Title:

Postprandial glycemia and appetite sensations in response to porridge made with rolled and pinhead oats.

Authors:

Javier T. Gonzalez, MRes and Emma J Stevenson, PhD.

Institution:

Brain, Performance and Nutrition Research Centre, School of Life Sciences, Northumbria University, Newcastle upon Tyne, UK.

Address of correspondence:

Javier Gonzalez
Brain, Performance and Nutrition Research Centre,
Northumberland Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST.
Email: javier.gonzalez@northumbria.ac.uk
Phone: 0191 243 7012

Running title:

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Conflict of interest:

The authors declare no conflict of interest.

Abbreviations used:

R, rolled oats; P, pinhead oats; VAS, visual analogue scales; IAUC, incremental area under the curve; GI, glycemic index; HGI, high glycemic index; LGI, low glycemic index; AUC, area under the curve.

Keywords: Glucose, Porridge, Appetite, Steel-cut

Abstract

Objective: To determine the influence of porridge made with milk, honey and either rolled (R) or pinhead (P) oats on postprandial glycemia and satiety.

Methods: 15 healthy participants were recruited, but due to non-compliance with the protocol only 13 participants are included in the final analysis. In a randomised, crossover design, participants consumed porridge made with milk, water, honey and either R or P oats. Finger prick blood samples were taken at baseline and 15, 30, 45, 60, 90 and 120 min following consumption of the porridge to determine blood glucose concentrations. Visual analogue scales (VAS) were used at the same time points to assess appetite sensations. Incremental area under the blood glucose concentration versus time curve (IAUC) ignoring area below the baseline was used to assess glycemia.

Results: Porridge made with P reduced the blood glucose IAUC by 19.51 mmol/L x 120 min (95% Confidence interval: 5.18, 33.84 mmol/L x 120 min; $P = 0.012$) although no difference in peak, or time to peak blood glucose concentrations were observed ($P = 0.603$ and 1.00, respectively). Hunger was not affected by the type of oats used ($P = 0.991$), yet participant felt fuller following consumption of R compared to P ($P = 0.024$).

Conclusions: Glycemia is improved yet feelings of fullness are attenuated following consumption of porridge made with P compared to R.

This study was registered on clinicaltrials.gov as NCT01222845.

INTRODUCTION

Postprandial glycemia is associated with reduced risk of obesity and disease [1, 2]. Even modest increases in blood glucose concentrations can be detrimental in young healthy subjects [3]. Low glycemic index (GI) foods can almost certainly influence metabolism [4, 5], although effects on satiety are less lucid.

When simple carbohydrates are ingested, those with a high GI (HGI) produce an increased satiety response [6] probably due to greater insulin release [7] . Yet, when using whole foods, this effect is generally inverted ([5, 8]). It may be that confounding factors are influencing the satiety response to low GI (LGI) foods. When reducing the GI of a meal by substituting low GI foods for high GI foods, there is generally a difference in the nutritional composition of the meal. Low GI foods commonly contain more fibre, fat and protein and less sugars than high GI foods with energy density often reduced. Previous studies that have matched carbohydrate, fat and protein content have not controlled the proportion of sugars or fibre [4, 9]. Fructose for instance, with a GI of 19 [10], has vastly different metabolic effects compared to glucose (by definition has a GI of 100), showing attenuated responses of insulin, leptin and ghrelin, and exaggerated blood lactate concentration in response to ingestion with meals [4, 11]. Therefore it becomes more difficult to distinguish whether effects are due to differences in GI or energy density, fibre or fructose content. Moreover, high fructose intake may be deleterious and upper limits on intake have been suggested [12].

Previous research has found that the primary reason for diabetic patients not following a diet plan was that the foods were unfamiliar [13]. Consequently, when recommending a LGI diet to the public, adherence may be greater if familiar foods (merely processed differently) can be consumed.

Glycemic responses to food depend upon a variety of factors [14] which include the processing of the food. Pinhead oats (P; also known as steel-cut oats) undergo minimal preparation, whereas rolled oats (R) are typically twice steamed and then rolled. This processing results in the gelatinisation of starch molecules, increasing the GI from 60 to 93 [15], yet the macronutrient composition and energy density are unaltered. Although comparisons in the glycemic response to these foods have been made [15], the oats were boiled for 15 min in water, which does not represent a usual cooking method. In the United Kingdom, people who eat a cereal breakfast consume it with milk on virtually every occasion [16]. People tend to find porridge more palatable when made with milk, and sweetened. Cooking is generally performed in a microwave for a shorter period of time. As milk proteins are insulinotropic [17], along with the cooking time and addition of a sweetener, this may influence the glycemic response. Therefore it is necessary to address whether pinhead and rolled oats produce different glycemic excursions when prepared in a fashion which is typical of the general population and subsequent effects of appetite. A further potential caveat with the previous comparison is that participants were offered a choice of tea or coffee with the porridge, the variable caffeine and phenolic content of these beverages may have confounded the glycemic response [18].

