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Viscosity of food influences perceived satiety: a video based online survey

*Ecaterina Stribiţcaia[a], John Blundell[b], Kwan-Mo You[a], Graham Finlayson[b], Catherine Gibbons[b], Anwesha Sarkar[a]**

[a] Food Colloids and Bioprocessing Group, School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, United Kingdom

[b] Appetite Control and Energy Balance Research, School of Psychology, University of Leeds, Leeds LS2 9JT, United Kingdom

*Corresponding author:
Prof. Anwesha Sarkar
Food Colloids and Bioprocessing Group,
School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK
E-mail address: A.Sarkar@leeds.ac.uk

Highlights

- A video-based survey was designed to assess how viscosity affects perceived satiety
- Flow behaviour of whey protein beverages containing xanthan gum was video-recorded
- High and medium viscous beverages were perceived to be more satiating (n=211)
- Visually perceived sensory attributes influenced the perception of satiety
- Video-based questionnaire could be a feasible tool to do remote sensory testing

Abstract

Food texture seems to offer a promising strategy for the control of expected satiety, satiety, satiation and daily caloric intake. The aim of this study was to examine the effect of food texture, more specifically the effect of different levels of viscosity, on perceived satiety through an online survey where the viscosity levels of protein-based beverages were visually perceived using a newly developed video-based demonstration. Whey protein beverages were prepared with viscosities being manipulated using xanthan gum and their viscosity and tribological properties were measured instrumentally. Subjects (n=211) watched beverages being poured in videos streamed online and were instructed to imagine drinking them. The results showed that instrumentally measured HV (high viscous) and MV (medium viscous) beverages were visually perceived by the participants as being more satiating immediately and 2 h later after the imagined drinking event as compared to LV (low viscous) beverages ($p<0.05$). Also, sensory attributes such as visually perceived smoothness, thickness, creaminess and watery were shown to be important factors in the perception of satiety (the creamier or thicker the beverage the higher the perceived satiety scores). Therefore, a video-based online demonstration is a highly feasible and convenient tool to measure the effect of food texture on perceived/expected satiety that can be useful in Covid-19 pandemic situation, latter necessitates online participation in many situations. More importantly, key role of food/beverage texture expressed through visual cues alone, may open new avenues of informing consumers about the degree of the perceived satiety/fullness even before the product is consumed.

Keywords: Video recording; questionnaire; expected satiety, food texture; rheology; lubricity

1. Introduction

Obesity is recognised as a major risk to the health of people across the world, and the problem is increasing dramatically (Deitel, 2003). The prevalence of obesity has nearly tripled over the last decades (WHO, 2018). Moreover, the overconsumption of foods is seen as one of the major determinants of obesity. Consequently, there has been a growing interest among scientists and food industries to design satiety-enhancing foods/beverages that would facilitate appetite control and would lead to a lower food intake in order to address global obesity crisis (Blundell, 2010; Chambers, McCrickerd, & Yeomans, 2015; Halford & Harrold, 2012).

Among the many features of food that influence eating and therefore affect satiety, food texture seems to be a promising strategy in the control of satiety, satiation and daily caloric intake (Stribiţcaia, Evans, Gibbons, Blundell, & Sarkar, 2020a). Satiation is the process believed to lead to the termination of eating, while satiety is the process that leads to the inhibition of the further eating during the inter-meal period (Blundell, et al., 2010). Recently a systematic review and a meta-analysis showed that texture of food may play a role in appetite control and the amount of food people eat, revealing that solid and high viscous foods/beverages can suppress appetite and reduce food intake to a greater degree when compared to liquid and low viscous foods/beverages (Stribiţcaia, et al., 2020a).

Moreover, it has been shown that food texture can also have an effect on expected satiety indicating that subtle manipulation of texture can increase expectations where thick drinks showed a greater expected satiety compared to thin drinks (McCrickerd, Chambers, Brunstrom, & Yeomans, 2012). Expected satiety is the extent to which foods/beverages are expected to confer satiety when they are compared on a calorie-for-calorie basis and has been studied along with portion/plate size, energy density, macronutrients, labelling, food texture and other factors (Brunstrom, Collingwood, & Rogers, 2010; Chambers, Ells, & Yeomans, 2013; Crum, Corbin, Brownell, & Salovey, 2011; Nguyen & Varela, 2021; Nguyen, Wahlgren, Almli, & Varela, 2017). Considering texture, the literature indicates an independent effect on expected satiety. For instance, Hogenkamp et al. (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011) showed that texture rather than flavour determines expected satiety, where solid and semi-solid foods were perceived as being more satiating than liquid and semi-liquid foods. In addition, McCrikered et al. (McCrickerd, et al., 2012) reported an effect of texture on expected satiety independently of energy load; thicker drinks (more viscous) were perceived by participants as being more filling than thinner drinks (less viscous). As such, the strong effect of texture alone on expected satiety was notable.

The mechanism by which food texture may influence expected satiety is that, from a cognitive perspective consumers may 'feel' that solid foods or thick beverages are more likely to be filling than liquid foods or thin beverages. In other words, consumers perceive that solid foods/thick beverages will contain more energy compared to liquid foods/thin beverages independent of their actual calories (de Graaf, 2012). Moreover, the perception of the role of food texture on satiety and satiation may be influenced through oro-sensory exposure time. It is known that solid foods/thick beverages need longer oral processing time as compared to liquid foods/thin beverages (Krop, et al., 2018). This may lead to an increased oro-sensory exposure and appears to be essential in the perception of satiety or expected satiety (McCrickerd, et al., 2012). Accordingly, the learned experience or the learned association between the sensory attributes of food and the metabolic response of the food after ingestion may explain the way consumers perceive/anticipate the satiating capacity of the food they are consuming.

Interestingly, the literature on food texture and expected satiety contains studies where participants are given the product to taste it and are then asked to evaluate its filling properties or its expected satiety using various forms of questionnaires (Hogenkamp, et al., 2011; McCrickerd, et al., 2012). Such studies are invariably laboratory-based. There has been some online work/survey on expected satiety in relation to macronutrient composition and energy load of the products/food (Buckland, Stubbs, & Finlayson, 2015), where perceived satiety was associated with lower energy density, lower fat and higher protein. However, less is known about the effect of food texture on expected satiety when assessed indirectly through online surveys using visual cues.

Recently, online surveys have become recognised as an efficient tool, and have been used to adjust and adapt the research to the current Covid-19 related pandemic situation; and to gather data in a faster, easier and more sustainable way (Bayudan-Dacuycuy, Orbeta Jr, Serafica, & Baje, 2020; Berg, Furrer, Harmon, Rani, & Silberman, 2018). In this context, an online survey clearly cannot directly measure a person's response to the taste or textural differences between foods. However, an interesting question arises about whether the effects of texture can be evaluated when foods are presently visually in a screen-based survey when the visual perception of texture of a beverage can be demonstrated using a video-recording. In such a situation, would visual cues alone be enough to convey the texture of a food to influence the feeling of perceived fullness?

A further factor to consider is whether food texture conveyed through such video-recording based visual cues influences food reward which incorporates the dimensions of "liking" and "wanting" (Finlayson, King, & Blundell, 2007). According to the definitions of Berridge, liking refers to the palatability (pleasure of eating a given food) and wanting refers to the disposition to eat (Berridge, 1996; Berridge, 2007). It is known that food with higher palatability can lead to a greater food intake (Spiegel, Shrager, & Stellar, 1989). Moreover, seeing the preferred food can increase hunger (Hill, Magson, & Blundell, 1984) suggesting that the palatability of food may have an effect on anticipated stimulation of appetite. However, little is known in regard to "liking" and "wanting" from a textural perspective of food and expected satiety. Therefore, liking and wanting was measured in this planned online video-based survey.

It is also known that sensory attributes can influence the expected satiety (Forde, Almiron-Roig, & Brunstrom, 2015). For instance, manipulating the thickness level in beverages can lead to different sensory perception in terms of smoothness and creaminess (Camps, Mars, De Graaf, & Smeets, 2016). It was shown that the more viscous the beverage was, the participants perceived them as being smoother and creamier. Therefore, it was important to investigate if such differences in sensory attributes such as smoothness (i.e. (absence of lumps), creaminess can be also observed or detected, to some extent, in video-based online survey. Furthermore, it was worth investigating whether there could be any relationship between such sensory attributes and expected satiety, in other words if sensory attributes can influence the perceived/expected satiety to some extent.

Understanding if food texture can have an impact on the way consumers perceive its filling/satiating value (before they consume the product/food) could be important to enable them to choose more filling/satiating food that would contribute to the overall control of consumption. In turn, this would inform the food industry sector on the development of satiety enhancing foods/beverages. Therefore, the aim of this study was to assess the effect of food texture, more specifically the effect of different levels of viscosity on perceived/expected satiety or on ratings of fullness through an online survey where the viscosity levels were demonstrated using video recording of samples. In other words, the impression of viscosity of the foods was conveyed by means of a video of beverages, varying in thickness/viscosity, being poured from one container to another. The beverages were prepared using whey protein with viscosity being manipulated using xanthan gum and their viscosities and tribological properties were measured instrumentally. Also, we investigated if there is a relationship between liking and wanting of beverages differing in their texture/viscosity, and perceived satiety or perceived fullness. The relationships among other visually perceived sensory attributes, such as smoothness, watery, creaminess and perceived satiety/fullness were also assessed. As a secondary aim, we also investigated whether there was any relationship between instrumentally measured parameters and visually perceived texture/ sensory attributes. In summary, this investigation employed a highly feasible yet simple method of an online survey with video recordings of food samples to assess the impact of the perception of food texture (viscosity) observed in the screen on perceived satiety and on elements of food reward and can be a highly feasible remote sensory testing approach in current pandemic situation.

