Starving your performance? Reduced pre-exercise hunger increases resistance exercise performance.

Abstract

Background: Pre-exercise food intake enhances exercise performance, due in part to the provision of exogenous carbohydrate. Food intake also suppresses hunger, but the specific influence of hunger on exercise performance has not been investigated. This study aimed to manipulate hunger by altering pre-exercise meal viscosity to examine whether hunger influences performance.

Methods: Sixteen resistance trained males completed two experimental trials ingesting either high viscosity semi-solid (SEM) and low viscosity liquid (LIQ) carbohydrate-containing meals 2 h before performing 4 sets of back-squat (85 ± 22 kg) and bench-press (68 ± 13 kg) to failure at 90% 1 repetition maximum. Subjective hunger/fullness, as well as plasma concentrations of glucose, insulin, ghrelin and PYY were measured before and periodically after the meal. Repetitions completed in sets were used to determine exercise performance.

Results: Hunger was lower, and fullness was greater during SEM compared to LIQ immediately before and during exercise ($P < 0.05$). Total repetitions completed for back-squat were ~10% greater in SEM (SEM 57 ± 9; LIQ 51 ± 7 reps; $P = 0.001$), with no difference in bench-press repetitions (SEM 48 ± 11; LIQ 48 ± 10 reps; $P = 0.621$). Post-prandial glucose concentrations were greater during LIQ (12% increase in peak glucose) but were similar throughout exercise.

Conclusion: This study demonstrates that exercise performance in back-squat was increased in the SEM trial, concomitant to a reduction in hunger. Therefore, this study provides novel data that suggests exercise performance might be influenced by hunger, at least for resistance exercise.

Key words: Weight training, Appetite, Liquid meal, Solid meal, Satiety

Introduction

The ergogenic effects of pre-exercise carbohydrate intake are well documented for endurance[1] and intermittent[2] exercise, but the effects on resistance-type exercise are less well understood. A recent study found that consumption of a typical high-carbohydrate breakfast meal containing 1.5 g carbohydrate/kg body mass increased subsequent resistance exercise performance compared to no breakfast[3], which may be due to the lethargy induced by a novel fasting stimulus[4]. Interestingly, a subsequent follow-up study showed this effect was unlikely due to the carbohydrate content of the meal, as viscous energy-free placebo and carbohydrate (1.5 g carbohydrate/ kg body mass) meals produced the same effects on resistance exercise performance. This research suggests the possibility of a placebo effect associated with pre-exercise carbohydrate/food consumption or a nocebo effect associated with breakfast omission[5], a finding also observed with endurance performance[6]. However, Naharudin et al.[5] observed that the performance responses mirrored appetite responses to meals, with the placebo and carbohydrate meals supressing hunger and also increasing performance. As such, hunger may be a mediating factor for the effect of pre-exercise carbohydrate intake on performance.

The ergogenic effects of carbohydrate intake before prolonged endurance and intermittent exercise are primarily thought to derive from effects on endogenous glucose stores[7]. Liver glycogen stores are depleted after an overnight fast and carbohydrate ingestion restores liver[8] and to a lesser extent muscle[9] glycogen. Therefore, when glycogen availability plays a role in fatigue development, there is a clear metabolic mechanism to explain the ergogenic effects of pre-exercise carbohydrate intake[7]. During resistance exercise, it seems unlikely that pre-exercise carbohydrate intake would influence performance via these mechanisms[10]. Whilst muscle glycogen is utilised during resistance exercise[11], it seems unlikely that the degree of muscle glycogen depletion elicited by resistance exercise of this volume (approximately 17-40% depletion) is sufficient to impair performance when the number of sets is consistent with typical contemporary resistance training programmes (i.e. 3-5 sets per exercise).

Although no research has examined the influence of hunger on exercise performance, other subjective sensations have been shown to influence performance, including thirst[12], heat[13] and pain[14]. Therefore, it is possible the results of previous studies reporting a placebo effect of a pre-exercise meal on performance[5,6] might, at least partially, be explained by the effects of the meal on hunger. Therefore, the purpose of this study was to examine if hunger influences resistance exercise performance, by providing pre-exercise carbohydrate-containing meals of different viscosities to elicit differences in subjective hunger[5,15,16] before exercise. It was hypothesised that the semi-solid meal would suppress hunger and increase performance.