Accordingly, the aim of the present study was to examine the influence of a porridge similar to that consumed in the "real-world" made with milk, honey and either P or R oats on postprandial glycemia and appetite ratings.

MATERIALS AND METHODS

Participants

Fifteen healthy participants were recruited from the staff and student population of Northumbria University, which was calculated to provide 80% statistical power to determine a detectable difference in GI of 16 with a mean GI of 80 at a significance level of $p < 0.05$ in accordance with published glycemic index methodology [19]. Results from 2 participants were excluded from the analysis as one participant failed to consume the porridge in the time allocated and another had performed physical activity prior to arrival sufficient to produce a baseline blood lactate concentration of 3.58 mmol/L. Hence data presented are from 13 participants (9 male, 4 female). Participant's age, height, body mass and body mass index (mean ± SD) were 25.7 ± 2.5 y, 176.3 ± 8.8 cm, 76.0 ± 14.4 kg and 24.3 ± 3.5 kg/m^2. Prior to recruitment, all participants provided informed written consent and the study was approved by the School of Life Sciences Ethics Committee at Northumbria University.

Experimental protocol

In a randomised, crossover design, separated by at least 2 d in line with standard GI methodology [19], participants consumed porridge made from 150 ml semi-skimmed milk (Tesco, Dundee, UK), 58 g of either rolled (R) or pinhead (P) oats (Healthysupplies.co.uk, Bob's Red Mill, Milwaukie, Oregon, USA), 100 ml of water and 5 g honey (Tesco, Dundee, UK). This porridge provides 1359 kJ (325 kcal) and 50 g of CHO (18% protein, 62% CHO, 20% fat). The porridge was cooked in a microwave oven on full power (1000 W) for 6 min, being stirred every 2 min. After cooking, the porridge was left to cool for 10 min and was served at 59 ± 5 and 59 ± 4°C (R and P, respectively). Oats were stored in individual portions at -20°C to prevent lipid oxidation.

On the day prior to trials, participants were asked not to perform any unusually vigorous activity and to maintain their normal dietary pattern. The evening meal was recorded on the first trial and replicated for the subsequent trial. Smoking was prohibited on test days.

Participants arrived in the laboratory before 1000, after a 10-14 h fast. Following baseline measurements, participants were provided with the test meal along with 250 ml water which they were asked to consume within 10 min. Further measurements were taken 15, 30, 45, 60, 90 and 120 min after the first mouthful was consumed.

Blood sampling and analysis

Capillary blood samples were collected at all measurement points from a pre-warmed hand by finger prick using a lancet device (Accu-Chek Afe-T-Pro Plus, Roche Diagnostics, Mannheim, Germany). Compression of fingers during sampling was minimal in an attempt to prevent hemolysis. Duplicate 20 µl microcapillary tubes of whole blood were obtained to determine blood glucose and lactate concentrations immediately using a glucose/lactate analyzer (Biosen C_line, EKF Diagnostics, Magdeberg, Germany). Postprandial blood lactate concentrations were determined due to previous differences found between high and low GI mixed meals [4] and its known effects on metabolism [20].

Subjective appetite ratings

Paper based, 100 mm visual analogue scales (VAS) were completed at all measurement points with opposing extreme states at each end of the scale. Questions asked included: how hungry do you feel?, how full do you feel?, how satisfied do you feel?, how much do you think you can eat?, how tired do you feel?, how thirsty do you feel?, and how jittery do you feel? and were used to determine hunger, fullness, satisfaction, prospective food consumption, tiredness, thirst, and jitteriness, respectively.

Physical composition of test meals

Retrospectively, the physical state of the test meals was examined. After determination of volume and mass (HF-1200G, A&D Instruments Ltd. Abingdon, UK) the porridges were then placed onto a sieve and left for 10 min to separate the solid and liquid components. Each component was then weighed to determine the proportion of the meals which were solid and liquid. This procedure was conducted 3 times for each porridge, on separate days and mean values were taken.

Statistical analysis

Statistical analyses of the dependent variables were performed using SPSS (Version 15, SPSS, Chicago, Illinois, USA). Blood glucose incremental area under the curve (IAUC) was calculated according to Wolever and Jenkins [21] using the trapezium rule ignoring the area below baseline. Area under the curve (AUC) values for subjective ratings were calculated using the trapezoidal rule. Individual peak blood glucose/lactate concentrations were presented by calculating the group mean of each individual's peak concentration. Individual time to peak concentrations were determined in the same manner. Paired samples t tests were used to identify differences in baseline, IAUC and AUC values along with the differences in the physical composition of the meals. A 2-way (trial x time) repeated measures ANOVA was used to determine differences in the dependent variables between trials. Where suitable, Holm-Bonferonni step-wise post hoc test was used to identify the location of a variance. Statistical significance was set at $p \leq 0.05$. All data are presented as mean ± SD.