2. Materials and methods

2.1. Participants

Participants (n=245) were recruited through University email distribution lists, social network platforms and Prolific online participant recruitment platform. Adults >18 years old possessing basic level of English skills (reading/ writing) could take part in the survey. From the total number of the participants who entered the survey, 87.92% (n=211, 57.1% females (121)) completed the entire survey. Of the whole sample who completed the survey (n=211), 37.7% (n=80) were employed full-time, 36.3% (n=77) were students, 12.7% (n=27) were employed half-time, 8.9% (n=19) were unemployed, 2.4% (n=5) were housewife/ househusband, 0.5% (n=1) were retired, 0.5% (n=1) were unable to work due to health disability and 0.5% (n=1) preferred not to declare their employability status. Participants were aged 18-64 years (average 28.95 ± 9.34) with a BMI calculated from self-reported height and weight that ranged between 17.44-52.66 kg/m^2 (average 25.01 ± 6.68).

2.2. *Beverages preparation and characteristics*

All the beverages were designed and prepared in the Food Science and Nutrition School Pilot Plant at the University of Leeds. The beverages were made from whey protein isolate powder – 15 g per 100 mL water. The viscosity of the beverages was manipulated by adding xanthan-gum (see Table 1 for the recipe of the beverages). The beverages had three levels of viscosity: low viscous (no xanthan-gum added), medium viscous (0.5 g xanthan-gum per 100g of solution) and high viscous (1 g xanthan-gum per 100 g of solution). A total of 200 mL of protein beverage was prepared for each condition. Whey protein isolate was purchased from MYPROTEIN (Manchester, UK). The xanthan gum was purchased from Special Ingredients (Special Ingredients Ltd, Chesterfield, UK). The whey protein powder was dissolved in distilled water and left to stir on a magnetic stirring plate for 2 h until a complete hydration was obtained. Afterwards, xanthan gum was added to the protein solution and the solution was left to stir for 2 h. Finally, the beverages were blended for 1 min with a hand blender (Braun, Germany). Immediately after preparation, short videos of each beverage were recorded.

2.3. *Videos of the beverages*

Each beverage was placed on a mini portable photo studio box (Bodhi200, UK) and short videos were taken of each beverage using a video camera (mobile phone camera). Each video shows the beverages being poured from one container into another (Fig.1- screenshot of the videos). For the full videos see Supplementary Table S1. A total of 200 mL of each protein solution (low, medium and high viscous) was poured into a transparent glass, where the viscosities were measured instrumentally. On average, each video lasted 12 s. In each video, a label about the protein content was added: high and low. As such, participants saw 6 short videos containing beverages differing in their viscosity (3 levels – low, medium and viscous) and protein content (2 levels – low and high). Hereafter, the beverages are referred throughout the article as: LVLP (low viscous/ low protein), LVHP (low viscous/ high protein), MVLP (medium viscous/ low protein), MVHP (medium viscous/ high protein), HVLP (high viscous/ low protein) and HVHP (high viscous/ high protein). Note, the protein content was not changed in the actually prepared beverages. As this study presented visual cues, the protein content was indicated only using the labels. There was no actual differential manipulation of protein content (all samples contained a standard 30 g whey protein). The label manipulation was included to test any possible effect of a perceived protein difference on the ratings of visually perceived satiety.

2.4. Apparent viscosity and lubricity of the beverages

The apparent viscosity of the beverages was measured with a rheometer (Kinexus Ultra+, Malvern Instruments Ltd, Worcestershire, UK) using a plate-plate geometry (diameter 60 mm) with a gap size of 0.5 mm. The samples were sealed off with a thin layer of silicone oil to prevent evaporation. Flow curves were obtained for all beverages after simulated oral processing at shear rates ranging from 0.01 to 1000 s^{-1} at 37 °C. A minimum of three replicates were measured for each beverage sample.

Although it is very difficult or almost impossible to assess lubricity visually, an instrumental analysis of frictional coefficients was performed. It is known that lubricity of food/ beverages can be translated into sensory attributes that can be perceived by consuming the food such as smoothness, pastiness or creaminess that can also influence satiety (Krop, Hetherington, Holmes, Miquel, & Sarkar, 2019; Krop, Hetherington, Miquel, & Sarkar, 2019; Sarkar & Krop, 2019; Sarkar, Soltanahmadi, Chen, & Stokes, 2021; Stribiţcaia, et al., 2021; Stribiţcaia, Krop, Lewin, Holmes, & Sarkar, 2020b). A soft tribology measurement was carried out to measure the lubricating properties of the beverages and a relation (if any) between these (instrumental and visually perceived sensory attributes) was examined. Lubricity of the beverages was measured using a MTM2 Mini-Traction Machine (PCS Instruments, UK). Polydimethylsiloxane (PDMS) ball (diameter of 19 mm, MTM ball Slygard 184, 50 Duro, PCS Instruments, London, UK) and disc (diameter of 46 mm, thickness of 4 mm) were used for the measurements (surface roughness of PDMS tribopairs, $R_a < 50$ nm). Approximately 30 g of the protein beverages of different viscosities was loaded onto the pot equipped with the PDMS disc; the ball was lowered onto the disc and then the pot was covered with a lid. The entrainment speed was decreased from 0.3 to 0.001 m s^{-1}, and the friction coefficients were recorded at slide-roll-ratio of 50 % at 2 N load with a Hertzian contact pressure of ~200 kPa (Sarkar, Andablo-Reyes, Bryant, Dowson, & Neville, 2019). The temperature was set and maintained at 37 °C, to imitate the temperature at which oral processing occurs. A minimum of three repetitions were carried out for each sample.

2.5. *Measure of perceived satiety, liking, wanting and sensory attributes*

Participants rated visually perceived satiety/fullness, liking, wanting, sensory attributes of the beverages (smoothness, thickness, creaminess, watery) and initial appetite sensations (before rating the perceived satiety of the beverages) using a visual analogue scale (VAS) of 100 mm anchoring from ‘Not at all’ to ‘Extremely’, which has been shown to be valid and reliable for appetite research (Flint, Raben, Blundell, & Astrup, 2000; Stubbs, et al., 2000), including expected satiety (Forde, et al., 2015). Participants were asked to rate perceived satiety immediately after observing the pouring of the protein beverages in the video and 2 h later. Participants were instructed to imagine how full they would be immediately after drinking the beverages and 2 h later. Table 2 shows the questions showed to the participants in the video-based online questionnaire used to assess all the subjective attributes mentioned above.

2.6. *Procedure*

After receiving the invitation to take part into the online survey, participants clicked on a link that directed them to the on line survey (Qualtrics XM Platform, USA, www.qualtrics.com). The experimental protocol of this study was approved by the University of Leeds, Faculty Research Ethics Committee (AREA 20-133, June 2021). Firstly, participants were provided with a participant information sheet with details about the survey and then informed consent was obtained before participants could proceed further. Participants then indicated their age, gender, employment status, self-reported their height and weight, and rated their initial appetite (hunger, fullness, desire to eat, prospective food consumption and thirst) on a VAS scale of 100 mm anchored from 'Not at all' to 'Extremely'. After this, participants were presented with the first video showing the beverage being gradually poured into a transparent glass (see Fig.1 for screenshot and Supplementary Table S1 for full videos). Participants were asked to watch each video carefully once or twice and answer several questions (see Table 2 for the questions) related to the video they had just watched. In total, there were 6 videos showing different textures (3 levels – low viscous, medium viscous and high viscous) and labels of protein content (2 levels – low protein and high protein). Each video followed by questions was presented on a separate page. After completing the survey, participants entered in to a prize draw to win 1 × £50, 2 × £20 and 3 × £30. Participants who were recruited through Prolific platform have been remunerated according to the platform suggestion - £7.5/h. Between 15 and 25 min were needed to complete this video-based online survey.

2.7. *Statistical analysis*

Data are presented as mean and standard deviations (SDs) in the text and tables, and as means and standard errors of means (SEMs) in the figures. All statistical analyses were performed using SPSS (IBM® SPSS® Statistics, v26, SPSS Inc, Chicago, USA). Differences between conditions were tested by repeated measures ANOVA for perceived satiety/ fullness. The differences in sensory attributes: smoothness, thickness, watery, creaminess, and liking and wanting of the protein beverages, were also assessed by repeated measures ANOVA. 3 × 2 level factorial repeated measure ANOVA was used to examine the main effect of the texture/viscosity (LV, MV, HV), protein content (LP, HP) and texture*protein content interaction on perceived satiety/fullness ratings. Where the assumption of sphericity had been violated, indicated by Mauchly's test, Greenhouse-Greisser corrected tests are reported. Statistical significant differences were calculated by Bonferroni corrected post-hoc t-tests and was set at $\alpha < 0.05$ level. Pearson correlations were performed to assess the relationship between perceived satiety/fullness ratings and sensory attributes and liking and wanting. Relationship between initial hunger state/rating and the perceived/expected satiety was assessed. In addition, the relationship between instrumental analysis and visually perceived sensory attributes were evaluated.

