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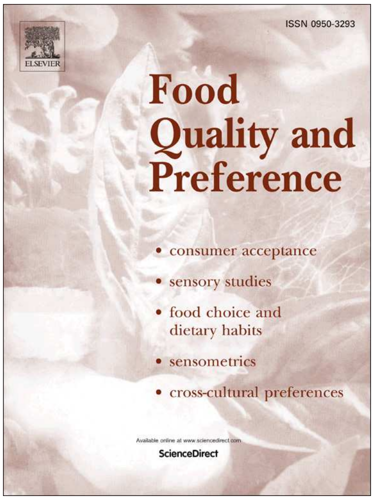

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The influence of oral lubrication on food intake: a proof-of-concept study

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Abstract

As overeating, overweight and obesity remain public health concerns, it is crucial to design satiety-enhancing foods that suppress appetite and lower snack intake. Existing research identifies oro-sensory targets to promote satiation and satiety, yet it remains unclear as to whether it is ‘chewing’ or ‘oral lubrication’ that might amplify satiation signals. In this study, techniques from experimental psychology, food material science and mechanical engineering have been combined to develop model foods to investigate the role of chewing and oral lubrication on food intake. Novel model gels, similar in pleasantness, were given as a preload then their effects on subjective appetite and intake of a salty snack were measured in a between-subjects design. Three mint flavoured hydrogels were engineered to vary in their texture (fracture stress) and lubrication (inverse of coefficient of friction), and a control group received mint tea. Results showed that snack intake was suppressed by 32% after eating the low chewing/high lubricating preload compared to the high chewing/low lubricating preload ($p < 0.05$). Hunger ratings decreased from t_1 to t_3 ($p < 0.05$), however differences between conditions were subtle and not significant. Thus, this proof-of-concept study demonstrates that manipulating oral lubrication is a promising new construct to reduce snack intake that merits future research in the oro-sensory satiety domain.

Keywords

Oral lubrication; Chewing; Satiation; Satiety; Hunger; Food intake

1. Introduction

There has been an upsurge in research efforts to design satiation- and satiety-enhancing foods that suppress appetite and prevent overconsumption. Satiation is defined as the processes leading to the termination of an eating event and satiety as the inhibition of appetite and further eating until the next meal, as described within the multifactorial concept of the 'satiety cascade' (Blundell et al., 2009). Both satiation and satiety responses contribute to the termination of a meal, and therefore understanding these processes is important for designing food-based approaches to limit overeating with potential in the longer term to influence weight management (Hetherington et al., 2013).

Although the role of oral processing on satiation and satiety has been well established, the quantitative understanding of which dimensions of oral processing influence this has remained elusive (Hetherington & Regan, 2011; Krop et al., 2018; Lasschuijt et al., 2017; Lavin et al., 2002). Based on a recent systematic review and meta-analysis on relating oral processing to satiety, it was demonstrated that extending the oro-sensory exposure time to foods leads to a significant reduction in self-reported hunger and food intake (Krop et al., 2018). Interestingly, in many, if not most of these satiety trials involving oro-sensory cues, 'food rheology' (i.e. liquid versus solid foods, texture/thickness manipulations) has been used as a 'gold standard'-design tool to influence the number of chews, oral residence time or eating rate, and thus, impact satiety outputs such as appetite ratings (hunger, desire to eat etc.), food intake and gut hormonal release (Hogenkamp et al., 2012; Larsen et al., 2016; Lavin et al., 2002). However, during oral exposure, food characteristics change dramatically due to lubrication by saliva as well as the saliva-food mixture that might coat the tongue and other oral surfaces that are of fundamental importance for deglutition and satisfaction (Stokes et al., 2013). Although oral lubrication or friction provided by food is a crucial aspect of this fundamental biological process occurring in the mouth, its' mechanistic effects on psychological and physiological consequences implicated in altering the motivation to eat remain under-researched (Krop et al., 2018).

The present study was designed to address this fundamental knowledge gap using a cross-disciplinary approach. Here we report the effects of novel ‘biopolymeric hydrogel’ preloads on appetite ratings and food intake from both the ‘chewing’ and ‘oral lubrication’ perspective, of which the latter has never been used as a construct in satiety trials. For the purposes of this study, we have focussed only on the external lubrication effects, i.e. any lubrication induced by the food material properties and not due to saliva. The selected hydrogels had no energy content and varied in texture in two specific domains: the chewing as well as the lubrication properties. The main objective was to investigate which food design factor between chewing and lubrication might lower snack intake, and whether this is reflected in subjective appetite. The second objective was to study whether the hydrogel preload effects were variable according to eating context (eating alone or in a group). The first hypothesis tested was that greater chewing would result in a lower food intake relative to lower chewing. The second hypothesis was that greater oral lubrication would reduce snack intake relative to lower lubrication. We further predicted that participants in the group setting would eat more snack compared to participants eating alone due to social facilitation, but that the preload effect would occur in both eating contexts.