RESULTS

Blood glucose

Fasting blood glucose concentrations were similar between trials (4.53 ± 0.27 and 4.51 ± 0.23 mmol/L for R and P, respectively; $p = 0.727$), and rose postprandially to similar individual peak concentrations (7.00 ± 0.93 and 6.93 ± 0.79 mmol/L for R and P, respectively; $p = 0.603$) at comparable individual time points (26.54 ± 6.58 and 26.54 ± 6.58 min for R and P, respectively; $p = 1.000$). Following the zenith, blood glucose responses began to differ (Figure 1), resulting in P producing an IAUC for blood glucose which was 81 ± 24% of that created by R (Figure 2; $p = 0.012$).

Blood lactate

Fasting blood lactate concentration was 0.60 ± 0.10 mmol/L for R and 0.66 ± 0.20 mmol/l for P ($p = 0.178$). Following consumption of the meals, blood lactate concentrations rose to a greater individual maximum concentration with P compared to R (1.34 ± 0.36 compared to 1.24 ± 0.44 mmol/L, respectively; $p = 0.041$), and reached individual peak concentrations at an earlier time (38.65 ± 7.40 compared to 49.04 ± 16.38 min, respectively; $p = 0.035$). Yet, no main effect was observed between trials for blood lactate concentration ($p = 0.303$).

Subjective appetite ratings

No detectable differences were observed in any of the fasting subjective rating measurements ($p = 0.212$, $p = 0.532$, $p = 0.916$, $p = 0.302$, $p = 0.729$ and $p = 0.683$ for hunger, fullness, satisfaction, prospective consumption, tiredness and thirst, respectively). No detectable difference was observed between trials in postprandial hunger sensations (Figure 3; $p = 0.991$), yet feelings of fullness were greater following consumption of R compared to P (Figure 4; $p = 0.024$). Moreover, peak fullness ratings tended to be higher (75 ± 17 and 68 ±

13 mm for R and P, respectively; $p = 0.068$), and occurred later (38 ± 23 and 21 ± 8 min for R and P, respectively; $p = 0.026$) following consumption of R compared with P.

The AUC for fullness was 17 ± 22% greater following ingestion of R compared to P, yet detectable difference was seen in any of the other subjective sensations (Table 1).

Physical composition of test meals

The total volume and mass of the test meals were similar, yet the percentage of the porridge which was solid was greater with R compared to P (Table 2). The coefficients of variation for total, liquid and solid masses were 0.1, 64.5 and 3.7 % for R, and 0.1, 25.5 and 65.5 for P, respectively.

DISCUSSION

The present study examined the influence of porridge, produced with P oats compared to that produced with the more regularly purchased R oats. Extending the findings of a previous study, where P was shown to reduce postprandial glycemia by ~30% compared to R in older (65-70 y) males [15], we found P reduced postprandial glycemia (as indicated by the IAUC) by ~20% in younger group of participants with a mix of genders. R oats are steamed and rolled, which leads to gelatinization and therefore increases the availability of starch to enzymatic degradation [15]. This may explain why R produce a greater glycemic response than P, as the rate of intestinal absorption would be enhanced.

The difference in the magnitude of change between the studies could be explained by the age and/or gender of the participants involved, although this is probably minimal due to the relative differences in blood glucose in a within-subject design. More probable is that the milk proteins provided in the present study produced a greater insulin response [17] and therefore augmented the rate of disappearance of glucose from the blood. However, as insulin was not determined, this is somewhat speculative. Also, the proportion of carbohydrate from the oats was reduced as milk and honey provided some carbohydrate. A final possibility is that the caffeine and/or polyphenol content of the coffee and tea provided with the meals by Granfeldt *et al.* influenced glucose disposal [18].

Interestingly, while hunger sensations were not different following the two meals, R produced greater feelings of fullness compared to P. A couple of possibilities could explain the differences in fullness. Firstly, the greater glycemic response by R compared to P, would lead to a greater insulinaemic response [15, 22], which, in the short-term can increase satiety [7, 23]. Secondly, retrospective analysis of the porridges revealed that the physical composition differed. Although the total volume and mass of the meals were similar, there was a significant difference in the proportion of which was solid and liquid. Previous studies have demonstrated that when the same meal is served in a homogenous, viscous state, as opposed to separate solid and liquid components, gastric emptying is delayed as displayed by a greater postprandial, antral cross-sectional area [24], and feelings of fullness are increased. Moreover, homogenous meals can increase postprandial insulinemia, and incretin responses, although glycaemia is not significantly affected [25].