Methods

Participants

Sixteen males (age 27 ± 3 years, body mass 71.56 ± 9.15 kg, height 1.73 ± 0.05 m, BMI 23 ± 4 kg/m^2) provided written consent before completing this study, which was approved by the University of Malaya Research Ethics Committee. All completed testing with no drop outs. Inclusion criteria were that participants should regularly consume solid breakfast meals, regularly perform back-squat and bench-press exercise and to be healthy with no contraindication to high-intensity exercise or allergy/intolerance to study foods. Participants ate solid breakfast 6 ± 1 mornings/week, had 5 ± 1 y resistance exercise experience, and at the time of the study were undertaking 4 ± 1 resistance training sessions/week (2 ± 1 sessions/week of both back-squat and bench-press). Sample size was computed using G*Power 3.0.10

software using an α of 0.05, β of 0.95. Based on a previous experiment[3], it was estimated that 16 participants would be sufficient to detect a 15% difference in back-squat performance.

Study design

The primary aim was to examine the effect of hunger on resistance exercise performance. Hunger was manipulated by increasing the viscosity of a carbohydrate-containing (1.5 g/kg body mass) pre-exercise meal, using a low-energy thickener to decrease hunger. Secondary aims were to examine the effect of viscosity on subjective appetite and appetite-related peptides. Participants visited the laboratory on four occasions, completing a 10-repetition maximum (10-RM) measurement, a familiarisation trial, and two experimental trials. On each experimental trial, participants consumed a different pre-exercise meal ~2 h before performing 4 sets of back-squat and bench-press, with each set performed to failure. The pre-exercise meals were either high viscosity semi-solid (SEM) or low viscosity liquid (LIQ) meals containing 1.5 g carbohydrate/kg body mass. Trials were randomised, counter-balanced using a coin toss to randomly allocate participants and a paired participant allocated in the opposite order. Trials were separated by ≥4 days.

Preliminary and familiarisation visits

During the first visit, participants performed 5 min cycling (1.5 W/kg body mass) and a 5 min self-selected warm-up, prior to 10-RM testing for back-squat and bench-press. Participants performed their first attempt of each at a weight close to their self-estimated 10-RM, with the load increasing until participants could not complete 10 repetitions. Attempts were separated by ≥3 min. The final completed set was termed the participant's 10-RM and used to determine load in subsequent trials (90% of 10-RM; back-squat 85 ± 22 kg; bench-press 68 ± 13 kg). On the second visit, participants were fully familiarised with all experimental trial procedures, but they consumed their habitual breakfast before commencing exercise.

Experimental trials

Participants recorded their diet and physical activity for two days before their first experimental trial, replicating these patterns before the second experimental trial. Participants also abstained from strenuous activity or consuming alcohol in this pre-trial period.

Participants arrived at the laboratory in the morning of experimental trials (~0800-0900) in a fasted state (>10 h). Baseline measurements of body mass, subjective appetite and capillary blood glucose, were collected, followed by a venous blood sample. Participants then consumed a test meal (SEM or LIQ) within 10 min. Additional measures of subjective appetite were taken 10, 45, 60 and 105 min after test meal initiation. Finger prick blood samples were collected at 15, 30, 45, 60 and 105 min post-meal and venous blood samples were drawn at 45 and 105 min post-meal.

After the final blood sample, participants performed 5 min cycling (1.5 W/kg body mass), before completing back-squat sets, then bench-press sets. Each exercise was preceded by 5 min self-selected stretching, followed by strength-based warm-up sets of 10 repetitions at 30% and 60% 10-RM. For each exercise, participants performed four sets to failure at 90% 10-RM, with 3-min rest between sets, following standard lifting technique. For back-squat, the bar was positioned across the back of participant's shoulders, with knees fully extended. Participants lower themselves until their thighs were parallel with the floor, before returning to the starting position. For bench-press, participants started with elbows fully extended, before lowering the bar until it lightly touched their chest, before returning to the starting position. Participants were asked to perform repetitions at their habitual cadence/velocity for all visits to maximise familiarity and ecologically validity. Repetitions were silently counted by a researcher. Standard verbal encouragement was given to the participants throughout. Subjective appetite ratings and finger-prick blood samples were collected after completion of the back-squat and bench-press sets. Water intake (0.5 mL/kg body mass) was provided immediately before warm-up, and before sets 1 and 3 of back-squat and bench-press.

Pre-exercise carbohydrate meals

Both carbohydrate meals were 5 mL/kg body mass, of which 15% (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 with tap water. After the squash and water were mixed, 1.5 g/kg body mass of maltodextrin was added to the solution (MyProtein, Northwich, UK) and mixed thoroughly. During SEM, 0.1 g/kg body mass of xanthan gum (MyProtein, Northwich, UK) was added and blended to thicken the solution. For this trial, participants ate the semi-solid meal with a standard spoon from a standard bowl. In LIQ, no thickener was added, and participants consumed this meal as a drink. Participants were also provided 3 mL/kg body mass water to drink with both meals. The nutritional content of meals is presented in **Table 1.**

Participants were blinded to the aim/hypothesis of the study. They were informed that the purpose was to test two pre-exercise meals of identical content. The difference in viscosity of the meals would have been apparent to the participants, but in an attempt to control expectancy effects, they were provided 3 capsules containing ~0.3 g maltodextrin in both trials and were told the ingredients used to thicken the meal in SEM were contained in the capsule in the LIQ trial, so both meals contained identical ingredients.

