Diurnal influences of fasted and non-fasted brisk walking on gastric emptying rate, metabolic responses, and appetite in healthy males

Victoria J McIver[1], Lewis R Mattin[1], Gethin H Evans[1], and Adora MW Yau[1].

[1]Department of Life Sciences, Manchester Metropolitan University, UK.

Corresponding author

Adora MW Yau

Department of Life Sciences, Manchester Metropolitan University, Manchester, Greater Manchester, M1 5GD.

Tel: +44 (0)161 247 5504

Email: a.yau@mmu.ac.uk

Running title

Metabolic and appetite responses to fasted exercise

Disclosure

The authors report no conflicts of interest in this work. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. VJM was supported by a Manchester Metropolitan University Vice Chancellor Studentship.

Abstract

Growing evidence suggests circadian rhythms, nutrition and metabolism are intimately linked. Intermittent fasting (IMF) has become an increasingly popular intervention for

metabolic health and combining IMF with exercise may lead to benefits for weight management. However, little is known about the diurnal variation of fasted exercise. This study aimed to investigate the diurnal influences on gastric emptying rate (GER), metabolic responses, and appetite to fasted and non-fasted exercise. Twelve healthy males completed four 45 min walks in a randomised order. Walks were completed in the morning (AM) and evening (PM) and either fasted (FASTED) or after consumption of a standardised meal (FED). GER of a semi-solid lunch was subsequently measured for 2 h using the ^{13}C breath test. Blood glucose concentration, substrate utilisation, and ratings of appetite were measured throughout. Energy intake was also assessed for the following 24 hours. GER T_{lag} was slower in PM-FASTED compared to AM-FASTED, AM-FED, and PM-FED (75 ± 18 min vs. 63 ± 14 min, P=0.001, vs. 65 ± 10 min, P=0.028 and vs. 67 ± 16 min, P=0.007). Blood glucose concentration was greater in the FED trials in comparison to the FASTED trials pre-lunch (P<0.05). Fat oxidation was greater throughout exercise in both FASTED trials compared to FED, and remained higher in FASTED trials than fed trials post-exercise until 30 min post lunch ingestion (all P<0.05). No differences were found for appetite post-lunch (P>0.05) or 24 h post-energy intake (P=0.476). These findings suggest that evening fasted exercise results in delayed GER, without changes in appetite. No compensatory effects were observed for appetite, and 24 h post-energy intake for both fasted exercise trials, therefore, increased fat oxidation holds positive implications for weight management.

Keywords: Appetite, brisk walking, diurnal variation, fasting, gastric emptying rate

Introduction

Growing interest in nutrition and the circadian system has produced many insights within recent years, with circadian rhythms, metabolism, and nutrition suggested to be intimately linked (Johnson et al. 2016; Wehrens et al. 2017). Intermittent fasting (IMF) has become an increasingly popular dietary strategy for metabolic health and inducing weight loss by increasing insulin sensitivity and fatty-acid mobilization, reducing inflammation, and by creating a state of negative energy balance (Mattson, Longo, Harvie, 2017). Exercise-induced health benefits alone are favorable for reducing a range of risk factors and preventing the onset of metabolic diseases (Borghouts and Keizer 2000; Mann, Beedie and Jimenez, 2014; Rennie et al. 2003; Speakman and Selman, 2003; Steig et al. 2011; Thompson et al. 2001; Whelton, Chin, Xin, He, 2002). Therefore, combining intermittent fasting with exercise may lead to benefits for weight management. Emerging evidence also suggests that morning-loaded energy distribution is a beneficial strategy for weight management (Garaulet *et al*. 2013; Jakubowicz et al. 2013). Morning calorie consumption was also associated with greater improvements in fasting glucose, insulin and triglycerides, and decreased hunger scores (Jakubowicz *et al*. 2013; Sutton et al. 2018) and serum lipid levels (Yoshizaki et al., 2013). Therefore, combining eating patterns with exercise that reduce or eliminate eating at particular times of the circadian cycle may result in sustained improvements in human health (Johnston, 2014; Longo and Panda, 2016; Mattson et al. 2014).

Many circadian rhythms exist within the human organism that are governed by ‘clocks’ located centrally and in most peripheral tissues. These central and peripheral clocks are based on clock genes and their protein products (Cermakian and Boivin 2009). Clock genes in peripheral tissues are primarily regulated by the central ‘master

clock' located in the suprachiasmatic nuclei (SCN) which is predominantly synchronized by the light/dark cycle (Albrecht, 2012). External factors such as food intake and exercise are also known to influence clock genes (Morris, Yang and Scheer, 2012). Clock genes have been established in various organs and tissues, regulating the timing of physiological processes, specifically those involved in the digestion of food, nutrient uptake, and nutrient metabolism (Ruddick-Collins et al. 2018). There has been a considerable amount of interest in the role of clock genes in regulating biochemical pathways and metabolic processes (Marcheva et al. 2014; Sahar and Sassone-Corsi, 2012). However, less attention has been given on examining how the circadian system affects eating patterns combined with exercise, and how this may affect gastric emptying rate (GER) and appetite regulation.

Diurnal variations are evident in gastrointestinal absorption rate and GER, by acting to control food intake differentially at different times of the day. Previous studies have observed slower emptying of the stomach in the evening (Goo et al. 1987; Grammaticos, Doumas and Koliaskos, 2015; Orr et al 2004). Thermic effect of food has been shown to follow a time of day variance, with elevated levels in the morning, which may contribute to the diurnal variation observed for GER (Morris et al. 2016). GER influences the release of nutrients into the intestines for absorption, affecting hormonal and metabolite responses essential for nutrient digestion and storage (Romon et al. 1993; Ruddick-Collins et al. 2018). Therefore, GER may play an important role in metabolic health. However, although the above-mentioned studies are informative there are some notable limitations, with very low sample size recruited (Goo et al. 1987; Grammaticos, Doumas and Koliaskos 2015), mice studies which may not translate to human physiology (Kentish et al. 2014), and none of the aforementioned studies included exercise. Consequently, it is still unknown how

circadian variations in GER following subsequent food and energy intake may differentially influence postprandial energy metabolism and on appetite regulation. Particularly, on the diurnal variation of fasted versus fed exercise on gastrointestinal function and appetite. Therefore, there is a largely unmet need to explore how meal timing along with exercise may impact GER, appetite and metabolic health.

The aim of this study was to investigate the effect of brisk walking in the fasted and non-fasted state on metabolic responses, appetite and GER of a subsequent meal at two different times of the day. It was hypothesized that (a) GER would be slower during evening trials in comparison to morning trials (b) evening and morning trials would result in differences in appetite and metabolic responses post-exercise (c) fat oxidation would be higher during fasted exercise, and carbohydrate oxidation would be higher during non-fasted exercise, regardless of time of day and (d) there would be no compensatory effects for appetite post-exercise.

Material and Methods

Participants

Twelve recreationally active men (Mean ± SD; age 25 ± 3 years; height 178 ± 6 cm; body mass 83 ± 12 kg; body fat 21 ± 6%; body mass index 26 ± 4 kg/m^2; $\dot{V}O_{2peak}$ 39 ± 4 ml/kg/min) volunteered to participate in this study. Sample size was determined by a power analysis based on data that would result in a detectable change in GER and fat oxidation with 80% power and at a significance level of 5%. Participants were not taking regular medication or with any known history of respiratory, cardiovascular, or chronic gastrointestinal disease as assessed by a health screen questionnaire. All participants were free from musculoskeletal injury and non-smokers. Participants were also classified as moderate or intermediate chronotypes according to the Munich

chronotype questionnaire by Roenneberg, Wirz-Justice, Merrow (2003). This ensured the exclusion of participants with an early diurnal phase also known as extreme morning chronotypes and extreme evening chronotypes since it is known that morning and evening types differ in the daily phase (Roenneberg, Wirz-Justice, Merrow, 2003). Participants recorded a 7-day habitual sleep diary leading up to each trial and the midpoint of sleep (sleep duration x timing of sleep) was calculated. Participants were not involved in shift work and did not report any disturbances to their normal sleep-wake cycle during the 1 week prior to data collection. All participants were informed of the details of the study both verbally and in writing prior to providing their written informed consent. The study was approved by the Faculty of Science and Engineering Research Ethics and Governance Committee (Reference: SE1617158).