2. Materials and methods

2.1. Participants

The study was performed at the University of Leeds, UK. Participants were recruited using a poster campaign around the university campus, departmental recruitment emails and emails sent to a database with people who signed up voluntarily with an interest in participating in human studies. Healthy male and female volunteers were eligible for the study, aged between 18-55 years, without any dental deficiencies or problems with chewing or swallowing, that did not have any food allergies or intolerances to the used study foods and were not taking any medications that might influence appetite or food intake. The experimental protocol of this study was approved by the University of Leeds, School of Psychology Research Ethics Committee (reference number PSC-190) and all participants signed informed consent before their participation. The aim was to recruit 60 participants, 15 in each group, to match previous studies on chewing (see Higgs and Jones (2013)). Participants were not told of the exact aim of the study, instead they were told that the aim of the study was to investigate the effect of a mint stimulus on their perception of a salty snack. Students from the School of Psychology were awarded course credits for their participation, while other participants were entered into a prize draw with three participants being randomly selected to win a £10 shopping voucher as compensation.

2.2. Experimental design

The study followed a between-subjects design where participants were assigned to one of four conditions. According to availability, participants were allocated to group or alone test sessions and within this randomly assigned to the preload condition. In the different conditions, participants received one of four preload hydrogels with different chewing and oral lubrication properties (see **Figure 1**). To study the effect of social interactions, testing sessions took place either individually or in groups of five to six people.

2.3. Study foods

A standardised lunch was given to all participants prior to the start of the study. The lunch consisted of a cheese sandwich, apple, an oatmeal flapjack and ad libitum water. The sandwich was prepared using two slices (186 kcal/80 g) of Kingsmill medium sliced 50/50 bread (Allied Bakeries, UK), 12 g (84 kcal) Flora buttery margarine (Unilever, UK) and 32 g (133 kcal) grated British medium cheddar cheese. A Braeburn apple was washed and cut in slices, and 100 g (47 kcal) was weighed out. The sandwich and apple were presented with an individually wrapped flapjack slice (159 kcal/37 g) (see **Figure 2a)**. All products were purchased at a local supermarket. Participants were instructed to consume all the foods provided, containing 609 kcal in total. For the ad libitum snack, ready salted crisps (Walkers Snack Foods Ltd., UK) were provided (526 kcal/100 g).

For the preloads, novel mint flavoured hydrogels were selected based on their different chewing and lubrication aspects as characterised in our previous work (Krop et al., 2019), see **Figure 1**. The differences in chewing and lubrication were achieved by varying the concentration of different gelling agents, i.e. κ-carrageenan (κC) and sodium alginate (NaA), or by introducing calcium alginate beads (CaA) to create textural complexity. The 3κC represents a 3 wt% κ-carrageenan hydrogel with high chewing and low oral lubricating properties; 1.5κC0.5NaA represents a mixed 1.5 wt% κ-carrageenan and 0.5 wt% Na-alginate hydrogel with low chewing and high lubricating properties; and 2.4κC0.2CaA$_{300}$ denotes 2.4 wt% κ-carrageenan with a layer of 0.2 wt% Ca-alginate beads, 300 μm in diameter, with medium chewing and high lubricating properties (Krop et al., 2019). The hydrogels were presented in bite-size round pieces (diameter 25 mm, height 10 mm) in small, shot-glass type plastic cups. Samples were standardised by volume, and weighed about 5-6 g each (3κC: 5.8 ± 0.4 g, 1.5κC0.5NaA: 5.3 ± 0.3 g and 2.4κC0.2CaA$_{300}$: 5.8 ± 0.3 g). The hydrogels were unsweetened, but flavoured with peppermint aroma and coloured with green food colouring to increase acceptability, and contained less than one kcal. Peppermint tea (Pure Peppermint, Twinings, UK), purchased at a local supermarket and coloured with the same food colouring as the gels, was used as a control preload matching the peppermint flavour and green colouring. The tea was presented in the same cups and filled up to the same height as the hydrogel samples.

2.4. Characterisation of the hydrogels

The instrumental properties of the hydrogels were characterised as related to the chewing and the lubrication aspects using texture analysis and tribology, respectively (**Figure 1a**). The sensory properties were analysed using descriptive analysis (**Figures 1b and c**). More in-depth details on the methodology and results have been published elsewhere (Krop et al., 2019).

Uniaxial single compression tests were performed on the hydrogels with a TA-TX2 Texture Analyser Micro Systems Ltd., Surrey, UK) using a cylindrical probe (diameter 59 mm), attached with a 50 kg load cell. The tests were carried out at room temperature at a constant speed of 1 mm/s and the deformation level was set at 80% strain. Measurements were performed in triplicate on at least four different preparation days, and mean values of fracture stress were calculated.

Tribology measurements were performed on the hydrogels after simulated oral processing in presence of artificial saliva using a Mini Traction Machine (MTM2, PCS Instruments, London, UK). The smooth steel surfaces in this device, commonly used in engineering disciplines, were replaced by a polydimethylsiloxane (PDMS) ball and disc set-up at 37 °C to mimic the oral surfaces (surface roughness, $R_a < 50$ nm) (Laguna et al., 2017). The rolling speed was reduced from 1000 to 1 mm/s at a load of 2N, using a slide-to-roll ratio (SRR) of 50%, and the coefficient of friction in the mixed lubrication regime (50 mm/s) was measured in triplicate.

A panel of 11 participants (4 male, 28.8 ± 5.5 years old) selected sensory attributes for the hydrogels related to chewing and oral lubrication after three training sessions and rated their intensities on a 100 mm visual analogue scale (Krop et al., 2019).

2.5. Study procedure

A schematic overview of the timeline and study procedure can be found in **Figure 2a**. On the day of testing, participants were instructed to eat their normal breakfast and attend the lab at lunchtime between 12:00-13:00 h. All participants were asked about their age, self-reported body mass index (BMI), health and dietary preferences, and tested for eating restraint using the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien et al., 1986). In addition, participants were provided with one of the novel preloads used in this study (3κC gel), and were asked for their liking and preparedness to eat similar stimuli for the purposes of this study. Then, the standardised lunch was served to control for participants' hunger, and panellists.

