

Accepted manuscript

Viscous placebo and carbohydrate breakfasts similarly decrease appetite and increase resistance exercise performance compared to a control breakfast in trained males

M.N. Naharudin^{1,2}, J. Adams¹, H. Richardson¹, T. Thomson¹, C. Oxinou¹, C. Marshall¹, D.J. Clayton^{1,3}, S.A. Mears¹, A. Yusof², C.J. Hulston¹ and L.J. James¹

1. National Centre for Sport and Exercise Medicine, School of Sport Exercise and Health Science, Loughborough University, Loughborough, LE11 3TU, UK
2. Centre for Sports and Exercise Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia
3. School of Science and Technology, Nottingham Trent University, Nottingham, NG11 8NS, UK

Shortened Title: Breakfast and resistance exercise performance

Key Words: Weight training; Strength; Nocebo; Fasting; Ghrelin.



This peer-reviewed article has been accepted for publication but not yet copyedited or typeset, and so may be subject to change during the production process. The article is considered published and may be cited using its DOI

10.1017/S0007114520001002

The British Journal of Nutrition is published by Cambridge University Press on behalf of The Nutrition Society

Abstract

Given the common view that pre-exercise nutrition/breakfast is important for performance, the present study investigated whether breakfast influences resistance exercise performance via a physiological or psychological effect. Twenty-two resistance trained, breakfast-consuming men completed three experimental trials, consuming water-only (WAT), or semi-solid breakfasts containing 0 g/kg (PLA) or 1.5 g/kg (CHO) maltodextrin. PLA and CHO meals contained xanthan gum and low-energy flavouring (~29 kcal) and subjects were told both 'contained energy'. Two hours post-meal, subjects completed 4 sets of back squat and bench press to failure at 90% 10 repetition maximum. Blood samples were taken pre-meal, 45 min and 105 min post-meal to measure serum/plasma glucose, insulin, ghrelin, GLP-1 and PYY concentrations. Subjective hunger/fullness were also measured. Total back squat repetitions were greater in CHO (44 (SD 10) repetitions) and PLA (43 ± 10 repetitions) than WAT (38 (SD 10) repetitions; $P < 0.001$). Total bench press repetitions were similar between trials (WAT 37 (SD 7) repetitions; CHO 39 ± 7 repetitions; PLA 38 (SD 7) repetitions; $P = 0.130$). Performance was similar between CHO and PLA trials. Hunger was suppressed and fullness increased similarly in PLA and CHO, relative to WAT ($P < 0.001$). During CHO, plasma glucose was elevated at 45 min ($P < 0.05$), whilst serum insulin was elevated ($P < 0.05$) and plasma ghrelin suppressed at 45 and 105 min ($P < 0.05$). These results suggest that breakfast/pre-exercise nutrition enhances resistance exercise performance via a psychological effect, although a potential mediating role of hunger cannot be discounted.

Introduction

Resistance exercise is regularly performed by athletes/recreational exercisers and performance in such sessions might have important implications for training volume, and consequently gains in muscle mass/strength⁽¹⁾, as well as for prevention of/recovery from injury. The pre-exercise meal, particularly its carbohydrate content, is an important component of an athlete's nutrition plan⁽²⁾, with current guidelines recommending 1-4 g carbohydrate/kg body mass should be consumed in the 1-4 h pre-exercise⁽³⁾. Previous research has demonstrated that consumption of carbohydrate in the hours before endurance exercise enhances performance⁽²⁾, but little is known about how such nutrition strategies influence performance in resistance-type exercise.

Carbohydrate intake at the first meal of the day following an overnight fast (i.e. breakfast) increases both liver⁽⁴⁾ and muscle^(5,6) glycogen. Muscle glycogen appears to be an important fuel source for resistance-type exercise, with a single exercise bout reducing muscle glycogen content by up to 40%^(7,8). Some have suggested that this muscle glycogen depletion might play a role in the development of fatigue during resistance exercise^(9,10). Consequently, the elevation of endogenous glycogen stores through pre-exercise feeding might delay fatigue and enhance performance⁽¹¹⁾. Indeed, commencing a bout of resistance exercise with reduced glycogen stores has been shown to reduce performance by some⁽¹²⁻¹⁴⁾, but not all⁽¹⁵⁾ studies. Similarly, we recently reported⁽¹⁶⁾ that compared to a no breakfast trial, an ecologically valid breakfast (containing 1.5 g carbohydrate/kg body mass) increased performance in 4 sets of back squat and 4 sets of bench press 2 h later. Collectively, these studies suggest that greater endogenous glycogen stores at the start of resistance exercise might increase performance.

However, there is another possible explanation, in that the results of these studies might be explained by the overtness of the methods used to manipulate pre-exercise nutritional state (i.e. conscious exercise/diet manipulation). Consequently, these previous studies might have been influenced by subjects' knowledge of, and preconceptions about, the intervention taking place. Indeed, Mears *et al.*⁽¹⁷⁾ recently demonstrated that a virtually energy-free placebo breakfast produces a similar increase in high-intensity cycling performance lasting ~20 min as a taste/texture matched high carbohydrate (2 g/kg body mass) breakfast, when compared to a water-only control breakfast. This suggests that a pre-exercise meal/breakfast might act as a placebo to enhance high-intensity aerobic performance, but whether these effects extend to resistance exercise (another high-intensity activity) and the related appetite effects are unknown.

Following an overnight fast hunger is elevated, with consumption of breakfast suppressing hunger⁽¹⁸⁻²⁰⁾, an effect that may be regulated by hormones involved in appetite regulation.

Whether such appetite effects play a role in any performance responses to pre-exercise feeding is unknown, since most studies have not measured the two in combination, but Naharudin *et al.*⁽¹⁶⁾ reported that the increased resistance exercise performance following breakfast occurred concurrently with a suppression in hunger. Therefore, if breakfast alters performance via a placebo, it is possible that the breakfast's effect on hunger might mediate the response.

Therefore, the aim of this study was to examine the effect of a pre-exercise high-carbohydrate breakfast meal on resistance exercise performance, compared to a texture and taste-matched placebo breakfast and a water control. This was to enable the physiological/metabolic effects of pre-exercise carbohydrate/energy intake to be separated from the potential psychological and/or appetite effects of eating a meal. It was hypothesised that the carbohydrate and placebo breakfast meals would increase resistance exercise performance compared to the control breakfast, with the carbohydrate breakfast meal also increasing resistance exercise performance compared the placebo breakfast meal.

Experimental Methods

Subjects

This investigation was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures were approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee (R17-P073). Written informed consent was obtained from all subjects before participation. Twenty-two men experienced with resistance exercise (age 23 (SD 3) years, body mass 77.9 (SD 8.1) kg, height 1.75 (SD 0.05) m, BMI 25.2 (SD 2.0) kg/m²) completed this study. Twenty-four subjects commenced the study, but one withdrew due to an injury unrelated to the study, whilst another withdrew due to illness, meaning he was unable to complete his final trial. For enrolment into the study, subjects had to be non-smokers, habitually consuming breakfast at least three mornings a week and to regularly include back squat and bench press as part of their weekly training. Subjects had 4.7 (SD 1.5) years resistance exercise experience, were performing 5 (SD 1) resistance training sessions/week, with 2 (SD 1) sessions/week of both back squat and bench press. All subjects reported eating breakfast 7 days/week. The sample size for this study was estimated from G*Power 3.0.10 software. Using an α of 0.05, statistical power of 0.95 and data from a previous study⁽¹⁶⁾, it was estimated that 22 subjects would be sufficient to detect a 15% difference in back squat performance between trials.