3. Results

3.1. Instrumental characteristic of the beverages and the relationship with visually perceived sensory attributes

Figure 2a shows the apparent viscosity of the beverages. It can be seen that the level of viscosity differed significantly between the beverages at orally relevant shear rate of 50 s^{-1} with HV (high viscous) having the highest mean: 321 mPa.s; followed by MV (medium viscous): 102 mPa.s and LV (low viscous): 15 mPa.s. In other words, addition of xanthan gum had a marked effect on increasing the viscosity of the whey protein beverages (Philips & Williams, 2000). Both HV and MV had a classic shear-thinning behaviour but LV had a Newtonian behaviour (Supplementary Fig. S1a). The difference in viscosity between the beverages was also obvious from the video demonstrations (see Supplementary Table S1).

In terms of the lubricity of the beverages (Fig. 2b), a significant difference between the friction coefficient of HV and LV, and between MV and LV beverages was observed in the boundary lubrication regime only (BL 0.001 m s^{-1}) (see Supplementary Fig. S1b for the friction coefficient versus entrainment speed curves). This means that the LV beverage containing no xanthan gum was the most lubricating as compared to the MV and HV ones (the lower the friction of coefficient the higher the lubricating properties of food/beverages) in the BL owing to the surface properties of whey protein, which has been previously reported (Kew, Holmes, Stieger, & Sarkar, 2021; Zembyla, et al., 2021).

A statistical relationship (see Table 3) between visually perceived smoothness and friction coefficient in boundary regime (BL 0.001 and BL 0.005; r=-0.909, $p<0.05$; r=-0.999, $p<0.001$ respectively) was noted. This means that the lower the friction coefficient (which means higher lubricating properties of the beverages), the higher the perceived of smoothness; and this suggests that ‘smoothness’ can be an important lubricating-related attribute (Kokini, Kadane, & Cussler, 1977; Upadhyay & Chen, 2019). More importantly, this suggests visually perceived smoothness inversely correlates with friction coefficient, which is similar to that obtained using taste-based perception of smoothness reported previously (Upadhyay & Chen, 2019). In addition, there was a positive relationship between smoothness and watery ($r = .930$, $p<0.001$) and an inverse relationship between smoothness and thickness ($r = -.932$, $p<0.001$), which was not expected. Creaminess (r=-0.953, $p<0.001$) and thickness (r=-0.996, $p<0.001$) were found to inversely correlated with watery, which appears to be logical.

3.2. Effect of protein beverages differing in texture on perceived satiety (immediate and 2 h later)

The effect of protein beverages differing in viscosity and protein label content on perceived satiety is shown in Fig. 3a (see Supplementary Table S2a for means and SDs values). There was an effect of viscosity (F(2,420) =240.06, $p<0.001$), no effect of protein label content (F(1,210) =2,53, $p=0.113$), and there was an interaction between texture*protein label content on perceived satiety/fullness immediately after drinking (F(2,420) =4.922, $p=0.008$). The pairwise comparison tests revealed that in the low protein label content condition immediate perceived satiety/fullness was significantly higher in HV compared to LV ($p<0.05$) and in MV compared to LV ($p<0.05$). The same pattern was noted in high protein content, where perceived satiety/fullness was significantly higher in HV compared to LV ($p<0.05$) and in MV compared to LV ($p<0.05$). Also, here perceived satiety/fullness was significantly higher in HV compared to MV ($p<0.05$).

The effect of protein beverages differing in viscosity and protein label content on perceived satiety after 2h is shown in Fig. 3b (see Supplementary Table S2b for means and SDs values). There was an effect of viscosity (F(2,420) =177.379, $p<0.001$), no effect of protein content (F(1,210) =1.384, $p=0.241$), and no effect of interaction texture*protein label content on perceived satiety/fullness 2 h later (F(2,420) =0.154, $p=0.857$). The pairwise comparison tests revealed that in the low protein label content condition, the perceived satiety/fullness 2 h later was significantly higher in HV compared to LV ($p<0.05$) and in MV compared to LV ($p<0.05$). Also, here perceived satiety/fullness was significantly higher in HV compared to MV ($p<0.05$). In the high protein content, perceived satiety/fullness was significantly higher in HV compared to LV ($p<0.05$) and in MV compare to LV ($p<0.05$).

3.3. Visually perceived sensory evaluation, and liking and wanting of the beverages

The means and SDs values of the visually perceived textural attributes, liking and wanting of the beverages are shown in Table 4.

Smoothness. There was an effect of viscosity (F(2,416) =295.275, $p<0.001$), no effect of protein label content (F(1,208) = 0.376, p=0.540), and no interaction between texture*protein label content on the perception of smoothness (F(2,416) =0.204, $p=0.816$). The pairwise comparison tests revealed that in the low protein content condition perceived smoothness was significantly higher in LV compared to MV and HV ($p<0.05$). In the high protein condition, again, perceived smoothness was higher in LV compared to MV and HV ($p<0.05$). Also, here perceived smoothness was higher in MV compared to HV ($p<0.05$).

Thickness. There was an effect of viscosity (F(2,420) =477.113, p<0.001), an effect of protein label content (F(1,210) =121.528, $p<0.001$), and there was an interaction between texture*protein label content on the perception of thickness (F(2,420) =54.104, $p<0.001$). The pairwise comparison tests revealed that in the low protein content condition perceived thickness was significantly higher in MV and HV compared to LV ($p<0.05$). In the high protein condition, again, perceived thickness was higher in HV compared to MV and LV ($p<0.05$). Also, here perceived thickness was higher in MV compared to HV ($p<0.05$).

Creaminess. There was an effect of viscosity (F(2,420) =114.439, $p<0.001$), an effect of protein label content (F(1,210) =108.394, $p<0.001$), and there was an interaction between texture*protein label content on the perception of creaminess (F(2,420) =54.81, $p<0.001$). The pairwise comparison tests revealed that in the low protein label content condition perceived creaminess was significantly higher in MV and HV compared to LV ($p<0.05$). In the high protein condition perceived creaminess was higher again in HV compared to MV and LV ($p<0.05$).

Watery. There was an effect of viscosity (F(2,416) =429.867, $p<0.001$), an effect of protein label content (F(1,208) = 68.902, $p<0.001$), and there was an interaction between texture*protein label content on the perception of wateriness (F(2.416) =71.228, $p<0.001$). The pairwise comparison tests revealed that in the low protein label content condition perceived wateriness was significantly higher in LV compared to MV and HV ($p<0.05$). In the high protein condition, again, perceived wateriness was higher again in LV compared to MV and HV ($p<0.05$).

Liking. There was an effect of viscosity (F(2,420) =4.194, $p=0.016$), but no effect of protein label content (F(1,210) =3.173, $p=0.076$), and an interaction between texture*protein label content on liking of the beverages (F(2.420) =5.275, $p=0.005$). The pairwise comparison tests revealed that in the low protein label content condition liking was significantly higher in LV and MV compared to HV ($p<0.05$). In the high protein condition, there was no significant difference between beverages ($p>0.05$).

Wanting. There was no effect of viscosity (F(2,412) =0.096, $p=0.908$), or effect of protein label content (F(1,206) = 0.005, $p=0.943$), or interaction between texture*protein label content on wanting of the beverages (F(2,412) =0.218, $p=0.804$). The pairwise comparison tests revealed that neither in the low protein label content nor in the high protein label content condition was there any significantly difference in wanting between the beverages ($p>0.05$).

3.4. Relationship between visually perceived sensory attributes, liking, wanting, initial hunger and perceived satiety/fullness.

It is important to understand the relationship (if any) between the visually perceived sensory attributes (*e.g.* smoothness, creaminess, thickness and watery), liking and wanting with the perceived satiety. There was a positive relationship between thickness and immediate perceived satiety, and perceived satiety 2 h later in all conditions: LVLP, MVLP, HVLP, LVHP, MVHP and HVHP, (*p=0.01*) (see Supplementary Table S3 – a, b, c, d, e, and f). Also, a positive relationship was noted between creaminess and immediately perceived satiety in HVLP, LVHP and MVHP conditions, ($p<0.005$), (see Supplementary Table S3 – c, d and e). A negative relationship could be noted between smoothness and immediate perceived satiety, and perceived satiety 2 h later in HVLP and LVHP conditions ($p<0.05$), (see Supplementary Table S3 – c and d). Also, a negative relationship was noted between wateriness and immediate perceived satiety, and perceived satiety 2 h later, ($p<0.05$) across all five conditions: MVLP, HVLP, LVHP, MVHP and HVHP, (see Supplementary Table S3 – b, c, d, e and f).

Liking, wanting and perceived satiety/fullness. There was a positive relationship between liking and immediate perceived satiety in LVHP only, ($p<0.05$), (see Supplementary Table S3 – d). In terms of wanting, there was a positive relationship between wanting and perceived satiety 2 h later in LVLP condition, ($p<0.05$) and between wanting and immediate perceived satiety and perceived satiety 2 h later in LVHP condition, ($p<0.05$), (see Supplementary Table S3 – d).

Initial hunger and perceived satiety. To check if the initial state of hunger might have impacted the perceived/expected satiety scores, we performed a Pearson's correlation. There was no relationship between initial hunger level and immediate perceived satiety and/or perceived satiety 2 h later in any of the conditions, (see Supplementary Table S3 – a, b, c, d, e and f).