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

Subjective appetite sensations

Subjective hunger and fullness were measured using visual analogue scales (“how hungry/full do you feel now?”), with written anchors of “not at all” and “extremely” at 0 and 100 mm, respectively[17]. How pleasant and filling the meal was perceived was determined using similar 100 mm visual analogue scales (“how pleasant/ filling was the meal?”) immediately post-meal (i.e. 10 min).

Blood sampling and analysis

For venous blood samples, 7 mL blood was drawn by venepuncture from an antecubital/cephalic vein after 15 min seated rest. Samples were mixed with EDTA (1.6 mg/mL; Sarstedt AG & Co., Nümbrecht, Germany) and centrifuged (2400 g, 15 min, 4°C), with plasma stored at -20°C until analysis. Plasma insulin (CV 6.2-10.2%), total ghrelin (CV 1.5-2.1%) and total peptide tyrosine-tyrosine (PYY) (CV 4.5-6.6%) concentrations were determined using ELISA (Merck Millipore Ltd, Watford, UK). Samples for an individual participant were analysed on the same ELISA plate, with Coefficient of Variations (CV) determined by one random sample from each plate repeated 8 times. Blood glucose concentration (CV 0.4%) was measured on the day of each trial using Accutrend Pluss (Roche Diagnostic, USA) from finger prick blood samples.

Statistical analyses

Data were analysed using SPSS software (Version 23.0; IBM Corp., Armonk, NY) and reported as mean ± standard deviation. Normality was checked using a Shapiro-Wilk test. Data containing 2 factors were analysed using 2-way repeated measures ANOVA, with significant effects followed by Holm-Bonferroni adjusted paired t-tests or Holm-Bonferroni-adjusted Wilcoxon Signed Rank tests, as appropriate. Data containing one factor were normally distributed and analysed using paired t-tests. Cohen's dz effect size (ES) was calculated for performance comparisons with dz > 0.2, 0.5 and 0.8 considered small, medium and large effects, respectively. Statistical significance was set at $P < 0.05$.

Results

Baseline measurement and meal perception

Baseline body mass (SEM 71.1 ± 8.8 kg; LIQ 71.4 ± 8.6 kg; $P = 0.307$), hunger (SEM 57 ± 21 mm; LIQ 53 ± 19 mm; $P = 0.428$) and fullness (SEM 22 ± 17 mm; LIQ 32 ± 19 mm; $P = 0.102$) were not different between trials. For meal perceptions, participants rated SEM less pleasant (SEM 35 ± 22 mm; LIQ 70 ± 11 mm; $P < 0.001$) and tended to rate SEM as more filling (SEM 78 ± 13 mm; LIQ 69 ± 22 mm; $P = 0.092$).

Resistance exercise performance

Total repetitions completed for back-squat (**Figure 1A**) were 11.6% (95% CI +5.6%, +17.5%; dz = 0.99) greater in SEM (SEM 57 ± 9 repetitions; LIQ 51 ± 7 repetitions ; $P < 0.01$). For back-squat repetitions completed over the 4 sets (**Figure 1B**), there was no interaction effect ($P = 0.549$), but there were trial ($P < 0.05$) and time ($P < 0.001$) effects. Repetitions in all sets were greater in SEM ($P <0.05$), with repetitions decreasing progressively over the four sets. For bench-press (**Figure 1C**), total repetitions were not different (+1.5% in SEM; 95% CI -3.1%, +6.2%; dz = 0.13) between trials (SEM 48 ± 11 repetitions; LIQ 48 ± 10 repetitions; $P = 0.621$). Over the 4 sets (**Figure 1D**), there were no interaction ($P = 0.694$) or trial ($P = 0.621$) effects, but there was a time effect ($P < 0.001$), with repetitions decreasing progressively over the sets. There was no trial order effect for total repetitions of back-squat (First trial 54 ± 8; Second trial 55 ± 8 reps; $P = 0.690$; dz = 0.10) or bench-press (First trial 48 ± 10; Second trial 47 ± 11 reps; $P = 0.426$; dz = 0.20).