It is interesting to note that fullness was the only subjective appetite sensation to differ between trials. It has been suggested that hunger and appetite are an accumulation of several sensations which differ between individuals [26] . Could hunger integrate a greater number of sensations than fullness, therefore being more complex to manipulate? Fullness has been shown to more strongly correlate with antral area than desire to eat [24] and shows significant associations with insulin IAUC where hunger does not [7] . This implies that the physiological signals influence fullness more than hunger or desire to eat, which could also be affected by environmental stimuli and past experiences [26].

Another intriguing observation is that no differences were observed in peak glucose concentrations or time to peak glucose concentration. Usually, LGI foods show a delayed and blunted peak in blood glucose concentration following consumption, compared to HGI foods. This is then normally followed by a more sustained blood glucose concentration. As P consisted of more liquid than R, then the liquid fraction (with milk and honey providing approximately 20% of the total carbohydrate load) may have been absorbed rapidly. Indeed blood glucose kinetics do appear to be altered by the physical state of a meal, showing a more rapid appearance, and clearance with separate solid/liquid components, although IAUC is unaffected [25], presumably the physical composition of P resulted in a faster rate of appearance of blood glucose than would have been seen if it consisted of more of a solid component. It could therefore be suggested that if the physical form of the meals were matched, the blood glucose kinetics for P would show a more traditional response where peak values would be blunted and the rate of appearance attenuated. Although a supposition, this it would also explicate the higher and earlier occurring peak blood lactate concentrations with P.

It could be seen as a potential caveat with the present study that insulin concentrations and gastric emptying were not measured. However, this study has shown that the glycemic and fullness responses do differ when porridge is made with P or R oats and consumed in a common manner. The reduction in blood glucose provides information for those wishing to reduce cardiovascular risk [27]. Strengths of the study include the use of duplicate capillary blood samples (the preferred method for GI testing [19]) and established appetite scales [28]. It also provides a clear avenue for future work would be to investigate the mechanisms of the difference glycemia from these oats, determining gastric emptying.

In conclusion, porridge made with P produces improved postprandial glycemic but reduced fullness responses compared to R. Yet feelings of hunger were not different. The reasons for the reduced feelings of fullness could be due to either lesser insulinemia, or a greater rate of gastric emptying from more of a liquid composition. Further work is required to elucidate whether these proposed mechanisms are indeed the cause of this response.

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REFERENCES

1. Thomas DE, Elliott EJ,Baur L: Low glycaemic index or low glycaemic load diets for overweight and obesity. Cochrane Database Syst Rev CD005105, 2007.
2. Esfahani A, Wong JM, Mirrahimi A, Srichaikul K, Jenkins DJ,Kendall CW: The glycemic index: physiological significance. J Am Coll Nutr 28 Suppl: 439S-445S, 2009.
3. Mah E, Noh SK, Ballard KD, Matos ME, Volek JS,Bruno RS: Postprandial hyperglycemia impairs vascular endothelial function in healthy men by inducing lipid peroxidation and increasing asymmetric dimethylarginine:arginine. J Nutr 141: 1961-8, 2011.
4. Stevenson E, Williams C,Nute M: The influence of the glycaemic index of breakfast and lunch on substrate utilisation during the postprandial periods and subsequent exercise. Br J Nutr 93: 885-893, 2005.
5. Stevenson EJ, Astbury NM, Simpson EJ, Taylor MA,Macdonald IA: Fat oxidation during exercise and satiety during recovery are increased following a low-glycemic index breakfast in sedentary women. J Nutr 139: 890-7, 2009.
6. Ford H, Frost G: Glycaemic index, appetite and body weight. Proc Nutr Soc 69: 199-203, 2010.
7. Flint A, Moller BK, Raben A, Sloth B, Pedersen D, Tetens I, Holst JJ,Astrup A: Glycemic and insulinemic responses as determinants of appetite in humans. Am J Clin Nutr 84: 1365-1373, 2006.
8. Stevenson EJ, Williams C, Mash LE, Phillips B,Nute ML: Influence of high-carbohydrate mixed meals with different glycemic indexes on substrate utilization during subsequent exercise in women. Am J Clin Nutr 84: 354-60, 2006.

