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Relationships of oral comfort perception and bolus properties in the elderly with salivary flow rate and oral health status for two soft cereal foods

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ABSTRACT

The aim of this study was to investigate food oral processing and bolus formation in the elderly population, and their relationship with the perception of oral comfort, for two soft cereal products of different composition: sponge-cake and brioche. Twenty subjects aged 65 and over participated in the study. They were classified in two groups according to dental status (poor vs. satisfactory) and presented various stimulated salivary flow rate (SSF) in each group. Food bolus properties (hydration ratio and apparent viscosity) were characterized after three chewing stages for both groups. Results showed that chewing duration did not depend on food product but rather on physiology: subjects with a poor dental status had a shorter chewing duration. For each chewing stage, sponge-cake boli showed a higher hydration ratio than brioche boli, which showed higher apparent viscosity. For sponge-cake, perception of oral comfort was primarily driven by SSF rate, irrespective of the dental status. In the case of brioche, oral comfort was also partially explained by SSF in the case of subjects with poor dental status. This result suggests that perception of oral comfort in brioche could be driven by product related attributes rather than oral health. For both foods, a phenomenological model of bolus viscosity as a function of stimulated salivary flow and chewing duration was proposed.

Keywords: food bolus, chewing, dental status, viscosity, hydration, cereals

Nomenclature

ANSM= Acronym for the French ‘National Agency of Drugs and Safety’;
B= Brioche;
BHR=Bolus hydration ratio (g of water/100g of product);
C1= 1/3 of total chewing duration, first chewing stage;
C2= 2/3 of total chewing duration, second chewing stage;
Chew=Perceived as easy to chew;
Comfort=Overall oral comfort perception score;
DM =Dry matter (g of dry matter/100g of product or bolus);
DS= Dental status;
Easiness=Perceived as easy to eat;
FOP = Food Oral Processing;
OC= Oral comfort;
Moisten=Perceived as easy to moisten;
Ø= Diameter of capillary die or mouthful size (mm or cm);
P= Poor (dental status);
PC= Principal Component
Pasty=Perceived pastiness;
PFU = Posterior functional unit;
S= Satisfactory (dental status);
SC= Sponge-cake;
SP= Swallowing point or total chewing duration or third chewing stage;
SSF or Φ_{stim}= Stimulated salivary flow rate (mL/min or mL/s);
Sticky=Perceived stickiness;
Swallow=Easy to swallow;
t_{CX} = Chewing duration at a given sequence (s);
WC= Water content (g of water/100 g of product or bolus);
$\eta(\dot{\gamma}=120s^{-1})$= Bolus apparent viscosity at $120s^{-1}$ (Pa.s);
$\dot{\gamma}$= Apparent shear rate (s^{-1});