*****Figure1*****

Subjective appetite sensation

There were interaction ($P < 0.001$), time ($P < 0.001$) and trial ($P < 0.01$) effects for hunger and fullness (**Figure 2**). Hunger was lower and fullness greater in SEM compared to LIQ at 45 min, 105 min, post-back-squat and post-bench-press ($P < 0\ 047$). Compared to pre-meal, hunger was lower at 10 and 45 min in SEM ($P < 0.002$); and lower at 10 min and greater at post-bench-press in LIQ ($P < 0.001$). Conversely, compared to pre-meal, fullness was greater at all post-meal time points in SEM ($P < 0.004$), but only 10 and 45 min in LIQ ($P < 0.001$).

*****Figure 2*****

Blood analyses

For plasma insulin concentration (**Figure 3A**), there were interaction ($P < 0.001$), time (P < 0.001) and trial ($P = 0.002$) effects. Plasma insulin was greater during LIQ at 45 min ($P < 0.001$) and 105 min ($P = 0.015$). Compared to pre-meal, plasma insulin increased at 45 and 105 min during both trials ($P < 0.001$). There were time ($P < 0.001$) and interaction ($P < 0.001$)

effects, but no trial effect (*P* = 0.059) for blood glucose (**Figure 3B**). Blood glucose concentration was greater at 30 min in LIQ compared to SEM, but no other time points reached statistical significance. Compared to pre-meal, blood glucose concentration was increased from 15 min until 105 min in both trials (P < 0.01).

For plasma total ghrelin (**Figure 4A**) and PYY (**Figure 4B)** concentrations, there were no interaction (*P* = 0.494; *P* = 0.451) or trial (*P* = 0.210; *P* = 0.281) effects, but there were time effects (both *P* < 0.01), with ghrelin decreased at 45 min and 105 min, and PYY increased at 45 min compared to pre-meal (*P* < 0.05).

*****Figure 3*****

*****Figure 4*****

Discussion

The purpose of this study was to investigate the effect of hunger on resistance exercise performance, with hunger manipulated by altering the viscosity of the pre-exercise meal. The main findings were, firstly, that the inclusion of the xanthan gum in SEM reduced hunger compared to LIQ. Secondly, in line with our hypothesis, participants completed ~12% more repetitions of back-squat exercise during SEM (57 ± 7 repetitions vs 51 ± 8 repetitions), although there was no difference between trials for repetitions performed during bench-press exercise (SEM 48 ± 11 repetitions; LIQ 48 ± 10 reps repetitions). These novel data suggest the effect a pre-exercise meal has on hunger, may influence its ergogenic effects.

We are not aware of any other data demonstrating hunger influences physical performance, but the notion is exciting, as it suggests a new mechanism by which pre-exercise carbohydrate/food intake enhances performance. Previous studies from our laboratory have demonstrated that the sensation of food intake is an important factor influencing exercise performance. We demonstrated that the negative effects of skipping breakfast on endurance and resistance exercise performance are offset when participants believe they are consuming a meal, even a virtually energy-free meal[5,6]. Observations that an energy-free semi-solid meal suppressed hunger[5] implied hunger (or the suppression of hunger) may modulate the beneficial performance effects of eating breakfast. The current study therefore extends these findings by demonstrating that carbohydrate provided in a semi-solid meal is more ergogenic than carbohydrate provided in a liquid meal, which we hypothesise to be due to their effects on hunger.

Perceptions have been shown to influence performance in other exercise settings. For example, thirst appears to contribute to performance decrements with dehydration[12]. In dehydrated cyclists, swallowing a small amount of water (25 mL every 5 min during exercise lasting ~20 min) increased endurance capacity compared to rinsing the mouth with the same volume[18], suggesting activation of oropharyngeal receptors in the throat/stomach might play a role in exercise performance capabilities. Similarly, the present study suggests the act of swallowing/processing food might act in a similar way to influence performance, via effects on hunger. Although no human data are available, one study reported that the olfactory system of mice selectively bred for high voluntary exercise was divergent to control mice, suggesting a role for the olfactory system in exercise behaviour[19]. The present study suggests that sensory processes involved in food ingestion (olfaction, oral processing etc.) may influence voluntary exercise performance. Alternatively, in the current study, it may be that feeling hungry compromises an individual's ability to focus on the exercise task, thus reducing performance. These results are not without limitation, none-the-least that the mechanisms proposed here are speculative and interrogating them was beyond the scope of the current study. Furthermore, whether these results can be extrapolated to females or elite athletes is unknown. It seems likely they would translate to females, but given recent evidence that resistance exercise in elite populations might produce near-total glycogen depletion in selective muscle fibres[20], means this population warrants further consideration/investigation.