Subjects gave voluntary informed consent prior to participation. This experiment was approved by from the Loughborough University Ethical Approvals (Human Participants) Sub-Committee.

Study design

The study examined the effect of a high carbohydrate pre-exercise breakfast on resistance exercise performance, whilst controlling for any placebo effect associated with breakfast/energy intake. Subjects visited the laboratory on 5 separate occasions: 10 repetition maximum (10-RM) measurement; familiarisation trial; and three experimental trials, during which subjects consumed a breakfast and ~2 h later performed an exhaustive bout of resistance exercise. The breakfasts used were a water-only control breakfast (WAT), and two low-energy viscous breakfasts, with the addition of no carbohydrate (PLA) or 1.5 g carbohydrate/kg body mass (CHO) as maltodextrin. Trials were arranged in a randomised order (randomisation by drawing trial orders for subjects out of a bag containing the 6 possible combinations), separated by ≥ 4 days and CHO and PLA breakfast meals were administered in a double-blind manner. Subjects were told the purpose of the experiment was to test two energy-containing breakfasts of different macronutrient composition against a no-breakfast control trial. They were not aware one of the breakfast trials contained virtually no energy.

Preliminary visit and familiarisation trial

After warming up (5 min cycling at 1.5 W/kg body mass) subjects completed 10 repetition maximum (10-RM) testing of back squat and bench press, each of which was preceded by 5 min of self-selected exercise-specific warm up. After some warm-up sets (self-selected), subjects were asked to perform their first attempt of each exercise at a weight close to their estimated 10-RM. The load increased incrementally thereafter until they could no longer complete 10 repetitions. Subjects were given at least 3 minutes rest between sets. The last completed set of 10 repetitions was termed subjects' 10-RM and was used to determine the study exercise workload. During a separate visit, subjects were fully familiarised with all procedures used in the experimental trials.

Pre-trial standardisation

Subjects were given a diet/activity diary and were asked to record their habitual diet and activities for two days before their first experimental trial, replicating these patterns before

subsequent trials. Subjects were asked to refrain from taking part in any vigorous activity or consumption of alcohol in the 2 days before trials.

Experimental trials

Subjects arrived at the laboratory after an overnight fast (10-13 h) at a time typical for them to consume breakfast (i.e. approx. 0800-0900). Baseline measurements of body mass and subjective appetite were made, and after 15 min seated rest, a venous blood sample was collected. Subjects then consumed their allotted breakfast meal within 10 min, with additional measures of subjective appetite taken immediately (i.e. 10 min), 45 min and 105 min post-meal provision. Further venous blood samples were collected at 45 min and 105 min. Subjects then completed the resistance exercise session described below.

Breakfast meals

During the two breakfast trials, subjects ate a semi-solid breakfast from a standard bowl using a standard spoon. The volume of the meal was 5 mL/kg body mass, of which 15% (i.e. 0.75 mL/kg body mass) was low-energy orange flavoured squash (Double Strength Orange squash, Tesco, Welwyn Garden City, UK), with the remainder made up of tap water. To this mixture, either 0 g carbohydrate/kg body mass (PLA) or 1.5 g carbohydrate/kg body mass of maltodextrin (Myprotein, Northwich, UK) was added and mixed thoroughly, before 0.1 g/kg body mass of Xanthan gum (Myprotein, Northwich, UK) was added and the mixture blended to thicken the solution and enhance the perception of energy intake⁽²¹⁾. PLA and CHO breakfasts were taste, texture and colour matched and were made the day before trials by an experimenter not involved in data collection. Additionally, 3 mL/kg body mass of tap water was consumed as a drink with meals. For the WAT trial, subjects consumed 8 mL/kg body mass of tap water to match the water content in PLA and CHO. The nutritional content of the breakfast meals is presented in Table 1.

At the end of the last experimental trial, subjects were informed of the contents of the breakfasts and the true aim of the study, before being asked if they could identify the breakfasts. If they answered yes, they were asked to say which was which.

*****Table 1*****

Resistance exercise performance

Subjects performed the same warm up described for the 10-RM testing, with the addition of two warm-up sets of 10 repetitions at 30% and 60% of 10-RM for each exercise. Subjects then performed four sets to failure at 90% of 10-RM. For each exercise, subjects performed standardised lifting technique, with two spotters assisting them to reach the starting position for each set. For the squat, the bar was held across the back of the subject's shoulders and they started with their knees fully extended. They then lowered themselves until their thighs were parallel with the floor, before returning to the starting position. For bench press, subjects started with their elbows fully extended and lowered the bar until it lightly touched their chest, before returning to the starting position. Every repetition was counted in silence and standardised verbal encouragement was given to the subjects throughout. All sets were separated by 3 min rest. Additional subjective appetite measures were made after the back squat and bench press exercise. Subjects consumed 0.5 mL/kg body mass of water immediately before the cycling warm up, as well as before sets 1 and 3 of back squat and bench press.

Subjective appetite sensations

Throughout experimental trials, subjects rated their subjective sensations of hunger, fullness, light-headedness, tiredness, alertness and head soreness using paper-based visual analogue scales with written anchors of “not at all”/“none at all” and “extremely”/“a lot” placed 0 and 100 mm, respectively⁽²²⁾.

Blood sampling and analysis

For each blood sample, ~10 mL blood was drawn by venepuncture from an antecubital/forearm vein after 15 min seated rest. Blood was dispensed into tubes (Sarstedt AG & Co., Nümbrecht, Germany) containing a clotting catalyst or EDTA (1.6 mg/mL), centrifuged (2400 g, 15 min, 4°C) and the resultant serum/plasma was stored at -20°C until analysis. Plasma glucose was determined using a colorimetric assay and an autoanalyzer (Horiba Medical UK, Northampton, UK; CV 0.5%), whilst serum insulin (Immunodiagnostic Systems, Bolden, UK; CV 5.1-12.1%) and total concentrations of plasma total ghrelin (CV 1.7-1.8%; Merck Millipore Ltd, Watford, UK), total glucagon-like peptide-1 (GLP-1; CV 2.5-8.2%; Merck Millipore Ltd) and total peptide tyrosine-tyrosine (PYY; CV 3.8-5.6%; Merck Millipore Ltd) were determined using commercially available ELISAs. Due to issues with blood collection for 2 subjects, blood samples were only collected from 20 subjects.