Preliminary trial

All participants attended a preliminary trial at least 7 days prior to the first experimental trial. During this visit, participants completed a physical activity and dietary habit questionnaire, Munich chronotype questionnaire, Pittsburgh sleep quality questionnaire, and the Epworth sleepiness scale questionnaire (Buysse Reynolds, Monk, Berman, Kupfer 1989). This visit also involved the collection of anthropometric measures of height, weight, body fat percentage, as well as familiarisation of the breath sampling procedures. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer and body mass to the nearest 0.01 kg using electronic scales (GFK 150; Adam Equipment Co. Ltd., Milton Keynes, UK). Body fat percentage was approximated using bioelectrical impedance analysis (Omron BF306; Kyoto, Japan).

Following this, all participants completed a peak oxygen uptake ($\dot{V}O_{2peak}$) test on a motorised treadmill. Initially, the treadmill speed was adjusted until a suitable brisk walking pace was determined. Participants were advised that brisk walking is defined

as an exercise intensity yielding a mild shortening of breath yet still enabling to converse. Participants then maintained this speed for five minutes. The speed of the treadmill was then increased to 8-12 $km \cdot h^{-1}$ and the gradient increased by 2.5% every 3 min until volitional exhaustion. Expired air was continuously collected using a breath-by-breath gas analyser (Oxycon Pro, CareFusion, Leipzig, Germany) and $\dot{V}O_{2peak}$ was calculated by averaging the maximum rate of oxygen consumption output consumed over the final 1 min period. Heart rate was measured continuously using a heart rate monitor (Polar H7, Kempele, Finland) and participants rating of perceived exertion (RPE) (Borg, 1895) was recorded every 3 min.

Before leaving the laboratory, participants were provided with food weighing scales and asked to record their physical activity and food intake in the 24 h before the start of their first experimental trial. Participants were then asked to replicate their activity and diet the day preceding their subsequent trials. In addition, participants were requested to refrain from alcohol consumption, strenuous exercise and caffeine ingestion 24 h before trials.

Experimental Trials

Participants completed four 5 h experimental trials in a randomised crossover fashion; two morning trials fasted (AM-FASTED) and non-fasted (AM-FED), and two evening trials fasted (PM-FASTED) and non-fasted (PM-FED). All morning trials commenced at 08:00 and evening trials commenced at 15:00. Randomisation of trials was achieved using the randomise tool within Microsoft Excel. All trials were separated by at least 7 days.

On the morning trials, participants were required to fast from 00:00 the evening before, and on the evening trials, participants were required to have breakfast and then fast

from 07:00 with the exception of plain water consumption. Ninety minutes prior to arrival at the laboratory, participants were asked to drink 500 ml of plain water to ensure an adequate and consistent level of hydration status and not drink anymore water after this point. Upon arrival at the laboratory, participants were asked to empty their bladder before body mass was recorded. Baseline assessments of appetite (hunger, fullness, prospective food consumption (PFC) and satisfaction) were made using 100 mm visual analogue scales (VAS) (Flint, Raben, Blundell and Astrup, 2000). Expired air samples were also collected for 10 min for the calculation of substrate utilisation. The average $\dot{V}O2$ and $\dot{V}CO2$ measurements from the last 5 min of expired air collection was used to calculate fat and carbohydrate oxidation rates using stoichiometric equations (Péronnet and Massicotte, 1991). This sampling method for expired air was adhered to for all resting expired air samples throughout.

Following baseline measurements, participants ingested the test 'breakfast' in FED within a 15 min period, or remained fasted in FASTED. The test 'breakfast' (meal 1) consisted of 30 g of breakfast cereal with 125 mL of semi-skimmed milk, and a croissant, which provided in total 1,438 kJ (341 kcal), and contained 10.2 g fat, 48 g carbohydrate and 11.2 g protein. This amount was chosen based on the recommended breakfast serving being of approximately 300-400 kcals (Public Health England, 2018). Participants consumed all of the breakfast within the 15 min window. Post breakfast ratings of appetite and substrate utilisation were measured at the end of the 15 min breakfast period. Participants then rested for 1 h before commencement of the exercise protocol. During this 1 h rest period, further measures of appetite were taken every 15 min and substrate utilisation every 30 min. The exercise protocol involved 45 min of brisk walking on a level motorised treadmill at the speed determined in the preliminary trial (range 5.9–7.0 $km \cdot h^{-1}$). The relative exercise intensity was 55 ±

0.8% VO_{2peak}. Heart rate and RPE were measured every 15 min throughout the exercise, with expired air measured continuously. The last 10 min of each 15 min segment was used to calculate substrate utilisation. After completion of the exercise bout, participants recovered for 30 min (showered if desired) before they ingested a standardised 'lunch' meal (meal 2). The meal was 800 g (2 cans) of vegetable soup (1584 kJ (376 kcal)), containing 6.8 g fat, 66.4 g carbohydrate, 8.8 g protein. Subjective feelings of appetite and substrate utilisation were measured every 15 min post ingestion for a total period of 2 h. The food served for AM and PM trials were identical. A schematic diagram of the experimental protocol is presented in figure 1.

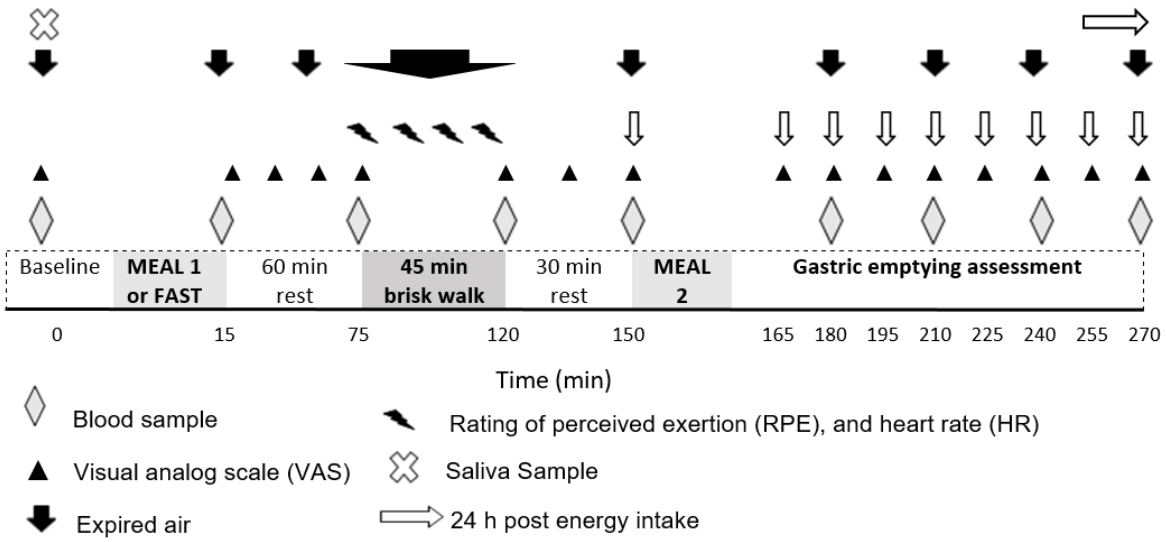

Figure 1: Schematic diagram of the experimental trial protocol.