These findings suggest that hunger/appetite may mediate the effects of pre-exercise nutrition on subsequent performance. Whilst more research is required to confirm this hypothesis, these findings provide evidence of an alternative mechanism by which nutrition might modulate performance. Exactly what accounts for this is unknown, but it is interesting to note that differential appetite ratings persisted throughout the exercise protocol, including during bench-press, where performance was not different between trials. This may suggest that hunger exerts a greater influence during exercises requiring activation of larger muscle groups. Alternatively, back-squat was performed before bench-press and previous research has reported that fatigue from prior arm cycling can influence leg cycling performance[21]. Therefore, it may be that fatigue from the back-squat exercise meant bench-press performance was less sensitive to the effects of hunger. Above all, in the current study, SEM decreased hunger to a greater extent than LIQ, which is consistent with prior studies reporting greater hunger suppression with solid compared to liquid meals[15,16]. A small amount of fibre (~5 g) was added to the meal in SEM. Although prior research has associated fibre with hunger suppression[22], a study found that apple juice with and without a comparably small amount of fibre (4.8 g) elicited similar appetite responses, but solid apple matched for fibre content with the fibre-containing juice decreased appetite and subsequent energy intake[23]. This suggests the meal state (solid vs. liquid) has a stronger effect on appetite than fibre content.

Previous studies have shown that glucose and insulin responses are similar between solid and liquid meals of identical macronutrient content[16], but differences were observed in the current study. With components of both meals otherwise identical, the reduced glucose and insulin responses observed in SEM were likely caused by the addition of fibre[24]. The slower appearance of glucose in the bloodstream after SEM may indicate a slower rate of gastric emptying[15]. However, there were no differences in gastrointestinal hormones (ghrelin and PYY) between trials. Ghrelin and PYY are orexigenic and anorexigenic hormones, respectively, responding to nutrient ingestion in a dose-dependent manner to the meal energy content[25]. In this study, semi-solid and liquid meals produced similar suppression of ghrelin and elevation of PYY, despite differences in subjective hunger/fullness between trials, suggesting they do not explain the performance or appetite effects observed.

Previous studies have shown a low glycaemic index (GI) pre-exercise meal may enhance endurance performance by stabilising glucose levels during exercise[26]. However, in the present study there were no differences in blood glucose between trials before or during exercise. Additionally, a recent systematic review and meta-analysis reported no consistent effect for low GI meals on performance[27]. Whilst differential postprandial glycaemic responses might evoke small differences in glucose metabolism and storage, this could not explain the findings in our previous study, where we provided semi-solid meals containing either 0 or 1.5 g/kg body mass of carbohdyrate[5]. These large differences in carbohydrate intake altered the metabolic response (glucose, insulin and ghrelin concentrations) and presumably glycogen levels (at least liver glycogen), but not performance. This suggests the relatively small difference in postprandial glycaemia in the present study is unlikely to explain the performance effects, highlighting differences in hunger/appetite as the likely explanation. Given the results of the present study, it would be interesting to know the potential mediating effect of hunger in previous studies showing low GI meals improve performance, since low GI meals decrease hunger compared to high GI meals[28].

Practical Application

These results demonstrate that sensations of hunger/appetite might influence human resistance exercise performance. Whether hunger influences other modes of exercise is unknown, but should be explored in future studies. these results have important practical implications, as they suggest that when maximal resistance exercise/strength performance is required, ensuring hunger is satiated may optimise performance. Whether the 12% difference in repetitions for back-squat would influence muscular hypertrophy with training is questionable, but in situations where repeated strength performance is required (e.g. CrossFit type exercise), these data might have important implications performance outcomes.

Conclusion

In conclusion, the results of the present study demonstrate that performance in 4 sets of back-squat exercise was enhanced by a high viscosity semi-solid breakfast meal compared to a liquid meal. These effects were preceded by suppression of appetite/hunger, suggesting that the performance effects observed were explained by the effects of the pre-exercise meals on hunger/appetite.

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Table

Table 1 Nutritional content of pre-exercise meals.

	Breakfast meal	
	SEM	**LIQ**
Energy (kJ)	1897 ± 249	1837 ± 241
Protein (g)	0.8 ± 0.1	0.5 ± 0.1
Carbohydrate (g)	109.0 ± 14.3	107.9 ± 14.2
Fat (g)	0.5 ± 0.1	0.5 ± 0.1
Fibre (g)	4.9 ± 0.7	0.5 ± 0.1
Total water intake (ml)	573.8 ± 73.2	572.5 ± 73.2

Semi-solid meal trial; SEM, and liquid meal trial; LIQ. Values are presented as mean ± SD, n = 16.