9. Ludwig DS, Majzoub JA, Al-Zahrani A, Dallal GE, Blanco I,Roberts SB: High Glycemic Index Foods, Overeating, and Obesity. Pediatrics 103: e26, 1999.
10. Foster-Powell K, Holt SH,Brand-Miller JC: International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr 76: 5-56, 2002.
11. Teff KL, Elliott SS, Tschop M, Kieffer TJ, Rader D, Heiman M, Townsend RR, Keim NL, D'Alessio D,Havel PJ: Dietary Fructose Reduces Circulating Insulin and Leptin, Attenuates Postprandial Suppression of Ghrelin, and Increases Triglycerides in Women. J Clin Endocrinol Metab 89: 2963-2972, 2004.
12. Tappy L, Le K-A: Metabolic Effects of Fructose and the Worldwide Increase in Obesity. Physiol Rev 90: 23-46, 2010.
13. Goldsmith MP, Davidson JK: Southern ethnic food preferences and Exchange values for the diabetic diet. J Am Diet Assoc 70: 61-4, 1977.
14. Arvidsson-Lenner R, Asp NG, Axelsen M, Bryngelsson S, Haapa E, Jarvi A, Karlstrom B, Raben A, Sohlstrom A, Thorsdottir I,Vessey B: Glycaemic index. Scand J Nutr 48: 84-94, 2004.
15. Granfeldt Y, Hagander B,Bjorck I: Metabolic responses to starch in oat and wheat products. On the importance of food structure, incomplete gelatinization or presence of viscous dietary fibre. European Journal of Clinical Nutrition 49: 189-199, 1995.
16. Gibson SA, Gunn P: What's for breakfast? Nutritional implications of breakfast habits: insights from the NDNS dietary records. Nutrition Bulletin 36: 78-86, 2011.
17. Nilsson M, Stenberg M, Frid AH, Holst JJ,Bjorck IM: Glycemia and insulinemia in healthy subjects after lactose-equivalent meals of milk and other food proteins: the role of plasma amino acids and incretins. Am J Clin Nutr 80: 1246-1253, 2004.

18. Johnston KL, Clifford MN,Morgan LM: Coffee acutely modifies gastrointestinal hormone secretion and glucose tolerance in humans: glycemic effects of chlorogenic acid and caffeine. Am J Clin Nutr 78: 728-33, 2003.

19. Brouns F, Bjorck I, Frayn KN, Gibbs AL, Lang V, Slama G,Wolever TM: Glycaemic index methodology. Nutr Res Rev 18: 145-71, 2005.

20. Rooney K, Trayhurn P: Lactate and the GPR81 receptor in metabolic regulation: implications for adipose tissue function and fatty acid utilisation by muscle during exercise. Br J Nutr 1-7, 2011.

21. Wolever T, Jenkins D: The use of the glycemic index in predicting the blood glucose response to mixed meals. Am J Clin Nutr 43: 167-172, 1986.

22. Bjorck I, Liljeberg H,Ostman E: Low glycaemic-index foods. Br J Nutr 83 Suppl 1: S149-55, 2000.

23. Holt SH, Brand Miller JC,Petocz P: Interrelationships among postprandial satiety, glucose and insulin responses and changes in subsequent food intake. Eur J Clin Nutr 50: 788-97, 1996.

24. Santangelo A, Peracchi M, Conte D, Fraquelli M,Porrini M: Physical state of meal affects gastric emptying, cholecystokinin release and satiety. Br J Nutr 80: 521-7, 1998.

25. Peracchi M, Santangelo A, Conte D, Fraquelli M, Tagliabue R, Gebbia C,Porrini M: The physical state of a meal affects hormone release and postprandial thermogenesis. Br J Nutr 83: 623-8, 2000.

26. Stubbs RJ, Hughes DA, Johnstone AM, Rowley E, Reid C, Elia M, Stratton R, Delargy H, King N,Blundell JE: The use of visual analogue scales to assess motivation to eat in human subjects: a review of their reliability and validity with an

evaluation of new hand-held computerized systems for temporal tracking of appetite ratings. Br J Nutr 84: 405-415, 2000.

27. Cavalot F, Petrelli A, Traversa M, Bonomo K, Fiora E, Conti M, Anfossi G, Costa G,Trovati M: Postprandial blood glucose is a stronger predictor of cardiovascular events than fasting blood glucose in type 2 diabetes mellitus, particularly in women: lessons from the San Luigi Gonzaga Diabetes Study. J Clin Endocrinol Metab 91: 813-9, 2006.

28. Blundell J, de Graaf C, Hulshof T, Jebb S, Livingstone B, Lluch A, Mela D, Salah S, Schuring E, van der Knaap H,Westerterp M: Appetite control: methodological aspects of the evaluation of foods. Obes Rev 11: 251-70, 2010.

Table 1. Subjective ratings following consumption of porridge made from different forms of oats.

	AUC (mm x 120 min)	
Subjective sensation	R	P
Hunger	4435 ± 1739	4634 ± 1951
Fullness	6917 ± 1900	5980 ± 1734
Satisfaction	6368 ± 1424	5945 ± 1706
Prospective consumption	5577 ± 2116	6058 ± 2160
Tiredness	4073 ± 1601	4109 ± 1671
Thirst	4811 ± 1967	4438 ± 1990

Values are expressed as mean ± SD. AUC, area under the curve; R, porridge made with rolled oats; P, porridge made with pinhead oats. *, significantly different to R, $p < 0.05$.