Blood sampling

Blood glucose concentration was measured via a capillary blood sample from the tip of the finger, with the participant in a seated position. Capillary blood samples were taken at baseline, post breakfast period, pre-exercise, immediately post-exercise, pre-soup ingestion, then every 30 min post soup ingestion. A 23-gauge single use sterile

lancet (Unistik-3, Owen Mumford, Oxford, UK) was used to create a small incision (approx. 3mm puncture) on the fingertip. From this incision a free-flowing capillary blood sample was collected in microvettes (Hemocue Glucose 201+ Microcuvettes, Ângelholm, Sweden) containing anticoagulant EDTA, lithium heparin. The blood was analysed immediately using a desktop plasma glucose analyser (Hemocue Glucose 201+ analyser, Ângelholm, Sweden).

Saliva melatonin sample and analysis

A saliva sample was collected at the beginning of all trials (AM trials 08:00; PM trials 15:00) by the passive drool method, in which the participant allows saliva to pool in his mouth and then drools (rather than spits) through a collection aidstraw into the collection tube (5016.02-SAL, Salimetrics Europe Ltd, Newmarket, Suffolk, UK). Saliva samples were immediately stored at −80°C until analysis. On day of analysis, saliva samples were thawed, vortexed and then centrifuged at 1500 × g for 15 min at 4°C. Melatonin concentrations were determined in duplicate using ELISA (Kit assay #1-3402, Salimetrics, State College, PA, USA).

Gastric emptying assessment

The vegetable soup contained 100 mg of ^{13}C-sodium acetate for the assessment of GER using the ^{13}C breath test method. A basal end-expiratory breath sample was collected pre-meal ingestion then at every 15 min intervals post meal ingestion for 2 h. Breath samples were analysed for the ratio of $^{13}CO_2$:$^{12}CO_2$ by non-dispersive infra-red spectroscopy (IRIS Dynamic, Kibion, Germany). The difference in the ratio of $^{13}CO_2$:$^{12}CO_2$ from baseline breath to post-ingestion breath samples are expressed as

delta over baseline (DOB). Half-emptying time ($T_{½}$) and time of maximum emptying rate (T_{lag}) were calculated utilising the manufacturers integrated software evaluation incorporating equations of a previously described formula (Ghoos et al. 1993).

Statistical Analysis

A three-way (trial x time of day x time across trial) repeated-measures analysis of variance (ANOVA) to assess trial (fasted vs. fed) x time of trial (morning vs. evening) x time across trial differences for blood glucose concentration, gastric emptying DOB, substrate oxidation, and VAS ratings. A two-way repeated measures ANOVA was used to assess trial (fasted vs. fed) x time of trial (morning vs. evening) differences for gastric emptying $T_{½}$ and T_{lag} data, melatonin concentration and 24-hour energy intake. A one-way repeated measures ANOVA was used to assess midpoint of sleep and body mass across trials. Sphericity for repeated measures was assessed, and where appropriate, Greenhouse–Geisser corrections were applied for epsilon <0.75, and the Huynh–Feldt correction adopted for less severe asphericity. Significant *F*-tests were followed by dependent Student's t-Tests or one-way repeated ANOVA and Bonferroni adjusted pairwise comparisons as appropriate. All analyses were carried out using IBM SPSS statistics (v25.0 for Windows; SPSS, Chicago, IL). The level of significance was set at $P<0.05$. Descriptive data are expressed as mean ± standard deviation (SD).

Results

There were no significant differences between trials (AM-FASTED vs. AM-FED vs. PM-FASTED vs. PM-FED) for midpoint of sleep (Mean ± SD; 02:40 ± 0.2 vs. 02:25 ± 0.4 vs. 02:32 ± 0.5 vs. 02:42 ± 0.5 respectively; $P = 0.159$). Sleep-wake times for the four trials were; 22:50 - 06:30 vs. 22:30 - 06:20 vs. 22:45 - 06:20 vs. 22:50 - 06:35

respectively. There were also no significant differences between trials forpre-trial body mass (82.94 ± 12.53 vs. 82.87 ± 12.55 vs. 82.79 ± 12.47 vs. 82.92 ± 12.55 kg for AM-FASTED, AM-FED vs. PM-FASTED, PM-FED; $P = 0.230$).

Melatonin

Two factor ANOVA demonstrated a main effect of time of trial ($P = 0.002$), no main effect of trial ($P = 0.345$) and no interaction ($P = 0.159$) for salivary melatonin concentration. Salivary melatonin concentration was significantly different between morning and evening trials (AM-FASTED, AM-FED vs. PM-FASTED, PM-FED; 21 ± 6, 23 ± 13 vs. 15 ± 12, 9 ± 5 pg/mL; $P = 0.002$).

Gastric Emptying rate

Two factor ANOVA demonstrated no main effect of time of trial ($P = 0.128$), no main effect of trial ($P = 0.111$) and no interaction ($P = 0.430$) for $T_{½}$ (Figure 2a). Two factor ANOVA demonstrated a main effect of time of trial ($P = 0.021$), no main effect of trial ($P = 0.256$) and an interaction ($P = 0.023$) for T_{lag} (Figure 2a). T_{lag} was slower in PM-FASTED compared to AM-FASTED, AM-FED and PM-FED (75 ± 18 vs. 63 ± 14 min, $P = 0.001$, vs. 65 ± 10 min, $P = 0.028$ and vs. 67 ± 16 min, $P = 0.007$). No trial x time interaction ($P = 0.341$) or main trial effect ($P = 0.332$) was observed for DOB, although, a main effect for time was found ($P < 0.001$; Figure 2b). Mean incremental area under curve (iAUC) for DOB were 2633 ± 978 vs. 2541 ± 1082 vs. 3343 ± 840 vs. 2774 ± 613 $^{13}CO_2$:$^{12}CO_2$ over 5 h for AM-FASTED, AM-FED, PM-FASTED, and PM-FED, respectively. No significant effect of trial ($P = 0.226$), time of day ($P = 0.075$), or interaction effect ($P = 0.177$) was observed.

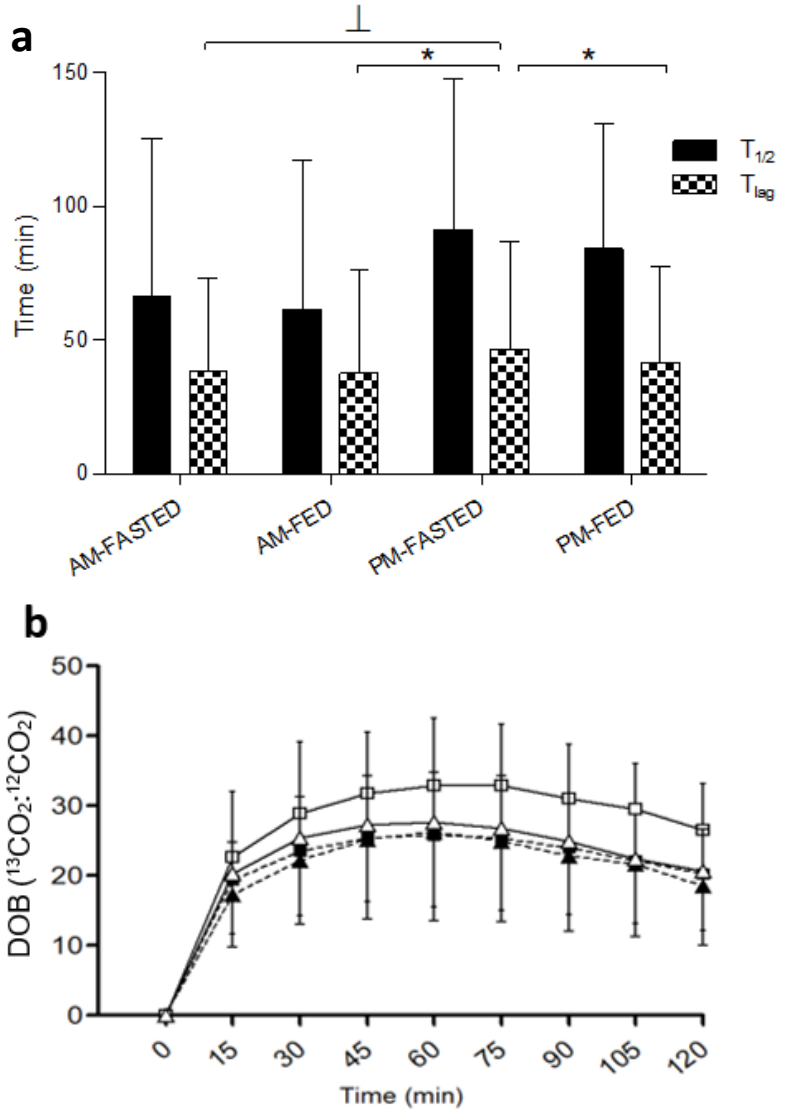

Figure 2: Gastric emptying assessment, AM-FASTED (■), AM-FED (▲) PM-FASTED (□) PM-FED (△). a) Gastric emptying half time ($T_{½}$) and time of maximal emptying rate (T_{lag}) b) Gastric emptying delta over baseline (DOB) for all four trials of MEAL 2 (800 g vegetable soup). *Indicates significance ($P < 0.05$) versus corresponding condition (i.e. FASTED vs. FED), ⊥ indicates significance versus corresponding time of day (i.e. FASTED AM vs FASTED PM). Values represent mean ± SD; n=12.

