when considering the outcomes of this
33 investigation versus our previous work. When exercise is undertaken following
34 ingestion of a high carbohydrate diet and ~ 4 h post-prandial, gross efficiency
35 measures appear to be higher (Cole et al., 2014). Whereas when carbohydrate is fed
36 during exercise as in the current study, this appears to have a detrimental effect on
37 gross efficiency measures – at least in the early stages of exercise. This would
38 support the notion that up until ~ 1 hour, the exercise demands are adequately met by
39 the endogenous carbohydrate stores and rather than providing any additional benefit,
40 carbohydrate intake may actually be detrimental to performance. An explanation for
41 this different outcome is likely because the muscle glycogen stores are not depleted
42 within 1 hour, even if undertaking maximal intensity exercise (Hawley, Schabort,
43 Noakes & Dennis, 1997). Therefore, only once these stores start to become depleted
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3 can the ergogenic effect of exogenous carbohydrate metabolism have an influence,
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5 as observed in this study towards the 90-120 minute time points.
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7 Whilst the current study limited its focus to the laboratory assessment of gross
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9 efficiency, it would be useful to measure the direct performance implications given
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11 that Jeukendrup & Martin (2001) suggest that a 1% difference in GE could elicit a 48
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13 second improvement in performance over a 40 km time trial. Furthermore whilst
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15 undertaking all measures in a controlled laboratory setting allowed careful control of
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17 external variables in this study, it would be of value to establish whether the
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19 outcomes are replicated outdoors where the pacing strategies and power profiles vary
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21 considerably in comparison to the constant steady-state loads set on the SRM
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23 ergometer in the laboratory. More research is also needed to clarify the energetic
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25 cost of nutrient feedings during exercise and the potential impact of this on gross
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27 efficiency. Additionally future work may wish to consider the impact of different
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29 doses of carbohydrate and/or caffeine to examine whether increasing or lowering the
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31 intake might lead to more optimal gross efficiency measures.
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38 **Conclusions**

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41 Reductions ~~Significant differences~~ in gross efficiency during a 2 hour submaximal
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43 cycling test are attenuated by carbohydrate ingestion whilst the consumption of
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45 caffeine has no benefit. As discussed above, this has implications for the laboratory
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47 assessment of gross efficiency and may have relevance to performance during
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49 cycling events of >2 hour duration.
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Table 1: Supplementation Design

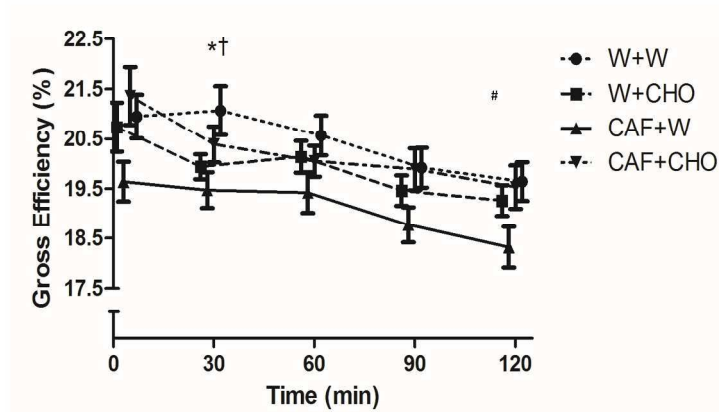
1-h Before Exercise	300ml Every 30-mins During Exercise
250 ml Water	Water
250 ml Water	6 % Carbohydrate Drink
250 ml Water+ 5mg·kg ⁻¹ b.w. Caffeine	Water
250 ml Water + 5mg·kg ⁻¹ b.w. Caffeine	6 % Carbohydrate Drink

Table 2. Gross Efficiency (%) across all conditions (mean \pm SEM).

Condition	Mean GE (%)	Standard Error (%)	95% Confidence Interval (%)		Effect Size (vs. W+W trial)
			Lower	Upper	
W+W	20.43	0.36	19.73	21.13	
W+CHO	19.91*	0.27	19.37	20.45	0.515
CAF+W	20.12*	0.35	19.44	20.81	0.237
CAF+CHO	20.24	0.34	19.59	20.90	

*Significant difference from W+W ($p < 0.05$)

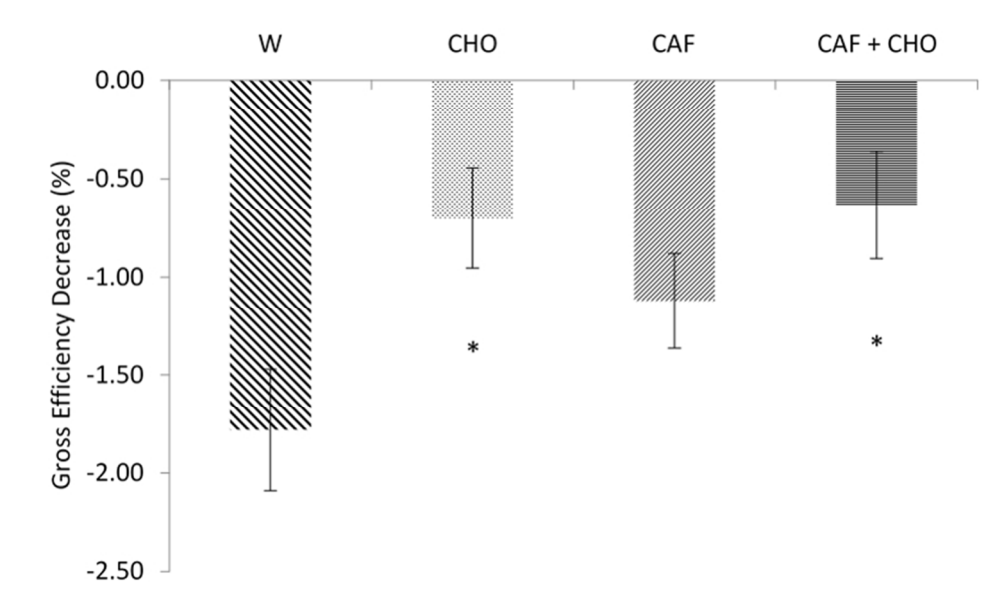
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Mean gross efficiency with time across all conditions