1. Introduction

The proportion of elderly people worldwide is growing rapidly. Over the first half of the current century, the global population aged 60 and over is projected to expand by more than three times, to reach nearly 2.1 billion in 2050 (United Nations, 2002; United Nations, 2015). Ageing is often associated with a degradation of the oral health status, where tooth loss, decreased muscle strength and tongue pressure, and reduced salivary flow are among the main factors responsible for eating difficulties and loss of eating pleasure in the elderly (Laura Laguna, Aktar, Ettelaie, Holmes, & Chen, 2016; Ship, 1999; Vandenberghe-Descamps et al., 2016; Wang & Chen, 2017; Xu, 2016). Moreover, olfactory and gustatory capacities are also reduced (Boyce & Shone, 2006; Methven, Allen, Withers, & Gosney, 2012), increasing the risk of food intake reduction, leading to malnutrition and other diseases (Henshaw & Calabrese, 2001; Maitre et al., 2014; Rolls, 1999; Schwartz, Vandenberghe-Descamps, Sulmont-Rossé, Tournier, & Feron, 2017). In this context, it has therefore become crucial to develop age-friendly food products with an improved nutritional value and enhanced enjoyment of eating in order to ameliorate the quality of life of the forthcoming senior population (Giacalone et al., 2016; Schwartz et al., 2017). Food Oral Processing (FOP) has been shown to be a crucial stage for texture, taste and aroma perception, as well as for sensory pleasure (Chen, 2009; Salles et al., 2011; Varela, Salvador, & Fiszman, 2009). A better understanding of the mechanisms involved in FOP is thus necessary (Chen, 2015; Laura Laguna & Chen, 2016). Research has shown that the elderly use strategies to compensate for oral impairments such as extending chewing duration, increasing the number of chewing cycles and swallowing larger particles of food (Mioche, Bourdiol, Monier, Martin, & Cormier, 2004; Peyron, Blanc, Lund, & Woda, 2004; Peyron, Woda, Bourdiol, & Hennequin, 2017). More recently, research focusing into establishing the concept of ‘eating capability’ in this population through physiology, showed that biting force and dental status influenced the oral processing duration, the number of chewing cycles, as well as liking and difficulty perception (L. Laguna & Sarkar, 2016; L. Laguna, Sarkar, & Chen, 2015; Laura Laguna, Hetherington, Chen, Artigas, & Sarkar, 2016; Laura Laguna, Sarkar, Artigas, &

Chen, 2015). Other studies have shown that food bolus properties can be related to the perception of texture and aroma (Devezeaux de Lavergne, Derks, Ketel, de Wijk, & Stieger, 2015; Jourdren, Saint-Eve, et al., 2016; Jourdren et al., 2017). Transforming food into a bolus that is ready to swallow is the main purpose of FOP (Prinz & Lucas, 1997). Therefore, studying its degree of transformation in the mouth by quantitatively characterizing its properties, such as hydration ratio, rheological behavior and particle size, is fundamental for the understanding of the underlying mechanisms.

It is common knowledge that, beyond the physiological and nutritional functions, eating is an enjoyable sensory experience that can be source of satisfaction and pleasure (Bourne, 2002). However, literature regarding the food enjoyment and comfortability, especially of the elderly, is quite scarce. Recently, Vandenberghe-Descamps, Labouré, Septier, Feron, & Sulmont-Rossé (2017) developed a questionnaire to assess oral comfort for a wide variety of foods. They also investigated the impact of dental status and salivary flow on the oral comfort perception (Vandenberghe-Descamps, Sulmont-Rossé, Septier, Feron, & Labouré, 2017). Xu (2016) highlighted the importance of taking into account pleasure and enjoyment when designing specialized foods for the elderly, so that optimum masticatory pleasure can be achieved. However, present foods targeted for the elderly are mainly focused on the nutritional needs, without considering enjoyment. They are often found as dietary supplements that produce taste-fatigue on the long-term and have low compliance (Gosney, 2003). Cereal products, besides from being staple foods in many countries, are affordable, nutritious and can be consumed regardless of culture and beliefs. They are widely consumed among the elderly population, who tends to orient towards a more ‘traditional’ dietary pattern (Andreeva et al., 2016). To this extent, the products selected for this study, sponge-cake and brioche, have been little studied and are good candidates for development since they have pleasant sensory properties. They have also a relative flexibility regarding formulation, opening the possibility for modifications including the enrichment with fibers or proteins to increase their nutritional value. Numerous studies have been carried out regarding FOP of cereal products such as bread, biscuits and breakfast flakes (Gao, Wong, Lim, Henry, &

Zhou, 2015; Jourdren, Panouillé, et al., 2016; Le Bleis, Chaunier, Montigaud, & Della Valle, 2016; Peyron et al., 2011; Tournier, Grass, Septier, Bertrand, & Salles, 2014; Young et al., 2016). All of the precedent studies were conducted on middle-age population. As far as we know, there is a lack of similar investigations on elderly population.