Subjective feelings of Appetite

315 A main effect of trial (FASTED vs. FED; $P < 0.001$), time of day ($P = 0.003$) and time
316 ($P < 0.001$) was observed for hunger, although no trial x time of day x time interaction
317 effect was observed ($P = 0.855$). Subjective feelings of hunger were generally lower
318 during the FED trials compared to the FASTED trials following ingestion of breakfast
319 with a number of time points showing significant differences ($P < 0.05$; Figure 3a).
320 However, there were no differences in subjective feelings of hunger between trials
321 following ingestion of lunch.

322 A main effect of trial ($P < 0.001$) and time ($P < 0.001$) was observed for fullness,
323 although no main effect for time of day ($P = 0.057$), or trial x time of day x time
324 interaction ($P = 0.074$) effect was observed. Subjective feelings of fullness were
325 generally greater during the FED trials compared to the FASTED trials following
326 ingestion of breakfast with a number of time points showing significant differences ($P
327 < 0.05$; Figure 3b). However, there were no differences in subjective feelings of
328 fullness between trials following ingestion of lunch.

329 A main effect of trial ($P = 0.008$), time of day ($P < 0.001$) and time ($P < 0.001$)
330 was observed for PFC although no trial x time of day x time interaction effect was
331 observed ($P = 0.577$). Subjective feelings of PFC were generally lower during the FED
332 trials compared to the FASTED trials following ingestion of breakfast with a number of
333 time points showing significant differences ($P < 0.05$; Figure 3c). However, there were
334 no differences in subjective feelings of PFC between trials following ingestion of lunch.

335 A main effect of trial ($P = 0.003$) and time ($P < 0.001$) was observed for food
336 satisfaction, however no main effect for time of day ($P = 0.078$), or trial x time of day x
337 time interaction effect ($P = 0.679$) was observed. Subjective feelings of food
338 satisfaction were generally greater during the FED trials compared to the FASTED

trials following ingestion of breakfast with a number of time points showing significant differences ($P < 0.05$; Figure 3d). However, there were no differences in subjective feelings of food satisfaction between trials following ingestion of lunch.

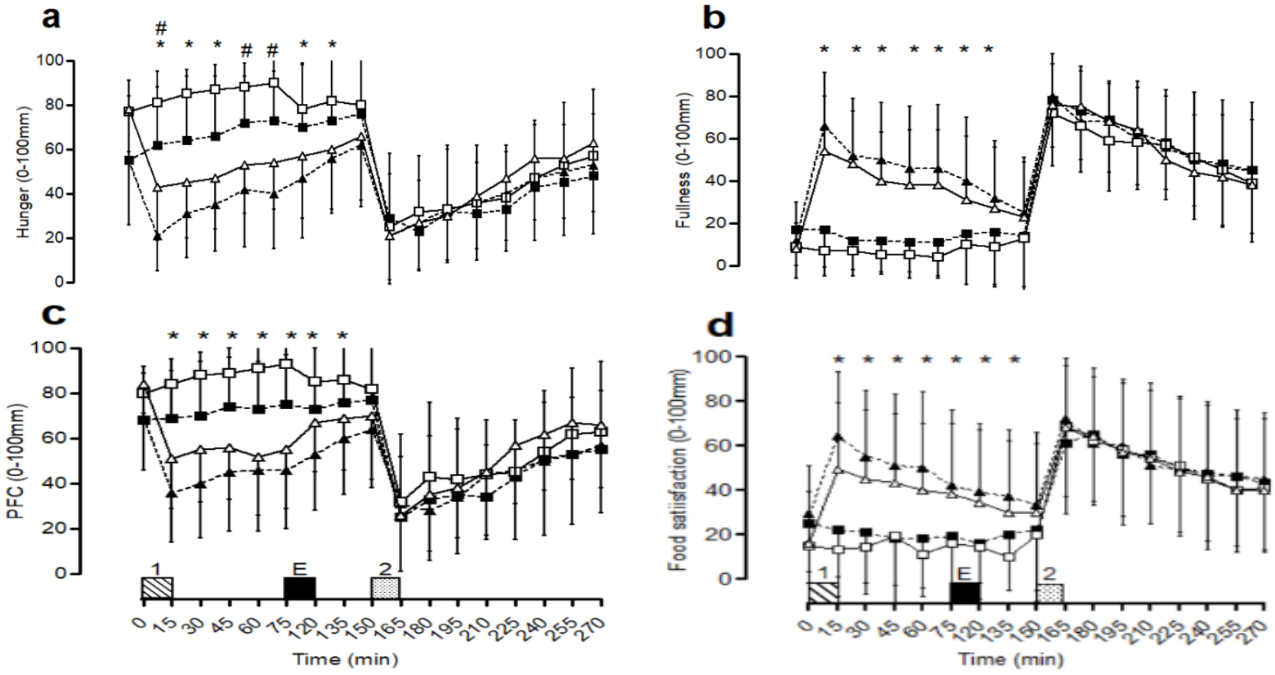

Figure 3: Appetite ratings during trials, AM-FASTED (■), AM-FED (▲) PM-FASTED (□) PM-FED (△). Appetite was assessed by 100 mm visual analogue scale (VAS); a) hunger, b) fullness, c) prospective food consumption (PFC) and d) food satisfaction. Values represent mean ± SD; n = 12. *Indicates significance (P < 0.05) versus corresponding condition (i.e. FASTED vs. FED), # indicates significant difference at one time-point compared to all trials. 1 = Meal 1, in which participants ingested a prescribed breakfast during the FED trial and remained fasted during the FASTED trial, E = Exercise period, where participants completed a 45 min brisk walk, 2 = Meal 2, where 800 g vegetable soup was ingested.

24 h post energy intake

Two factor ANOVA demonstrated no main effect of time of day (P = 0.170), no main effect of trial (P = 0.564) and no interaction (P = 0.718) for 24-hour energy intake (Table 1).

Table 1: 24 h post trial energy intake and macronutrient breakdown for participants (n = 12; mean ± SD).

	AM-FASTED	AM-FED	PM-FASTED	PM-FED
Energy intake (kcal)	2789 ± 520	2704 ± 655	2639 ± 668	2490 ± 749
Protein (g)	138 ± 33	145 ± 70	126 ± 54	127 ± 59
Carbohydrate (g)	332 ± 106	296 ± 71	237 ± 119	273 ± 83
Fat (g)	104 ± 43	110 ± 43	134 ± 80	101 ± 49

Substrate oxidation

A main effect for trial (P < 0.001*)*, and time *(*P < 0.001*)* was observed for CHO oxidation, however, no main effect for time of day (P = 0.296) or trial x time of day x time interaction effect was observed (P = 0.366; Figure 4a). CHO oxidation was greater in PM-FED compared to AM-FASTED and PM-FASTED, and AM-FED compared to AM-FASTED throughout exercise at 15 min (P = 0.004; P = 0.007; P = 0.021 respectively), 30 min (P < 0.001; P = 0.003; P =0.006), and 45 min (P = 0.001; P = 0.001; P = 0.005). CHO oxidation was higher in AM-FED compared to PM-FED and PM-FASTED at 1.5 h after soup ingestion (240 min; P = 0.005; P = 0.022) (Figure 4a). Mean iAUC for CHO oxidation was 72.4 ± 34.6 vs. 93.3 ± 30.7 vs. 59.3 ± 33.1 vs. 96.2 ± 31.3 g/min over 5 h for AM-FASTED, AM-FED, PM-FASTED, and PM-FED, respectively. A significant effect of trial (P = 0.001) was observed but no significant time of day effect (P = 0.581) or interaction effect (P = 0.368).