4. Discussion

In this study, we investigated the role of visually distinct different levels of viscosity (LV, MV and HV) of whey protein beverages without/ with addition of xanthan gum along with a label of different protein content (low and high) on immediate and 2 h later perceived satiety/fullness using a video-based remote online survey for the first time. It was instrumentally verified that the protein beverages were indeed significantly different from each other in viscosity at orally relevant shear rates due to the addition of xanthan gum (Philips & Williams, 2000). To understand if lubricity can be a confounding factor, the friction coefficients were measured. It was found that the friction coefficients of LV in the boundary lubrication regime was significantly lower than those of MV or HV due to surface interaction of whey protein with hydrophobic surfaces in absence of xanthan gum (Kew, et al., 2021; Zembyla, et al., 2021). In addition to the effect of viscosity of perceived satiety, we also investigated the relationship (if any) between visually perceived sensory attributes, liking, wanting and perceived satiety.

There was a clear effect of visually perceived texture/viscosity on perceived satiety/ fullness. It appeared that MV (medium viscous) and HV (high viscous) beverages were perceived as being more filling/satiating compared to LV (low viscous) beverages immediately after imaging drinking and 2 h later. Interestingly, although in this study we used a video online method to assess the role of texture/viscosity on perceived/expected satiety, the results are similar to the laboratory studies, where a strong effect of texture was noted on expected satiety (Hogenkamp, et al., 2011; McCrickerd, et al., 2012). Moreover, as previous studies showed, when texture is assessed in combination with other characteristics/factors, such as flavour, creaminess or energy content (Hogenkamp, et al., 2011; McCrickerd, et al., 2012), texture appears to have a strong and independent effect on expected satiety. Similar effects were noted in the current study where there was an effect of texture/viscosity on perceived satiety irrespective of the protein label content (low and high). As such, on one hand it emphasises once again the strong effect of the texture on perceived/expected satiety, however, on the other hand it may suggest that the other factors, such as protein label content in the current study may not be important factors for perceived/expected satiety when they are assessed/presented along with texture of food/beverage.

In terms of the perceived sensory attributes of the beverages, there were effects both of texture and protein content, except for smoothness. Participants perceived the LV beverage smoother than MV and HV, regardless the protein label content. This is in close agreement with the instrumental characterized friction coefficient results where LV was found to be most lubricious and strong inverse relationship existed between smoothness and friction coefficient. Similar smoothness-tribology relationships have been noted in previous study where smoothness was measured in laboratory studies using participants tasting the samples. For thickness, it was noted that participants perceived the MV and HV beverages as being thicker compared to LV one, which is in agreement with the instrumental rheological measurements. This again highlights a clear promise of video-based online assessment of textural perception which has received rare attention in literature (Upadhyay & Chen, 2019). Interestingly, LV beverage was perceived as being thicker in the low protein condition compared to the high protein condition. The same pattern was seen for the creaminess, where both the MV and HV beverages were perceived as being creamier than LV; and LV beverage was perceived creamier in the low protein compared to the high protein condition. For wateriness, participants perceived the LV beverage more watery compared to MV and HV ones. Interestingly again, the LV beverage was perceived more watery in the high protein vs low protein condition. It is hard to explain why LV beverage was perceived thicker and creamier in the low protein compared to the high protein condition, and more watery in the high protein condition. One may expect to see the vice versa, as has been shown previously in the literature, where beverages high in their protein content have been perceived as being more viscous than low protein beverages by consumers (Legarová & Kouřimská, 2010). This pattern of events is quite difficult to interpret, but it suggests that a perception of a protein label content can exert different effects according to the presence of other sensory features. A likely explanation of the discrepancy in results of the current study, could be that sensory attributes have been assessed based on visual cues rather than tried/tasted by consumers.

In terms of the relationship between visually perceived sensory attributes and perceived satiety, in line with our expectations, the thicker or the creamier the beverages gave rise to the highest scores for the perceived satiety/fullness. Likewise, as expected, the attribute watery led participants to perceive the beverages to be less satiating/filling. Such relationships, where the sensory attributes or food texture contribute to the perception of the expected satiety/fullness have been previously noted in the literature. For instance, Forde et al. showed that the more solid the food is (hotdogs, burgers, stakes) the greater the expected satiation or the more filling the food is, compared to semi-solid ones (mashed vegetables) (Forde, van Kuijk, Thaler, de Graaf, & Martin, 2013). The same was noted in Hogenkamp et al. study where higher thickness in both yogurts and soups predicted higher expected satiation (Hogenkamp, Mars, Stafleu, & de Graaf, 2010).

Interestingly, the results of the current study derived from a visually presented online demonstration, indicated the key role of texture expressed through visual cues only. This indicated that participants may have an intuitive/ learned knowledge that foods/beverages that have higher sensory intensity (thicker, creamier) have a higher satiating effect in contrast to foods/beverages with less sensory intensity (watery) (Forde, et al., 2013). And this intuitive/ learned knowledge/experience may be related to the oro-sensory exposure time (de Graaf, 2012) – the longer the oro-sensory exposure time is the greater the expected satiety/fullness will be. Although participants in the current study did not taste the beverages, the results suggest that they might have used their previous learnt experience to assess the satiating properties of the beverages based on the videos.

With respect to liking, it was noted that LV and MV beverages were liked more compared to HV but only in the low protein content condition. In terms of wanting, there was no difference irrespective of texture or protein label content. It is important to mention that the beverages in the current study differed in their viscosity significantly, showed both by the instrumental analysis (rheology) and by visual cues. Therefore, it is not a surprise that LV and MV were liked more compared to HV, and we tend to believe that this could be due to the fact that HV beverages were too viscous to be liked.

A positive relationship between liking and immediate perceived satiety/fullness in the LVHP condition (the more the beverage was liked the more filling or satiating it was perceived to be immediately after drinking) was noted. Additionally, a positive relationship between wanting and perceived satiety/fullness 2h later was noted in the LVLP condition (the more the beverages was wanted the greater would be the perceived satiety 2 h later); and between wanting and both immediate and 2 h later perceived satiety/fullness in LVHP condition. Interestingly, studies that used more or less the same methodology *i.e.* pictures to assess the expected satiety of different products found no relation between liking/palatability and expected satiety (Brunstrom & Shakeshaft, 2009; Pilgrim & Kamen, 1963) contrary to the current study. It is known that the preferred food can increase hunger and such it can be suggested that the palatability of food may have an effect on anticipated stimulation of the appetite (Hill, et al., 1984). Therefore, in a perfect scenario of the appetite/ satiety research, one would expect to see no differences in palatability of the products (as the products are control for palatability so that this does not affect the desired outcome). However, we need to take into account that we did not measure appetite ratings before and after each video and it is hard to know if the relationships between liking and perceived satiety seen in the current study may have been mediated by the hunger state after seeing the videos. As such, the findings of this study may suggest that someone may select food based on palatability and the expectation that this food or beverage would be more satiating compared to some less palatable food.

Strengths and limitations

One of the main strengths of the current study is showing that a video online demonstration could be a potential tool to assess the role of food texture on perceived/expected satiety. Of course this approach still needs to be validated. Reproducible results have been reported in the literature, where by using picture images of standard food, consumers were able to discriminate between differences in how filling or satiating foods are expected to be (Brunstrom, Shakeshaft, & Scott-Samuel, 2008) and this gives confidence for a further investigation of this method. Also, the idea of collecting data quicker and in larger samples compared to laboratory methods should be acknowledged.

However, there are some limitations to recognise in such kind of research. Firstly, it should be taken into account that the findings are based only on videos (visual cues), as such it cannot be assumed that the same findings would be found in situation where participants taste the product. Validation requires simultaneous and parallel testing with visual and taste conditions. When based on visual cues only, it can be difficult for consumers/participants to detect subtle differences in texture, such as lubricity. It is certain that texture experienced in the mouth will generate a distinct pattern of sensations from the purely visual experience. This is particularly with respect to smoothness, creaminess which are extremely hard to understand by visual cues, and thus the results and empirical correlations to instrumental data should be read with caution. Secondly, the fact that the beverages were presented as being poured from one container to another (not packed or in a bottle) also could have affected the findings (Laguna, et al., 2020). We wanted to exclude as many confounding factors as possible and wanted make sure that we show the flow of the beverage only, that it is visible enough to participants. We therefore excluded use of bottles, which might have influenced their decision in the survey. However, on the other side it might be seen as a downfall/ limitation of the study as consumers are more familiar seeing food/ beverage packed in bottles and poured from a bottle to a glass rather than poured from one container to another, and this might have influenced to results to some extent. Thirdly, with only 3 levels of variation across the samples (low, medium and high viscous), it makes difficult to have enough variability in the sensory attributes to interpret its effect on expected satiety. Therefore, the results, especially on correlation must be interpreted with caution. Finally, there were many other factors that were not accounted for and could have also impacted the results of the current study. To mention some, health status such as eating disorders, diabetes, social and culture differences, time of the day and familiarity with the food/ beverages could have contributed to the results (Forde, et al., 2015; Heatherton & Polivy, 2013; Irvine, Brunstrom, Gee, & Rogers, 2013; Kristensen, 2000).