Given this context, the aim of this study was to determine the relationships between bolus properties, oral health status and perceived oral comfort in elderly for two cereal foods: sponge-cake and brioche. Two physiology criteria were selected to assess the oral health status of participants: dental status and salivary flow rate. Other oral physiological parameters such as tongue pressure have been described also as makers of oral health in elderly (Tamine et al., 2010). However, they reflect principally dysphagia symptoms (Yoshida et al., 2006) that are not considered in this study. Moreover, it has been shown that solid foods require teeth action rather than tongue to be processed (Funami, 2016; Ishihara et al., 2013). In this purpose, the impact of dental status and salivary flow rate on food bolus hydration ratio and rheological properties was investigated for both products. Secondly their relationships with the perception of oral comfort were assessed.

2. Materials and Methods

2.1 Subjects

Twenty French subjects (9 men and 11 women, aged 65-82 years, mean 72 ± 5 years) participated in the study. Their dental status was assessed by determining the number of Posterior Functional Units (PFU's), defined as pairs of opposing posterior teeth (premolars and molars). Depending on the number of PFU's, participants were classified within two different groups. Since the maximum number of PFU's for a complete dentition (third molars excluded) is 8, a satisfactory dental status was considered to be of at least 7 PFU's. Conversely, a poor dental status was considered to be inferior or equal to 4 PFU's (Leake, Hawkins, & Locker, 1994). Only individuals entering in these two categories were included in the study. The number of PFU's was evaluated visually by a dentist at bare eye and also by asking participants to chew a 200µm thick articulating paper according to the procedure described by Vandenberghe-Descamps et al. (2016).

The salivary flow rates (mL/min) of participants were determined on the day of the experimentation with and without mechanical stimulation as described by Neyraud et al. (2012). The mean, stimulated and unstimulated, salivary flow rates along with a general description of the 20 subjects are shown in Table 1. The observed salivary flow values are within the range usually encountered in literature for healthy adults, including elderly (Chen, 2009; Vandenberghe-Descamps et al., 2016). Additionally, the salivary flow rates, both stimulated and unstimulated, were not dependent on dental status ($p>0.05$) as already observed by Vandenberghe-Descamps et al. (2016).

All subjects agreed on the content of the study and signed informed consent. This study was approved by the local ethical committee and the French National Agency of Drugs and Safety (ANSM) (ID RCB n°2016-A00916-45).

2.2 *Product samples*

Brioche and sponge-cake were provided by CERELAB® (Dijon, France). Their composition and density values are shown in Table 2. Products were offered to the participants as cylinders of 20 cm^3. Portions of each product were cut just before the beginning of the experimentation with a knife and a circular steel cutter of diameter (Ø)=3 cm for sponge-cake (h=2.8 cm) and Ø=5 cm for brioche (h=1 cm) and given to the subjects as mouthfuls for consumption and bolus generation during the experimental procedure.

2.3 Experimental procedure

Every subject participated in one collective and six individual sessions, for a total of seven sessions of approximately 1 h. The collective session aimed at determining the individual swallowing point of both products. Participants were asked to consume the product mouthful (20 cm^3) in a natural manner and were recorded on video while doing it. They were asked to point out the swallowing moment by raising their hand. Total chewing duration was calculated as the time elapsed from the placement of the food inside the mouth and the swallowing point, which was defined right after the first swallow. The number of chewing cycles were determined from this recording as well and one chewing cycle was defined after a complete sequence of opening-occlusion. Chewing frequency was calculated from this data by dividing the number of chewing cycles by the chewing duration. Water (Evian, France) was offered freely after each mouthful. The procedure was repeated twice for each product. During the individual sessions, participants were asked to chew the product mouthful and to expectorate the food bolus into a Petri dish at three mastication stages according to their individual total chewing duration: 1/3 of total chewing duration (C1), 2/3 of total chewing duration (C2) and just before the swallowing point (total chewing duration, SP). They repeated the procedure once for each product. Food boli were collected at the three stages (C1, C2 and SP) for further characterization. At the end of a randomly selected individual session, participants were also asked to respond the oral comfort assessment questionnaire. They repeated the questionnaire once for each product on a different session. In both collective and individual sessions, products were randomly distributed.

