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Combined effect of eating speed instructions and food texture modification on eating rate, appetite and later food intake

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ABSTRACT

Modifying food texture and eating slowly each reduce appetite and energy intake. No study has evaluated the effect of combining these measures to slow eating speed and determine the effect on appetite. The aim of this study was to investigate whether there is a combined effect of manipulating oral processing behaviours (OPBs) in this manner on self-reported satiety and subsequent food intake. A 2 × 2 design was used with four breakfast conditions in total. Twenty-four participants attended four study visits where they were asked to consume one of two isocaloric fixed-portion breakfasts differing in texture: 1) granola with milk and 2) yogurt with muesli and conserve. Participants consumed each breakfast twice, with verbal instructions to chew slowly at one visit and at a normal rate at another. Consumption was video-recorded to behaviourally code OPBs. Participants completed visual analogue scales of self-reported appetite measures at the beginning of the test session, immediately prior to and immediately after breakfast consumption. They also completed a food diary documenting food intake for the remainder of the day. The breakfast designed to be eaten slowest (the harder-textured meal with instructions to eat slowly) was eaten at a slower rate, with a greater number of chews per bite and a slower bite rate ($p < 0.001$) compared to the other meals. No differences were observed between the breakfast conditions on subjective measures of post-prandial satiety, or subsequent energy or macronutrient consumption. Results of this study highlight that combined effects of texture and instructions are most effective at reducing eating rate, though eating slower was not shown to enhance post-meal satiety. Reduced eating speed has previously been shown to reduce ad-libitum energy intake. Future research should consider combined approaches to reduce eating speed, to mitigate the risk of overconsumption within meals.

1. Introduction

As the prevalence of overweight and obesity in the adult population is increasing (Flegal et al., 2016), there is a need for effective interventions that can be easily adopted to moderate energy intake. Several studies have investigated the impact of instructing individuals to eat slowly by giving a specific number of chews per bite, and shown that this can reduce both eating speed and energy intake (Martin et al., 2007; Zhu et al., 2013). The effect on chewing slower on post-meal appetite remains unclear, with some studies showing that slower eating reduced feelings of hunger and enhances fullness, while others fail to replicate this effect. For example, Zhu and colleagues showed an enhanced feeling of fullness and lower feelings of hunger when participants were verbally instructed to consume the same portion of pizza slower, by chewing 40 vs 15 times per bite (Zhu et al., 2013). Martin et al. also demonstrated that reducing eating rate is associated with lower ratings of desire to eat, normalised for the amount of food consumed (Martin et al., 2007). Conversely, Karl et al. showed that appetite ratings were unaffected by

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eating a test meal at 20 g/min versus 80 g/min (Karl et al., 2013). Slower eating in individuals with type 2 diabetes who are overweight or obese has been down to increase fullness and decrease hunger ratings (Ai Ting et al., 2021; Angelopoulos et al., 2014), suggesting that it could also be a potential strategy in reducing appetite in this population.

Studies have shown that eating slowly or with a greater number of chews per bite results in lower ad libitum energy intake, with no differences reported in post-meal satiety (McCrickerd et al., 2017). Indeed, in a study by Andrade et al., slower eating resulted in reduced ad libitum energy intake but increased satiety (Andrade et al., 2008). In this regard, slowing intake may reduce intake and provide a similar level of satiety for fewer calories (Andrade et al., 2008; Li et al., 2011; Shah et al., 2015).

Texture has also been shown to influence appetite; increasing the hardness and elasticity of solid foods has been demonstrated to reduce bite size, eating rate and food intake (Bolhuis & Forde, 2020). Softer textured foods are normally ingested quickly, have a shorter oro-sensory exposure time, tend to be eaten with larger bites and have a lower satiety on a calorie for calorie basis, compared to harder textured foods (de Graaf, 2011; Forde et al., 2013a, 2017; Robinson et al., 2014).

There is a growing body of research focussing on the manipulation of oral processing behaviours (OPBs), such as eating rate, using food-based texture differences to influence appetite and energy intake (Bolhuis et al., 2014; Ferriday et al., 2016; Forde et al., 2013b). Greater oral processing through strategies such as increased chewing has been shown to lead to a reduced food intake and decrease self-reported hunger, potentially through changes in satiety-related gut hormone responses (Miquel-Kergoat et al., 2015). Studies have shown that instructing participants to consume each bite with a larger number of chews results in lower post-prandial ghrelin concentrations and increased postprandial concentrations of the anorectic hormone Glucagon-like peptide 1 (Li et al., 2011; Zhu et al., 2013). Furthermore, a study by Kokkinos et al. demonstrated that when an ice cream meal was consumed over 30 min, the area under the curve of the post-prandial rise in Peptide YY was higher than when the ice cream was consumed over 5 min (Kokkinos et al., 2010).