Statistical Analyses

Data were analysed using SPSS (Version 23.0; IBM Corp., Armonk, NY). All data were checked for normality using a Shapiro-Wilk test. Data containing two factors were analysed using two-way repeated measures ANOVA. Data containing one factor were analysed using one-way repeated measures ANOVA. Where ANOVA indicated significant effects, *post-hoc* Holm-Bonferroni-adjusted paired sample *t*-tests or Holm-Bonferroni-adjusted Wilcoxon Signed Rank tests were used, as appropriate. Statistical significance was set at $P < 0.05$ and data are presented as means \pm SD. Cohen's *d*z effects sizes (ES) were calculated for pairwise differences in performance, with 0.2, 0.5 and 0.8 considered the thresholds for small, medium and large effect sizes, respectively.

Results

Baseline measures and breakfast meal perception

Subjects baseline body mass was comparable between trials (WAT 77.4 (SD 8.3); PLA 77.5 (SD 8.4); CHO 77.4 (SD 8.4) kg; $P = 0.671$). Additionally, baseline hunger ($P = 0.543$), fullness ($P = 0.961$), alertness ($P=0.313$), light-headedness ($P=0.904$), head soreness ($P = 0.894$) and tiredness ($P = 0.941$) were similar between trials. Subjects rated the breakfast meals similarly (un)pleasant (WAT: 34 (SD 19) mm; PLA: 27 (SD 19) mm; CHO: 27 (SD 23) mm; $P = 0.462$) but rated PLA (73 (SD 19) mm) and CHO (79 (SD 16) mm) more filling than WAT (34 (SD 24) mm $P < 0.001$), with no difference between PLA and CHO ($P = 0.176$).

Thirteen subjects stated they thought they could detect a difference between PLA and CHO breakfasts, with 11 correctly identifying the trials after they were notified what the trials were. Of these thirteen subjects, seven (back squat) and eight (bench press) performed better in the CHO trial compared to the PLA trial.

Resistance exercise performance

Total repetitions for back squat (Figure 1A) were greater in PLA ($P < 0.001$; ES = 1.03 large) and CHO ($P < 0.001$; ES = 1.25 large) than WAT, with no difference between PLA and CHO ($P = 1.000$; ES = 0.04). For back squat repetitions completed over the 4 individual sets (Figure 1B), there were trial ($P < 0.001$), time ($P < 0.001$) and interaction ($P = 0.002$) effects. Repetitions in set 1 ($P < 0.001$) and 2 ($P < 0.001$) were greater in CHO and PLA compared to WAT, with no other differences between trials. For bench press, total repetitions were not different between

trials (Figure 2A; $P = 0.130$). Pairwise comparisons between trials yielded effect sizes of 0.31 (small) for WAT vs PLA, 0.63 (medium) for WAT vs CHO and 0.05 (trivial) for PLA vs CHO. There were trial ($P = 0.01$) and time ($P < 0.001$) effects, but no interaction effect ($P = 0.234$) for bench press repetitions completed over the 4 individual sets (Figure 2B). Repetitions in set 1 were greater in CHO compared to WAT ($P = 0.039$), with no other differences.

*** Figure 1***

Figure 2

Subjective appetite sensation

There were trial ($P < 0.001$), time ($P < 0.001$) and interaction ($P < 0.001$) effects for sensations of hunger and fullness (Figure 3). Hunger was lower during PLA and CHO compared to WAT at all time points after breakfast ($P \leq 0.002$). Conversely, fullness was greater during PLA and CHO compared to WAT at all time points after breakfast ($P \leq 0.027$), with the exception of post-bench press in CHO, which tended to be greater ($P = 0.055$). Compared to pre-meal, hunger was reduced, and fullness was increased at 10 min, 45 min and 105 min in CHO and PLA, and post-back squat in CHO ($P < 0.05$). Hunger and fullness were not different between PLA and CHO ($P \geq 0.144$). Whilst there was a main effect of time for sensations of alertness, light-headedness, head-soreness and tiredness ($P < 0.001$), there were no trial ($P \geq 0.319$) or interaction ($P \geq 0.074$) effects (data not shown).

Figure 3

Blood analyses

There were time ($P = 0.003$) and interaction ($P < 0.001$) effects, but no trial ($P = 0.087$) effect for plasma glucose concentration (Figure 4A). Compared to pre-meal, plasma glucose was increased at 45 min during CHO, returning to baseline at 105 min. Plasma glucose concentration

did not change during WAT or PLA and after Holm-Bonferroni correction there were no between-trial differences. For serum insulin concentration, there were time ($P < 0.001$), trial ($P < 0.001$) and interaction ($P < 0.001$) effects. Insulin concentration (Figure 4B) was increased at 45 min and 105 min compared to pre-meal in CHO only ($P < 0.001$) and additionally was greater at 45 min and 105 min in CHO compared to WAT and PLA ($P < 0.001$). For plasma ghrelin concentration (Figure 5A), there were trial ($P < 0.001$) and interaction ($P = 0.045$) effects, but no time effect ($P = 0.206$). Compared to pre-meal, plasma ghrelin was decreased at 105 min in CHO only ($P = 0.010$) and was lower in CHO compared to both WAT and PLA at 45 min ($P < 0.003$) and 105 min ($P < 0.003$). For plasma GLP-1 concentration (Figure 5B), there were no trial ($P = 0.940$) or interaction ($P < 0.391$) effects, but there was a main effect of time ($P < 0.001$), with concentrations increasing at 45 min relative to pre-meal ($P = 0.008$). For plasma PYY concentration (Figure 5C), there were trial ($P = 0.035$) and time ($P = 0.005$) effects, but no interaction effect ($P = 0.329$). After Holm-Bonferroni correction, there were no differences between trials or from pre-meal.

Figure 4

Figure 5

Discussion

The aim of this study was to investigate the physiological and psychological effects of a pre-exercise high-carbohydrate breakfast meal on performance in a subsequent bout of resistance exercise in trained males. The main findings were that subjects completed more repetitions of back squat after consumption of virtually energy-free placebo and high-carbohydrate breakfast meals compared to the water-only control trial (PLA +14.9%; CHO +15.7%; $P < 0.001$), with no difference between the placebo and carbohydrate breakfast meals ($P = 1.000$). Smaller (PLA +3.9%; CHO +4.7%), non-significant ($P = 0.130$) effects were observed for bench press. These results suggest that a pre-exercise breakfast meal likely influences resistance exercise performance via a psychological, rather than physiological effect, possibly acting as a placebo to enhance subsequent performance, at least in habitual breakfast consumers.

This study is the first to demonstrate that performance in a single bout of resistance exercise is enhanced when subjects believe they have consumed an energy-containing pre-exercise meal. This supports previous observations in a high-intensity cycling time trial lasting ~20 min⁽¹⁷⁾ and yields novel findings to optimise pre-exercise nutritional intake for resistance exercise.

Importantly, the present study demonstrates that in well rested men, consumption of a high carbohydrate pre-exercise breakfast meal has no additional benefit over that of a placebo when 4 sets of both back squat and bench press are performed ~2 hours later.