5. Conclusions

Although it needs to be validated, a video based online demonstration showed a highly feasible method to assess the role of food/beverage texture perceived particularly viscosity on expected satiety. In addition, sensory attributes such as smoothness, thickness and creaminess were shown to be important characteristics of perceived satiety for the beverages in this study. Nevertheless, one should be cautious interpreting these results as all the textural attributes in this study have been assessed online based on observing the visual behaviour using videos and thus the perception can be different when consuming these beverages in real life particularly with respect to smoothness and creaminess. When presented along some other factors, a perception of high or low protein label content appears to have a weak and unpredictable effect on expected satiety. Thus, this study demonstrates an excellent remote sensory tool for understanding the effect of viscosity on perceived satiety that can be highly useful in the current Covid-19 pandemic situation where in person laboratory visits are highly restricted in many countries. However, it is worth recommending that this is not a tool to replace tasting for sensory evaluation of food products as textural properties of food are multidimensional. Although viscosity was perceived visually in this study, not all textural properties such as smoothness, creaminess, astringency *etc.* can be assessed just by visual observations and need tasting evaluation by consumers.

References

Bayudan-Dacuycuy, C., Orbeta Jr, A. C., Serafica, R. B., & Baje, L. K. C. (2020). Towards a sustainable online work in the Philippines: Learnings from the online survey of market and nonmarket work during the enhanced community quarantine.

Berg, J., Furrer, M., Harmon, E., Rani, U., & Silberman, M. S. (2018). Digital labour platforms and the future of work. *Towards Decent Work in the Online World. Rapport de l'OIT*

Berridge, K. C. (1996). Food reward: brain substrates of wanting and liking. *Neuroscience & Biobehavioral Reviews 20*, 1-25.

Berridge, K. C. (2007). Brain reward systems for food incentives and hedonics in normal appetite and eating disorders. In *Appetite and body weight* (pp. 191-II): Elsevier.

Blundell, J. (2010). Making claims: functional foods for managing appetite and weight. *Nature Reviews Endocrinology 6*, 53-56.

Blundell, J., de GC, Hulshof T, Jebb S, Livingstone B, Lluch A, Mela D, Salah S, Schuring E, van , & der Knaap H, W. M. (2010). Appetite control: methodological aspects of the evaluation of foods. *Obesity Reviews, 11*, 251-270.

Brunstrom, J. M., Collingwood, J., & Rogers, P. J. (2010). Perceived volume, expected satiation, and the energy content of self-selected meals. *Appetite, 55*, 25-29.

Brunstrom, J. M., & Shakeshaft, N. G. (2009). Measuring affective (liking) and non-affective (expected satiety) determinants of portion size and food reward. *Appetite, 52*, 108-114.

Brunstrom, J. M., Shakeshaft, N. G., & Scott-Samuel, N. E. (2008). Measuring 'expected satiety'in a range of common foods using a method of constant stimuli. *Appetie, 51*, 604-614.

Buckland, N. J., Stubbs, R. J., & Finlayson, G. (2015). Towards a satiety map of common foods: Associations between perceived satiety value of 100 foods and their objective and subjective attributes. *Physiology behavior, 152*, 340-346.

Camps, G., Mars, M., De Graaf, C., & Smeets, P. A. (2016). Empty calories and phantom fullness: a randomized trial studying the relative effects of energy density and viscosity on gastric emptying determined by MRI and satiety. *The American Journal of Clinical Nutrition, 104*, 73-80.

Chambers, L., Ells, H., & Yeomans, M. R. (2013). Can the satiating power of a high energy beverage be improved by manipulating sensory characteristics and label information? *Food Quality and Preference, 28*, 271-278.

Chambers, L., McCrickerd, K., & Yeomans, M. R. (2015). Optimising foods for satiety. *Trend in Food Science & Technology, 41*, 149-160.

Crum, A. J., Corbin, W. R., Brownell, K. D., & Salovey, P. (2011). Mind over milkshakes: mindsets, not just nutrients, determine ghrelin response. *Health Psychology 30*, 424.

de Graaf, C. (2012). Texture and satiation: the role of oro-sensory exposure time. *Physiology behavior, 107*, 496-501.

Deitel, M. (2003). Overweight and obesity worldwide now estimated to involve 1.7 billion people. *Obesity Surgery, 13*, 329.

Finlayson, G., King, N., & Blundell, J. (2007). Liking vs. wanting food: importance for human appetite control and weight regulation. *Neurosciene & Behavioral Reviews, 31*, 987-1002.

Flint, A., Raben, A., Blundell, J., & Astrup, A. (2000). Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *International journal of obesity 24*, 38-48.

Forde, C. G., Almiron-Roig, E., & Brunstrom, J. M. (2015). Expected satiety: application to weight management and understanding energy selection in humans. *Current Obesity Reports, 4*, 131-140.
Forde, C. G., van Kuijk, N., Thaler, T., de Graaf, C., & Martin, N. (2013). Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation. *Appetite, 60*, 208-219.
Halford, J. C., & Harrold, J. A. (2012). Satiety-enhancing products for appetite control: science and regulation of functional foods for weight management. *Proceedings of the Nutrition Society 71*, 350-362.
Heatherton, T. F., & Polivy, J. (2013). Chronic dieting and eating disorders: A spiral model. In *The etiology of bulimia nervosa* (pp. 149-172): Taylor & Francis.
Hill, A. J., Magson, L. D., & Blundell, J. E. (1984). Hunger and palatability: tracking ratings of subjective experience before, during and after the consumption of preferred and less preferred food. *Appetite, 5*, 361-371.
Hogenkamp, P. S., Mars, M., Stafleu, A., & de Graaf, C. (2010). Intake during repeated exposure to low- and high-energy-dense yogurts by different means of consumption. *The American Journal of Clinical Nutrition, 91*, 841-847.
Hogenkamp, P. S., Stafleu, A., Mars, M., Brunstrom, J. M., & de Graaf, C. (2011). Texture, not flavor, determines expected satiation of dairy products. *Appetite, 57*, 635-641.
Irvine, M. A., Brunstrom, J. M., Gee, P., & Rogers, P. J. (2013). Increased familiarity with eating a food to fullness underlies increased expected satiety. *Appetite, 61*, 13-18.
Kew, B., Holmes, M., Stieger, M., & Sarkar, A. (2021). Oral tribology, adsorption and rheology of alternative food proteins. *Food Hydrocolloids, 116*, 106636.
Kokini, J. L., Kadane, J. B., & Cussler, E. L. (1977). Liquid texture perceived in the mouth. *Journal of Texture Studies, 8*, 195-218.
Kristensen, S. (2000). Social and cultural perspectives on hunger, appetite and satiety. *European journal of clinical nutrition, 54*, 473-478.
Krop, E. M., Hetherington, M. M., Holmes, M., Miquel, S., & Sarkar, A. (2019). On relating rheology and oral tribology to sensory properties in hydrogels. *Food Hydrocolloids, 88*, 101-113.
Krop, E. M., Hetherington, M. M., Miquel, S., & Sarkar, A. (2019). The influence of oral lubrication on food intake: A proof-of-concept study. *Food Quality and Preference, 74*, 118-124.
Krop, E. M., Hetherington, M. M., Nekitsing, C., Miquel, S., Postelnicu, L., & Sarkar, A. (2018). Influence of oral processing on appetite and food intake – A systematic review and meta-analysis. *Appetite, 125*, 253-269.
Laguna, L., Gómez, B., Garrido, M. D., Fiszman, S., Tarrega, A., & Linares, M. B. (2020). Do Consumers Change Their Perception of Liking, Expected Satiety, and Healthiness of a Product If They Know It Is a Ready-to Eat Meal? *Foods, 9*, 1257.
Legarová, V., & Kouřimská, L. (2010). Sensory quality evaluation of whey-based beverages. *Mljekarstvo: časopis za unaprjeđenje proizvodnje i prerade mlijeka 60*, 280-287.
McCrickerd, K., Chambers, L., Brunstrom, J. M., & Yeomans, M. R. (2012). Subtle changes in the flavour and texture of a drink enhance expectations of satiety. *Flavour, 1*, 1-11.
Nguyen, Q. C., & Varela, P. (2021). Identifying temporal drivers of liking and satiation based on temporal sensory descriptions and consumer ratings. *Food Quality and Preference, 89*, 104143.
Nguyen, Q. C., Wahlgren, M. B., Almli, V. L., & Varela, P. (2017). Understanding the role of dynamic texture perception in consumers' expectations of satiety and satiation. A case study on barley bread. *Food Quality and Preference 62*, 218-226.

Philips, G., & Williams, P. (2000). (Eds.), Handbook of food hydrocolloids. In (pp. 103-115): Woodhead Publisging Limited, Cambridge, UK: CRC Press.

Pilgrim, F. J., & Kamen, J. M. (1963). Predictors of human food consumption. *Science, 139*, 501-502.

Sarkar, A., Andablo-Reyes, E., Bryant, M., Dowson, D., & Neville, A. (2019). Lubrication of soft oral surfaces. *Current Opinion in Colloid & Interface Science, 39*, 61-75.

Sarkar, A., & Krop, E. M. (2019). Marrying oral tribology to sensory perception: a systematic review. *Current Opinion in Food Science, 27*, 64-73.

Sarkar, A., Soltanahmadi, S., Chen, J., & Stokes, J. R. (2021). Oral tribology: Providing insight into oral processing of food colloids. *Food Hydrocolloids, 117*, 106635.

