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# Biophysical basis of taste modulation by viscous solutions in humans

Béatrice Aubert, Anthony Lima, Benjamin Le Révérend*

*Nestlé Research Center, Vers-Chez-Les-Blanc, Lausanne, Switzerland*

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ABSTRACT

In this work, we determine experimentally the effect of viscous polymer solutions on taste perception in humans. It is experimentally demonstrated using a range of concentrations of thickening polymers Xanthan Gum (XG), Guar Gum (GG) and Locust Bean Gum (LBG) in order to modulate shear viscosity in a systematic manner. We particularly focus on salty taste using a model tomato soup in order to obtain relevant sensory data. By using a wide range of concentrations of the different polymers, we were able to vary the apparent viscosity ($\eta$) of the system in both a low and high shear flow regimes ($\eta_L$ for $\gamma \approx 10^{-1}s^{-1}$ and $\eta_H$ for $\gamma \approx 10^{+2}s^{-1}$). We report that $\eta_L$ seems to control taste perception in such systems. This is coherent with existing literature on the topic in both model and more complex food systems, although it brings one important novelty, the systems form a continuum in this dimensions and there are no visible effects of the individual gums. We end this article by trying to offer a theory to explain why very low stresses (and deformation rates) are important in such thickened fluids to understand taste perception.



## 1. Introduction

It has been discussed for decades how flavour perception is modified upon the addition of thickeners beyond the textural modification evidently induced (Cook, Linforth, & Taylor, 2003; Kostyra & Barylko-Pikielna, 2007; Le Révérend, Norton, Cox, & Spyropoulos, 2010; Malone, Appelqvist, & Norton, 2003; Moskowitz, 1970; Rosett, Kendregan, Gao, Schmidt, & Klein, 1996; Scherf, Pflaum, Koehler, & Hofmann, 2015; Stieger, 2011; Yven, Guichard, Giboreau, & Roberts, 1998). A rather striking fact about sodium perception is that some condiments, sauces and certain types of cheese contain as much sodium as sea water (e.g. condiments are supposed to be eaten in small quantities and bring a lot of taste to foods, can contain up to 1000 mg Na/100 g and sea water about 1100 mg Na/100 g). However, those products are certainly not perceived as salty as sea water. Since real foods, as opposed to model NaCl solutions, also contain other tastants, there is a chance that taste–taste interactions would explain this, but there is also some evidence in the literature that the food matrix itself could have an impact on the perception of saltiness. In this study, we are interested in the effect of the presence of polymers in solution.

First evidence of such a link between viscosity and saltiness perception was presented in the 1970s. Work by Pangborn, Trabue and Szczesniak (Pangborn, Trabue, & Szczesniak, 1973) showed that gums (hydroxypropylcellulose, carboxymethyl-cellulose, sodium alginate and xanthan) had an impact on several basic tastes. However since they were not able to demonstrate a clear trend between viscosity and tastant reduction, they attributed the reduction in taste intensity to particular interactions between hydrocolloids and sodium ions. The systematic studies by Moskowitz and Arabie (Moskowitz, 1970) as well as Christensen (Christensen, 1980) are also indicating that the use of hydrocolloids reduces taste intensity. In both studies the authors studied the systematic effect of gums on saltiness perception by using different amounts of those gums to modify the viscosity of the liquid system. Cellulose gum was used by Moskowitz (1970) to increase apparent viscosity levels from 1 to 1000 mPa•s (at an unspecified shear rate). The authors found that viscosity ($\eta$) was decreasing the perceived saltiness ($\Psi$) according to a power law $\Psi \propto \eta^n$. The exponent $n$ was found to be the lowest ($n = -0.12$) at low sodium concentrations, suggesting that viscosity impacted saltiness more for lower concentration of sodium in the product and less so at higher sodium concentrations, although in the latter case the effect was still reported as significant ($n = -0.06$). Similar data were published by Christensen (1980) using sodium carboxymethyl cellulose (CMC) between 1 and 2000 mPa•s (again at an unspecified shear rate). Those data confirmed that the effect of viscosity seems more substantial for solutions with lower concentrations of sodium chloride (60%

* Corresponding author.
*E-mail address:* benjamin.lereverend@rdls.nestle.com (B. Le Révérend).

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reduction at 0.05 M NaCl and 30% reduction at 0.80 M NaCl). In a second experiment, the author compared three different CMC gums of different molecular weight and found that the higher molecular weight CMC was more effective in reducing saltiness than the low molecular weight CMC, even when those were viscosity matched. The authors concluded that since viscosity was matched, but effectiveness at reducing saltiness was not, additional effects due to the particular gum must play a role.

However, the mechanisms of these potential interactions between certains gums and sodium ions were not systematically studied and hence did not produce generic conclusions. This was approached by Rosett et al. (Rosett, Shirley, Schmidt, & Klein, 1994, 1995, 1996). which used NMR transverse relaxation rates to characterize $Na^+$ mobility in different types of gum solutions and products (low-sodium chicken broths). They also confronted their physical assessments with various sensory assessments of saltiness perception. At lower levels of $Na^+$ concentration, lower $Na^+$ mobility and reduced saltiness perception were reported in the presence of ionic polysaccharides (XG and $\kappa$-carrageenan), but not in the presence of non-ionic ones (LBG and GG). Addition of KCl or $CaCl_2$ was reported to enhance both $Na^+$ mobility and saltiness perception whereas viscosity did not have an effect on saltiness perception in their study. For low-sodium chicken broths, a reduction of perceived saltiness was reported upon addition of (ionic) xanthan gum, but not upon addition of starch. The NMR relaxation data did not correspond to these findings in terms of $Na^+$ mobility, which was attributed to limitations of the standard technique with these products.