Previous research has mainly focussed on the effects of a pre-exercise meal on endurance performance^(2,23–25). To our knowledge, only two studies have isolated the effect of a pre-exercise meal on resistance exercise performance^(16,26). Naharudin *et al.*⁽¹⁶⁾, observed that performance in 4 sets of back squat and 4 sets of bench press were both greater 2 h after a typical high carbohydrate breakfast (1.5 g carbohydrate/kg body mass) compared to a water only breakfast. The increases in back squat (~15%) and bench press (~6%) performance in this previous study¹⁶ were almost identical to those observed in the present study (~15% and ~4%, respectively), suggesting these previous findings are also likely to be explained by a placebo effect associated with pre-exercise feeding. Fairchild *et al.*⁽²⁶⁾ reported similar performance responses in 3 repetitions of isokinetic knee extension/flexion for up to 90 min after consuming either a 75 g carbohydrate drink or a placebo drink. The failure of carbohydrate to enhance performance when delivered in a placebo-controlled manner in the study of Fairchild *et al.*⁽²⁶⁾ further supports the theory that a pre-exercise meal/carbohydrate consumption might enhance resistance exercise performance via a placebo effect.

Muscle glycogen is an important fuel source for resistance exercise and muscle glycogen depletion, particularly of type II muscle fibres, has been shown to decrease maximal strength⁽¹²⁾. The degree of muscle glycogen depletion during resistance exercise is related to the work completed⁽⁷⁾ and thus, if sufficient work is undertaken, muscle glycogen levels could become depleted to a level where performance capabilities are compromised⁽⁹⁾. In the CHO trial, plasma glucose was increased at 45 min, whilst serum insulin was increased at 45 min and 105 min, with no changes in the WAT and PLA trials. These findings suggest that the glucose in the CHO meal was absorbed and available for use before/during exercise. Carbohydrate feeding after an overnight fast has been shown to increase liver⁽²⁷⁾ and, to a lesser extent, muscle^(28,29) glycogen stores. Although neither was measured in the present study, representing a limitation of our work, these results suggest that augmentation of these stores (at least typical meal carbohydrate intake) might not be necessary to maximise resistance exercise performance. It is possible that the amount of carbohydrate and/or the timing of the exercise in relation to the meal might have influenced the observed responses. Taylor *et al.*⁽²⁹⁾ sequentially measured muscle glycogen content for 7 h after ingestion of a high-carbohydrate breakfast meal (289 g carbohydrate or ~4.2 g/kg body mass), observing peak increases (~15%) 4 h post-meal, with a ~3% increase at 2 h post-meal. Similarly, Chryssanthopoulos *et al.*⁽²⁸⁾ reported ~11% increase in muscle glycogen

content 3 h after consuming a high carbohydrate breakfast meal (2.5 g carbohydrate/kg body mass). Therefore, in the present study, greater carbohydrate intake or allowing longer between the meal and exercise might have produced a slightly greater increase in muscle glycogen and possibly influenced performance. However, this seems unlikely, given that resistance exercise itself does not produce substantial glycogen depletion. In the present study, subjects rested for 48 h before each trial, meaning that muscle glycogen stores were likely to be high pre-meal, possibly accounting for the ineffectiveness of the carbohydrate breakfast meal to enhance performance. In many athletic settings, resistance training might occur only a few hours after another training session where glycogen may have been depleted. In this situation, it seems logical that addition of carbohydrate to the meal consumed before resistance exercise is more likely to be ergogenic, as it will also assist with recovery and replacement of glycogen used in the previous exercise bout⁽¹⁴⁾.

For endurance exercise lasting ~120 min at ~70% $\dot{V}O_2$ max, consuming carbohydrate (> 1.1 g/kg body mass) in the 1-4 h before exercise appears to enhance exercise performance/capacity by ~9-15%^(28,30,31). At these submaximal exercise intensities muscle and liver glycogen depletion contribute to fatigue^(10,25), meaning that small differences in pre-exercise glycogen levels might influence performance⁽⁶⁾. In contrast, whilst muscle glycogen is used during resistance exercise, 3-6 sets of 6-12 repetitions of a single exercise only reduces muscle glycogen by 17-40%^(7,32-34). Therefore, 4 sets of an exercise, as used in the present study, is unlikely to deplete local muscle glycogen to a level that would influence performance. The number of sets of each exercise performed in the present study was chosen to reflect current guidelines for those engaged in resistance training programmes, nominally 3-5 sets per exercise⁽³⁵⁾. Therefore, the present study suggests that any small increase in pre-exercise muscle glycogen caused by pre-exercise carbohydrate intake is unlikely to influence performance. Whether pre-exercise carbohydrate intake enhances performance in situations where substantially more than 4 sets are performed is not known and should be investigated in future studies. Furthermore, in practice, many resistance training sessions include more than 2 exercises and therefore in situations where multiple exercises using the same muscle groups are performed, pre-exercise carbohydrate intake may offer a benefit.

Liver glycogen has been shown to be an important fuel source in endurance exercise⁽³⁶⁾, but its relevance to performance in resistance exercise is unknown. Liver glycogen is depleted during an overnight fast and although not measured in the present study, consumption of ~120 g carbohydrate in the CHO trial would likely have increased liver glycogen⁽⁴⁾, whilst continued

fasting in the PLA and WAT trials would likely produce a further decline in liver glycogen⁽²⁷⁾. Therefore, exercise in the PLA and CHO trials likely commenced with very different liver glycogen levels. The finding that performance was not different between these trials, therefore suggests that differences in liver glycogen within the range of normal daily fluctuations related to fasting and feeding are unlikely to influence performance in resistance exercise of this nature.

The results of the present study closely replicate the results of a previous study, where both high carbohydrate and placebo breakfasts, consumed 2 h before exercise, similarly enhanced high-intensity cycling performance lasting ~20 min⁽¹⁷⁾. To our knowledge, the present study and that of Mears *et al*⁽¹⁷⁾ are the only studies to report the placebo effects of a pre-exercise meal, specifically breakfast. Breakfast is considered an important meal by many^(37,38), and as such it would be interesting to know whether the placebo effect of pre-exercise meals extends to other eating occasions. Regarding carbohydrate intake during exercise, a placebo effect has been observed during ~1 h cycling⁽³⁹⁾, but not during ~3 h of cycling⁽⁴⁰⁾. Combined, these studies suggest that any placebo effect associated with energy (or carbohydrate) intake is possibly duration dependent and is more likely to affect performance during exercise of shorter duration. It is possible that consuming a typical meal might produce a larger placebo effect than consumption of an atypical viscous meal of relatively low palatability. Although a limitation of the present study is that this effect cannot be discerned, the similarity in appetite and performance responses between this and our previous study⁽¹⁶⁾, suggests it is unlikely to be a major factor.

We used xanthan gum to increase the viscosity of the meals in the PLA and CHO trials to enhance the perception of energy intake. Previous research has shown that increasing the viscosity of a liquid/semi-solid meal increases subsequent satiety^(21,41,42). Consistent with these previous findings, we observed reduced hunger and increased fullness following the PLA and CHO meals compared to the WAT meal. Whilst there was a small amount of energy (~122 kJ/~29 kcal) in the PLA meal, contributed by xanthan gum and the orange squash, it seems unlikely this energy would cause these effects on subjective appetite, a notion that is supported by our results for the gut peptides PYY, GLP-1 and ghrelin. PYY and GLP-1, which are reported to exert anorexigenic effects⁽⁴³⁾, were not different between trials, despite greater hunger and lower fullness post-meal in WAT compared to PLA and CHO. Furthermore, ghrelin, reported to exert an orexigenic effect⁽⁴⁴⁾, was reduced in the CHO trial only and therefore we observed differences in ghrelin with (i.e. WAT vs CHO) and without (i.e. PLA vs CHO) differences in appetite, as well as no difference in ghrelin, despite a difference in appetite (i.e. WAT vs PLA).