A main effect of trial (P < 0.001) and time (P < 0.001) was observed for fat oxidation, however, no main effect for time of day (P = 0.469) or trial x time of day x time interaction effect was observed (P = 0.740; Figure 4b). Fat oxidation was greater pre-exercise in PM-FASTED compared to PM-FED (0.11 ± 0.04 vs. 0.06 ± 0.02 g/min; P = 0.003), and greater throughout exercise for both FASTED compared to FED trials (all P<0.05). At pre-lunch, fat oxidation was also greater in AM-FASTED and PM-FASTED than PM-FED (P = 0.018; P = 0.020), and AM-FASTED remained higher than PM-FED 30 min post soup ingestion (P = 0.041) (Figure 4b). Mean iAUC for fat oxidation was 18.8 ± 10.2 vs. 8.7 ± 7.7 vs. 19.5 ± 9.2 vs. 9.3 ± 9.7 g/min over 5 h for AM-FASTED, AM-FED, PM-FASTED, and PM-FED, respectively. A significant effect of trial (P = 0.002) was observedwith fat oxidation being higher in the FASTED trials compared to FED trials. No time of day (P = 0.774), or interaction effect (P = 0.991) was observed.

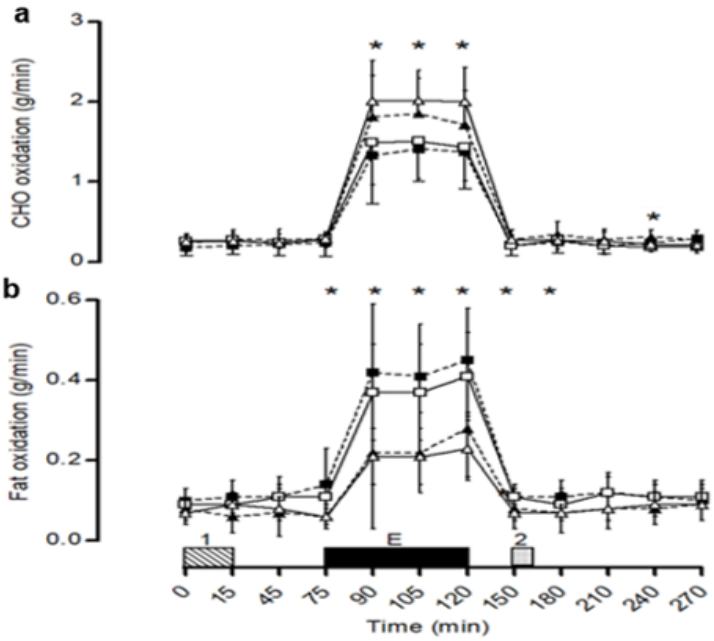

Figure 4: Substrate utilisation during the trials AM-FASTED (■), AM-FED (▲) PM-FASTED (□) PM-FED (△). a) Carbohydrate oxidation and b) fat oxidation. Values represent mean ± SD; n = 12. *Indicates significance (P < 0.05) versus corresponding

condition (i.e. FASTED vs. FED), ⊥ indicates significance versus corresponding time of day (i.e. FASTED AM vs FASTED PM). 1 = Meal 1, in which participants ingested a prescribed breakfast during the FED trial and remained fasted during the FASTED trial, E = Exercise period, where participants completed a 45 min brisk walk, 2 = Meal 2, where 800 g vegetable soup was ingested.

Blood glucose concentration

A main effect of trial ($P = 0.007$) and time ($P < 0.001$) was observed for glucose concentration, although no main effect for time of day ($P = 0.854$), or trial x time of day x time main interaction effect ($P = 0.058$) was observed. Baseline glucose concentrations were higher in the morning AM-FED trial in comparison to PM-FASTED trial ($P = 0.001$), no further differences during baseline collection. Blood glucose concentration pre-exercise was greater in AM-FED compared to PM-FASTED (5.80 ± 1.30 vs. 4.34 ± 0.31 mmol/L; $P = 0.014$), and greater in PM-FED compared to AM-FASTED and PM-FASTED (6.38 ± 1.15 vs. 4.69 ± 0.58; $P = 0.005$ and 4.34 ± 0.31 mmol/L; $P = 0.001$). No differences between trials were seen post- exercise ($P>0.05$), however, blood glucose concentration was greater at 150 min pre-lunch in AM-FED compared to AM-FASTED (5.28 ± 0.63 vs. 4.71 ± 0.40 mmol/L; $P = 0.042$) (Figure 5a). A significant time of day effect ($P = 0.024$) for iAUC for glucose concentrations was observed, but no significant trial ($P = 0.915$), or interaction effect ($P = 0.677$) (Figure 5b).

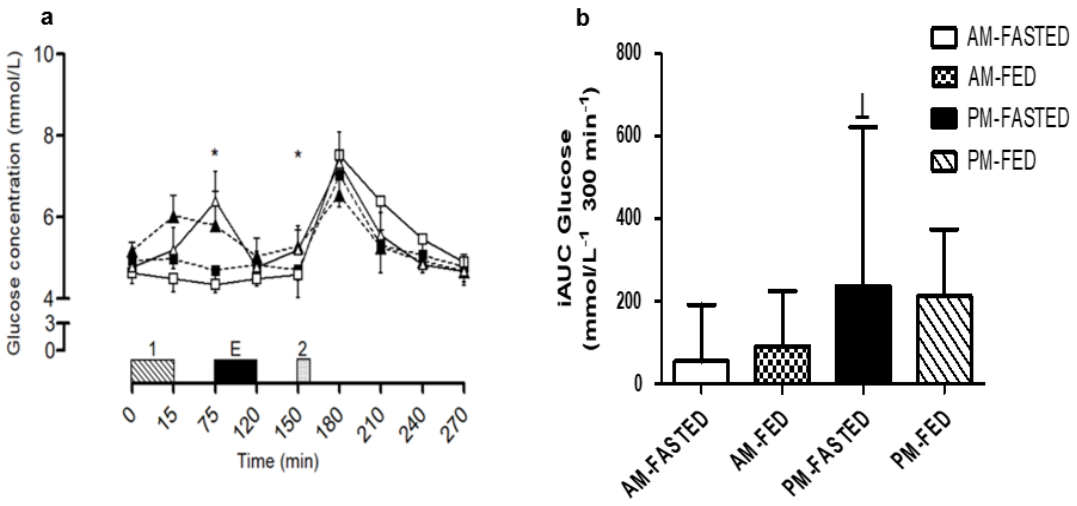

Figure 5: Blood glucose responses. a) Blood glucose concentrations during trials, AM-FASTED (■), AM-FED (▲) PM-FASTED (□) PM-FED (△) and b) Incremental area under curve (iAUC) over the trials. Values represent mean ± SD; n = 12. *Indicates significance ($P < 0.05$) versus corresponding condition (i.e. FASTED vs. FED). ⊥ indicates significance versus corresponding time of day (i.e. FASTED AM vs FASTED PM). 1 = Meal 1, in which participants ingested a prescribed breakfast during the FED trial and remained fasted during the FASTED trial, E = Exercise period, where participants completed a 45 min brisk walk, 2 = Meal 2, where 800 g vegetable soup was ingested.