Previous research has manipulated eating rate using instructions (Shah et al., 2014) and food texture (Ferriday et al., 2016) separately, yet no study to date has explored whether there is a combined effect of manipulating eating rate and intake using both food texture and verbal instructions to chew slowly, using breakfast as a test meal. The primary aim of this randomised crossover breakfast study was to investigate whether there is a combined effect of manipulating OPBs, through both the consumption of foods differing in texture classified as "fast" or "slow" foods with verbal instructions to chew slowly or at a normal rate, on self-reported satiety. A secondary aim of the study was to investigate whether the combined effect of food texture and verbal instructions can impact later energy and nutrient intake during the same test day.

2. Methods

2.1. Participants

Healthy male and female participants living in Northern Ireland were recruited using several recruitment methods, including an A4 poster advertisement and word of mouth. Individuals who were interested in participating in the study contacted the researcher for more information. If the participant met the eligibility criteria, the study visits were scheduled. Participants were deemed eligible to take part in the study if they were over the age of 18 years and had no dietary restrictions, including allergies to any of the foods used in the study.

The study was performed in accordance with the Helsinki Declaration guidelines. The study was granted ethical approval by the School of Medicine, Dentistry and Biomedical Science Ethics Committee at Queen's University, Belfast (Ref: 18.41v2). The study was conducted between October 2018 and May 2019. Written consent was obtained from all participants at the beginning of the first study visit before data collection commenced.

2.2. Study design

The study was designed as a randomised crossover experiment, and eligible participants attended the Centre for Public Health on four occasions after an overnight fast, with at least one week in between each visit. The duration of the study visits and breakfast sessions were not fixed, however the majority were completed in less than 90 min. To reduce demand awareness, participants were informed that the aim of the study was to investigate the effect of time spent eating breakfast on mood; and were given the following title for the research project; "*Can spending a longer period of time eating breakfast impact mood?*".

Participants attended four breakfast sessions as part of the study; consuming two different breakfasts twice. The two breakfast options were served in isocaloric portions of 400 kcal, with one breakfast defined as "slow" (in terms of eating rate) with a crunchy texture designed to take longer to consume, and the other breakfast as "fast" with a smoother texture designed to take less time to consume. Certain commonly eaten breakfast foods were used to create these breakfast options with as different a texture as possible given the resources and time available. Crunchy granola was used for the "slow" option whilst a smooth textured yoghurt was used as the basis of the "fast" option.

Nutritional information and the components of both breakfast options are shown in Table 1. Across four breakfast conditions both breakfasts were consumed twice; once with instructions to eat at their normal eating speed until the breakfast was finished, and once with instructions to eat as slowly as possible until the breakfast was finished, although they were not formally told the specific OPBs of interest. All meals were weighed before and after consumption to determine in grams how much had been consumed by the participant. Whilst there were obvious texture differences between the breakfast meals, participants were not made aware of the goals of the study or the classification of each meal as 'fast' or 'slow.' The order of meals were randomly allocated using block randomisation, and test meal presentation was counterbalanced to neutralise possible learning effects.

2.3. Sample size

This study was powered using a previously reported standard deviation of the mean change in self-reported fullness (using VAS) before and after consuming a breakfast meal (Watson et al., 2022). For this crossover study a sample of 21 participants achieves more than 80% power to detect a mean difference in change in self-reported fullness between the 'slow' breakfast eaten slowly and the 'fast' breakfast eaten at a normal pace of 13 units on the VAS ($P < 0.05$; paired *t*-test). To allow for anticipated participant dropout, a total of 24 participants were recruited.

2.4. Data collection and analysis

2.4.1. Socio-demographic and anthropometric data

Participants were given several questionnaires as part of the first study visit to assess demographic and health and lifestyle information and these were completed using Qualtrics (https://www.qualtrics.com/uk/), an online survey tool. Anthropometric data including height, weight, waist and hip circumference were collected during the first study visit.