These results suggest that, at least after a single meal, there can be discordant responses for the subjective and physiological regulators of appetite and possibly questions the appetite regulating effects of these endocrine signals in such settings. None-the-less, the differential response for ghrelin, as well as glucose and insulin, demonstrates that the CHO breakfast meal induced a physiological response. Interestingly, the differences in hunger/fullness between trials matched the differences in performance. Whether hunger can influence performance is not known and not possible to delineate in the present study, but it is possible that these subjective appetite sensations might mediate the effects of a pre-exercise breakfast/meal on human performance.

Finally, the management of energy balance is of great importance for both athletes and recreational exercisers, particularly for those exercising to reduce or control body mass/fat. Omission of breakfast increases appetite in the morning^(16,18–20) and whilst, in some settings, this produces a small increase in energy intake at lunch^(18,19), total daily energy intake is generally reduced^(37,45,46). However, breakfast omission also appears to reduce daily energy expenditure⁽⁴⁷⁾, attenuating the energy deficit created by omission of breakfast. The results of the present study and that of Mears *et al.*⁽¹⁷⁾ suggest that a low-energy high-viscosity pre-exercise breakfast might be an effective strategy to maintain exercise performance in situations of energy deficit, although whether this strategy has any effect on habitual daily energy expenditure remains to be seen. Furthermore, the present study observed reductions in appetite in the placebo breakfast that were similar to the carbohydrate-containing breakfast and comparable to responses reported previously following ecologically valid breakfasts^(16,19). Although speculative, this suggests that a low-energy high-viscosity placebo breakfast might also attenuate/prevent the increase in energy intake at a lunch meal. Future studies should seek to evaluate these effects.

In conclusion, the results of the present study demonstrate that performance in 4 sets of back squat exercise and 4 sets of bench press exercise were similarly enhanced by both placebo and carbohydrate-containing pre-exercise breakfast meals. This suggests that any performance effects of pre-resistance exercise energy/carbohydrate intake are likely caused by psychological effects, rather than any physiological/metabolic effect of the energy/carbohydrate content of the meal, at least in well-rested habitual breakfast consumers and that subjective appetite sensations, such as hunger, might be involved in these responses.

Acknowledgements

The authors thank all subjects who gave their time and commitment to complete this study. LJJ is part of the National Institute for Health Research (NIHR) Leicester Biomedical Research Centre, which is a partnership between University Hospitals of Leicester NHS Trust, Loughborough University and the University of Leicester. This report is independent research by the National Institute for Health Research. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health.

Financial Supports

This study is funded by the Research Management and Monitoring Research Fund - PG170-2014B and University of Malaya Research Grant - UM.0000215/HRU.OP/RU027-2015.

Conflict of Interest

LJJ has received funding for his research from Volac International Ltd, PepsiCo Inc, British Summer Fruits and The Collagen Research Institute, has performed consultancy work for Lucozade Ribena Suntory, has received conference fees from Danone Nutricia and PepsiCo Inc. and has received honoraria from PepsiCo Inc. In all cases, these payments have been paid to LJJ's employer and not to LJJ.

Authorship

MNN and LJJ formulated the research question and designed the study. MNN, JA, TT, HR, CO and CM collected data. MNN, LJJ, AY analysed the data. MNN and LJJ wrote the article with assistance from AY, DJC, CJH, SAM, JA, TT, HR, CO and CM.

References

1. Ralston GW, Kilgore L, Wyatt FB, *et al.* (2018) Weekly Training Frequency Effects on Strength Gain: A Meta-Analysis. *Sport Med - Open* **4**(1), 36, 1-24.
2. Ormsbee MJ, Bach CW & Baur, DA (2014) Pre-exercise nutrition: The role of macronutrients, modified starches and supplements on metabolism and endurance performance. *Nutrients* **6**(5), 1782–1808.
3. Burke LM, Hawley JA, Wong SHS *et al.* (2011) Carbohydrates for training and competition. *J. Sports Sci* **29**(Suppl 1), S17–S27.
4. Nilsson LH & Hultman E (1973) Liver glycogen in man - the effect of total starvation or a carbohydrate-poor diet followed by carbohydrate refeeding. *Scand J Clin Lab Invest* **32**(4), 325–330.
5. Coyle EF, Coggan AR, Hemmert MK, *et al.* (1985) Substrate usage during prolonged exercise following a preexercise meal. *J Appl Physiol* **59**(2), 429–433.
6. Chryssanthopoulos C, Williams C, Nowitz A, *et al.* (2002) The effect of a high carbohydrate meal on endurance running capacity. *Int J Sport Nutr Exer Metab* **12**(2), 157–171.
7. Robergs RA, Pearson DR, Costill DL, *et al.* (1991) Muscle glycogenolysis during differing intensities of weight-resistance exercise. *J Appl Physiol* **70**(4), 1700–1706.
8. Haff GG, Stone, MH, Warren BJ, *et al.* (1999) The effect of carbohydrate supplementation on multiple sessions and bouts of resistance exercise. *J Strength Cond Res* **13**(2), 111–117.
9. Lambert CP & Flynn, MG (2002) Fatigue during high-intensity intermittent exercise: application to bodybuilding. *Sport Med* **32**(8), 511–522.
10. Ørtenblad N, Westerblad H & Nielsen, J (2013) Muscle glycogen stores and fatigue. *J Physiol* **591**(18), 4405–4413.
11. Coyle EF, Coggan AR, Hemmert MK, *et al.* (1986) Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *J Appl Physiol* **61**(1), 165–172.
12. Jacobs I, Kaiser P & Tesch P (1981) Muscle strength and fatigue after selective glycogen depletion in human skeletal muscle fibers. *Eur J Appl Physiol Occup Physiol* **46**(1), 47–53.