Spiegel, T. A., Shrager, E. E., & Stellar, E. (1989). Responses of lean and obese subjects to preloads, deprivation, and palatability. *Appetite 13*, 45-69.

Stribiţcaia, E., Evans, C. E., Gibbons, C., Blundell, J., & Sarkar, A. (2020a). Food texture influences on satiety: systematic review and meta-analysis. *Scientific Reports, 10*, 1-18.

Stribiţcaia, E., Gibbons, C., Sier, J., Boesch, C., Blundell, J., Finlayson, G., & Sarkar, A. (2021). Effects of oral lubrication on satiety, satiation and salivary biomarkers in model foods: A pilot study. *Appetite, 165*, 105427.

Stribiţcaia, E., Krop, E. M., Lewin, R., Holmes, M., & Sarkar, A. (2020b). Tribology and rheology of bead-layered hydrogels: Influence of bead size on sensory perception. *Food Hydrocolloids, 104*, 105692.

Stubbs, R. J., Hughes, D. A., Johnstone, A. M., Rowley, E., Reid, C., Elia, M., Stratton, R., Delargy, H., King, N., & Blundell, J. (2000). 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. *British Journal of Nutrition, 84*, 405-415.

Upadhyay, R., & Chen, J. (2019). Smoothness as a tactile percept: Correlating 'oral' tribology with sensory measurements. *Food Hydrocolloids, 87*, 38-47.

WHO. (2018). Obesity and overweight. In: World Health Organization Fact sheet [cited]Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.

Zembyla, M., Liamas, E., Andablo-Reyes, E., Gu, K., Krop, E. M., Kew, B., & Sarkar, A. (2021). Surface adsorption and lubrication properties of plant and dairy proteins: A comparative study. *Food Hydrocolloids, 111*, 106364.

Table 1. Recipe of the beverages

	LV[a]	**MV[b]**	**HV[c]**
Whey Protein (g)	30	30	30
Water (g)	170	169.5	169
Xanthan-gum (g)	0	0.5	1
Total (g)	**200**	**200**	**200**

[a]Low viscous
[b]Medium viscous
[c]High viscous

Table 2. Subjective attributes and questions assessed in the online survey.

Subjective attributes	Questions
a) Immediately perceived expected satiety/ fullness	a) How full do you think you will be immediately after eating this portion of food?
b) Perceived expected satiety/ fullness 2 h after	b) How full do you think you will be 2 hours after eating this portion of food?
Smoothness	How smooth do you think this drink is?
Thickness	How thick (viscous) do you think this drink is?
Watery	How watery do you think this drink is?
Creaminess	How creamy do you think this drink is?
Liking	How pleasant does this drink typically taste?
Wanting	How much do you want to consume this drink right now?

Table 3. Pearson's correlations between perceived sensory attributes (smoothness, thickness, creaminess and wateriness) and instrumental viscosity analysis as a function of shear rate (50 s^{-1}) and lubricity analysis where data is expressed as friction coefficients at boundary (0.001; 0.005 m s^{-1} speed) and mixed (0.05 m s^{-1}; 0.1 m s^{-1} at speed) lubrication regimes for the HV (high viscous), MV (medium viscous) and LV (low viscous) beverages. Green colour indicates positive and orange colour a negative correlation with $p < 0.05$ in light colours and $p < 0.01$ in the darker shades.

	1	2	3	4	5	6	7	8	9	10	11
	Smoothness	***Thickness***	***Creaminess***	***Wateriness***	***Viscosity at 50 s^{-1}shear rate***	***Lubr. 0.1 m s^{-1}***	***Lubr. 0.05 m s^{-1}***	***Lubr. 0.005 m s^{-1}***	***Lubr. 0.001 m s-***	***Liking***	***Wan ting***
1	1										
2	-.932**	1									
3	-0.789	.957**	1								
4	.930**	-.996**	-.953**	1							
5	-0.781	0.718	0.592	-0.690	1						
6	0.416	-0.405	-0.367	0.446	0.242	1					
7	-0.579	0.526	0.424	-0.489	.961**	0.500	1				
8	-.909*	.841*	0.701	-.822*	.970**	0.000	.866*	1			
9	-.999**	.933**	0.791	-.934**	0.771	-0.432	0.565	.902*	1		
10	0.725	-0.443	-0.184	0.438	-0.706	0.091	-0.605	-0.751	-0.716	1	
11	-0.085	0.325	0.473	-0.317	-0.283	-0.540	-0.406	-0.157	0.092	0.537	1

Table 4. Means and SDs for visually perceived sensory attributes, liking and wanting ratings for the beverages.

	Low protein			High protein		
	LV	**MV**	**HV**	**LV**	**MV**	**HV**
Smoothness	81.27 ± 19.76^{a}	53.46 ± 26.71^{b}	50.22 ± 26.65^{b}	80.79 ± 19.90^{a}	54.32 ± 24.42^{b}	51.29 ± 25.18^{c}
Thickness	48.33 ± 24.46^{a}	76.57 ± 17.59^{b}	77.27 ± 19.39^{b}	25.94 ± 23.04^{a}	69.41 ± 18.44^{b}	75.18 ± 17.21^{c}
Creaminess	60.08 ± 23.70^{a}	69.81 ± 21.67^{b}	69.32 ± 23.32^{b}	38.14 ± 23.44^{a}	63.91 ± 20.59^{b}	66.13 ± 22.46^{b}
Watery	47.59 ± 25.74^{a}	22.37 ± 18.21^{b}	22.43 ± 19.27^{b}	69.27 ± 25.39^{a}	24.92 ± 17.20^{b}	22.72 ± 17.60^{b}
Liking	54.19 ± 25.94^{a}	50.70 ± 28.12^{a}	48.07 ± 29.02^{b}	50.07 ± 25.36	49.16 ± 27.79	48.92 ± 29.03
Wanting	38.54 ± 29.97	39.04 ± 31.07	37.88 ± 31.61	37.78 ± 27.50	38.10 ± 29.49	38.11 ± 30.58

A statistical significance ($p>0.05$) between conditions is denoted by different letters in superscripts (^{abc}).

FIGURE 1.

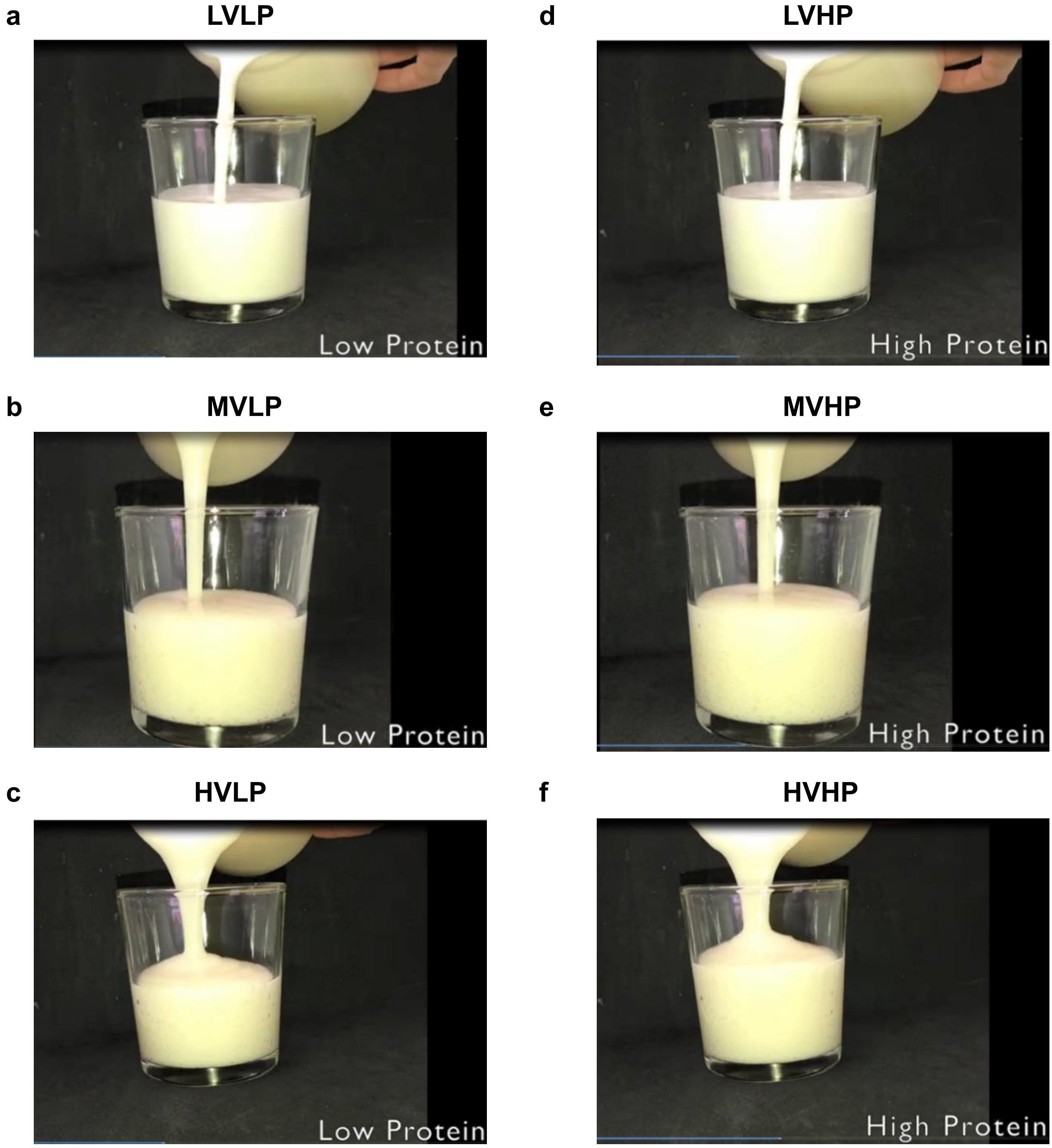


Fig. 1. Images captured from the videos shown to the participants displaying the beverages being poured from one container into another (transparent glass). In total there were six beverages: a) Low viscous low protein (LVLP), b) medium viscous low protein (MVLP), c) High viscous, low protein (HVLP), d) Low viscous high protein (LVHP), e) Medium viscous high protein (MVHP), and f) High viscous high protein (HVHP). For the full videos, see Supplementary Table S1.