Discussion

A meal in the evening following fasted exercise elicits a slower maximal gastric emptying rate in comparison to a meal following morning fasted and evening non-fasted exercise. Appetite does not follow a diurnal variation following fasted low intensity exercise, and regardless of the time of day, fasted exercise favors fat oxidation which may help induce a negative energy balance without a subsequent compensatory response in energy intake. This study adds novel insights into the

452 diurnal variation of GER, appetite and metabolism in response to fasted versus fed
453 exercise.

454 To the authors knowledge, this is the only study that has investigated the diurnal
455 variation of GER response from a subsequent meal following fasted versus fed
456 exercise. Previous studies that have examined the effect of GER between morning
457 and evening have found half time was significantly delayed in the evening (Goo et al.
458 1987; Grammaticos, Doumas, and Koliaskos, 2015; Orr et al 2004). The current study
459 only found a significance in maximal emptying time only, not half time. This may be
460 due to the meal context in the current study in comparison to others when measuring
461 gastric emptying. Goo et al (1987) found that in 16 healthy males, only gastric
462 emptying half-times for the evening (20:00) meal were significantly longer for solids
463 but not liquids when compared with morning (08:00) emptying half-times. The present
464 study used a soup meal that contained a large liquid component, which may be an
465 explanation for the lack of difference in half time as a greater delay of emptying with
466 solid food compared with liquids is commonly observed (Hellstrom, Gryback and
467 Jacobsson, 2006). In addition to this, it is well known that variations in gastric emptying
468 can have a major impact on the postprandial glycemic profile, and incretin hormone
469 secretion (Marathe et al. 2013; Trahair et al. 2014). Whether a delayed gastric
470 emptying in the evening versus morning would be more beneficial for appetite
471 regulatory hormone in response to weight management is unknown and requires
472 further study. This may be of particular importance for some clinical populations, such
473 as overweight and type 2 diabetes, with research providing a number of strategies to
474 optimise postprandial glycemic control based on modulation of GER (Jones et al.
475 2001; Marathe et al. 2013; O'Keefe, 2011; Philips et al. 2015). It is suggested that a
476 slower rate of nutrient delivery to the small intestine would be desirable to compensate

for the delay in insulin release and the resistance to its actions (Marathe et al. 2013). However, it is difficult to draw accurate comparisons due to no existing studies measuring gastric emptying at different times of day in response to exercise. Therefore, more literature is required to build a clearer understanding, and also to explore whether appetite regulatory hormones are affected between morning and evening exercise.

Similar to gastric emptying, it is well documented that fat, carbohydrate (CHO), and glucose metabolism display a time-of-day dependent rhythms, which align with daily rhythms in behaviours, such as sleep/wake, feeding/fasting, and activity cycles (Bailey, Udoh and Young 2014; Kalsbeek, Fleur and Fliers, 2014; Kessler et al. 2017). Previous evidence has observed higher fat oxidation rates in the evening in comparison to morning (Darakh et al. 2014; Mohebbi and Azizi, 2011), while in contrast, CHO and glucose metabolism are higher in the morning in comparison to the evening (Kessler et. 2017; Qian and Scheer 20176). However, these conclusions do not translate on to the current study findings, with no time of day effect observed in any of the energy metabolism measures, only between trials (fasted versus. fed exercise). A possible explanation for the lack of time of day variance may be due to the exercise elicited within the current study (55% $\dot{V}O_{2peak}$). Previous studies that observed a time-of-day variance in fat/CHO oxidation conducted higher exercise intensities (Mohebbi, Azizi and Tabari 2011; Suk, 2015). It is thought that during periods of increased physical activity, non-insulin mediated glucose utilisation increases, and the relative contribution of aerobic to anaerobic utilization being dependent upon exercise intensity (Alberts et al. 2006; Calvo, et al. 2008; Melzer, 2011; Rohling et al. 2016; Rose and Richter 2005). Nevertheless, energy metabolism is predominantly dependent on feeding behaviours, and regardless of time of day,

fasted exercise favoured fat oxidation, while eating before exercise elicits a greater CHO oxidation response (Achten and Jeukendrup 2004; Bachmen, 2016; Iwayama, 2017). This corresponds with existing literature, that fasting elicits fat metabolism, while feeding induces a greater CHO metabolism. It would be interesting to examine the energy metabolism of time-of-day on an intensity/mode of exercise that elicited a greater energy response.

The present study hypothesised that evening and morning trials would result in differences in appetite and metabolic responses post-exercise. However, appetite stabilised across all trials post-exercise, which corresponds with the substrate utilisation and glucose findings. This may be due to a suppression of appetite which has been reported during and briefly following moderate-to-high intensity bouts of running exercise (Broom, Batterham, King and Stensel 2008; Vatansever-Ozen, Tiryaki-Sonmez, Bugdayci and Ozen 2011). The combined lack of differences in hunger and energy metabolism post exercise, followed by no differences in 24 h post-energy intake, could suggest that regardless of an increased energy expenditure being incurred from exercise there will likely be no compensatory increase in energy intake post-exercise to account for the omission of energy intake prior to exercise. This may, therefore, create a small short-term negative energy balance and if sustained in the long-term, the cumulative effects may have an important role in weight maintenance, which has been found in previous studies from fasted exercise. Previous studies have found that alternate day fasting combined with endurance exercise was effective for weight loss for obese participants following 12-week training programme (Bhutani et al. 2013) and fasting before morning exercise decreased 24-hour energy intake (Bachman, Deitrick and Hillman, 2016). Further research on both the shorter-term effects of an acute bout of exercise and the cumulative effects of frequent fasted

exercise at various times of day over a period of time is required to fully understand if compensatory effects occur.

In conclusion, these findings demonstrate that GER is sensitive to time of day variation in response to a meal following fasted exercise. In the postprandial stages, regardless of time of day, appetite, blood glucose concentration, substrate utilisation, and 24 h post energy intake is not sensitive to an acute bout of low-intensity exercise in the fasted state compared to the fed state. Fasted exercise favors fat oxidation, whilst eating before exercise favors CHO oxidation. The indication that no compensatory increase in energy intake will occur post exercise potentially holds positive implications for fasted brisk walking in the long-term control of weight management. Future research is warranted to investigate how appetite regulatory hormones associated with gastric emptying respond to fasted versus. fed exercise at different times of day.

Acknowledgments

The authors would like to acknowledge Dave Maskew of Manchester Metropolitan University for his technical support in the laboratory.

Statement of authors' contributions to manuscript: VJM, AMWY, GHE conceived and designed the experiments; VJM and LRM performed the experiments; VJM analysed the data; VJM wrote the paper with contributions from AMWY and GHE. All authors have read and approved the final manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

Achten, J., & Jeukendrup, A. E. (2004). Optimizing fat oxidation through exercise and diet. Nutrition. https://doi.org/10.1016/j.nut.2004.04.005

Alberts, P., Johansson, B. G., & McArthur, R. A. (2006). Characterization of Energy Expenditure in Rodents by Indirect Calorimetry. In *Current Protocols in Neuroscience*. https://doi.org/10.1002/0471142301.ns0923ds36

Albrecht, U. (2012). Timing to Perfection: The Biology of Central and Peripheral Circadian Clocks. *Neuron*. https://doi.org/10.1016/j.neuron.2012.04.006

Bachman, J. L., Deitrick, R. W., & Hillman, A. R. (2016). Exercising in the Fasted State Reduced 24-Hour Energy Intake in Active Male Adults. *Journal of Nutrition and Metabolism*. https://doi.org/10.1155/2016/1984198

Bailey, S. M., Udoh, U. S., & Young, M. E. (2014). Circadian regulation of metabolism. *Journal of Endocrinology*. https://doi.org/10.1530/JOE-14-0200

Bhutani, S., Klempel, M. C., Kroeger, C. M., Trepanowski, J. F., & Varady, K. A. (2013). Alternate day fasting and endurance exercise combine to reduce body weight and favorably alter plasma lipids in obese humans. *Obesity*. https://doi.org/10.1002/oby.20353