13. Leveritt M & Abernethy PJ (1999) Effects of carbohydrate restriction on strength performance. *J Strength Cond Res* **13**(1), 52–57.
14. Oliver JM, Almada AL, Van Eck L, *et al.* (2016) Ingestion of high molecular weight carbohydrate enhances subsequent repeated maximal power: A randomized controlled trial. *PLoS One* **11**(9), e0163009.
15. Mitchell JB, DiLauro PC, Pizza F, *et al.* (1997) The effect of preexercise carbohydrate status on resistance exercise performance. *Int J Sport Nutr* **7**(3), 185–196.
16. Naharudin MN, Yusof A, Shaw H, *et al.* (2019) Breakfast omission reduces subsequent resistance exercise performance. *J Strength Cond Res* **7**(1), 1766–1772.
17. Mears SA, Dickinson K, Bergin-Taylor K, *et al.* (2017) Perception of breakfast ingestion enhances high intensity cycling performance. *Int J Sports Physiol Perform* **13**(4), 504–509.
18. Chowdhury EA, Richardson JD, Tsintzas K, *et al.* (2016) Effect of extended morning fasting upon ad libitum lunch intake and associated metabolic and hormonal responses in obese adults. *Int J Obes* **40**(2), 305–311.
19. Clayton DJ, Barutcu A, Machin C, *et al.* (2015) Effect of breakfast omission on energy intake and evening exercise performance. *Med Sci Sports Exerc* **47**(12), 2645–2652.
20. Clayton DJ, Stensel DJ & James LJ (2016) Effect of breakfast omission on subjective appetite, metabolism, acylated ghrelin and GLP-17-36 during rest and exercise. *Nutrition* **32**(2), 179–185.
21. Fiszman S & Varela P (2013) The role of gums in satiety/satiation. A review. *Food Hydrocoll* **32**(1), 147–154.
22. Flint A, Raben A, Blundell JE, *et al.* (2000) Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *Int J Obes*. **24**(1), 38–48.
23. Neuffer PD, Costill DL, Flynn MG *et al.* (1987) Improvements in exercise performance: effects of carbohydrate feedings and diet. *J Appl Physiol* **62**(3), 983–988.
24. Coggan AR & Coyle EF (1987) Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *J Appl Physiol* **63**(6), 2388–2395.

25. Coyle EF & Coggan AR (1984) Effectiveness of carbohydrate feeding in delaying fatigue during prolonged exercise. *Sports Med* **1**(6), 446–458.
26. Fairchild TJ, Dillon P, Curtis C. *et al.* (2016) Glucose ingestion does not improve maximal isokinetic force. *J Strength Cond Res* **30**(1), 194–199.
27. Bawden SJ, Stephenson MC, Ciampi E, *et al.* (2014) A low calorie morning meal prevents the decline of hepatic glycogen stores: a pilot in vivo ¹³C magnetic resonance study. *Food Funct.* **5**(9), 2237–2242.
28. Chryssanthopoulos C, Williams C, Nowitz A *et al.* (2004) Skeletal muscle glycogen concentration and metabolic responses following a high glycaemic carbohydrate breakfast. *J Sports Sci* **22**(11-12), 1065–1071.
29. Taylor R, Price TB., Katz LD, *et al.* (1993) Direct measurement of change in muscle glycogen concentration after a mixed meal in normal subjects. *Am J Physiol* **265**(2 Pt 1), E224–229.
30. Sherman WM, Brodowicz G, Wright DA, *et al.* (1989) Effects of 4 h preexercise carbohydrate feedings on cycling performance. *Med Sci Sport Exerc* **21**(1), 598–604.
31. Sherman WM, Peden MC & Wright DA (1991) Carbohydrate feedings 1 h before exercise improves cycling performance. *Am J Clin Nutr* **54**(5), 866–870.
32. Tesch PA, Ploutz-Snyder LL, Yström L, *et al.* (1998) Skeletal muscle glycogen loss evoked by resistance exercise. *J Strength Cond Res* **12**(1), 67–73.
33. MacDougall JD, Ray S, Sale DG, *et al.* (1999) Muscle substrate utilization and lactate production during weightlifting. *Can J Appl Physiol* **24**(3), 209–215.
34. Haff GG, Koch AJ, Potteiger JA, *et al.* (2000) Carbohydrate supplementation attenuates muscle glycogen loss during acute bouts of resistance exercise. *Int J Sport Nutr Exerc Metab* **10**(3), 326–339.
35. Ratamess NA (2009) American College of Sports Medicine position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc* **41**(3), 687–708.
36. Gonzalez JT, Fuchs CJ, Betts JA, *et al.* (2016) Liver glycogen metabolism during and after prolonged endurance-type exercise. *Am J Physiol Endocrinol Metab* **311**(3), E543–E553.

37. Clayton DJ & James LJ (2015) The effect of breakfast on appetite regulation, energy balance and exercise performance. *Proc Nutr Soc* **75**(3), 319–327.
38. Betts JA, Chowdhury EA, Gonzalez JT, *et al.* (2016) Is breakfast the most important meal of the day? *Proc Nutr Soc* **75**(4), 464–474.
39. Clark VR, Hopkins WG, Hawley JA, *et al.* (2000) Placebo effect of carbohydrate feedings during a 40-km cycling time trial. *Med Sci Sports Exerc* **32**(9), 1642–1647.
40. Hulston CJ & Jeukendrup AE (2009) No placebo effect from carbohydrate intake during prolonged exercise. *Int J Sport Nutr Exerc Metab* **19**(3), 275–284.
41. Marciani L, Gowland PA, Spiller RC, *et al.* (2000) Gastric response to increased meal viscosity assessed by echo-planar magnetic resonance imaging in humans. *J Nutr* **130**(1), 122–127.
42. Marciani L, Gowland PA, Spiller RC, *et al.* (2001) Effect of meal viscosity and nutrients on satiety, intragastric dilution, and emptying assessed by MRI. *Am J Physiol Liver Physiol* **280**(6), G1227–G1233.
43. Batterham RL, Cowley MA, Small CJ, *et al.* (2002) Gut hormone PYY3-36 physiologically inhibits food intake. *Nature* **418**(6898), 650–654.
44. Cummings DE & Overduin J (2007) Review series gastrointestinal regulation of food intake. *J Clin Invest* **117**(1), 13–23.
45. Gonzalez JT, Veasey RC, Rumbold PLS, *et al.* (2013) Breakfast and exercise contingently affect postprandial metabolism and energy balance in physically active males. *Br J Nutr* **110**(4), 721–732.
46. Edinburgh RM, Hengist A, Smith HA, *et al.* (2019) Skipping breakfast before exercise creates a more negative 24-hour energy balance: A randomized controlled trial in healthy physically active young men. *J Nutr* **149**(8), 1326–1334.
47. Betts JA, Richardson JD, Chowdhury EA, *et al.* (2014) The causal role of breakfast in energy balance and health: A randomized controlled trial in lean adults. *Am J Clin Nutr* **100**(2), 539–547.

Table 1. Nutritional content of breakfast meals.

	WAT	PLA	CHO
Protein (g)	0 (SD 0)	0.8 (SD 0.1)	0.8 (SD 0.1)
Carbohydrate (g)	0 (SD 0)	2.4 (SD 0.1)	119.2 (SD 12.4)
Fat (g)	0 (SD 0)	0.6 (SD 0.1)	0.6 (SD 0.1)
Fibre (g)	0 (SD 0)	5.4 (SD 0.6)	5.4 (SD 0.6)
Energy (kJ)	0 (SD 0)	122 (SD 13)	2075 (SD 216)
Water (mL)	623 (SD 65)	623 (SD 65)	623 (SD 65)

Carbohydrate (CHO), placebo (PLA) and water-only (WAT) breakfast meals.

Values are presented as mean (SD).