2.4 Oral comfort assessment

Perception of oral comfort (OC) was assessed using a questionnaire recently developed (Vandenberghe-Descamps, Labouré, et al., 2017). This questionnaire is composed of 5 multi-variate sections with structured scales. Each section of the questionnaire refers to a different dimension of OC: general comfort, easiness of bolus formation, pain feeling, texture and flavor of the product. Further detail of the sections and subsections is given in the appendix (Table A.1). Questions were answered by participants while consuming the products. They were asked to consume one mouthful of product for each section of the questionnaire. Water (Evian, France) was offered to rinse the mouth at the beginning and the end of the questionnaire but not in-between.

2.5 Bolus characterization

2.5.1 Capillary rheometry

The rheological properties of products and boli were determined by capillary rheometry as previously described by Le Bleis, Chaunier, Della Valle, Panouillé, & Réguerre (2013). A mechanical texture analyzer (TA.XTplus, Stable Micro Systems, UK) equipped with a cylindrical piston with flat head and a capillary die fixed at the bottom to a cylindrical barrel, were used as a capillary rheometer. Boli were loaded into the capillary die immediately after collection. Each product was tested at three values of apparent shear rate ($\dot{\gamma}$ = 10, 42 and 333 s^{-1}) according to different combinations of the piston speed (50 or 200 mm/min) and capillary die diameter (Ø=2 or 4 mm). From these shear rate values and pressure measurements, the apparent viscosity η was calculated. Variations of $\eta(\dot{\gamma})$ were shown to follow a power law, as reported by Le Bleis et al., 2016 in the case of bread boli, with little variation of the flow index, close to 0.3. The value of $\eta(\dot{\gamma}=120s^{-1})$ for each subject and each chewing stage was selected to characterize bolus viscosity from a typical shear rate value of the oropharynx at the beginning of swallowing (Zhu, Mizunuma, & Michiwaki, 2014). Two boli were required to repeat the measurement for each of the three chewing stages for all of the three apparent shear rate values, leading to a total of 2x3x3=18 boli per subject for each product.

2.5.2 Bolus hydration ratio

Bolus hydration ratio was determined on part of the bolus used for rheological characterization, in order to reduce the number of collected boli and avoid subject exhaustion. After capillary rheometry, part of the extruded bolus was weighed before and after staying in an oven during 24 h at 130°C. The bolus hydration ratio was expressed as the amount of saliva incorporated to the food product and was calculated according to the procedure reported by Repoux et al., 2012 for cheese boli (1). All reported values are on a wet basis.

$$(1) \qquad \text{Added saliva } (\%) = \left[\frac{\text{bolus}_{\text{WC}}}{\text{bolus}_{\text{DM}}} \times \text{product}_{\text{DM}}\right] - \text{product}_{\text{WC}}$$

Where:

bolus $_{\text{WC}}$ =bolus water content $\left(\frac{g\ of\ water}{100\ g\ of\ bolus}\right)$

bolus $_{\text{DM}}$ =bolus dry matter $\left(\frac{g\ of\ dry\ matter}{100\ g\ of\ bolus}\right)$

product $_{WC}$ =product's water content$\left(\frac{g\ of\ water}{100\ g\ of\ product}\right)$

product $_{DM}$ =product's dry matter $\left(\frac{g\ of\ dry\ matter}{100\ g\ of\ product}\right)$

2.6 Statistical analysis

Differences between products and subjects for chewing parameters were investigated using a two-way Analysis of Variance (ANOVA) model (product + subject) on the last chewing stage. As for bolus properties, these differences were investigated for each chewing stage using a repeated measures ANOVA model (product + subject + chewing stage), where the chewing stage was the repeated factor. For oral comfort scores, a two-way ANOVA model (product + subject) was used. The Student-Newman-Keuls test was used for a post-hoc multiple comparison test.