Table 2. Physical composition of the test meals

Physical characteristic	R	P
Volume (ml)	500 ± 0	500 ± 0
Mass (g)	492.73 ± 0.27	492.56 ± 0.45
Solid component (% of total mass)	95 ± 3	28 ± 18*
Liquid component (% of total mass)	5 ± 3	72 ± 18*

Values expressed as mean ± SD. R, porridge made with rolled oats; P, porridge made with pinhead oats. *, significantly different to R, $p < 0.05$.

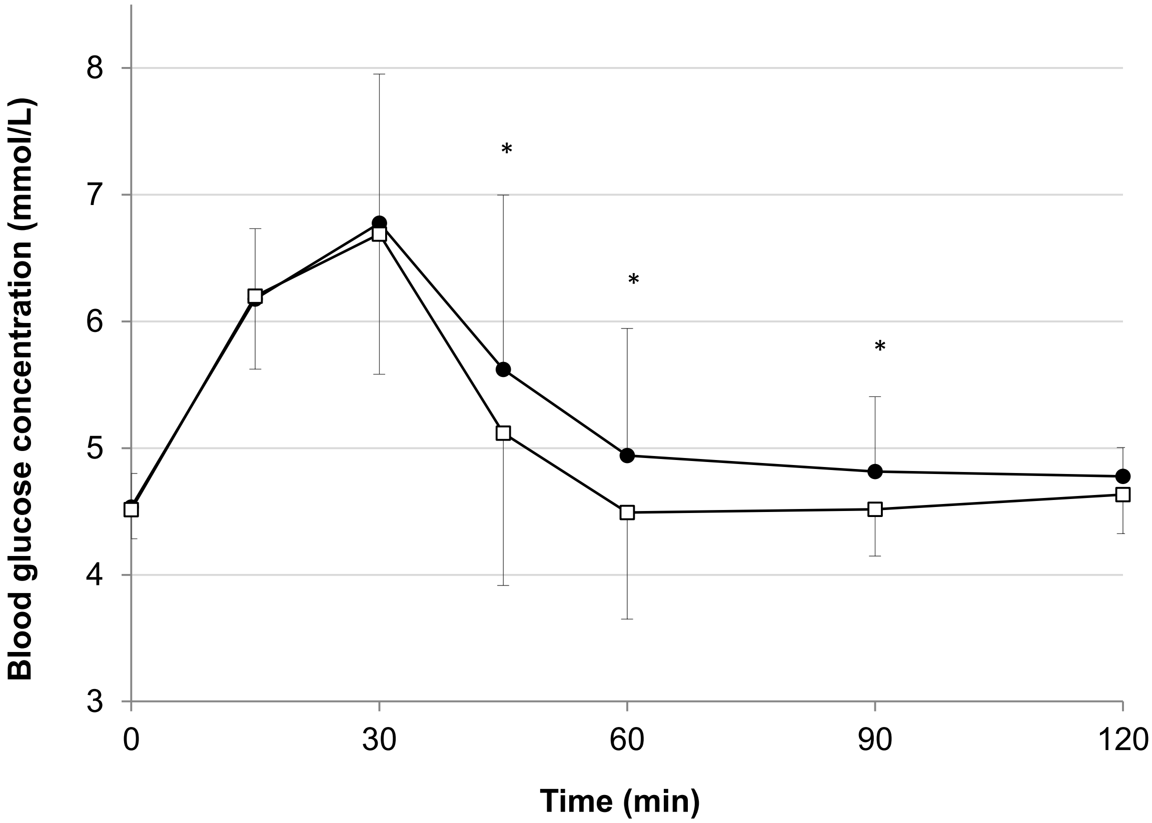
Figure legends:

Figure 1. Blood glucose concentration following consumption of porridge made with rolled (●) and pinhead (□) oats. * $p < 0.05$ indicates significant difference between trials. Values are mean ± SD.