2.4.2. Self-reported appetite measures

To assess self-reported hunger, satiety, fullness, prospective food consumption and desire to eat, visual analogue scales (VAS) were used: 100 mm in length anchored with positive and negative terms (e.g "How full do you feel?" 0- Not at all, 100- Extremely) (Flint et al., 2000). Participants were asked to complete these ratings three times during the

Table 1
Nutritional information for the fast and slow breakfast options.

Breakfast Option	Breakfast Components	Quantity	Nutrient Information							
			Energy (kcal)	Fat (grams)	Saturated fat (grams)	Protein (grams)	Carbohydrate (grams)	Sugar (grams)	Fibre (grams)	Salt (grams)
Slow	Sainsbury's Raisin, Nut and Honey Granola	79.2 g	350	11.2	3.2	8.2	51.4	14.7	5.7	0.2
	Semi-skimmed milk (supermarket own brand)	100 ml	50	1.8	1.1	3.6	4.8	4.8	0	0.1
	Total	-	400 kcal	12.6	4.3	11.5	54.6	19.5	5.5	0.3
Fast	Sainsbury's Taste the Difference Blackcurrant conserve	22.4 g	57.2	0.2	0.1	0.1	13.4	12.4	0.5	0.1
	Activia Grains and Nuts yoghurt	240 g	268	9.4	4.8	9	34.8	32	4	0.3
	Alpen Original Recipe Muesli	20 g	74.8	1.1	0.2	2.2	13	4.2	1.5	0.1
	Total	-	400 kcal	10.7	5.1	11.3	61.2	48.6	6.1	0.4

study visit; at the beginning of the test session, immediately prior to breakfast consumption and immediately after breakfast consumption, with timings based on previously conducted studies (Watson et al., 2022). Between the baseline VAS and VAS completed immediately prior to breakfast consumption, the participants completed demographic and health questionnaires (at the first visit) and reviewed food diaries with the researcher to allow clarification (at subsequent visits). These hunger and satiety ratings were embedded alongside distractor ratings including how 'stressed', 'happy', 'alert', 'energetic' and 'clear-headed' the participant was and were disguised as "Mood Ratings". This technique has been used in a previous study which assessed self-reported appetite (McCrickerd et al., 2017).

2.4.3. Oral processing behaviours

All participants OPBs were video-recorded during breakfast consumption for post-hoc behavioural coding using a technique previously described elsewhere (Forde et al., 2013a). Briefly, participants were seated at a table with a laptop equipped with a webcam approximately 30 cm away. Each participant was video recorded while they consumed the test breakfast. The same sized bowl and spoon were used at each visit. Participants had access to water during the session, and the researcher left the room whilst the participant was eating to avoid influencing eating behaviour. Participants were informed prior to the session that they would be recorded whilst eating the breakfast, although they were not able to see themselves on the camera/video display while being recorded. They were asked to minimise head movements and stay in front of the web-cam during recording.

A behavioural annotation software (ELAN 4.9.1, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands) was used to code the video recordings of the breakfast sessions for OPBs (Fogel et al., 2017; Forde et al., 2017). Frequencies of three key events (bites, chews and swallows) were recorded using a coding scheme developed for the software, and the duration of a single continuous event (total oral exposure time) was also simultaneously coded. Using this approach it was possible to derive a measure of total time spent by each test meal in-mouth during consumption (total oral exposure time).

Total oral exposure time was (seconds) was divided by the amount (grams) of food consumed to calculate the mean eating rate (grams/second) of each test meal. Total weight of food consumed was divided by the number of bites required to consume the test meal to calculate the average bite size. Other measures such as chew rate (chews/second), bite rate (bites/second) and chews/bite were also calculated. All video coding was completed by a single coder and was validated through standard reliability measures by a second trained coder to achieve an acceptable range (minimum 80% of agreement). Further details on this methodology have been published previously (Forde et al., 2013a).

2.4.4. Dietary intake

Food intake for the remainder of the day of the study visit was recorded using a food diary completed by the participant. Food diaries were entered into Nutritics© dietary assessment software to estimate total energy intake and intakes of macronutrients on the days the breakfast options were consumed.