Bird, S. R., & Hawley, J. A. (2017). Update on the effects of physical activity on insulin sensitivity in humans. *BMJ Open Sport and Exercise Medicine*. https://doi.org/10.1136/bmjsem-2016-000143

Borg, G. A. (1982). Borg`s RPE Scale.pdf. *Medicine & Science in Sports & Exercise*. https://doi.org/-

Borghouts, L. B., & Keizer, H. A. (2000). Exercise and insulin sensitivity: A review. *International Journal of Sports Medicine*. https://doi.org/10.1055/s-2000-8847

Broom, D. R., Batterham, R. L., King, J. A., & Stensel, D. J. (2008). Influence of resistance and aerobic exercise on hunger, circulating levels of acylated ghrelin, and peptide YY in healthy males. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*. https://doi.org/10.1152/ajpregu.90706.2008

Buysse, D.J., Reynolds, C.F., Monk, T.H., Berman, S.R., Kupfer, D.J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research. https://doi.org/10.1016/0165-1781(89)90047-4*Calvo, J. A., Daniels, T. G., Wang, X., Paul, A., Lin, J., Spiegelman, B. M., … Rangwala, S. M. (2008). Muscle-specific expression of PPARγ coactivator-1α improves exercise performance and increases peak oxygen uptake. *Journal of Applied Physiology*. https://doi.org/10.1152/japplphysiol.01231.2007

592 Cermakian, N., & Boivin, D. B. (2009). The regulation of central and peripheral
593 circadian clocks in humans. *Obesity Reviews*. https://doi.org/10.1111/j.1467-
594 789X.2009.00660.x

595 Darvakh, H., Nikbakht, M., Shakerian, S., & Mousavian, A. S. (2014). Effect of
596 circadian rhythm on peak of maximal fat oxidation on non-athletic men. *Zahedan*
597 *Journal of Research in Medical Science*.

598 Flint, A., Raben, A., Blundell, J. E., & Astrup, A. (2000). Reproducibility, power and
599 validity of visual analogue scales in assessment of appetite sensations in single
600 test meal studies.

601 Garaulet, M., Gómez-Abellán, P., Alburquerque-Béjar, J. J., Lee, Y. C., Ordovás, J.
602 M., & Scheer, F. A. J. L. (2013). Timing of food intake predicts weight loss
603 effectiveness. *International Journal of Obesity*.
604 https://doi.org/10.1038/ijo.2012.229

605 Ghoos, Y. F., Maes, B. D., Geypens, B. J., Mys, G., Hiele, M. I., Rutgeerts, P. J., &
606 Vantrappen, G. (1993). Measurement of gastric emptying rate of solids by
607 means of a carbon-labeled octanoic acid breath test. *Gastroenterology*.
608 https://doi.org/10.1016/0016-5085(93)90640-X

609 Goo, R. H., Moore, J. G., Greenberg, E., & Alazraki, N. P. (1987). Circadian variation
610 in gastric emptying of meals in humans. *Gastroenterology*.
611 https://doi.org/10.1016/0016-5085(87)90913-9

612 Grammaticos, P. C., Doumas, A., & Koliakos, G. (2015). Morning and night gastric
613 emptying half-time differed more than 220% in two young healthy adults.
614 *Hellenic Journal of Nuclear Medicine*.

615 Hamid Mohebbi, Mohammad Azizi, E. T. F. (2011). EFFECT OF TIME OF DAY ON
616 MFO AND FATMAX DURING Hamid Mohebbi , Mohammad Azizi , Elma Tabari.
617 *FACTA UNIVERSITATIS Series: Physical Education and Sport*.

618 Hamid Mohebbi, Mohammad Azizi, E. T. F. (2011). EFFECT OF TIME OF DAY ON
619 MFO AND FATMAX DURING Hamid Mohebbi , Mohammad Azizi , Elma Tabari.
620 *FACTA UNIVERSITATIS Series: Physical Education and Sport*.

621 Hellström, P. M., Grybäck, P., & Jacobsson, H. (2006). The physiology of gastric
622 emptying. *Best Practice and Research: Clinical Anaesthesiology*.
623 https://doi.org/10.1016/j.bpa.2006.02.002

624 Iwayama, K., Kawabuchi, R., Nabekura, Y., Kurihara, R., Park, I., Kobayashi, M., …
625 Tokuyama, K. (2017). Exercise before breakfast increases 24-h fat oxidation in
626 female subjects. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0180472

627 Jakubowicz, D., Barnea, M., Wainstein, J., & Froy, O. (2013). High Caloric intake at
628 breakfast vs. dinner differentially influences weight loss of overweight and obese
629 women. *Obesity*. https://doi.org/10.1002/oby.20460

Johnston, J. D., Ordovás, J. M., Scheer, F. A., & Turek, F. W. (2016). Circadian Rhythms, Metabolism, and Chrononutrition in Rodents and Humans. *Advances in Nutrition*. https://doi.org/10.3945/an.115.010777

Jones, K. L., Russo, A., Stevens, J. E., Wishart, J. M., Berry, M. K., & Horowitz, M. (2001). Predictors of delayed gastric emptying in diabetes. *Diabetes Care*. https://doi.org/10.2337/diacare.24.7.1264

Kalsbeek, A., La Fleur, S., & Fliers, E. (2014). Circadian control of glucose metabolism. *Molecular Metabolism*. https://doi.org/10.1016/j.molmet.2014.03.002

Kentish, S., O'Donnell, T., Kennaway, D., Wittert, G., & Page, A. (2014). Circadian variation of gastric vagal afferent satiety signals are abolished by diet induced obesity. *Obesity Reviews*. https://doi.org/10.1111/obr.12145

Kessler, K., Hornemann, S., Petzke, K. J., Kemper, M., Kramer, A., Pfeiffer, A. F. H., … Rudovich, N. (2017). The effect of diurnal distribution of carbohydrates and fat on glycaemic control in humans: A randomized controlled trial. *Scientific Reports*. https://doi.org/10.1038/srep44170

Longo, V. D., & Panda, S. (2016). Fasting, Circadian Rhythms, and Time-Restricted Feeding in Healthy Lifespan. *Cell Metabolism*. https://doi.org/10.1016/j.cmet.2016.06.001

Maki, K. C., Phillips-Eakley, A. K., & Smith, K. N. (2016). The Effects of Breakfast Consumption and Composition on Metabolic Wellness with a Focus on Carbohydrate Metabolism. *Advances in Nutrition: An International Review Journal*. https://doi.org/10.3945/an.115.010314

Mann, S., Beedie, C., & Jimenez, A. (2014). Differential effects of aerobic exercise, resistance training and combined exercise modalities on cholesterol and the lipid profile: review, synthesis and recommendations. *Sports Medicine*. https://doi.org/10.1007/s40279-013-0110-5

Marathe, C. S., Rayner, C. K., Jones, K. L., & Horowitz, M. (2013). Relationships between gastric emptying, postprandial glycemia, and incretin hormones. *Diabetes Care*. https://doi.org/10.2337/dc12-1609

Marcheva, B., Ramsey, K. M., Peek, C. B., Affinati, A., Maury, E., & Bass, J. (2013). Circadian clocks and metabolism. *Handbook of Experimental Pharmacology*. https://doi.org/10.1007/978-3-642-25950-0-6

Mattson, M. P., Longo, V. D., & Harvie, M. (2017). Impact of intermittent fasting on health and disease processes. *Ageing Research Reviews*. https://doi.org/10.1016/j.arr.2016.10.005

Melzer, K. (2011). Carbohydrate and fat utilization during rest and physical activity. *E-SPEN*. https://doi.org/10.1016/j.eclnm.2011.01.005

668 Morris, C. J., Garcia, J. I., Myers, S., Yang, J. N., Trienekens, N., & Scheer, F. A. J.
669 L. (2015). The human circadian system has a dominating role in causing the
670 morning/evening difference in diet-induced thermogenesis. *Obesity*.
671 https://doi.org/10.1002/oby.21189