Figures

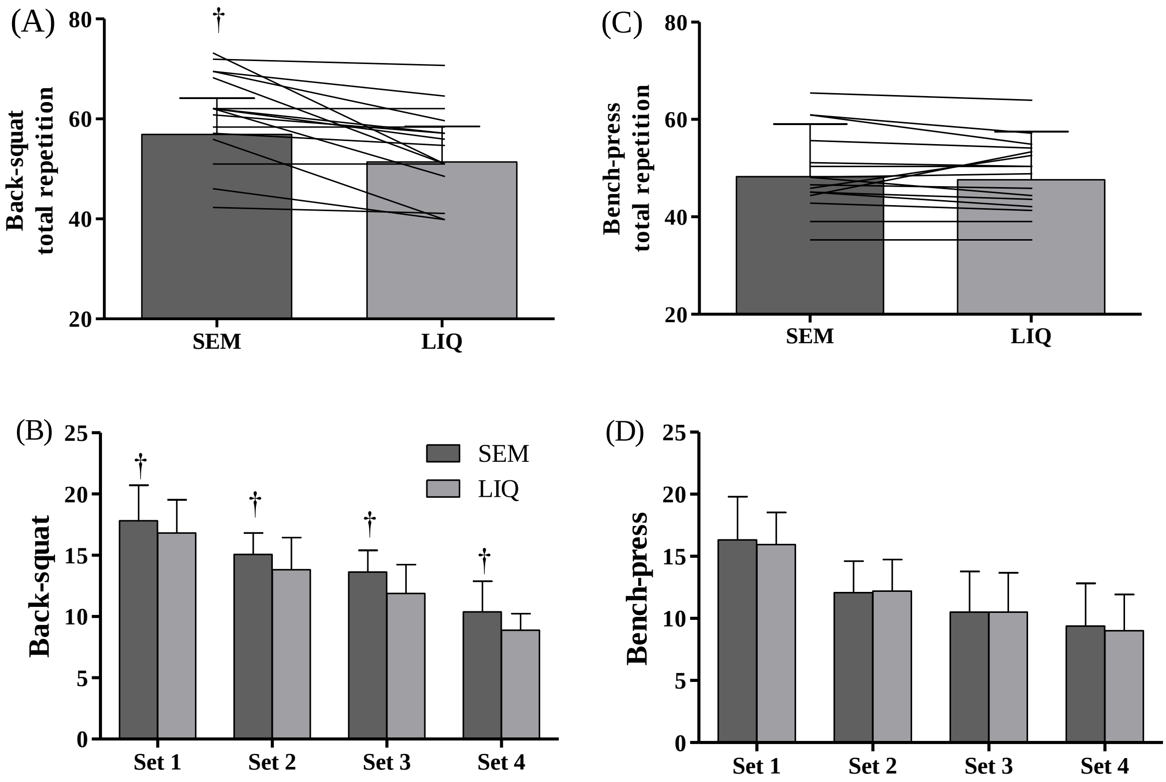

Figure 1 (A) Total number of repetitions for back-squat and **(B)** individual set repetitions for back-squat. Semi-solid (SEM) and (LIQ) meal trials. **(C)** Total number of repetitions for bench-press and **(D)** individual set repetitions for bench-press. Semi-solid (SEM) and (LIQ) meal trials. Dagger (†) denotes significant difference between trials ($P < 0.05$). Values are mean ± SD.