Participants were asked to return to the lab 3 h after lunch for the snack, and instructed not to eat or drink anything besides water between sessions. Next, participants completed the pre-preload (t_1) appetite questionnaire, by rating their level of hunger, fullness, desire to eat, appetite, thirst, nausea, desire to eat something sweet and desire to eat something salty on a 100 mm visual analogue scale (VAS), anchored from 'not at all' to 'extremely'. After the appetite ratings, participants were offered the preload stimuli and 50 mL of water. Males received five units and females four to account for the difference in body size, and therefore the oral cavity, between men and women. Participants were instructed to finish the mint stimuli within 10 minutes by consuming the first mint stimulus followed by a sip of water until all mint stimuli and water were consumed. Afterwards, the perceptions of the mint stimulus were evaluated (VAS ratings), followed by another appetite questionnaire (t_2). Then, the participants were offered a snack of 100 g ad libitum ready salted crisps (pre-weighed amount, 526 kcal), as shown in **Figure 2a**. To distract the participants form the true nature of the study, they rated their desire to eat and pleasantness of the crisps after a first bite. After that, participants were instructed to eat a normal sized snack, eat as much as they liked within 15 minutes until they felt comfortably full, and to rate their sensory perception of the crisps.

Immediately after the snack, participants re-rated appetite (t_3) and answered a final debrief questionnaire, which invited participants to consider the true purpose of the study.

2.6. Oral processing characteristics

To analyse the eating behaviour and make sure participants followed the study protocol, a small selection of the participants were asked permission to video record them while eating the preload model food (n = 21). A digital camera (Panasonic SDR-H90) on a tripod was positioned in front of the participant, and participants were instructed to look straight into the camera while eating the preloads. Videos were analysed using The Observer XT 12 software (v12.5, Noldus Information Technology, The Netherlands). A coding scheme was created to analyse the chewing behaviour, including number of chews (**Figure 1a**) and eating duration, adapted from previous studies (Laguna et al., 2016). A chew was defined as the moment the jaw was at the lowest level during a masticatory cycle (closing action) and eating duration as the time between first bite and swallowing, identified as the first main swallow at the end of the rhythmic rotary chewing movements (**Figure 2b**). From these characteristics, the chewing frequency could be calculated by dividing the number of chews by the total eating duration (Forde et al., 2013; Laguna et al., 2016).

2.7. Statistical analysis

All statistical analyses were performed using SPSS (IBM® SPSS® Statistics, v24, SPSS Inc, Chicago, USA). Results are presented as mean ± standard error of mean (SEM), and significance level was set at $p < 0.05$ (2-tailed), unless stated otherwise. Differences between conditions were tested by independent factorial analysis of variance (ANOVA) for food intake and repeated measures to assess condition effects on appetite ratings, followed if appropriate by a post-hoc Bonferroni correction for multiple comparisons. Pearson's product moment correlations were calculated to assess the relationship between the different preload conditions and hunger ratings at the three different time points.

3. Results

3.1. Participants*' characteristics*

In total, 59 participants completed the study. Before the start of the study, the participants' liking and their preparedness to eat the novel preload foods (3*κ*C gel) were recorded. The mean liking for the test food was 35 ± 23 mm and all participants indicated they were willing to eat the model foods as part of this study. After data collection was completed, four participants were excluded from the analysis due to the following reasons – three participants ate less than 12.5 g of the snack, which is less than half the size of a normal portion, indicating that these participants had not complied with the instruction to eat a normal snack; one participant consumed all of the provided snack, and thus, exhibited the 'cleaning-the-plate' effect suggesting that eating was influenced simply by availability. Thus, the data for 55 participants (16 male, 39 female) were analysed (see **Table 1**). Participants ranged in age from 18 to 45 years (mean 26 ± 1 years) and BMI from 18 to 33 (mean 23 ± 0.4 kg/m^2). Eating restraint from the DEBQ showed that three males (>2.89) and six females (>3.39) were restrained eaters (van Strien et al., 1986), with a mean score of 2.17 ± 0.2 for males and 2.59 ± 0.1 for females.

3.2. Effect of oral processing on snack intake

The difference in oral processing between the three preloads, as characterised by video analysis, instrumental analysis (fracture properties and tribology) and sensory panel, is shown in **Figure 1**. The 3*κ*C hydrogel showed a high fracture stress (218 kPa) on compression as well as a high number of chews (**Figure 1a**), indicating that it is a hard gel that has to be chewed before swallowing. The coefficient of friction from the tribology measurements, however, was relatively high ($\mu = 0.26$), indicating that it has low lubricating properties. The opposite was found for the preload 1.5*κ*C0.5NaA, with low fracture stress (27 kPa) and correspondingly low number of chews, and low coefficient of friction ($\mu = 0.01$), indicating it is both low chewing and high lubricating. The sensory properties further corroborate this, as the chewing-related attributes, such as ‘firm’, ‘chewy’ and ‘elastic’, were rated high for 3κC and low for 1.5κC0.5NaA (**Figure 1b**). In addition, the 3κC hydrogel scored lower on the lubrication-related attributes, such as ‘smooth’, ‘pasty’ and ‘melting’, whereas 1.5κC0.5NaA scored higher on the same attributes (**Figure 1c**). The hydrogel with beads, 2.4κC0.2CaA$_{300}$, showed fracture stress (104 kPa), number of chews and chewing attribute ratings between the 3κC and 1.5κC0.5NaA samples, and therefore was characterised as medium chewing. The coefficient of friction of 2.4κC0.2CaA$_{300}$ was similar to that of the 1.5κC0.5NaA hydrogel, and therefore characterised as high lubricating, and 2.4κC0.2CaA$_{300}$ was scored as intermediate on the lubrication-related sensory attributes as well.

