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Omission of a carbohydrate-rich breakfast impairs evening endurance exercise performance despite complete dietary compensation at lunch

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Abstract

Omission of a carbohydrate-rich breakfast followed by consuming an *ad libitum* lunch impairs evening exercise performance. However, it is unclear if this is due to breakfast omission *per se*, or secondary to lower carbohydrate intake over the day. To test whether impaired evening performance following breakfast omission persists when complete dietary compensation occurs at lunch, in a randomised cross-over design, eleven highly trained cyclists (age: 25 ± 7 y, VO_2max: 61 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$) completed two trials: breakfast (B) and no breakfast (NB). During B, participants consumed an individualised breakfast (583±54 kcal; 8-9am) and lunch (874±80 kcal; 12-2pm), whilst during NB participants fasted until 12pm and then consumed a standardised lunch (1457±134 kcal: 12-2pm). The overall energy (1457±134 kcal) and macronutrient profile (carbohydrate: 81.5±0.4%, fat: 5.8±0.1%, protein: 12.7±0.3%) was identical in both trials, with timing the only difference. Mean power output during a 20 km time trial performed in the evening was ~3% lower in NB compared to B (mean difference [95% CI]: -9.1 [-15.3, -2.9] watts, $p<0.01$ for condition main effect). No differences in heart rate, blood glucose or blood lactate concentrations were apparent, but perception of effort appeared to be higher in the early stages of the time trial in NB compared to B despite lower power output. Impaired high-intensity endurance performance in the evening following breakfast omission is related to meal timing rather than carbohydrate intake / availability. Provision of an early morning high-carbohydrate meal should be considered to optimise evening exercise performance.

Key words: Nutrition, Exercise, Performance, Physiology

Introduction

Prolonged high-intensity endurance exercise depends on both liver and skeletal muscle glycogen availability and, as such, provision of adequate carbohydrate intake in the hours prior to exercise is recommended as an ergogenic aid (Burke et al., 2011; Burke and Hawley, 2018). In agreement, there is evidence that consuming a carbohydrate-rich meal 3-4 hours prior to morning or early afternoon exercise increases pre-exercise liver and skeletal muscle glycogen availability compared with an extended overnight fast (Chryssanthopoulos et al., 2004; Coyle et al., 1985; Shulman et al., 1990). The majority of studies demonstrate that this translates into improved performance during prolonged (>60 min) endurance exercise challenges in the morning or early afternoon (Chryssanthopoulos et al., 2002; Neufer et al., 1987; Schabort et al., 1999; Sherman et al., 1989), and this may be further improved by also supplementing carbohydrate *during* exercise (Chryssanthopoulos et al., 2002; Wright et al., 1991). Carbohydrate-rich breakfast also improves performance during both shorter duration high-intensity endurance exercise (Galloway et al., 2014; Mears et al., 2018), and during resistance exercise (Naharudin et al., 2020, 2019). However, accumulating evidence suggests these effects may be psychological (placebo) rather than physiological in origin (Mears et al., 2018; Naharudin et al., 2020). Irrespective of the potential mechanisms, current evidence indicates morning or early afternoon exercise performance will be optimised by consuming a carbohydrate-rich meal several hours prior to the event (Clayton and James, 2016). Accordingly, recommendations suggest consumption of between 1-4 g of carbohydrate per kilogram of body mass for up to 4-hours prior to exercise (Kerksick et al., 2017).

Interestingly, aside from a general recommendation to consume a diet rich in carbohydrate (Kerksick et al., 2017), less attention has been given to the role of diet in advance of 4-hours prior to exercise on the same day. This is somewhat surprising considering exercise performance can often commence in the late afternoon or evening (e.g. evening fixtures, and evening sessions in sports such as track cycling or athletics). These occasions provide a large time window (8-12 hours) to modify and optimise nutrition *throughout* the day. As an example, only limited research has considered the effect of early morning feeding strategies (i.e. breakfast) on exercise performance commencing in the late afternoon and evening. Intriguingly, two recent studies suggest consuming a high carbohydrate breakfast improves, or conversely, omitting the breakfast impairs, exercise performance later in the day (Clayton et al., 2015; Cornford and Metcalfe, 2018). In both these studies, participants either consumed or omitted a carbohydrate-rich breakfast between 8-9 am and then ate an *ad libitum* meal at lunchtime (Clayton et al., 2015; Cornford and Metcalfe, 2018). This feeding pattern reduced total carbohydrate and energy intake prior to late afternoon / evening exercise (4:30 – 6pm), ultimately worsening performance of a 60-minute (30-min steady state followed by 30-min work capacity) cycling test (Clayton et al., 2015) and a 2000-m rowing time trial (Cornford and Metcalfe, 2018).