2.5. Statistical analysis

Statistical analyses were conducted using SPSS®, and a p value of <0.05 was considered statistically significant. All hypotheses were specified prior to data collection and the analytic plan was pre-specified. Repeated measures ANOVAs were created to test the study's primary outcome: to investigate if there were differences in the different appetite scale measures post-meal across the four different breakfast conditions.

To investigate if there were differences between energy consumed in Kcal and intakes of nutrients such as carbohydrate, fat and protein (in grams) later in the day post-breakfast consumption, between the four breakfast options repeated measures ANOVAs were created.

Repeated measures ANOVAs were created to explore differences in appetite measures at other time-points as well as change in measures between time-points between the four breakfast options. Paired sample t-tests were conducted to investigate if there were differences in appetite measures between baseline and post consumption, and pre and post consumption, for each of the breakfast options.

Repeated measures ANOVAs were also used to investigate if there were differences in OPBs between the four breakfast options. Pairwise comparisons with adjustment for multiple comparisons (Least Significant Difference) were also used to investigate differences between the individual groups (breakfast conditions).

Several variables required log transformation and these are presented as geometric means and 95% CI, and logged versions of these variables are used in the analyses presented.

3. Results

3.1. Participant characteristics

A total of 24 participants were recruited to take part in this randomised crossover trial, with one participant excluded from analysis due to missing data on the study's primary outcome. Descriptive characteristics of the remaining 23 participants are summarised in Table 2.

3.2. Impact of texture and verbal instructions on oral processing behaviour

The OPBs observed for each of the four test breakfasts are summarised in Table 3, and show significant differences between them for eating

Table 2
Descriptive characteristics of study participants.

Baseline Characteristic		
No. of participants		23
Age (Mean (SD))		31.1 (8.8)
Gender	*Male* (N (%))	7 (30.4)
	Female (N (%))	16 (69.6)
Ethnicity	*White* (N (%))	19 (82.6)
	Mixed/Multiple ethnic background (N (%))	1 (4.3)
	Asian (N (%))	3(13.0)
Weight (kg) (Mean (SD))		66.1 (11.5)
BMI (kg/m^2) (Mean (SD))		23.5 (2.8)
Waist circumference (cm) (Mean (SD))		78.5 (9.6)
Hip circumference (cm) (Mean (SD))		97.2 (5.8)
Waist hip ratio (Mean (SD))		0.8 (0.1)
Highest level of education achieved	*A-Level/Leaving certificate/Equivalent* (N (%))	1 (4.3)
	Diploma/Certificate (N (%))	1 (4.3)
	Primary degree (N (%))	7 (30.4)
	Postgraduate/Higher degree (N (%))	14 (60.9)
Self-reported eating rate	*Relatively slow* (N (%))	2 (8.7)
	Medium (N (%))	7 (30.4)
	Relatively fast (N (%))	13 (56.5)
	Very fast (N (%))	1 (4.3)
Breakfast eating	*Every day* (N (%))	19 (82.6)
	Most days (N (%))	3 (13.0)
	Some days (N (%))	1 (4.3)
Occupation	*Student* (N (%))	10 (43.5)
	In employment (N (%))	12 (52.2)
	Retired (N (%))	1 (4.3)

rate (grams/second), chews per bite and bite rate (seconds). The harder textured meal was eaten approximately twice as slowly than the softer textured meal when instructed to eat normally and when instructed to eat slowly. Instructing participants to eat slowly also reduced eating rate by around 30% regardless of the meal being consumed. Compared to the other three breakfast options, the breakfast option designed to be eaten slowest (the granola with instructions to eat slowly) was eaten with a slower eating rate, greater number of chews per bite, and a slower bite rate ($p < 0.001$ obtained from repeated measures ANOVA). This breakfast condition was eaten more than 60% slower than the softer textured breakfast with instructions to eat at a normal rate. For the yogurt breakfast, instruction to eat slowly resulted in an increase in total oral exposure time. For the granola breakfast, instruction to eat slowly resulted in increased total oral exposure time as well as a reduced chew rate. When eating at a normal speed, the granola was eaten with a statistically significantly smaller bite size, a longer total oral exposure time and a longer chew rate than the yogurt. When instructed to eat slowly, participants consumed the granola breakfast with a smaller bite size and a longer total oral exposure time.