672 Morris, C. J., Yang, J. N., & Scheer, F. A. J. L. (2012). The impact of the circadian
673 timing system on cardiovascular and metabolic function. *Progress in Brain*
674 *Research*. https://doi.org/10.1016/B978-0-444-59427-3.00019-8

675 Morris, C. J., Yang, J. N., Garcia, J. I., Myers, S., Bozzi, I., Wang, W., … Scheer, F.
676 A. J. L. (2015). Endogenous circadian system and circadian misalignment
677 impact glucose tolerance via separate mechanisms in humans. *Proceedings of*
678 *the National Academy of Sciences*. https://doi.org/10.1073/pnas.1418955112

679 O'Keefe, J. H., Abuannadi, M., Lavie, C. J., & Bell, D. S. H. (2011). Strategies for
680 optimizing glycemic control and cardiovascular prognosis in patients with type 2
681 diabetes mellitus. *Mayo Clinic Proceedings*.
682 https://doi.org/10.4065/mcp.2010.0434

683 Orr, W. C., Heading, R., Johnson, L. F., & Kryger, M. (2004). Review article: sleep
684 and its relationship to gastro-oesophageal reflux. *Alimentary Pharmacology and*
685 *Therapeutics*. https://doi.org/10.1111/j.1365-2036.2004.02239.x

686 Péronnet, F., & Massicotte, D. (1991). Table of nonprotein respiratory quotient: an
687 update. *Canadian Journal of Sport Sciences = Journal Canadien Des Sciences*
688 *Du Sport*.

689 Phillips, L. K., Deane, A. M., Jones, K. L., Rayner, C. K., & Horowitz, M. (2015).
690 Gastric emptying and glycaemia in health and diabetes mellitus. *Nature Reviews*
691 *Endocrinology*. https://doi.org/10.1038/nrendo.2014.202

692 Public Health England (2018). Plans to cut excess calorie consumption unveiled.
693 Steps to reduce 20% of calories in popular foods by 2024 announced to tackle
694 childhood obesity. Available at: https://www.gov.uk/government/news/plans-to-cut-
695 excess-calorie-consumption-unveiled

696 Qian, J., & Scheer, F. A. J. L. (2016). Circadian System and Glucose Metabolism:
697 Implications for Physiology and Disease. *Trends in Endocrinology and*
698 *Metabolism*. https://doi.org/10.1016/j.tem.2016.03.005

699 Rennie, K. L., McCarthy, N., Yazdgerdi, S., Marmot, M., & Brunner, E. (2003).
700 Association of the metabolic syndrome with both vigorous and moderate
701 physical activity. *International Journal of Epidemiology*.
702 https://doi.org/10.1093/ije/dyg179

703 Roenneberg, T., Wirz-Justice, A., Merrow, M. (2003). Life between clocks: daily
704 temporal patterns of human chronotypes. *Journal of Biological Rhythms.*
705 *https*://doi.org/10.1177/0748730402239679

706 Röhling, M., Herder, C., Stemper, T., & Müssig, K. (2016). Influence of Acute and
707 Chronic Exercise on Glucose Uptake. *Journal of Diabetes Research*.
708 https://doi.org/10.1155/2016/2868652

709 Romon, M., Edme, J. L., Boulenguez, C., Lescroart, J. L., & Frimat, P. (1993).
710 Circadian variation of diet-induced thermogenesis. *American Journal of Clinical*
711 *Nutrition*.

712 Rose, A. J., & Richter, E. A. (2005). Skeletal Muscle Glucose Uptake During
713 Exercise: How is it Regulated? *Physiology*.
714 https://doi.org/10.1152/physiol.00012.2005

715 Rose, A. J., Kiens, B., & Richter, E. A. (2006). Ca2+-calmodulin-dependent protein
716 kinase expression and signalling in skeletal muscle during exercise. *Journal of*
717 *Physiology*. https://doi.org/10.1113/jphysiol.2006.111757

718 Ruddick-Collins, L. C., Johnston, J. D., Morgan, P. J., & Johnstone, A. M. (2018).
719 The Big Breakfast Study: Chrono-nutrition influence on energy expenditure and
720 bodyweight. *Nutrition Bulletin*. https://doi.org/10.1111/nbu.12323

721 Sahar, S., & Sassone-Corsi, P. (2012). Regulation of metabolism: The circadian
722 clock dictates the time. *Trends in Endocrinology and Metabolism*.
723 https://doi.org/10.1016/j.tem.2011.10.005

724 Smith, C. S., Reilly, C., & Midkiff, K. (1989). Evaluation of Three Circadian Rhythm
725 Questionnaires With Suggestions for an Improved Measure of Morningness.
726 *Journal of Applied Psychology*. https://doi.org/10.1037/0021-9010.74.5.728

727 Speakman, J. R., & Selman, C. (2004). Physical activity and resting metabolic rate.
728 *Proceedings of the Nutrition Society*. https://doi.org/10.1079/pns2003282

729 Steig, A. J., Jackman, M. R., Giles, E. D., Higgins, J. A., Johnson, G. C., Mahan, C.,
730 MacLean, P. S. (2011). Exercise reduces appetite and traffics excess nutrients
731 away from energetically efficient pathways of lipid deposition during the early
732 stages of weight regain. *AMERICAN JOURNAL OF PHYSIOLOGY-*
733 *REGULATORY INTEGRATIVE AND COMPARATIVE PHYSIOLOGY*.
734 https://doi.org/10.1152/ajpregu.00212.2011

735 Suk, M. H., Moon, Y. J., Park, S. W., Park, C. Y., & Shin, Y. A. (2015). Maximal fat
736 oxidation rate during exercise in Korean women with type 2 diabetes mellitus.
737 *Diabetes and Metabolism Journal*. https://doi.org/10.4093/dmj.2015.39.4.328

738 Sutton, E. F., Beyl, R., Early, K. S., Cefalu, W. T., Ravussin, E., & Peterson, C. M.
739 (2018). Early Time-Restricted Feeding Improves Insulin Sensitivity, Blood
740 Pressure, and Oxidative Stress Even without Weight Loss in Men with
741 Prediabetes. *Cell Metabolism*. https://doi.org/10.1016/j.cmet.2018.04.010

742 Thompson, P. D., Crouse, S. F., Goodpaster, B., Kelley, D., Moyna, N., & Pescatello,
743 L. (2001). The acute versus the chronic response to exercise. *Medicine and*
744 *Science in Sports and Exercise*.

Trahair, L. G., Horowitz, M., Marathe, C. S., Lange, K., Standfield, S., Rayner, C. K., & Jones, K. L. (2014). Impact of gastric emptying to the glycemic and insulinemic responses to a 75-G oral glucose load in older subjects with normal and impaired glucose tolerance. *Physiological Reports*. https://doi.org/10.14814/phy2.12204

Vatansever-Ozen, S., Tiryaki-Sonmez, G., Bugdayci, G., & Ozen, G. (2011). The effects of exercise on food intake and hunger: Relationship with acylated ghrelin and leptin. *Journal of Sports Science and Medicine*.

Wehrens, S. M. T., Christou, S., Isherwood, C., Middleton, B., Gibbs, M. A., Archer, S. N., Johnston, J. D. (2017). Meal Timing Regulates the Human Circadian System. *Current Biology*. https://doi.org/10.1016/j.cub.2017.04.059

Whelton, S. P., Chin, A., Xin, X., & He, J. (2002). Effect of aerobic exercise on blood pressure: A meta-analysis of randomized, controlled trials. *Annals of Internal Medicine*. https://doi.org/10.7326/0003-4819-136-7-200204020-00006

Yoshizaki, T., Midorikawa, T., Hasegawa, K., Mitani, T., Komatsu, T., & Togo, F. (2014). Associations between diurnal 24-hour rhythm in ambulatory heart rate variability and the timing and amount of meals during the day shift in rotating shift workers. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0106643