To investigate the impact of oral health status in chewing parameters and oral comfort scores, a two-way Analysis of Covariance (ANCOVA) model with interaction (dental status + stimulated salivary flow + dental status*stimulated salivary flow) was carried out. Regarding bolus properties, in order to take account for variability over time, a three-way ANCOVA model was applied by adding total chewing time as explanatory variable (chewing time + stimulated salivary flow + dental status*stimulated salivary flow). For every statistical procedure, a significance level of $\alpha=0.05$ was used.

Pearson correlation coefficients were calculated when needed between bolus properties, oral comfort scores and chewing parameters. Finally, Principal Component Analysis (PCA) was used to study the relationship between all of the variables cited above.

All statistical analyses were performed with XLSTAT software (v.2016 18.06, Addinsoft, USA).

3 Results and discussion

3.1 Chewing parameters and bolus properties

Average chewing parameters and bolus properties regardless of dental status and salivary flow are shown in Table 3. For the chewing duration and the number of cycles, the ANOVA performed on the last chewing stage (SP) showed a significant subject effect ($p<0.0001$), but no product effect. This means that despite the differences of composition and properties between the products, subjects do not modify their duration of chewing from one product to another. Comparable results were reported by Le Révérend, Saucy, Moser, & Loret (2016) in the case of healthy adults, where little variation was observed in the chewing duration and number of chewing cycles of brittle cereal products. Chewing duration and number of cycles were strongly correlated as shown by Pearson coefficients ($r_{\text{Sponge-cake}} = 0.91$; $r_{\text{Brioche}} = 0.94$, $p<0.001$). Therefore, chewing frequency remained relatively constant across subjects and was the only chewing parameter where the subject effect was not significant ($p>0.05$), meaning there is little inter-individual variability. This result is in accordance with those previously reported for other type of foods (Devezeaux de Lavergne, Derks, Ketel, de Wijk, & Stieger, 2015; Yven et al., 2012). Indeed, chewing frequency is reported to be a distinctive feature of the human species, with values close to 1.3 Hz (Lucas, 2004), and it does not seem to be affected by age (Peyron et al., 2004).

Conversely, bolus properties showed significant differences between products ($p<0.0001$), besides subject ($p<0.0001$) and chewing stage ($p<0.0001$) effects. Generally, the hydration ratio increased with time, and therefore with each chewing stage; while the apparent viscosity decreased. For bolus hydration ratio, products differed at every chewing stage, while for bolus apparent viscosity they only did at the last two chewing stages (C2 and SP). For both products, initial viscosity before chewing (C0) was significantly ($p<0.05$) higher for sponge-cake (2164±12 Pa.s) than for brioche (1561±21 Pa.s), likely because of lower fat content. This difference decreases after the first chewing stage (C1), where both products apparent viscosity becomes close to each other (i.e. 500 Pa.s). Interestingly, during the last two sequences (C2 and SP), the apparent viscosity of brioche exceeds that of sponge-cake, contrasting with their initial values. Regarding the bolus hydration ratio, even if both products have close water content values (Table 2), the amount of added saliva was significantly ($p<0.001$) higher for sponge-cake than for brioche. This particular feature may be explained by the higher porosity of the sponge-cake, reflected by its lower density value, although its lower fat and higher sucrose contents could also have an influence. Hence, sponge cake would absorb more efficiently the water present in saliva. This result is in agreement with those reported by Mathieu, Monnet, Jourdren & Panouillé (2016), who compared the hydration kinetics of different bread structures and found higher hydration rates for more porous structures.