3.3. Relationship between oral processing behaviours and self-reported appetite measures

Participants ratings of hunger, desire to eat and prospective food consumption significantly decreased from baseline and pre-consumption to immediately post-consumption for each of the four breakfast conditions ($p < 0.001$ obtained from paired sample *t*-test). Ratings for fullness and satiety significantly increased from baseline and pre-consumption to immediately post-consumption, for all four breakfast options ($p < 0.001$ obtained from paired sample *t*-test). These results can be seen in Table 4.

Ratings for baseline fullness significantly differed between the groups ($p < 0.05$ obtained from repeated measures ANOVA) with participants reporting significantly lower fullness ratings prior to consumption of the granola eaten normally. No significant differences in any of the other appetite ratings investigated were observed between the four breakfast options at baseline, pre-consumption or post-consumption, and change in appetite between the time points ($p > 0.05$). These results can be seen in Tables 4 and 5.

Table 3
Oral processing behaviours for the four breakfast options.

Oral Processing Behaviour	Breakfast Option				
	Yoghurt eaten normally (N_{max} = 23)	Yoghurt eaten slowly (N_{max} = 23)	Granola eaten normally (N_{max} = 23)	Granola eaten slowly (N_{max} = 23)	*P value*
Eating rate[a] (grams/second)	1.1 (0.9, 1.3)	0.8 (0.66, 0.9)	0.6 (0.5, 0.7)	0.4 (0.4, 0.5)	$<0.001^{a,b,c,d,e,f}$
Average bite size (grams)	13.6 (4.0)	12.7 (3.5)	11.6 (2.4)	11.0 (2.9)	$<0.001^{b,c,e}$
Chews per bite[a]	15.0 (12.3, 17.8)	19.0 (15.3, 22.7)	28.4 (23.0, 33.7)	32.2 (26.5, 37.9)	$<0.001^{b,a,b,c,d,e,f}$
Total oral exposure time[a] (seconds)	239.6 (200.5, 278.7)	339.7 (285.8, 393.6)	343.0 (284.3, 401.8)	492.0 (404.1, 579.9)	$<0.001^{a,b,c,e,f}$
Bite rate (seconds)	1.1 (0.0)	1.1 (0.0)	0.1 (0.0)	0.0 (0.0)	$<0.001^{a,b,c,d,e,f}$
Chew rate[a] (seconds)	1.1 (1.1, 1.2)	1.1 (1.0, 1.2)	1.3 (1.2, 1.4)	1.1 (1.1, 1.2)	$<0.001^{2b,d,f}$

Results presented as Mean (SD). *$p < 0.05$ obtained from repeated measures ANOVA with sphericity assumed.
[a]significant difference between the yoghurt eaten normally and the yoghurt eaten slowly.
[b]significant difference between the yoghurt eaten normally and the granola eaten normally.
[c]significant difference between the yoghurt eaten normally and the granola eaten slowly.
[d]significant difference between the yoghurt eaten slowly and the granola eaten normally.
[e]significant difference between the yoghurt eaten slowly and the granola eaten slowly.
[f]significant difference between the granola eaten normally and the granola eaten slowly.
[a] variable was logged transformed and presented as geometric mean (95% CI).
[b] p value obtained from repeated measures ANOVA with Greenhouse-Geisser test. The following refer to results from Pairwise comparisons -

3.4. Relationship between oral processing behaviours and energy and nutrient intake later in the day

Intakes of energy and nutrients (carbohydrate, protein and fat), consumed later in the day after consumption of each breakfast option, can be seen in Table 6. There were no significant differences observed ($p > 0.05$ obtained from repeated measures ANOVA).

4. Discussion

The current study sought to compare the independent and combined effect of texture manipulation and verbal instructions on OPBs and post-meal appetite and energy intakes. Results showed that each manipulation independently reduced eating rate, but that the combined effect of manipulating both food texture and using verbal instructions had the strongest effect on both eating rate and food oral processing behaviour. Participants that ate at a slower rate for the harder textured meal (granola) with verbal instructions to slow down their rate of consumption, had the slowest eating rate overall. However, despite this reduction in eating speed there were no significant effects on post-meal satiety appetite ratings or late energy intake.

Breakfast texture and instructions to eat normally or slowly both had a significant impact on participants eating rate and OPBs, with the

Table 4
Self-reported appetite measure at each time-point for the four breakfast options.