In more recent work, increasing the concentration of other gums, such as HPMC (Cook, Hollowood, Linforth, & Taylor, 2002, 2003) or $\kappa$-carrageenan (Cook et al., 2003) produced similar effects. In particular, dropping the mass concentration of HPMC from 1 to 0.2% allowed a reduction in sodium by 25% without modifying saltiness (paired comparison tests). A typical property of such gums is that they confer shear thinning, i.e. their viscosity decreases with increasing shear rate, therefore solutions matched at a specific shear rate may exhibit very different viscosities at other shear rates (higher or lower), i.e. they are not really viscosity matched. A better understanding of the flow regimes in the mouth during the perception of saltiness is necessary when trying to build a conceptual model of the saltiness perception.

The model proposed by Le Révérend, Norton and Bakalis (Le Révérend et al., 2013), for example, assumes the existence of two compartments in the mouth, an infinitely well mixed region in the bulk of the mouth and a non-mixed, diffusion controlled region close to the tongue, similar to the oral pellicle. Based on this theory, one can argue that the relevant fluid mechanics to understand saltiness perception are twofold; the behavior of the fluid near a rest condition (low shear viscosity) and the quality of the mixing between the polymer solution and saliva. Based on our literature findings there seems to be interesting data but some confusion between molecular or physical effects. One could formulate several hypotheses to account for the effect of thickeners on saltiness perception. Here we formulate two, that we tested and we report our results and conclusions: either there is a molecular interaction between the polymer and sodium (H1) or a mechanical reduction of advective mass transfer due to the presence of the polymer increasing the solution viscosity (H2). The latter is likely to be dependent on shear rates (or stresses) that the fluid experiences in the oral cavity.

## 2. Materials and methods

We aimed to confirm or infirm H1 and H2 above, by designing model food systems which were thickened with different gums, Xanthan Gum (XG, ionic, Cargill Satiaxane CX910), Guar Gum (GG, non-ionic, Danisco, Meyprodor) and Locust Bean Gum (LBG, non-ionic, Danisco, Grinsted LBG 246) with different concentrations ($[LBG] \in \{0.3-2.1 \text{ wt.\%}\}$, $[GG] \in \{0.4-1.6 \text{ wt.\%}\}$, $[XG] \in \{0.15-0.8 \text{ wt.\%}\}$) so that they would have matched viscosities of $\eta_L \in \{50,10,1\} Pa\cdot s$ at $\gamma \approx 10^{-1} s^{-1}$ or matched viscosities $\eta_H \in \{1,0.1,0.01\} Pa\cdot s$ at $\gamma \approx 10^{+2} s^{-1}$. For all gums complete hydration of the gums was ensured by dissolving in water (Aqua Panna, Nestlé Waters) under mechanical stirring at 80 °C during 1 h. The viscosity map of the sample set is plotted on Fig. 1. Those systems were flavoured with tomato base (non-salted) provided by Nestlé Product Technology Center Singen and with Sodium Chloride concentration [NaCl] at 1 and 2% (weight by weight), corresponding to 0.171 and 0.342 M respectively. To those samples, a non thickened solution containing only the tomato base and NaCl was added as a reference point in the low viscosity product space.

The viscosity of the samples was obtained by measuring the flow curve of the materials using a double gap geometry (DG26.7) driven by a stress controlled rheometer (Anton Paar, Physica MRC 500) at 40 °C. The required concentrations for each of the samples were adjusted empirically in order to obtain the required $\eta_L$ and $\eta_H$ for each of the gums tested in this experimental plan.

This yielded to a total of 38 samples that were described by a trained external panel. The panel ($n = 11$, only women from 40 to 55 years old) was trained to perform monadic descriptive profiling of reconstituted dehydrated soups with a sensory glossary containing aroma (Tomato, Vegetable), flavour (Tomato, Salty, Sweet, Bitter, Acid), texture (Thick, Mouth-coating, Astringent), persistence and trigeminal (Tingling) attributes, until they reached good discrimination and reproducibility. Unthickened tomato soup were firstly presented to the panelists at different salt concentrations (in water first, then added to unsalted tomato flavoured soup bases) which allowed to estimate the panels capability in discriminating various salt levels in a tomato soup base. The panel was also further trained by performing ranking tests on increasing viscosity samples, and by performing saltiness scoring of coded samples. The performance of the panel was checked in terms of individual discrimination and panel consensus and was found satisfactory according to the Nestlé internal standards. Up to 9 products were evaluated per session with 5 min pause between samples during which panellists were provided with freshly opened Vittel water and white unsalted crackers as palate cleaners. A 10-min break has also been granted in the middle of the session (after the first 5 products). The panelists were instructed to evaluate the samples (randomized across five sessions) on the attributes listed in the glossary. The perceived magnitudes were recorded on visual analog unstructured scale varying from 0 to 10 and anchored on the left and right by the labels None (corresponding to 0) and Very (corresponding to 10).

To determine if there was any difference among samples, the Analysis of Variance (ANOVA) with two factors; Product (Fixed Factor) and Subject (Random Factor) was computed. The Least Significant Difference (LSD) multiple paired comparison test was performed when a significant difference was detected with the ANOVA. The limit of significance ($\alpha$ risk) was set at $\alpha = 5\%$.

## 3. Results

The different attributes that were significantly different across our 1 and 2% NaCl sample sets were Saltiness (further noted $\Psi$), Tomato (flavour), Thickness and Mouthcoating. Since the main modification between the samples was viscosity, we were not surprised that Thickness and Mouthcoating of the samples were significantly modified.

On the specific focus of this study, it is the first time to our