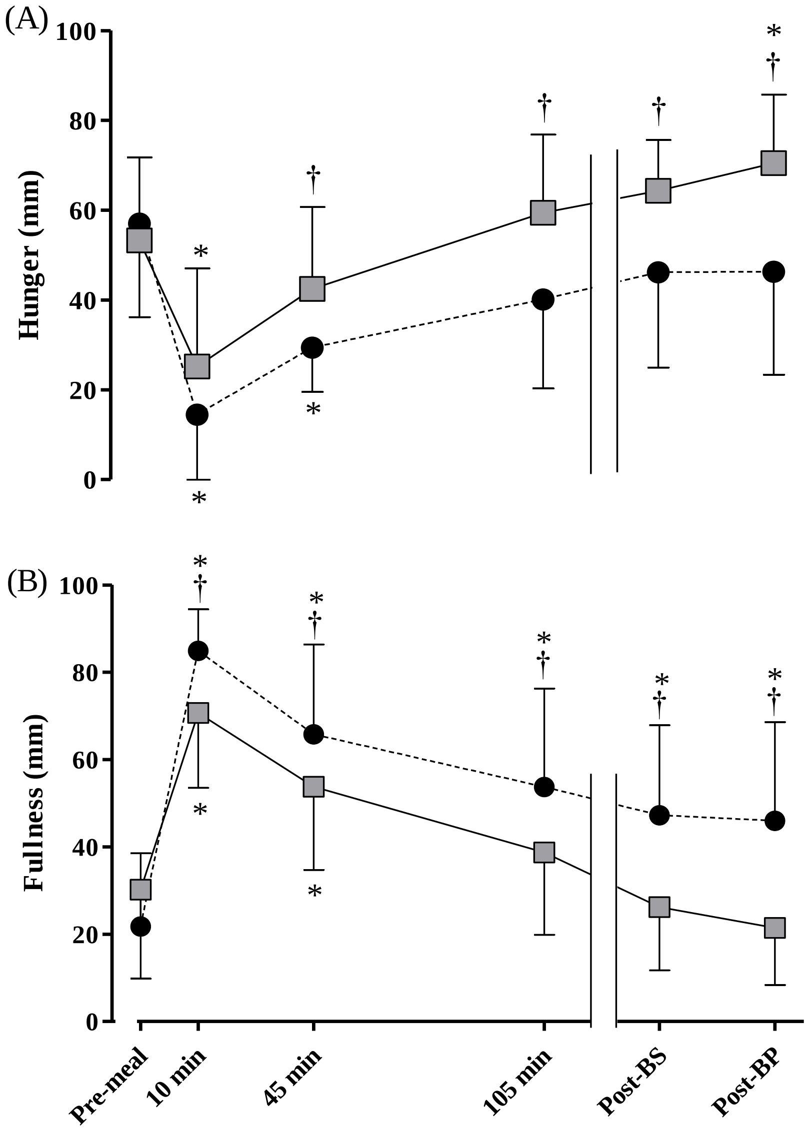

Figure 2. Subjective appetite ratings of **(A)** hunger and **(B)** fullness throughout the experimental trials. Black circle (●) represents the semi-solid (SEM), and grey square (■) represents liquid (LIQ) trial. Post-BS (post-back-squat) and Post-BP (post-bench-press) ratings were measured right after both exercise's final set. Dagger (†) denote SEM significantly different to LIQ, whilst asterisk (*) denotes significantly different from pre-meal ($P < 0.05$). Values are mean ± SD