Self-reported appetite measure	Time point	Breakfast Option				*P value*
		Yoghurt		Granola		
		Normal (N_{max} = 23)	*Slow* (N_{max} = 23)	*Normal* (N_{max} = 23)	*Slow* (N_{max} = 23)	
Hunger	*Baseline*	72.1 (16.1)	65.5 (18.1)	68.0 (24.5)	75.6 (21.4)	0.3
	Pre-consumption	71.0 (23.9)	68.5 (19.4)	75.3 (23.5)	76.6 (19.5)	0.2
	Post-consumption	29.5 (21.5)[1,2]	26.8 (22.6)[1,2]	31.1 (20.9)[1,2]	26.7 (22.0)[1,2]	0.7
Fullness	*Baseline*	22.9 (13.5)	25.9 (16.5)	16.7 (11.5)	21.4 (14.6)	<0.05*[3]
	Pre-consumption	24.6 (18.8)	29.5 (18.7)	19.4 (16.7)	22.4 (18.2)	0.1
	Post-consumption	71.4 (15.8)[1,2]	70.9 (16.7)[1,2]	69.6 (12.5)[1,2]	69.2 (17.5) [1,2]	0.9
Satiety	*Baseline*	48.5 (22.9)	46.6 (22.2)	49.1 (18.4)	51.2 (23.8)	0.8
	Pre-consumption	53.0 (22.1)	48.4 (23.6)	51.7 (24.7)	44.4 (24.8)	0.1
	Post-consumption	68.7 (18.9)[1,2]	70.3 (11.0)[1,2]	69.3 (11.8)[1,2]	71.7 (12.0)[1,2]	0.8
Desire to eat	*Baseline*	71.1 (18.3)	69.8 (16.1)	69.9 (21.0)	78.2 (20.7)	0.4
	Pre-consumption	77.2 (16.6)	69.5 (20.0)	76.2 (17.6)	78.6 (17.1)	0.1[1]
	Post-consumption	29.9 (24.4)[1,2]	25.8 (22.7)[1,2]	31.9 (22.7)[1,2]	27.4 (22.4)[1,2]	0.5
Prospective food consumption	*Baseline*	76.2 (16.8)	71.2 (19.9)	76.6 (16.3)	75.1 (15.9)	0.6
	Pre-consumption	75.6 (19.0)	72.1 (20.3)	79.5 (14.6)	76.7 (18.6)	0.2
	Post-consumption	33.6 (25.8)[1,2]	31.1 (24.0)[1,2]	33.6 (22.6)[1,2]	31.7 (24.4)[1,2]	0.8[3]

Results presented as Mean (SD). *$p < 0.05$ obtained from repeated measures ANOVA with sphericity assumed. [1]$p < 0.001$ obtained from paired sample *t*-test for comparison of baseline and post-consumption. [2]$p < 0.001$ obtained from paired sample *t*-test for comparison of pre- and post-consumption. [3]p value obtained from repeated measures ANOVA with Greenhouse-Geisser test.

Table 5
Change in self-reported appetite measures at each time-point for the four breakfast options.

Self-reported appetite measure	Change in self-reported appetite measure	Breakfast Option				*P value*
		Yoghurt		Granola		
		Normal (N_{max} = 23)	*Slow* (N_{max} = 23)	*Normal* (N_{max} = 23)	*Slow* (N_{max} = 23)	
Hunger	*Baseline to Post-consumption*	−42.6 (20.8)	−38.9 (24.2)	−36.1(26.9)	−49.0 (27.6)	0.2
	Pre-consumption to Post-consumption	−41.6 (27.2)	−42.2 (27.1)	−44.2 (28.5)	−49.9 (28.9)	0.5
Fullness	*Baseline to Post-consumption*	48.1 (21.8)	42.4 (21.2)	51.8 (16.9)	44.8 (22.5)	0.2
	Pre-consumption to Post-consumption	46.8 (25.1)	41.4 (23.1)	50.2 (23.1)	46.7 (21.7)	0.4
Satiety	*Baseline to Post-consumption*	18.8 (21.5)	22.2 (28.1)	19.5 (20.7)	20.6 (24.0)	0.9
	Pre-consumption to Post-consumption	15.6 (21.5)	22.0 (25.3)	17.6 (26.5)	27.3 (25.2)	0.1
Desire to eat	*Baseline to Post-consumption*	−42.0 (30.2)	−44.6 (21.4)	−40.7 (27.5)	−51.5 (30.3)	0.4
	Pre-consumption to Post-consumption	−41.9 (29.2)	−42.4 (22.8)	−41.0 (26.7)	−41.0 (26.7)	0.6
Prospective food consumption	*Baseline to Post-consumption*	−42.6 (23.8)	−39.3 (27.0)	−41.9 (25.8)	−43.5 (26.4)	0.9
	Pre-consumption to Post-consumption	−47.1 (27.5)	−43.6 (25.8)	−45.3 (26.5)	−50.7 (27.4)	0.8

Results presented as Mean (SD). *$p < 0.05$ obtained from repeated measures ANOVA with sphericity assumed. [1]p value obtained from repeated measures ANOVA with Greenhouse-Geisser test.