The preliminary evidence described suggests that the timing of dietary intake early in the day is an important consideration for both prolonged and short duration high-intensity exercise performance later in the day, even when lunch is consumed. However, the lower total energy and carbohydrate intake reported following omission of breakfast combined with an *ad libitum* lunch in both studies raises the important question of whether exercise performance was impaired due to breakfast omission (i.e. meal timing) *per se* or rather was secondary to the lower carbohydrate / energy intake and hence availability.

To the best of our knowledge, no study has examined exercise performance in the evening following consumption or omission of breakfast but with equivalent dietary intake throughout the day. Therefore, in the present study we investigated whether the impairment in evening high-intensity exercise performance following breakfast omission persists when complete dietary compensation is provided at lunch. We hypothesised that omission of a carbohydrate-rich breakfast would impair exercise performance.

Methods

Participants

Eleven highly trained and competitive triathletes and/or road cyclists (1 female) were recruited to take part in this study and completed the full experimental procedures (mean ± SD: age: 25 ± 7 y, height: 1.78 ± 0.05 m, body mass: 74.4 ± 10.0 kg, BMI: 23 ± 2 $kg{\cdot}m^{-2}$, VO_2max: 61 ± 5 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, *W*max: 386 ± 48 W). Participants were recruited from local cycling or triathlon teams and were included if they were completing regular cycling-based training and/or competition (>4 hours/week) and were self-reported regular breakfast eaters (>50 kcal within 2 hours of waking on >4 days/week) (Betts et al., 2014). Exclusion criteria included anyone <18 or >40 years of age, regular breakfast skippers (not meeting definition of breakfast eater above), and anyone with contraindications to high-intensity exercise, including a history of chronic cardiovascular or metabolic disease, or high blood pressure during screening (>140/90 mmHg or resting heart rate >100 bpm). The experimental procedures and requirements were explained to all participants, both verbally and in writing, before they gave their informed consent to participate. All participants were informed of the study aims but not the study hypothesis. The study protocol was approved by the A-STEM departmental ethics committee at Swansea University (ref: 2018-142) and the experiment was conducted in accordance with the Declaration of Helsinki.

Pre-experimental procedures

Prior to the main experiment, all participants attended the lab on two separate occasions. During the first visit, measures of height (to the nearest 0.1 cm) and body mass (to the nearest

0.1 kg) were taken, and then participants completed an incremental cycling test to volitional exhaustion on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The test started with a 2-minute warm-up at 50 watts (female) or 75 watts (males) and then the resistance subsequently increased by 1 W every 2 seconds until the point of volitional exhaustion, which was defined as an inability to maintain a pedal cadence >50 rpm. Participants respired through a rubber face mask connected to an online metabolic cart (Jaegar Vyntus, Vyaire, IL, USA) for continuous breath by breath measurement of oxygen uptake (VO_2). Maximal oxygen uptake (VO_2max) was calculated as the highest value for a 15-breath rolling VO_2 that was achieved during the test, whilst maximal power output (Wmax) and maximal heart rate were also recorded. At least 3 days later, participants performed a single familiarisation session for the 20 km time trial (as 20 km time trial performance is highly reproducible in well trained cyclists (Thomas et al., 2012)). The 20 km time trial was completed in full using the same protocol as during the main experiments (described below), but with no measurements taken or prior nutritional strategies put in place.