The amount of snack eaten was significantly different after the four preload conditions ($p < 0.01$), with snack intake suppressed by 32% after the soft/high lubricating mint stimulus (1.5κC0.5NaA, 37 ± 3 g) compared to the hard/low lubricating stimulus (3κC, 59 ± 6 g), see **Figure 3a**. The overall snack intake also differed between session types ($p < 0.01$), with the intake in the group sessions being higher (59 ± 4 g) than when eating alone (44 ± 3 g), as was expected due to the social setting. **Figure 3b** shows the difference in snack intake between conditions separated by session type (alone or in a group). No interaction effects were found between condition and session type ($p = 0.604$). Also, the effect of gender was analysed but main effects and interactions were not significant, consistent with previous research (Hetherington & Regan, 2011), therefore all subsequent analyses were reported for the group as a whole: male and female, and individual and group sessions together.

3.3. Effect of oral processing on subjective appetite ratings

Hunger ratings did not differ by condition, nor was there a significant condition by time interaction. However, the hunger ratings did change over the different time points (t_1 - t_3, see

Figure 4a), with a significant decrease over time (F(2, 102) = 14.87, $p < 0.001$). Post-hoc tests revealed that hunger at t_3 was significantly lower than at t_1 and t_2. There was no significant difference between ratings at t_1 and t_2. Similar effects were found for desire to eat (F(2, 102) = 14.15, $p < 0.001$) and appetite (F(2, 102) = 14.34, $p < 0.001$), see **Supplementary Figures 1a and 1b**. The fullness ratings mirrored those of the hunger, desire to eat and appetite ratings showing a significant time effect (F(2, 102) = 11.97, $p < 0.001$), where fullness ratings at t_3 were significantly higher than t_1 and t_2 ratings (see **Figure 4b**).

There was no significant effect of condition on thirst ratings (**Figure 4c**), nor was there any interaction effect of condition by time. However, there was an effect of time alone (F(2, 96) = 31.62, $p < 0.001$). Post hoc tests revealed that t_3 thirst was higher than at t_1 and t_2. Thirst ratings were also lower at t_2 compared to t_1 at the start of the second session. There were no interaction effects between conditions and time points, and there was no effect of condition on desire to eat something sweet or desire to eat something salty. However, desire to eat something sweet (F(2, 96) = 4.52, $p < 0.05$) and desire to eat something salty (F(2, 96) = 33.28, $p < 0.001$) did significantly change over time (**Supplementary Figures 1c and 1d**). To make sure none of the preloads invoked a stronger feeling of nausea, due to the novelty of the model foods or the presence of the hydrocolloids in the preloads, nausea was rated over time as well (**Figure 4d**). There was no significant main effect of preload condition or time point, nor was there any interaction effect of condition vs time.

3.4. Perception of the study foods

The pleasantness, strength of the mint flavour, sweetness or chewiness of the preload foods were rated on 100 mm VAS. One-way ANOVA indicated that pleasantness, mint flavour and sweetness did not differ between the preload conditions. However, the chewiness of the preload samples was significantly different (F(3, 51) = 31.30, $p < 0.001$). The post hoc test indicated that the mint tea (control sample) was not perceived as chewy at all (mean 3 ± 2 mm), the 1.5κC0.5NaA was significantly more chewy (mean 37 ± 8 mm) than the mint tea, and 3κC (mean 77 ± 7 mm) and 2.4κC0.2CaA$_{300}$ (mean 67 ± 6 mm) were the most chewy.

3.5. Correlations

Pearson correlations between chewiness of the preload and the snack intake showed that they were not related ($r = 0.056$, $p = 0.687$). Food intake between the different preloads also did not correlate with the perceived pleasantness ($r = -0.132$, $p = 0.338$) or any potentially induced nausea after eating the preload foods ($r = -0.189$, $p = 0.168$).

4. Discussion

The present study investigated whether model hydrogels with varying chewing and oral lubrication properties had a significant influence on self-reported appetite measures, such as hunger, fullness and desire to eat, as well as the intake of a snack. It was hypothesized that more chewing would lead to lower food intake, as reported in previous studies (Krop et al., 2018). Interestingly, results showed that snack intake was only lowered after the consumption of the soft/high lubricating preload sample (1.5κC0.5NaA) compared to the hard/low lubricating preload (3κC), suggesting that not the chewing but the lubricating properties governed subsequent intake of a salty snack. Sensory ratings for the different preloads did not reveal a significant difference in terms of pleasantness, strength of mint flavour or sweetness, and therefore these characteristics could not account for the suppressed food intake after the soft/high lubricating preload (1.5κC0.5NaA). Nevertheless, there was no significant difference between the soft/high lubricating preload (1.5κC0.5NaA) and medium/high lubricating preload (2.4κC0.2CaA$_{300}$). Therefore, it seems unlikely that the instrumental measure of coefficient of friction alone can explain the mechanism of lubrication behind the lower snack intake after the soft/high lubricating preload (1.5κC0.5NaA). Previous research analysing the hydrogel preloads using a sensory panel found that the soft/high lubricating preload (1.5κC0.5NaA) was rated more ‘smooth, ‘pasty’ and ‘melting’ compared to the medium/high lubricating preload (2.4κC0.2CaA$_{300}$), see **Figure 1c**, though they were rated similarly for other indices of lubrication (Krop et al., 2019). In particular, this pastiness was defined as ‘a sensation of the presence of wet/soft (immiscible) solids in the mouth’, which could result in a certain amount of mouth coating. Such mouth-coating aspects of sodium alginate (1.5κC0.5NaA) have previously been reported as related to a mouth moistening and hydrating property (Cook et al., 2017), which in turn might lead to a lower snack intake. To make sure this mouth-coating did not lead to any lingering feelings of nausea, the nausea ratings were checked and no significant differences were found between conditions after the consumption of any of the preloads.