Table 6
Intakes of energy and nutrients later in the day after consuming each breakfast option.

Breakfast Option	Intake on test day			
	Energy* (kcal)	Carbohydrate* (grams)	Fat (grams)	Protein (grams)
Yoghurt eaten normally (N_{max} = 23)	1481.5 (1265.1, 1698.0)	163.4 (130.9, 195.8)	59.1 (25.8)	69.9 (24.0)
Yoghurt eaten slowly (N_{max} = 22)	1615.0 (1336.6, 1893.3)	162.8 (129.8, 195.8)	70.6 (35.8)	66.0 (24.7)
Granola eaten normally (N_{max} = 23)	1364.6 (1112.7, 1616.6)	144.3 (119.4, 169.2)	57.0 (39.9)	58.6 (26.9)
Granola eaten slowly (N_{max} = 23)	1516.7 (1215.9, 1817.6)	163.9 (129.3, 198.7)	64.4 (38.2)	63.9 (29.4)
P value	0.2[1]	0.5	0.3	0.3

Results presented as Mean (SD). P value obtained from repeated measures ANOVA with sphericity assumed. [1]p value obtained from repeated measures ANOVA with Greenhouse-Geisser test. *values log10 transformed and presented as geometric mean (95% CI).

breakfast designed to be eaten slowest (the granola with instructions to eat slowly) having a slower eating rate, a smaller average bite size, higher number of chews per bite, longer total oral exposure time and slower bite rate compared to the three other breakfasts. This is similar to previous findings (Bolhuis et al., 2014; Bolhuis & Forde, 2020; Forde et al., 2017), which observed that harder textured foods had slower eating rates, longer total oral exposure times, higher numbers of chews per bite and a smaller average bite size. When the 'fast' yogurt breakfast was eaten slowly, it had a lower total oral exposure time and faster chew rate than the granola eaten at a normal speed. This suggests that texture played a more significant role in altering OPBs than eating instruction.

Although the four breakfast options had differing OPBs, and associations have been observed previously between manipulation of these behaviours and appetite measures (Andrade et al., 2008; Ferriday et al., 2016), no significant differences were observed between the four breakfast options and self-reported appetite measures post-breakfast consumption, or change in appetite between baseline and post-consumption or between pre- and post-consumption. The granola breakfast eaten slowly was associated with significantly reduced fullness ratings at baseline compared to the other breakfasts. As conditions were randomised, this is likely to have occurred by chance. There is evidence to suggest that verbal instructions to eat slowly or increase the number of chewing cycles or manipulating food texture in isolation can influence appetite (McCrickerd et al., 2017; Shah et al., 2014; Zhu et al., 2013), however findings from this study would suggest a lack of a combined effect of these two forms of OPB manipulation.

Altering eating rate using external manipulations such as instructing individuals to eat slowly has been purported to disrupt the normal eating experience (Bolhuis et al., 2014; Forde et al., 2013a, 2013b, 2017). An alternative approach is to manipulate the eating rate of the food by changing the foods texture, such that individuals adopt their normal OPBs in a more automatic manner in response to the texture challenge encountered (Bolhuis et al., 2014; Forde et al., 2013a, 2013b, 2017). In this study, the harder textured meal was indeed eaten at a slower rate than the softer textured meal when eaten under normal conditions.