Main Experimental Trials

Participants took part in a randomised cross-over trial with two experimental conditions: breakfast (B); and no breakfast (NB). Each experimental condition consisted of a different pattern of dietary intake at breakfast and lunch followed by an assessment of 20 km cycling performance that evening between 5 and 7pm (at least 4 and no longer than 5 hours after lunch). The timing of lunch and the time trial was standardised *within* but not between individuals (i.e. during each repeated condition, each participant consumed their lunch and completed the time trial at a similar time). Each trial was separated by at least 5 and no more than 7 days. On the day prior to each trial, and during each trial day, participants were asked to avoid any structured exercise (except the time trial) and any consumption of alcohol or caffeine. Nutritional intake on the day prior to each trial was not strictly controlled but participants were asked not to deviate from their normal dietary patterns.

Meal provision

On the evening prior to both trials, participants were provided with weighed food packages for the following day to consume at home with clear instructions on intake and timing (with explicit instruction to consume nothing other than water *ad libitum*). Compliance was ensured/monitored through regular contact by text / photo message, with participants asked to send photo messages to investigators at the start and end of consuming each meal (Martin et al., 2009). In the breakfast condition, participants were provided with a standardised composition high-carbohydrate breakfast meal (between 8 and 9am) totalling 20% of their individually predicted energy requirements (method described below), followed by a standardised composition 'lunch' meal (between 12 and 2pm) which contained 30% of their individually predicted energy requirements. In the no breakfast trial, participants extended their overnight fast until 12pm (from 10pm the previous evening), and then consumed a high-carbohydrate lunch meal containing 50% of their individually predicted daily energy requirements. As such, the overall dietary intake, including food items, calorie and macronutrient content, were identical between the two trials, with the only difference being the timing of intake (**Figure 1A**).

Estimated daily energy requirements were calculated from resting metabolic rate (derived from the Harris and Benedict equation, revised by Mifflin et al (1990)) which was multiplied by a physical activity level of 1.75. The food items provided were typical breakfast items similar to those in previous studies (Clayton et al., 2015; Cornford and Metcalfe, 2018) and included corn flakes and semi-skimmed milk, plain white bagels and jam, and orange juice (Tesco, UK). This provided a macronutrient profile of 81.5±0.4% carbohydrate, 5.8±0.1% fat and 12.7±0.3%

protein. Water consumption was allowed *ad libitum* throughout each condition, but participants only consumed out of a water bottle that we provided so water intake could be estimated (the number of refills was noted by participants). There was no significant difference in estimated water intake between trials (B: 3.0±1.3 *vs* NB: 2.6±0.8 litres, *p*=0.10).

Appetite Ratings

Perceptions of hunger, desire to eat, fullness and prospective food consumption were measured at key time points throughout the day using 100mm visual analogue scales (Flint et al., 2000), from which a composite appetite score was calculated using the following formula: (desire to eat + hunger + (100 - fullness) + prospective consumption) / 4 (Anderson et al., 2002). Appetite ratings were recorded immediately upon waking, immediately post-breakfast, 1 h post-breakfast, immediately pre- and post-lunch, 1 h post-lunch and pre-exercise.

20 km time trial

To examine the effect of the dietary intervention on substrate oxidation, prior to the 20 km time trial participants completed a 10-minute steady state exercise phase at 40% of Wmax (160±9 W). Participants wore a rubber face mask connected to a portable breath-by-breath gas analyser for measurement of substrate oxidation by indirect calorimetry (Metalyzer 3B, Cortex, Liepzig, Germany). Rates of carbohydrate and fat oxidation ($g \cdot min^{-1}$) and energy expenditure ($kJ \cdot min^{-1}$) were calculated from measurements of VO_2 and VCO_2 using stoichiometric equations proposed by Frayn (1983) and subsequently modified by Jeukendrup and Wallis (2005). Breath by breath data were smoothed into 1 min averages and the mean rate of oxidation from the final 5 minutes was used in the statistical analysis. Substrate oxidation data were available for n=9 due to technical difficulties. This also served as a warm-up for the time trial.

Immediately following this steady state exercise phase, a 20 km time trial was performed on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands).