Besides the difference in snack intake between 1.5κC0.5NaA and 3κC, snack intake after the hard/low lubricating (3κC) and tea (no chewing/low lubricating) did not show a significant difference, indicating that it was not the chewing properties that determined snack intake after the preload. This is not consistent with previous research, which showed that higher level of chewing did indeed reduce food intake (Krop et al., 2018; Lasschuijt et al., 2017; Lavin et al., 2002). This might be explained by the short exposure time of 10 minutes and the low amount of elicited chewing in this period, indicating that the total chewing time may not have been sufficiently long to influence food intake. Future research incorporating more hydrogel pieces into the preload to increase overall chewing time may find a more pronounced effect on food intake. However, there are other studies that confirm no impact of chewing on food intake (Julis & Mattes, 2007).

In addition, it was found that snack intake was greater in a group setting compared to eating alone, confirming the hypothesis that social interactions during a snack increases food intake (Redd & de Castro, 1992).

The effect size was considered relatively small, which is also consistent with previous research investigating oro-sensory stimulation (Hetherington & Regan, 2011). This may be related to a small effect of chewing or lubrication during oral processing, or the amount of preload gels (four or five units per participant) was rather small. The novelty of the preload hydrogels and their generally low rated pleasantness were a consideration in providing a limited amount of the preload foods (Pliner & Hobden, 1992), as well as not wanting to prevent any further food intake due to the volume of the preload. The present study also found that preload foods with varying chewing and oral lubrication properties did not significantly influence self-reported appetite measures, such as hunger, fullness and desire to eat, indicating that one preload did not lead to higher or lower self-reported appetite ratings than any of the other preloads. In addition, a decrease in hunger, desire to eat, appetite and desire to eat something salty, and an increase in fullness ratings were observed over time in the following snack intake in all preload conditions. Thus, this confirmed that the participants consumed the snack until satiety was reached.

5. Limitations

Limitations of the study include the lack of a fully factorial design with model foods representing hard/high lubricating and soft/low lubricating properties. In a future replication study, hydrogels with these qualities could be developed to improve the matrix for comparisons. In addition, the in-vivo oral lubrication effects of the preloads, i.e. the lubrication contributed by the bio-lubricant saliva (internal) versus hydrogels (external), were not checked whereas the chewing properties were measured by video analysis of the chewing behaviour. Furthermore, the sample size was smaller than planned and this limits extrapolation from this study; future studies should use a larger sample. Also, the use of ready salted crisps as a salty snack in the current study may have influenced the results. Liking for the crisps may have overshadowed the chewing and oral lubrication effects of the preloads. A larger effect may have been found had we included a sweet snack since intake is influenced by individual food preferences. On the other hand, increasing variety by providing both salty and sweet snacks might stimulate appetite and increase intake (Rolls et al., 1981), and overpower any effects due the preloads.

An independent between-subjects design was used in the present study to facilitate easier panel recruitment and flexibility. Better results might have been obtained with a within-subjects design where the random noise would be minimized (Stone & Sidel, 2004). However, a within-subjects design would have resulted in increased familiarity with the preload hydrogels, and would be associated with increased expected satiation and satiety.

6. Conclusions

The aim of this study was to investigate whether chewing and lubrication during oral processing, manipulated by hydrogel preloads, influenced snack intake and self-reported appetite ratings. Results from this proof-of-concept study demonstrated that snack intake was reduced following the soft/high lubricating preload relative to the hard/low lubricating preload, which was not predicted. The mechanism by which oral lubrication rather than chewing played a prominent role in reducing subsequent food intake of a salty snack was associated with the sensory 'mouth-coating' aspects of the preload; however, exact biological cross-talk between mouth-coating, tactile perception and mechano-receptor stimulated satiation, as well as the role of food material-saliva interactions in both satiation and satiety, demand systematic future studies.

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Declarations of interest

None.

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Figure legends

Figure 1. Schematic representation of the three different preload gels made up of a κ-carrageenan (κC) gel matrix alone or with the addition of sodium alginate (NaA) or calcium alginate beads (CaA) to create distinct chewing and lubrication properties. These properties were based on instrumental characterisation by texture analysis (fracture properties) and tribology (the inverse of the coefficient of friction at 50 mm/s is a measure of oral lubrication at orally relevant speeds), as well as characterisation of the oral processing behaviour (number of chews) using frame-by-frame video analysis (a). The sensory properties (mean ± SD) of the same hydrogels were evaluated using descriptive analysis as related to either chewing (b) or oral lubrication (c), with 3*κ*C (■), 1.5*κ*C0.5NaA (■), 2.4*κ*C0.2CaA$_{300}$ (■). Data was adapted from Krop et al. (2019).