FIGURE 2.

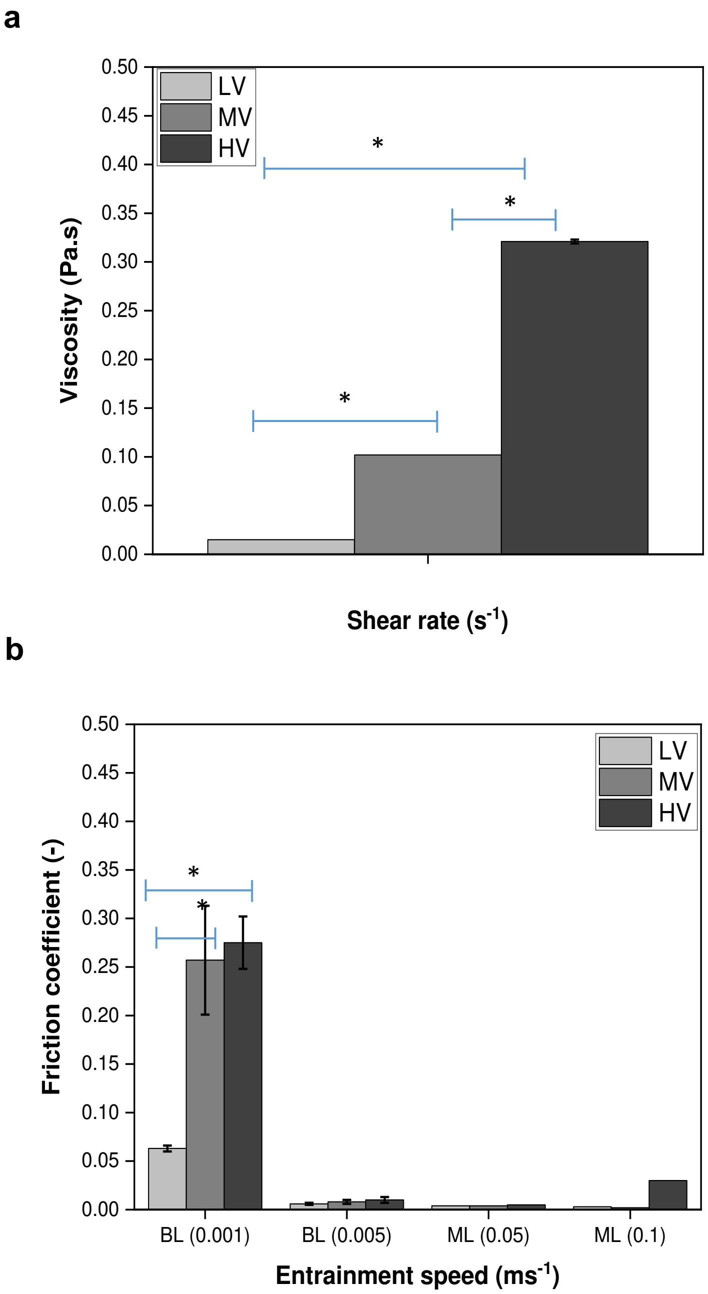


Fig. 2. Instrumental viscosity (a) as a function of orally relevant shear rate (50 s^{-1}) and lubricity analysis (b) where data is expressed as friction coefficients at boundary (0.001; 0.005 m s^{-1} speed) and mixed (0.05 m s^{-1}; 0.1 m s^{-1} at speed) lubrication regimes for the HV (high viscous), MV (medium viscous) and LV (low viscous) beverages, respectively at various speeds. Error bars represent standard error of means (±SEMs). Significant differences between the beverages are shown by the blue lines with asterisks above each line. A lower friction coefficient represents higher lubrication properties of the beverages. BL = boundary regime, ML = mixed regime.

FIGURE 3.

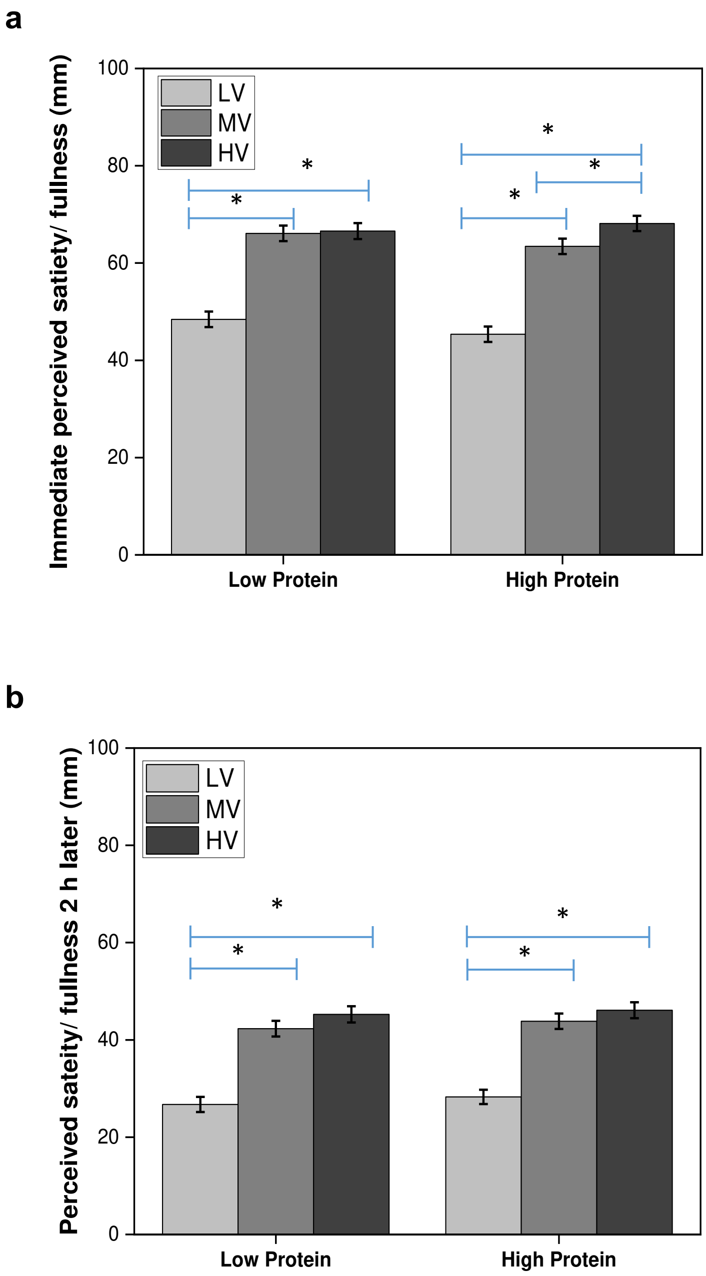


Fig. 3. Mean and standard error of means (±SEM) of immediately perceived satiety/ fullness (a) and satiety/ fullness perceived 2 h later (b) of the protein beverages in the low and high protein conditions between low viscous (LV – grey), medium viscous (MV – light grey) and high viscous (HV – dark grey). Significant differences between the beverages are shown by the blue lines with asterisks above each line.