The ergometer was set in linear mode, with the linear factor (L) calculated using the formula $L= W/(\text{rpm})^2$ and set to produce a power output equivalent to 75% of their individual maximal power output achieved during the VO_2max test when cycling at a cadence of 90 rpm. Participants could increase their power output by increasing their cadence and *vice versa*. Participants were instructed to complete the distance as quickly as possible and were blinded to all relevant performance variables except the distance remaining which was displayed on a screen directly in front of them. No verbal encouragement was provided, and no music was allowed. Power output was recorded continuously during the test (Lode Ergometry Manager, Lode, Groningen, The Netherlands), whilst heart rate and ratings of perceived exertion (RPE) were recorded every 2500 metres. As RPE is a psychophysical variable and should be interpreted together with the physical stimulus (i.e. power output), we also calculated the ratio of power output to RPE as an outcome variable (Sanders et al., 2018). This was calculated by dividing the mean power output over each 2500 m of the time trial by the RPE at that equivalent time point. A capillary blood sample was obtained using an aseptic technique prior to the warm-up and then on immediate completion of the 20 km time trial and analysed for glucose and lactate concentrations (Biosen C-line, EKF Diagnostics, Cardiff, UK).

Statistical Analysis

Sample size was based on the mean and standard deviation of the observed difference in evening time trial performance from a previous similar study (Cornford and Metcalfe, 2018), we calculated that n=11 participants would provide >80% power to detect an effect size (dz) of 0.94 with an alpha of 0.05. All data were analysed using Graphpad Prism 8 for macOS (Version 8.4.2, San Diego, CA, USA). All data were first checked for any substantial deviation from a normal distribution using the Shapiro-Wilk test. Several variables showed consistent evidence of deviating from a normal distribution, including power output and RPE at several points during the time trial, overall time trial performance (average power output) and pre time-trial blood lactate concentrations. For variables where the only comparison was between breakfast and extended morning fasting (e.g. substrate oxidation, time trial performance in seconds), then paired sample t-tests were applied for normally distributed variables and Wilcoxon matched pairs were applied for non-normally distributed variables. For variables with an additional factor of time (e.g. time of day for appetite ratings, and time point during the time-trial for power output, heart rate, RPE, and blood glucose and lactate concentrations) then data were analysed using a two-way (condition × time) repeated measures analysis of variance (ANOVA) regardless of any deviation from a normal distribution (Maxwell and Delaney, 2004). If appropriate interaction effects were observed, then *post hoc* comparisons between the same time point in the breakfast and no breakfast trials were made using the Holm-Sidak stepdown method. Alpha was set at 0.05 and data are presented as means and standard deviations unless indicated otherwise.

Results

Appetite Responses and Substrate Oxidation

There was a main effect of time and a condition × time interaction effect for appetite ratings throughout the day (both $p<0.001$). Appetite scores were similar between conditions upon waking and immediately prior to lunch, but higher throughout the rest of the morning (i.e. post-breakfast, all $p<0.05$), and lower throughout the rest of the afternoon (i.e. post-lunch, all $p<0.05$), in the no breakfast compared with the breakfast condition (**Figure 1B**). The dietary intervention resulted in a shift in substrate oxidation during submaximal steady state exercise in the evening: rates of carbohydrate oxidation were higher (1.55 ± 0.46 *vs* 1.22 ± 0.42 $g \cdot min^{-1}$, $p<0.05$), and rates of fat oxidation were lower (0.55 ± 0.19 *vs* 0.76 ± 0.22 $g \cdot min^{-1}$, $p<0.001$) in the no breakfast trial compared with the breakfast trial. The rate of energy expenditure during the steady state exercise was not significantly different between conditions (B: 47.7±7.4 *vs* NB: 44.8±7.1 $kJ \cdot min^{-1}$, *p*=0.08).