Figure legends

Figure 1. Back squat repetitions in total over the four sets (A) and in each of the four sets (B) during the carbohydrate (CHO), placebo (PLA) and water (WAT) trials. † denotes significantly different to WAT ($P < 0.05$). Values are mean (SD).

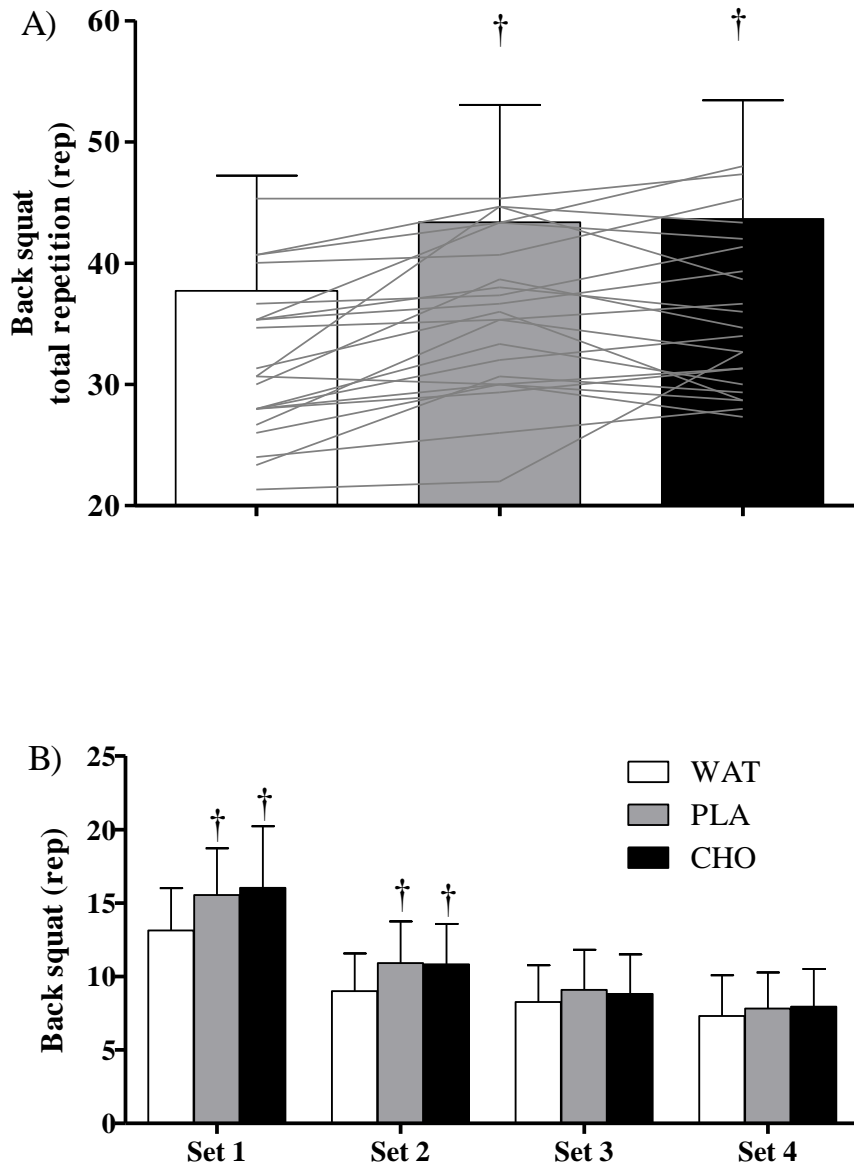


Figure 2. Bench press repetitions in total over the four sets (A) and in each of the four sets (B) during the carbohydrate (CHO), placebo (PLA) and water (WAT) trials. † denotes significantly different to WAT ($P < 0.05$). Values are mean (SD).

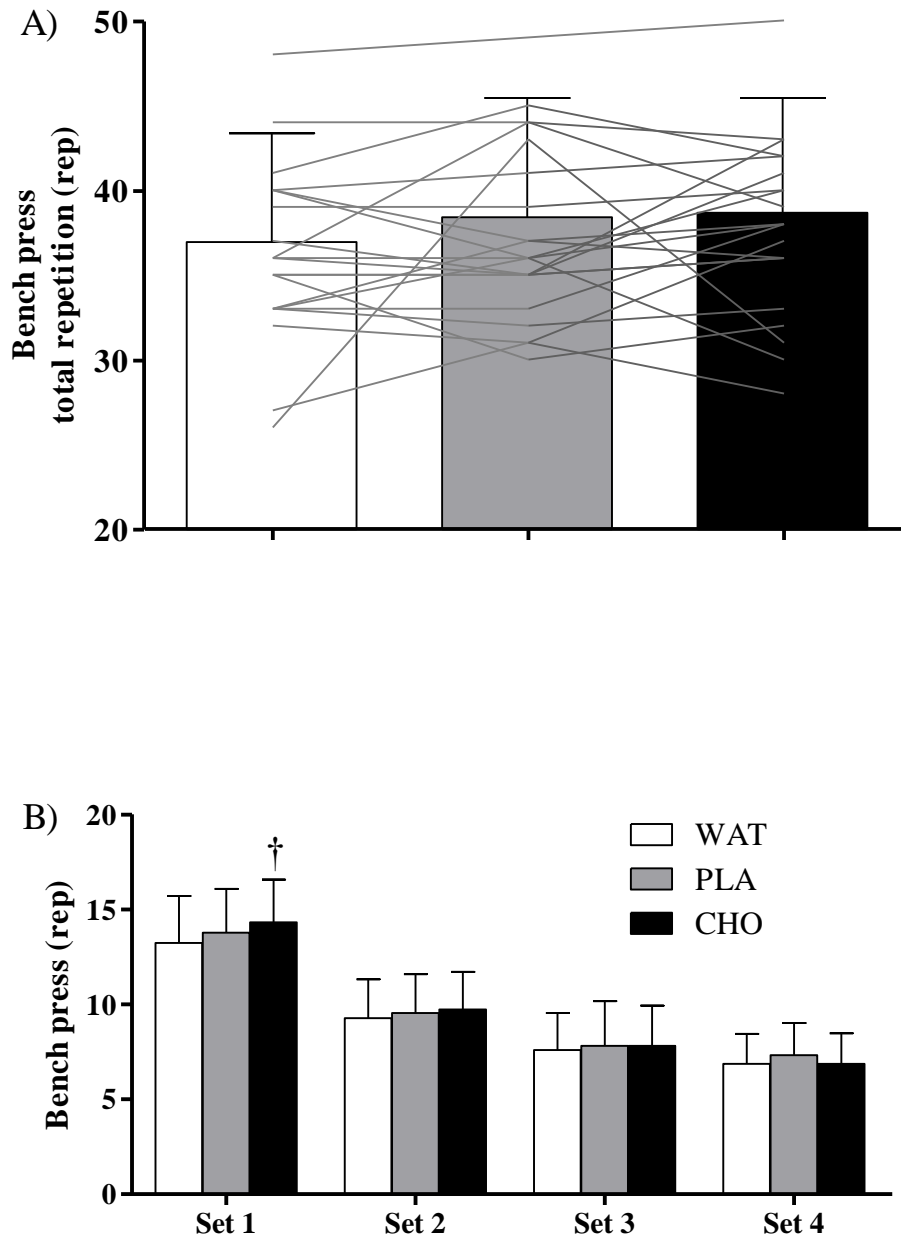


Figure 3. Subjective ratings of hunger (A) and fullness (B) during the carbohydrate (CHO), placebo (PLA) and water (WAT) trials. † denotes significantly different to WAT ($P < 0.05$). * denotes significantly different from pre-meal ($P < 0.05$). Values are mean (SD). BS: back squat; BP: bench press.