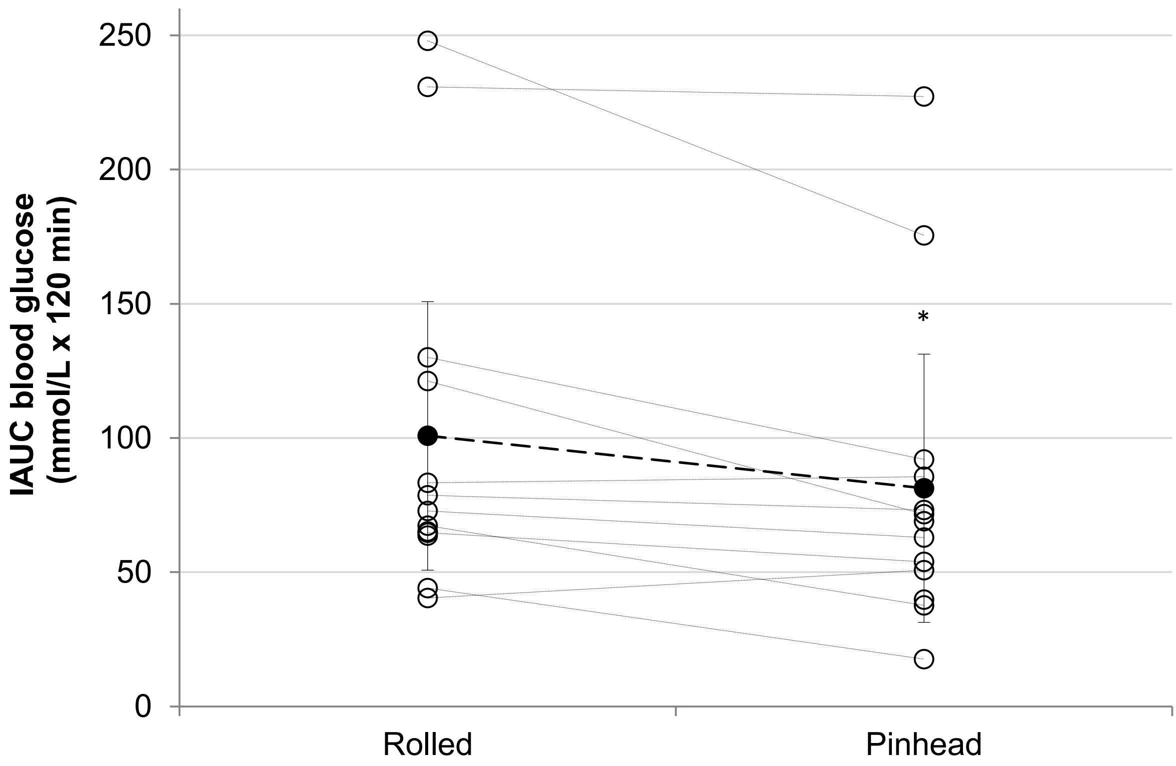
Figure 2. Individual (○) and mean ± SD (●) incremental area under the blood glucose curve for 120 min following consumption of porridge made with rolled or pinhead oats. * $p < 0.05$ indicates significant difference between trials.

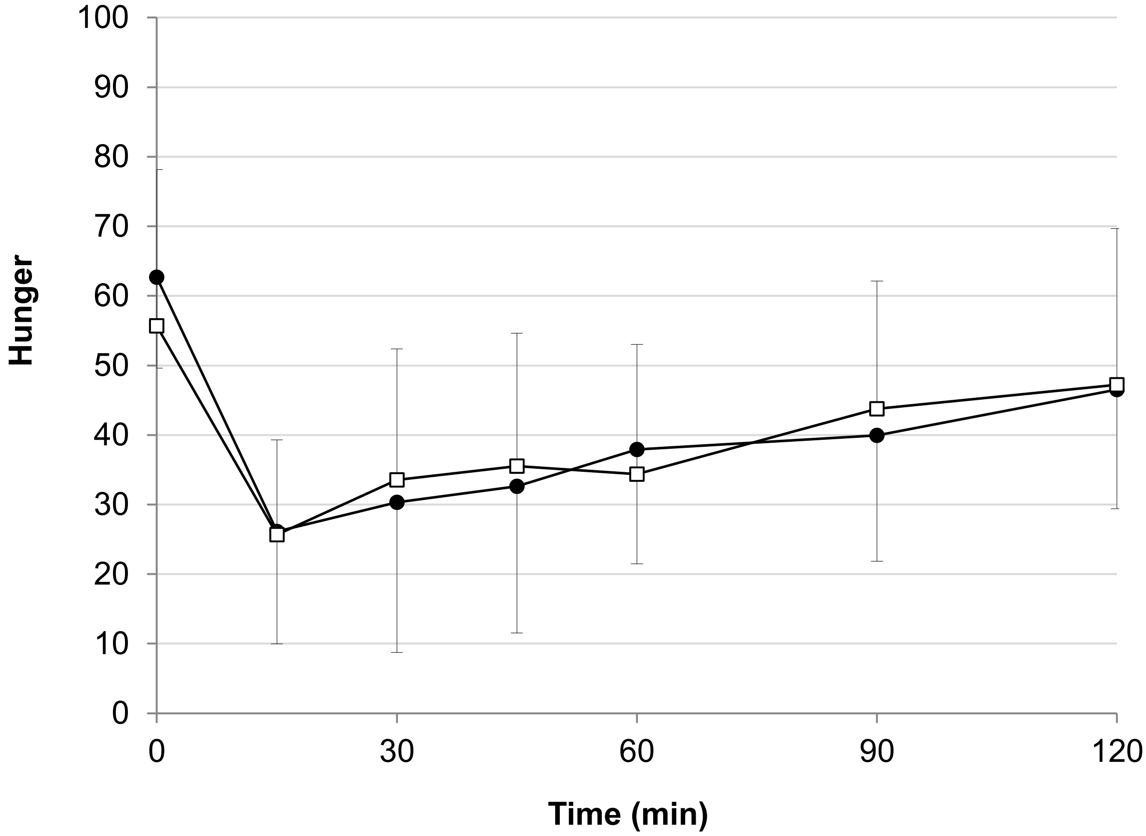
Figure 3. Hunger sensations following consumption of porridge made with rolled (●) and pinhead (□) oats. Values are mean ± SD.