Effect on 20 km Time Trial Performance

For power output during the 20 km time trial, there was a main effect of time (*p*<0.001) and a main effect of condition (*p*<0.01) but no condition × time interaction: mean power output was ~3% lower during the time trial in the no breakfast condition compared with the breakfast condition (285±54 *vs* 294±56 W; mean difference [95% CI]: -9.1 [-15.3, -2.9] W; **Figure 2A and 2B**). This corresponded to more time taken to complete the time trial in the no breakfast compared with the breakfast condition (1113±326 *vs* 1075±294 secs, *p*=0.02). There was no significant familiarisation or order effect on 20 km time trial performance (mean power was 281±48 W during familiarisation *vs* 287±54 W during trial 1 *vs* 289±53 W during trial 2, *p*=0.13).

Heart Rate and Blood Lactate and Glucose Responses

There were no differences in the heart rate response during the time trials between the conditions (**Figure 3A**). Blood glucose (B: 4.14±0.44 *vs* NB: 4.23±0.73 mmol/L) and lactate (B: 2.11±0.99 *vs* NB: 2.37±0.88 mmol/L) concentrations were similar prior to each time trial. Blood glucose (B: 5.47±0.92 and NB: 4.94±0.59 mmol/L) and blood lactate (B: 11:52±2.39 and NB: 10.99±2.12 mmol/L) increased following the time trial (both *p*<0.001 for time main effect). The change in blood glucose (B: 1.33±0.74 *vs* NB: 0.71±0.69 mmol/L) and lactate (B: 9.41±2.68 *vs* NB: 8.62±2.18 mmol/L) concentration during the time trials was not different between conditions (both *p*>0.05 for condition x time interaction effect).

Ratings of Perceived Exertion

RPE increased during the course of each of the time-trials (main effect of time: *p*<0.001) and a condition x time interaction effect (*p*<0.05) suggested the pattern of change over time was different between conditions (**Figure 3B**). *Post-hoc* analysis suggested limited differences between the conditions at specific time points, with higher RPE in the no breakfast trial at the 2500 m time point only (B: 12.4±1.7 *vs* NB: 13.4±1.1 au, *p*<0.01). For the ratio of power / RPE, there was a significant main effect of time (*p*<0.001), condition (*p*<0.01) and a condition x time interaction (*p*<0.001): *post-hoc* analysis revealed higher power output / RPE early in the time trial (2500 m: B: 23.7±6.3 *vs* NB: 20.2±3.7 W/RPE, *p*<0.001; 5000 m: B: 20.7±4.5 *vs* NB: 19.3±3.5 W/RPE, *p*=0.08) with numerical (and statistical) differences becoming negligible from 7500 m onwards (**Figure 3**C).

Discussion

The main finding of the present study is that evening high-intensity endurance exercise performance following the omission of a carbohydrate-rich breakfast is impaired even when the energy and carbohydrate missed at breakfast is subsequently replaced at lunch. This observation is novel and of importance because it indicates the crucial role of early morning nutrition, alongside considerations of type and amount, in order to optimise exercise performance taking place in the late afternoon or evening. Specifically, this study shows that missing or delaying an early morning meal (i.e. breakfast) cannot necessarily be compensated for by providing a meal of equal nutritional value later in the day.

The present work extends the findings of previous studies which have found a decrease in evening endurance performance following breakfast omission (Clayton et al., 2015; Cornford and Metcalfe, 2018). Firstly, it provides the first evidence to suggest that this effect is due to the omission of the breakfast *per se* and not a result of lower total carbohydrate (or energy) intake observed prior to exercise in those earlier studies where lunch was consumed *ad libitum* (Clayton et al., 2015; Cornford and Metcalfe, 2018). Breakfast omission resulted in a decrease in mean power output during the time trial of ~9 watts (~3%). This difference in performance is of a similar magnitude to that observed in the previous study (where overall energy and carbohydrate intake was lower) which employed a 30-min cycling work capacity test in recreationally active individuals (Clayton et al., 2015). This study is the first to demonstrate that this effect also occurs in highly trained individuals ($VO_2max > 60 ml \cdot kg^{-1} \cdot min^{-1}$). Previous studies have observed that 20 km time trial performance is very reproducible in highly trained cyclists (comparable to our cohort), reporting a typical error for average power of 1.9% and a smallest worthwhile change of 1.8% (Thomas et al., 2012). Therefore, the performance decrement due to breakfast omission observed in the present study can be considered meaningful. An interesting area for further research is to determine the practical relevance of the current findings for performance in other ecologically valid settings. Indeed, it is noteworthy that the majority of evening performance events involve intermittent games type exercise, with physiological demands that are different to the ~20 min cycling time trial that was applied in the current study (Krustrup et al., 2006; Mohr et al., 2005).