CRediT author statement

Ecaterina Stribitcaia: Conceptualization, Writing- Original draft preparation, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing- Reviewing & Editing; Visualization; Project administration; **John Blundell**: Methodology, Writing- Reviewing & Editing; Supervision**; Kwan-Mo You: Formal analysis, Investigation,** Data curation, Visualization; **Graham Finlayson: Formal analysis,** Software, Writing- Reviewing and Editing, Validation*;* **Catherine Gibbons:** Writing- Reviewing and Editing***;* Anwesha Sarkar**: Conceptualization, Writing- Reviewing & Editing, Visualization, Supervision, Funding acquisition

Viscosity of food influences perceived satiety: a video based online survey

*Ecaterina Stribițcaia[a], Kwan-Mo You[a], John Blundell[b], Graham Finlayson[b], Catherine Gibbons[b], Anwesha Sarkar[a]**

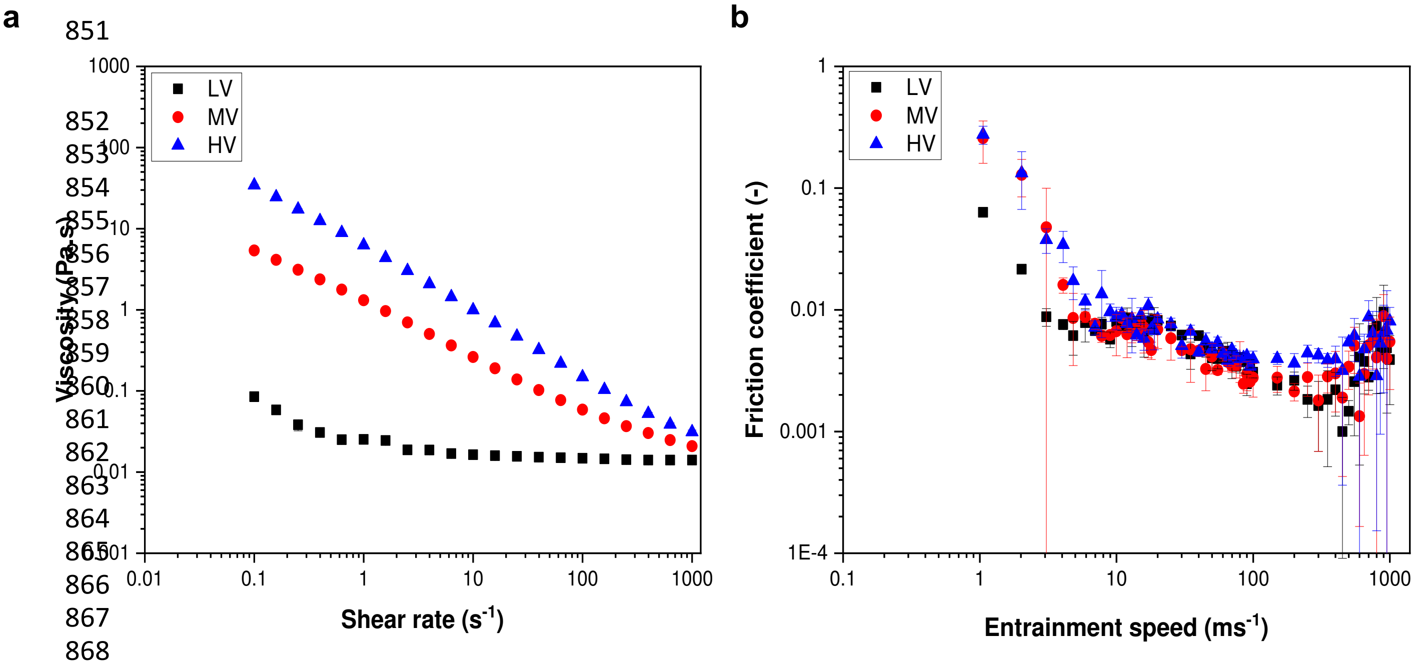
[a] Food Colloids and Bioprocessing Group, School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, United Kingdom

[b] Appetite Control and Energy Balance Research, School of Psychology, University of Leeds, Leeds LS2 9JT, United Kingdom

*Corresponding author:
Prof. Anwesha Sarkar
Food Colloids and Bioprocessing Group,
School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK
E-mail address: a.sarkar@leeds.ac.uk

Supplementary Table S1. Videos of the beverages.

	Low protein	High protein
Low Viscous	LVLP.mp4	LVHP.mp4
Medium Viscous	MVLP.mp4	MVHP.mp4
High Viscous	HVLP.mp4	HVHP.mp4



Supplementary Figure S1. Apparent viscosity as a function of shear rate (a) and lubricity analysis (b) where data is expressed as friction coefficients at different entrainment speed for the HV (high viscous), MV (medium viscous) and LV (low viscous) beverages. Data are presented as means and SDs.

Supplementary Table S2. Means and SDs of the immediate perceived satiety (a) and perceived satiety 2 h later (b) for both low and high protein content and different textures – LV (low viscous), MV (medium viscous) and HV (high viscous|)[a].

a	**Immediate perceived satiety**		**b**	**Perceived satiety 2 h later**	
	Low protein	*High protein*		*Low protein*	*High protein*
LV	48.43 ± 23.32 ^{a}	45.36 ± 23.17 ^{a}	***LV***	26.72 ± 22.59 ^{a}	28.28 ± 21.39 ^{a}
MV	66.1 ± 23.16 ^{b}	63.44 ± 23.14 ^{b}	***MV***	42.31 ± 23.50 ^{b}	43.84 ± 23.00 ^{b}
HV	66.58 ± 23.91 ^{b}	68.14 ± 22.86 ^{c}	***HV***	45.25 ± 24.59 ^{c}	46.09 ± 23.88 ^{b}

[a] A statistical significant difference ($p<0.05$) between the beverages is denoted by different letters in superscripts (^{abc}).

Supplementary Table S3. Pearson's correlations between initial hunger (Hunger0) and immediate perceived satiety (FullNow) and perceived satiety 2 h later (Full2h), between sensory attributes (smooth, thick, watery and creamy), wanting and liking in LVLP (a), MVLP (b), HVLP (c), LVHP (d), MVHP (e), and HVHP (f) conditions. Green colour indicates positive and orange colour a negative correlation with p < 0.05 in light colours and p < 0.01 in the darker shades.

a **LVLP**

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	LVLPFullNow	-0.017	1							
3	LVLPFull2h	-0.085	.480**	1						
4	LVLPSmooth	0.029	0.088	-0.049	1					
5	LVLPThick	0.050	.279**	.210**	-0.123	1				
6	LVLPWatery	0.043	-0.009	-0.103	.301**	-.517**				
7	LVLPCreamy	.150*	0.108	0.097	.144*	.373**	-.154*			
8	LVLPWant	.281**	0.083	.138*	.220**	.176*	-0.082	.285**	1	
9	LVLPLike	0.072	0.116	0.063	.274**	0.101	0.072	.246**	.615**	1

b **MVLP**

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	MVLPFullNow	0.019	1							
3	MVLPFull2h	-0.036	.651**	1						
4	MVLPSmooth	.175*	-0.036	-0.123	1					
5	MVLPThick	-0.013	.422**	.229**	-0.015	1				
6	MVLPWatery	0.018	-.161*	-.139*	.338**	-.297**	1			
7	MVLPCreamy	-0.013	0.115	0.079	.194**	.291**	0.007	1		
8	MVLPWant	.319**	-0.036	-0.007	.490**	-0.090	.190**	.222**	1	
9	MVLPLike	0.090	-0.064	-0.054	.498**	-0.025	.174*	.263**	.782**	1

c **HVLP**

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	HVLPFullNow	0.112	1							
3	HVLPFull2h	-0.016	.638**	1						
4	HVLPSmooth	.174*	-.135*	-.205**	1					
5	HVLPThick	0.051	.463**	.333**	-.297**	1				

6	HVLPWatery	-0.041	-.227**	-.183**	.423**	-.408**	1			
7	HVLPCreamy	-0.042	.180**	0.115	0.065	.301**	-.176*	1		
8	HVLPWant	.325**	-0.068	-0.027	.496**	-0.103	.163*	.250**	1	
9	HVLPLike	.180**	-0.050	-0.076	.503**	-0.069	0.100	.291**	.819**	1

Supplementary Table S3 (continuation).

d) **LVHP**

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	LVHPFullNow	0.072	1							
3	LVHPFull2h	-0.070	.643**	1						
4	LVHPSmooth	-0.054	-.142*	-.161*	1					
5	LVHPThick	0.117	.348**	.274**	-.254**	1				
6	LVHPWatery	-0.095	-.240**	-.224**	.304**	-.552**	1			
7	LVHPCreamy	.144*	.176*	0.125	-0.043	.388**	-.290**	1		
8	LVHPWant	0.118	.162*	.217**	0.029	0.108	-0.023	.246**	1	
9	LVHPLike	0.074	.176*	0.121	.146*	0.087	-0.017	.265**	.698**	1

e **MVHP**

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	MVHPFullNow	0.053	1							
3	MVHPFull2h	-0.025	.588**	1						
4	MVHPSmooth	.137*	-0.035	-0.101	1					
5	MVHPThick	0.007	.374**	.341**	-0.006	1				
6	MVHPWatery	-0.003	-.224**	-.183**	.252**	-.337**	1			
7	MVHPCreamy	0.024	.153*	0.103	.223**	.307**	-.145*	1		
8	MVHPWant	.237**	0.032	0.090	.520**	0.045	0.093	.309**	1	
9	MVHPLike	.146*	0.056	-0.007	.529**	0.116	0.049	.392**	.806**	1

Supplementary Table S3 (continuation).

HVHP

f

		1	2	3	4	5	6	7	8	9
1	Hunger0	1								
2	HVHPFullNow	0.078	1							
3	HVHPFull2h	-0.041	.593**	1						
4	HVHPSmooth	.148*	-0.050	-0.057	1					
5	HVHPThick	0.021	.304**	.258**	0.053	1				
6	HVHPWatery	-0.077	-.249**	-.139*	.202**	-.289**	1			
7	HVHPCreamy	-0.100	0.079	0.080	.190**	.271**	-0.055	1		
8	HVHPWant	.232**	0.014	0.069	.460**	-0.009	0.019	.295**	1	
9	HVHPLike	.161*	0.003	-0.006	.493**	0.072	0.000	.398**	.808**	1

Conflict of Interests

Declarations of interest: none