Figure 2. Timeline and study procedures of each experimental phase with appetite ratings scored on visual analogue scales (VAS) as a function of time (a). Frame-by-frame video

analysis of oral processing behaviour (eating duration from first bite to swallowing and number of chews) (b).

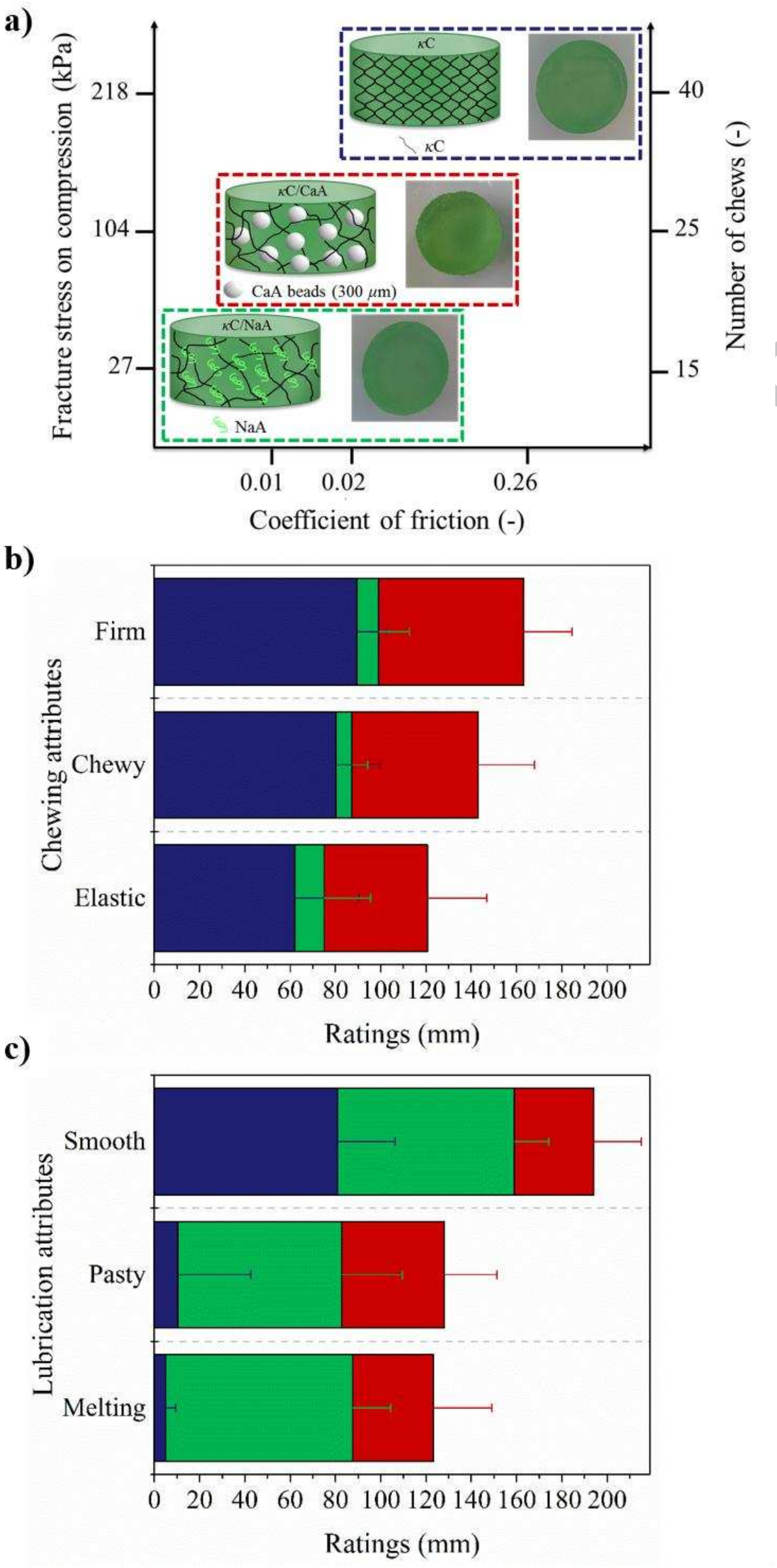
Figure 3. Mean (± SEM) snack intake after the four preload conditions (a) and mean (± SEM) snack intake split between the individual sessions (solid fill, n = 34) and group sessions (diagonal lines, n = 21) (b), with 3κC (■), 1.5κC0.5NaA (■), 2.4κC0.2CaA$_{300}$ (■) and mint tea (■). Different lower case letters indicate statistically significant differences between conditions ($p < 0.05$).