The decrease in self-selected power output in the no breakfast trial was evident from the onset of the time trial and was maintained throughout. It is noteworthy that the largest numerical difference in power output was apparent during the first 2500 m and this was associated with both a higher absolute perception of effort and a lower ratio of power output to perception of effort in the no breakfast trial at the same time point. It is possible that the difference in pacing arose due to either physiological and/or psychological mechanisms. From a physiological perspective, our data show that total energy or carbohydrate intake is not a key driver, but it is possible that the altered pattern of intake manifests in differences in liver and skeletal muscle glycogen availability prior to the evening exercise bout, as well as substrate utilisation during exercise.

The higher rate of carbohydrate oxidation observed during the low-moderate intensity steady state exercise in the breakfast omission trial is likely from exogenous carbohydrate and indicative of ongoing digestion, absorption and processing of the (large) lunch meal (Hunt et al., 1985; Moore et al., 1981). A higher rate of CHO oxidation would be expected to facilitate better performance, so either this was not maintained during the time trial (we did not measure this to avoid any impact on our primary outcome), or the time trial was too short for the alteration in substrate oxidation to overcome the impact of other factors exerting a detrimental effect on pacing. The delayed feeding combined with this ongoing gastric emptying may have resulted in less skeletal muscle and liver glycogen storage during the no breakfast trial compared to the breakfast trial, and hence lower availability at the onset of the time trial. Whether these (likely small) differences would explain the poorer performance is unclear. On the one hand, the finite availability of glycogen is only thought to become *limiting* to performance over more extended exercise durations (Burke et al., 2011). On the other hand, a role for glycogen concentrations in *regulating* self-selected exercise intensity during a time trial has previously been proposed but is far from conclusive (Rauch et al., 2005).

It is perhaps more likely – on the basis of current evidence – that the observed performance difference is due to a psychological effect. Indeed, whilst breakfast omission has previously been shown to negatively impact high intensity endurance exercise performance in the morning (Galloway et al., 2014), more recent evidence from studies where participants were blinded to meal status strongly suggests this is due to a placebo effect (Mears et al., 2018). In the present study, participants were aware that, overall, they were consuming an identical diet in both conditions, but it remains possible that consuming a meal earlier in the day will still be associated with an expectation of better performance and encourage participants to adopt a more positive pace during the time trial and 'tolerate' a higher power output for the same perception of effort, or *vice versa*. The possibility of the placebo effect of breakfast extending to evening exercise performance should be addressed in future studies.

There are number of other possible extensions of the current study which provide opportunities for future research. Firstly, we are in part reliant on self-reported compliance to the dietary interventions because they were implemented outside of the laboratory setting, by providing participants with individualised food packages to consume at home with strict instructions on intake and timing. However, our appetite and crucially, evening substrate oxidation data suggests that compliance was high and should partly assuage any concerns due to this element of our study design. Our findings should also be considered in the context of a small sample size combined with some variation in the observed effect on exercise performance (**Figure 2B**). Future laboratory studies should look to replicate our findings and provide additional insight by including mechanistic outcomes (e.g. tissue specific and whole-body substrate availability) throughout the day. A further limitation of our study is that we did not strictly control dietary intake on the day prior to each experimental trial and it is possible that participants may have adjusted their dietary intake in anticipation of the upcoming dietary restrictions (e.g. increased their energy intake the evening prior to the no-breakfast trial). However, it is interesting to note that if participants did consciously or subconsciously increase their total energy or CHO intake on the evening prior to the no breakfast compared to the breakfast trial, then this hasn't negated the performance decrement of missing breakfast on the trial day (i.e. we still observed the effect). Following on from this, it is noteworthy that our proof of principle study involved quite an extreme manipulation of dietary intake and it will be interesting to investigate whether less extreme manipulations of nutrient timing, for example spacing out the lunch meal over the course of the afternoon, are still associated with an impairment of performance. Finally, a strength of our study was that the participants were all habitual breakfast consumers (representing the majority of the population) but future work may want to determine responses in those that skip breakfast.