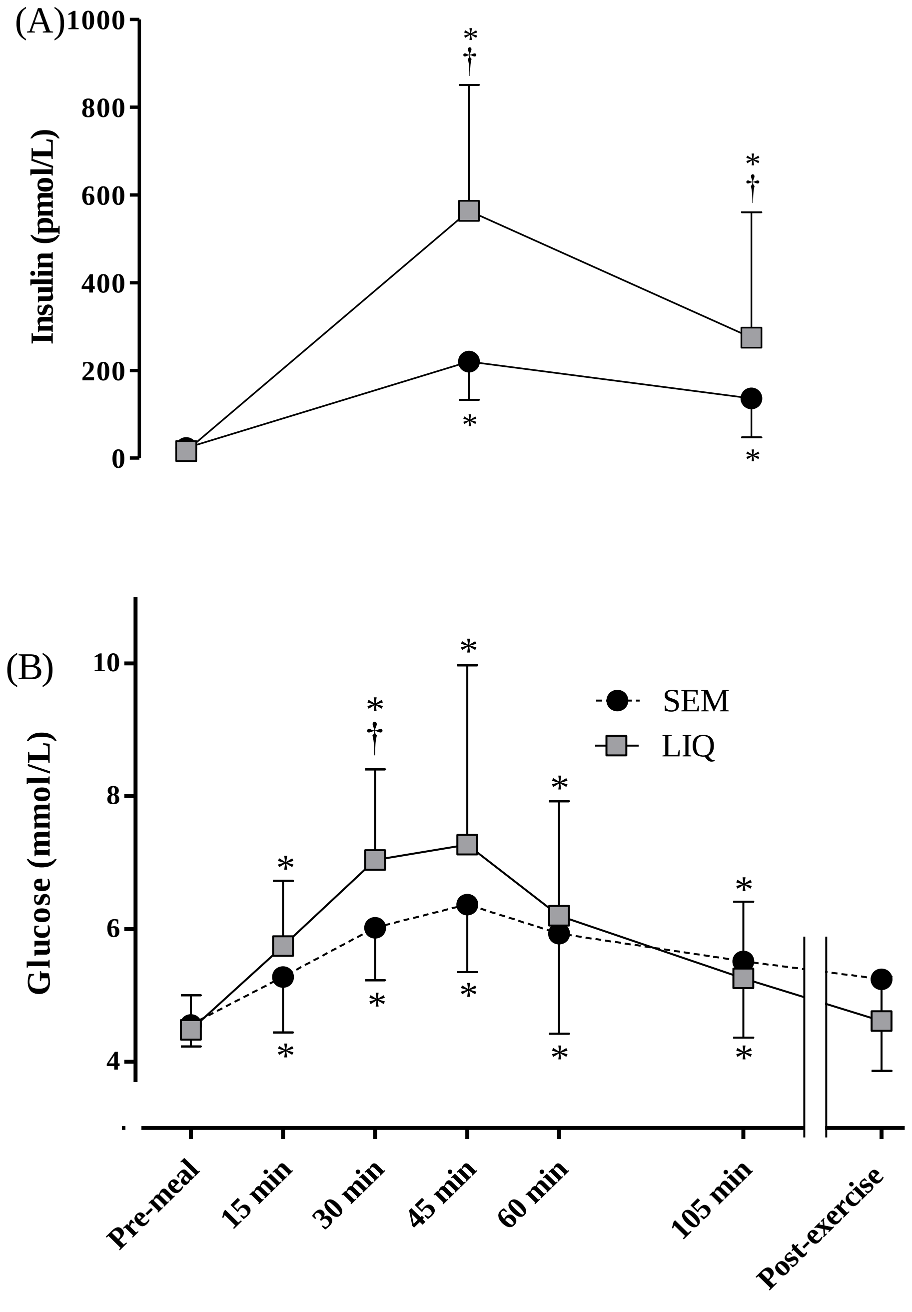

Figure 3 (**A**) Plasma insulin and (**B**) blood glucose response measured at specified time points. Black circle (●) represents semi-solid (SEM) and grey square (■) represents liquid meal trial (LIQ). Dagger (†) indicates significantly different between SEM and LIQ at particular time point, whilst asterisk (*) denotes significantly different from pre-meal ($P < 0.05$). Values are mean ± SD

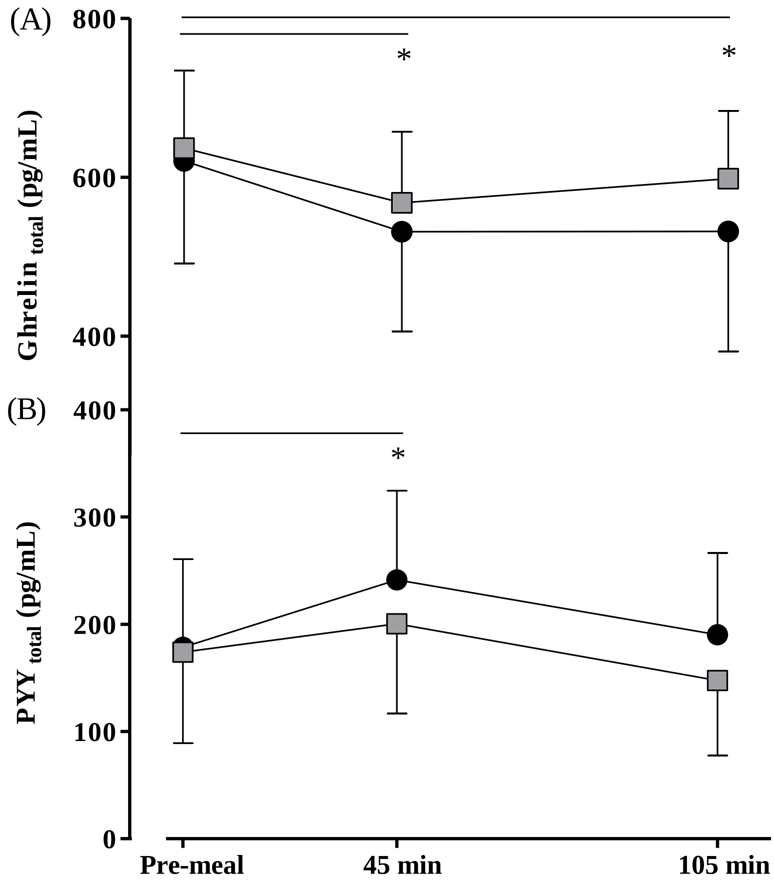

Figure 4 Plasma (**A)** $Ghrelin_{total}$ and (**B)** PYY_{total}, measured at specified time points before exercise protocol was commenced. Black circle (●) represents the semi-solid (SEM) and grey square (■) represents liquid meal (LIQ). Asterisk (*) denotes time compared to pre-meal ($P < 0.05$). Values are mean ± SD.