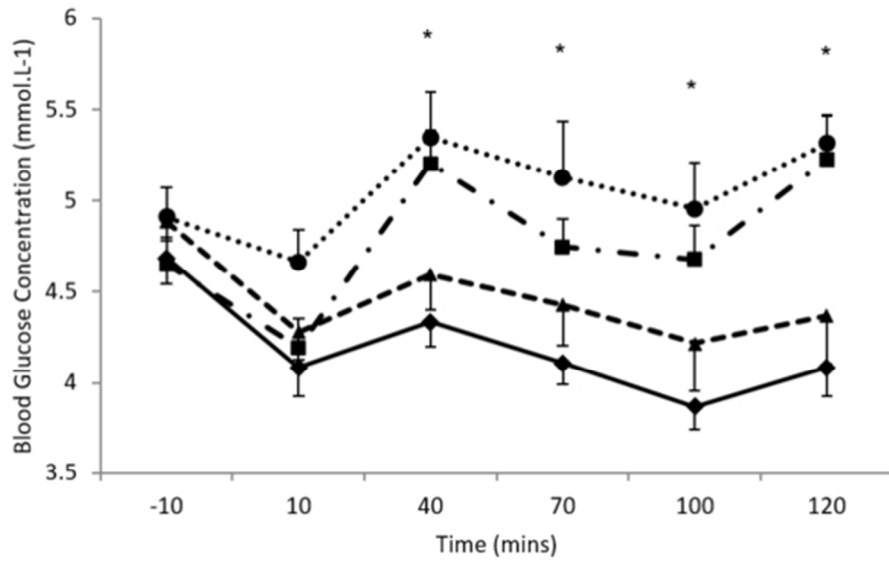
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Mean decrease in gross efficiency from start to end of 2 hour trials.

Review Only



Mean blood glucose concentrations with time across all conditions.

252x151mm (66 x 66 DPI)

Review Only

Table 3. Summary of existing studies where nutritional supplementation has influenced gross efficiency or energy expenditure.

Publication	Dietary/Supplement Protocol	Exercise Design	Gross Efficiency/Energy Expenditure
Ivy et al, 1983	30g CHO ingestion at 60, 90, 120 & 150 min during exercise.	Walking to exhaustion at 45% $\dot{V}O_{2max}$	Control: 120 min = 9.65 kcal·min ⁻¹ 180 min = 9.77 kcal·min ⁻¹ Exhaustion = 9.80 kcal·min ⁻¹ Carbohydrate: 120 min = 9.67 kcal·min ⁻¹ 180 min = 9.85 kcal·min ⁻¹ Exhaustion = 10.58 kcal·min ⁻¹
Neufer et al., 1987	1) LCHO = 45 g liquid carbohydrate 5 min pre-exercise 2) SCHO = 45 g solid carbohydrate 5 min pre-exercise 3) Placebo 5 min pre-exercise 4) M + SCHO = 200 g carbohydrate meal 4 hr pre-exercise + 45 g Solid carbohydrate 5 min pre-exercise.	45 min cycling at 77% $\dot{V}O_{2max}$ then 15 min TT	GE during 15 min TT: Placebo = 23.70% LCHO = 24.48% SCHO = 24.23% M+SCHO = 25.45%
Coggan & Coyle, 1989	After 135 min of exercise participants were fed either: 1) 3 mg·kg ⁻¹ CHO in the form of a 50% solution. 2) Placebo	Cycling TTE at 70% $\dot{V}O_{2max}$	165 min: Carbohydrate = 15.91 kcal·min ⁻¹ Placebo = 15.06 kcal·min ⁻¹
Febbraio et al, 1996	Prior to exercise & every 15 min: 1) 14% CHO solution 2) 7% CHO solution 3) Placebo	Cycling TTE at 70% $\dot{V}O_{2max}$	Higher energy expenditure following CHO ingestion but <1 kcal·min ⁻¹ difference between conditions.

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McConnell et al, 1996	250 ml Fluid at start & 15 min intervals 1) 7% CHO 2) Placebo 3) Placebo + 21% CHO at 90, 105 & 120 min	2 hr at 70% $\dot{V}O_{2max}$ + 15min TT	Placebo: Mean = 17.10 kcal·min ⁻¹ 7% CHO: Mean = 17.14 kcal·min ⁻¹ Placebo + 21% CHO: Mean = 17.10 kcal·min ⁻¹
Nikolopoulos et al., 2004	Pre-exercise: 8 ml·kg ⁻¹ 1) 6.4% CHO 2) Placebo During exercise: 2 ml·kg ⁻¹ every 15 min	Cycling TTE at 84% $\dot{V}O_{2max}$	GE at 45min: Placebo = 23.68% CHO = 23.47% GE at Fatigue: Placebo = 23.13% CHO = 23.12%
Dumke et al., 2007	CHO or placebo beverage	2.5 hr cycling	Mean GE: Placebo = 20.02% CHO = 19.06%

Note: CHO = Carbohydrate, TT = Time trial, TTE = Time to Exhaustion.