In conclusion, these data show that the impairment in evening high-intensity exercise performance following breakfast omission is still observed when complete dietary compensation is provided at lunch, indicating that the poorer performance is related to meal timing rather than carbohydrate intake / availability. This suggests that providing an early morning high-carbohydrate meal should be considered in order to optimise evening exercise performance.

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We have no conflict of interest to declare.

Data Availability

The raw data for this study is available from the corresponding author on reasonable request.

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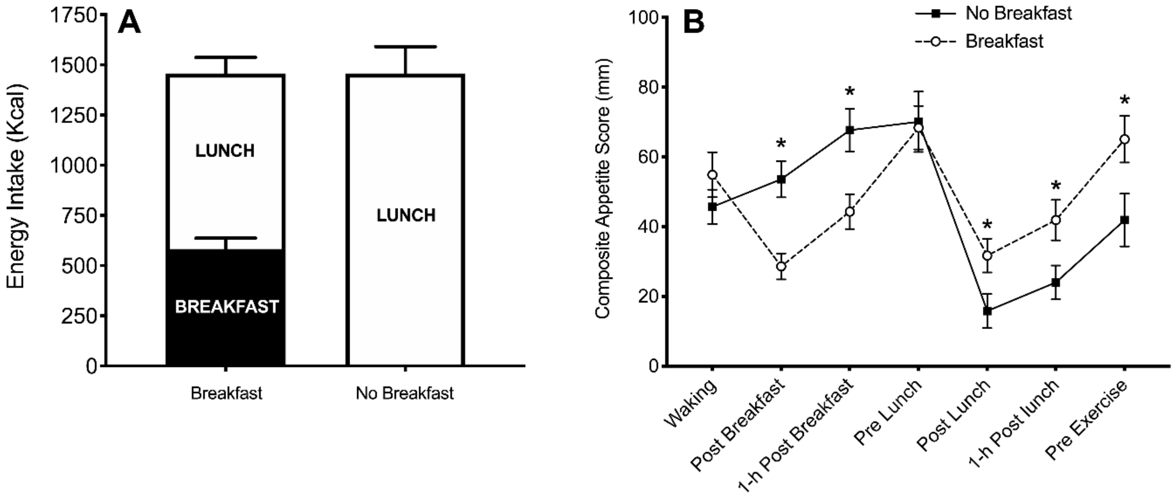
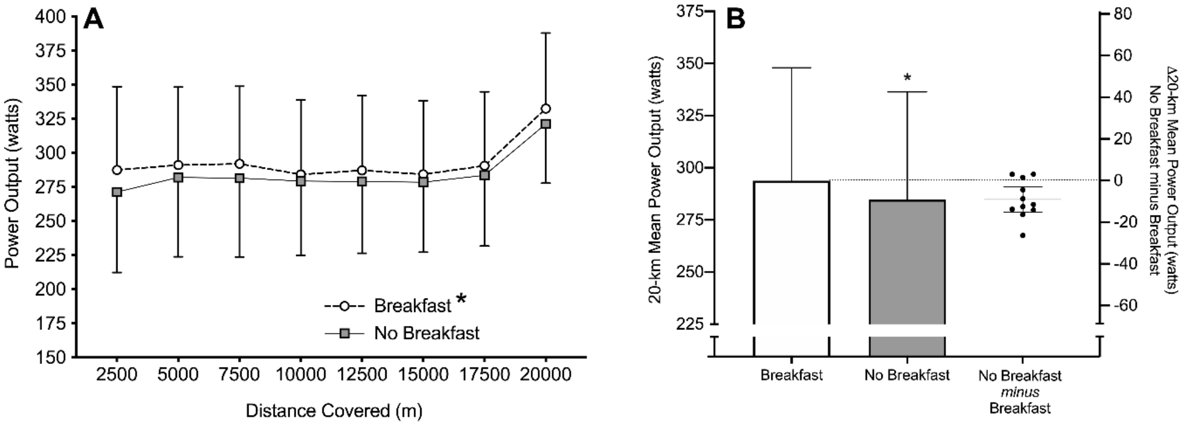
Figure Legends