Figure 4. Fullness sensations following consumption of porridge made with rolled (●) and pinhead (□) oats. * $P<0.05$ indicates significant difference between trials. Values are mean ± SD.



Blood glucose concentration (mmol/L)
8
7
6
5
4
3
*
*
*
0
30
60
90
120
Time (min)


IAUC blood glucose
(mmol/L x 120 min)
250
200
150
100
50
0
*
Rolled
Pinhead


Hunger
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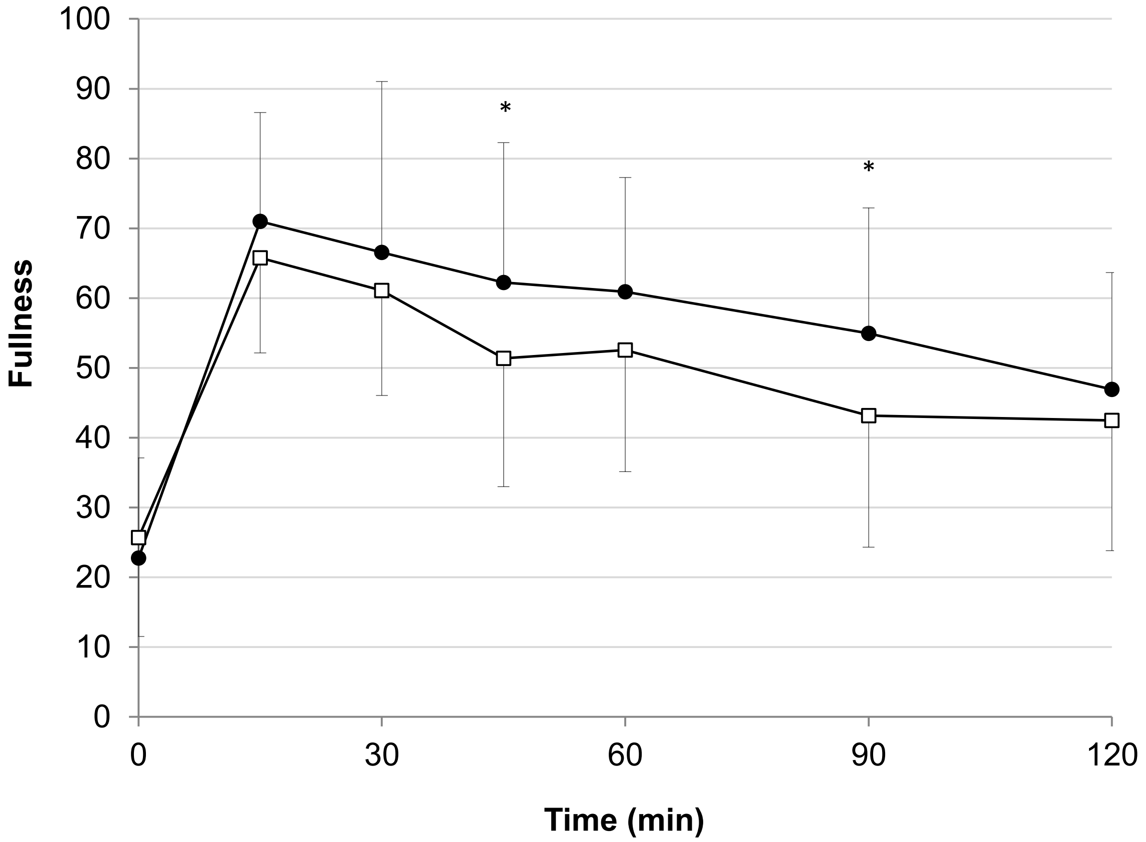
90
80
70
60
50
40
30
20
10
0
0
30
60
90
120
Time (min)


Fullness
100
90
80
70
60
50
40
30
20
10
0
0
30
60
90
120
Time (min)
*
*