Although the four breakfast options were isocaloric at 400 kcal they differed in volume, which could explain why appetite ratings were not affected as expected (Martin et al., 2007). The breakfasts also differed in weight, with the yogurt-based breakfast weighing more. Furthermore, the breakfast options were comprised of different food items. The sensory and eating characteristics of composite foods (i.e. the combination of foods with different textures within a meal or bite) is complex such that the characteristics of one component can influence the eating properties of another (van Eck & Stieger, 2020). Even small changes to a composite foods texture have previously been shown to influence eating rate and total energy intake, with the addition of granola particles reducing energy intake by approximately 7% in a previous trial (Mosca et al., 2019). This complex relationship in how different food texture components interact during consumption to influence both eating rate and intake merits further consideration, as the current findings suggest texture effects are likely to be most effect in limiting meal size, rather than in enhancing post-meal feelings of fulness.

Several studies have shown that consumption of harder textured foods, eating under slow conditions or increasing the number of chews leads to a reduced food intake and meal size (Andrade et al., 2008; Bolhuis et al., 2014; Smit et al., 2011; Zhu & Hollis, 2014). Research findings surrounding the manipulation of OPBs and its effect on subsequent energy and food intake are conflicting. In this study where fixed portion test meals were consumed there was no effect on subsequent energy or macronutrient intake. However, in studies where test meals were given ad libitum, it has been shown that altering OPBs can reduce overall energy intake for the day. Bolhuis et al. demonstrated that consumption of a harder textured lunch meal resulted in a 13% reduction in energy intake at that meal compared to a softer textured meal without compensation at the later evening meal, resulting in a reduction in overall energy intake for the day of 11% (Bolhuis et al., 2014). Similarly, McCrickerd et al. found that a thicker textured meal resulted in reduced energy intakes without compensation over the remainder of the day (McCrickerd et al., 2017). In the current study, no significant differences were observed in intakes of energy, carbohydrate, fat or protein later in the day after consuming each breakfast option. However, it is possible that if OPBs were altered in a similar fashion with meals offered ad libitum, there may be differences in total energy intake over the day. Further study is required to determine the effects of altering OPBs on subsequent food intake and overall energy intake.

This breakfast study was conducted with a randomised crossover design. This study design has a number of advantages, including each participant acting as their own control, therefore minimising the confounding effect of covariates. Previous research has only looked at either food texture modification or verbal instructions to eat slowly in isolation, therefore this study has the added benefit of testing a subjective and objective measure together.

This study was adequately powered for the primary outcome, however, the sample size of 24 may not be powered for the other outcomes investigated. Dietary intake data was collected using four-day food diaries, and aspects of appetite were measured using a VAS. Both are self-report measures susceptible to bias, such as social desirability and recall bias. Previous studies have evaluated levels of the orexigenic gastrointestinal hormone ghrelin to assess appetite in a more objective manner (Li et al., 2011), and this should be considered in future studies.

The two breakfast options were designed to have the greatest texture difference possible within the breakfast meal setting whilst still being isocaloric. However, ensuring the breakfasts were isocaloric necessitated a volume difference, which could have explained the lack of difference in appetite measures post-consumption. The breakfast options were also not nutrient matched, and had differing amounts of sugar, fat and protein, which again could have explained the non-significant results. Following food diary analysis, it is clear that the breakfast options selected are not regularly eaten by the study population. If this work were to be repeated, efforts should be made to ensure meal options are chosen to accurately represent habitual food choices. However, this may prove challenging if differences in texture are to be maintained.

5. Conclusions

We showed that the combined effect of manipulating OPBs through both verbal instruction to eat slowly and food-based texture differences had the strongest effect in reducing eating speed for a test meal. Differences in eating speed did not have a significant impact on post-meal satiety ratings or later energy intake. Future research should explore the interplay between food texture manipulations and eating guidance to develop strategies that optimally reduce eating speed to control energy intake and maximise satiety per kcal consumed.

Author contributions

MW, JW and GMcK contributed to the study concept and design and the study analysis plan. SW, CF and GAT provided guidance on study design, methods and analyses. MW conducted the study assessments, managed the data collection and performed the analyses. MW drafted the manuscript. MW, JWH and HOH critically reviewed and revised the manuscript. The authors read and approved the final manuscript.

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Ethical statement

The study was performed in accordance with the Helsinki Declaration guidelines. The study was granted ethical approval by the School of Medicine, Dentistry and Biomedical Science Ethics Committee at Queen's University, Belfast (Ref: 18.41v2). The study was conducted between October 2018 and May 2019. Written consent was obtained from all participants at the beginning of the first study visit before data collection commenced.

Declaration of competing interest

The authors have no conflicts of interest to disclose.

Data availability

Data will be made available on request.

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