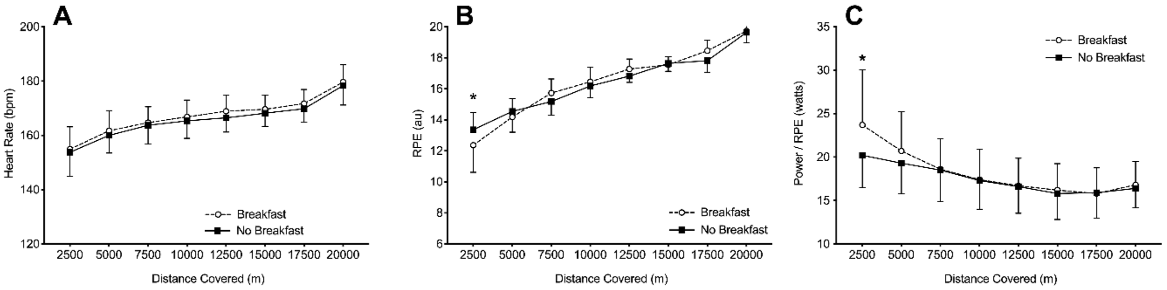
Figure 1 Energy intake at breakfast and lunch (A) and appetite ratings across the day (B) during the breakfast and no breakfast trials. Energy intake data is presented as mean ± SD, whilst appetite ratings are presented as mean ± SEM for visual clarity. * denotes $p<0.05$ a difference between the breakfast and no breakfast trials at that specific time point.

Figure 2 Power output every 2500 m during the 20 km time-trials (A) and the difference in mean power output during the time-trial between the breakfast and no breakfast trials (B). Power output data is presented as mean ± SD on A and on the left-hand axis of B. Right-hand axis on B represents the difference between conditions, presented as the mean ± 95 CI, with black dots representing individual participant difference scores (no breakfast trial *minus* breakfast trial i.e. negative data points reflect impaired performance with breakfast). * denotes $p<0.01$ for main effect of condition.

Figure 3 Heart rate (A), RPE (B) and Power / RPE (C) every 2500 m during the 20 km time trials. Data is presented as mean ± SD. * denotes $p<0.05$ for comparison between breakfast and no breakfast at that time point.

A
Energy Intake (Kcal)
1750
1500
1250
1000
750
500
250
0
LUNCH
BREAKFAST
LUNCH
Breakfast
No Breakfast
B
Composite Appetite Score (mm)
100
80
60
40
20
0
No Breakfast
Breakfast
*
*
*
*
*
Waking
Post Breakfast
1-h Post Breakfast
Pre Lunch
Post Lunch
1-h Post lunch
Pre Exercise


A
Power Output (watts)
400
375
350
325
300
275
250
225
200
175
150
2500
5000
7500
10000
12500
15000
17500
20000
Distance Covered (m)
Breakfast *
No Breakfast
B
20-km Mean Power Output (watts)
375
350
325
300
275
250
225
*
Breakfast
No Breakfast
No Breakfast *minus* Breakfast
Δ20-km Mean Power Output (watts) No Breakfast minus Breakfast
80
60
40
20
0
-20
-40
-60


A
Heart Rate (bpm)
200
180
160
140
120
2500
5000
7500
10000
12500
15000
17500
20000
Distance Covered (m)
Breakfast
No Breakfast
B
RPE (au)
20
18
16
14
12
10
8
6
*
2500
5000
7500
10000
12500
15000
17500
20000
Distance Covered (m)
Breakfast
No Breakfast
C
Power / RPE (watts)
35
30
25
20
15
10
*
2500
5000
7500
10000
12500
15000
17500
20000
Distance Covered (m)
Breakfast
No Breakfast