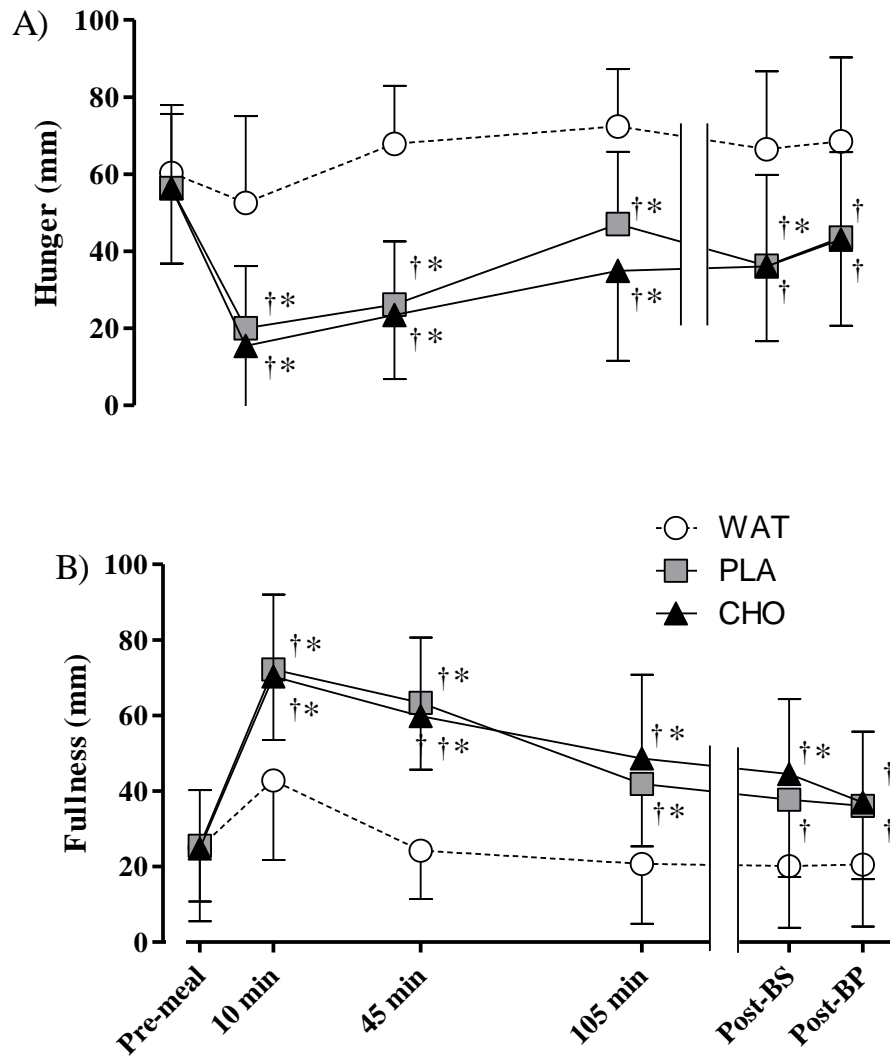


Figure 4. Plasma glucose (A) and insulin (B) concentrations during the carbohydrate (CHO), placebo (PLA) and water (WAT) trials. † denotes significantly different to WAT ($P < 0.05$). * denotes significantly different from pre-meal ($P < 0.05$). Values are mean (SD).

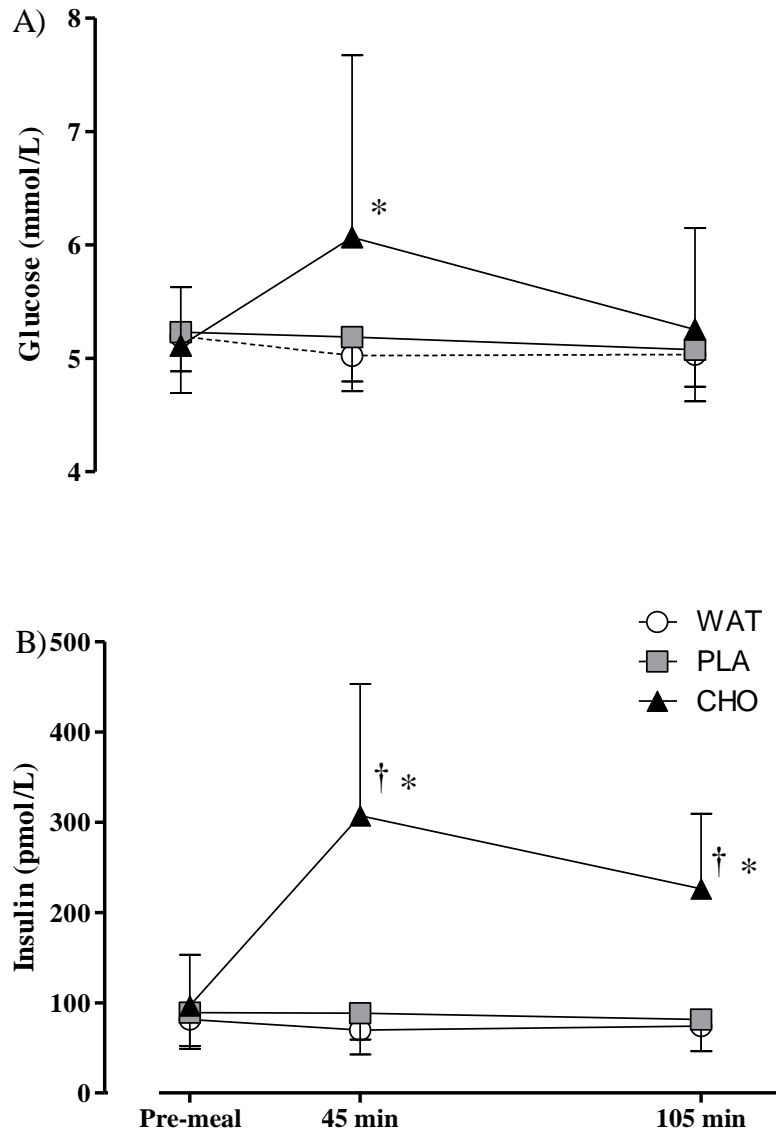


Figure 5. Plasma Ghrelin (A), GLP-1 (B) and PYY (C) concentrations during the carbohydrate (CHO), placebo (PLA) and water (WAT) trials. † denotes significantly different to WAT ($P < 0.05$). * denotes significantly different from pre-meal ($P < 0.05$). Values are mean (SD).