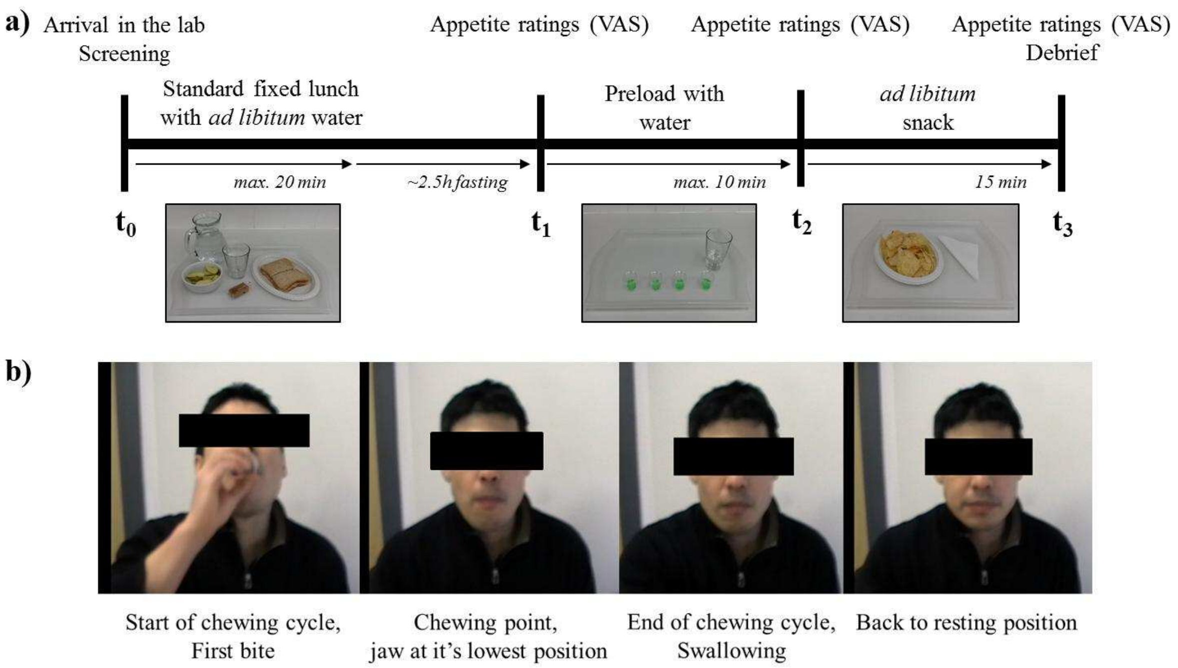
Figure 4. Mean (± SEM) hunger (a), fullness (b), thirst (c) and nausea (d) ratings over time for the four preload conditions, with 3κC (□), 1.5κC0.5NaA (▲), 2.4κC0.2CaA$_{300}$ (●) and mint tea (▽), and t_1 before preload, t_2 immediately after preload and t_3 immediately after the snack. Asterisks (*) indicate statistically significant differences ($p < 0.05$).

Tables

Table 1. Number of participants in the different preload conditions and eating contexts, as well as the mean (± SEM) age and BMI values for the different participant groups.

	Total	Male	Female	Age (years)	BMI (kg/m^2)
3κC	**13**	5	8	29 ± 3	22.6 ± 0.5
Individual	8	5	3		
Group	5	0	5		
1.5κC0.5NaA	**13**	3	10	23 ± 2	21.8 ± 0.8
Individual	7	2	5		
Group	6	1	5		
2.4κC0.2CaA$_{300}$	**15**	3	12	27± 2	22.7 ± 0.9
Individual	10	2	8		
Group	5	1	4		
Mint tea	**14**	5	9	26 ± 1	25.0 ± 1.0
Individual	9	3	6		
Group	5	2	3		
Total	**55**	**16**	**39**	**26 ± 1**	**23.0 ± 0.4**
Individual	34	12	22		
Group	21	4	17		


a)
Fracture stress on compression (kPa)
218
104
27
Number of chews (-)
40
25
15
Coefficient of friction (-)
0.01
0.02
0.26
κC
κC
κC/CaA
CaA beads (300 μm)
κC/NaA
NaA
b)
Chewing attributes
Firm
Chewy
Elastic
0 20 40 60 80 100 120 140 160 180 200
Ratings (mm)
c)
Lubrication attributes
Smooth
Pasty
Melting
0 20 40 60 80 100 120 140 160 180 200
Ratings (mm)



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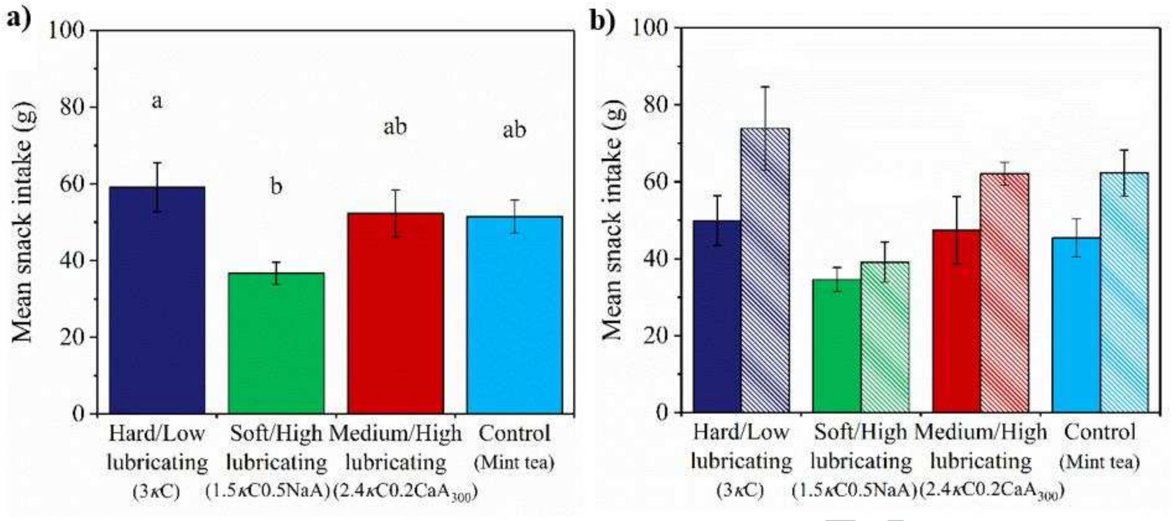
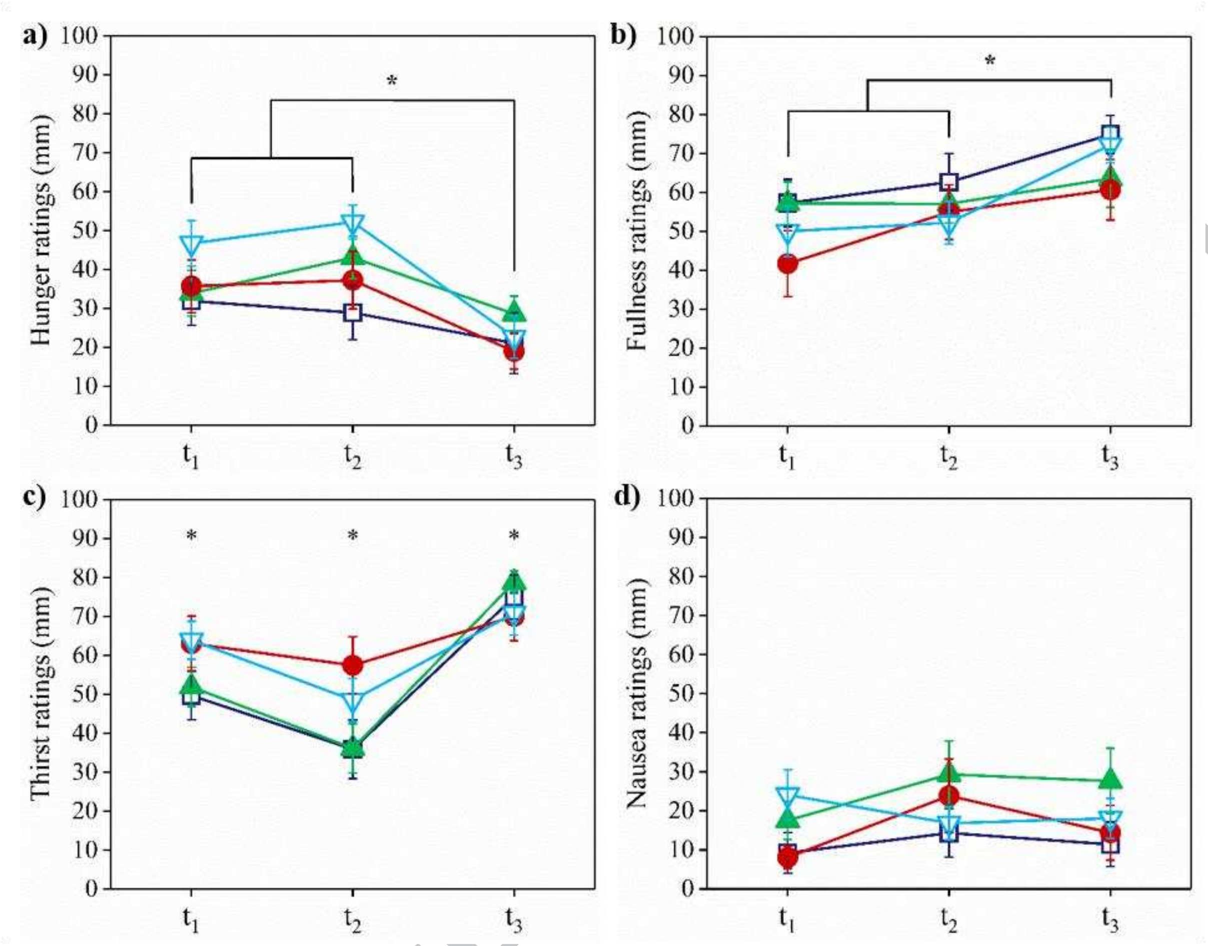

a)
b)
Mean snack intake (g)
0
20
40
60
80
100
a
b
ab
ab
Hard/Low lubricating (3κC)
Soft/High lubricating (1.5κC0.5NaA)
Medium/High lubricating (2.4κC0.2CaA300)
Control (Mint tea)


a)
Hunger ratings (mm)
100
90
80
70
60
50
40
30
20
10
0
*
t$_1$
t$_2$
t$_3$
b)
Fullness ratings (mm)
100
90
80
70
60
50
40
30
20
10
0
*
t$_1$
t$_2$
t$_3$
c)
Thirst ratings (mm)
100
90
80
70
60
50
40
30
20
10
0
*
*
*
t$_1$
t$_2$
t$_3$
d)
Nausea ratings (mm)
100
90
80
70
60
50
40
30
20
10
0
t$_1$
t$_2$
t$_3$

FQAP short communication highlights

The influence of oral lubrication on food intake: a proof-of-concept study

- Increased chewing is known to enhance satiation
- Hydrogels were engineered to vary in chewing and oral lubrication
- Gels were then consumed by volunteers before a snack
- Unexpectedly a 32% reduction in snack intake was found following a *low chewing/high lubricating* gel compared with a *high chewing/low lubricating* gel
- Lubrication therefore may offer a construct to promote satiation