3.2 Impact of oral health status on chewing parameters and bolus properties:

The influence of the oral health status on the chewing parameters and bolus properties was determined by ANCOVA model, and the results are presented in Table 4. As previously mentioned, given its high correlation with the number of chewing cycles, only the chewing duration (SP) was included to represent chewing parameters. The dental status (DS) influenced the SP for both products and it was longer for participants with a satisfactory DS (positive β coefficient). However, the interaction between DS and stimulated salivary flow rate (SSF), close to significance for sponge-cake and significant for brioche, suggests that a high SSF can counterbalance the observed DS effect. As for the bolus hydration ratio, it is clear that SSF is the main factor of influence for both products, which means higher flow rates lead to more hydrated boli (positive β coefficient). The bolus apparent viscosity was also highly impacted by the SSF, although in the opposite sense (negative β coefficient). DS, on the other hand, showed little impact on bolus properties. Only in the case of brioche, individuals with a satisfactory DS produced a bolus with a higher apparent viscosity. Nevertheless, likewise the chewing duration, there was a significant interaction with SSF. A hypothesis to explain the two previous interactions could reside in the well-known theory of the ‘swallowing threshold’ (Hutchings & Lillford, 1988), which stipulates that all individuals swallow at determined time, degree of structure and degree of lubrication that depends on food product. Since in this case, the SSF has shown to be the main variable involved in the reduction of bolus apparent viscosity, it could be hypothesized that individuals with a high SSF will achieve the degree of bolus viscosity needed to trigger swallowing in a shorter chewing duration, than their counterparts with a lower SSF. This could explain why individuals with a satisfactory DS, but a low SSF, need a longer chewing duration to produce a bolus with a similar degree of viscosity than those with high SSF. From another perspective, the composition of saliva, mucins in particular, adds lubricating properties to saliva (Wu, Csako, & Herp, 1994) and therefore could also be partially responsible for the 'faster swallowing' of individuals with high SSF. However, in the present study the composition of saliva was not investigated. Overall, the stimulated flow rate appears to be the key parameter that determines bolus properties just before swallowing, whatever the dental status. A similar conclusion was obtained by Yven, Bonnet, Cormier, Monier, & Mioche (2006) who worked on meat products and subjects with impaired mastication. These authors hypothesized that the level of moisture is more important in triggering the swallow event than is the level of comminution of the product.

3.3 Phenomenological model of apparent viscosity from stimulated flow rate

Hydration ratio and bolus apparent viscosity were found to be correlated ($r_{\text{Sponge-cake}} = -0.72$; $r_{\text{Brioche}} = -0.81$, $p<0.0001$), as previously observed by (Le Bleis et al., 2013) in the case of bread boli. Therefore, the decrease of bolus viscosity over time depends on the hydration ratio and more interestingly on the SSF of the subject. Similar results were obtained by Loret et al. (2011), who observed that rheological properties of boli from breakfast flakes were related to the bolus water content, which was concurrently correlated to the saliva flow of the subject. As a consequence, the variations of bolus apparent viscosity can be represented as a function of the theoretical amount of saliva in the mouth (Fig.1), expressed by the product of SSF by the chewing duration (Le Bleis et al., 2016).

(2) $$Theoretical\ Saliva\ (mL) = \Phi_{stim} \times t_{CX}$$

Where:

ϕ_{stim} =Stimulated salivary flow rate $(\frac{mL}{s})$

t_{CX} = Chewing duration at a given sequence (s)

From Figure 1, the decrease of the apparent viscosity over time can be fitted through a power law model and modelled from a single physiology parameter with an acceptable R^2 coefficient, close to 0.6. Likely the data scattering, and lack of fit, may be due to inter-individual variability that is not explained by SSF, such as saliva composition and food fragmentation. Le Bleis et al. (2016) have taken into account the effect of fragmentation by dividing flow rate by the particle size in order to consider the increase of contact surface and absorption capacity of the food. This opens prospect for a more complete model by including other factors such as the particle size and the degree of fragmentation of food in future studies.

3.4 Perception of oral comfort and impact of oral health status

Unlike bolus properties, the perception of oral comfort (OC) was not significantly different between products, as reflected by the two-way ANOVA performed on the scores obtained for every of the 26 questions included in the questionnaire (see Appendix, Table A.2). Moreover, both products were considered to be very comfortable. The scores of the sensory attributes related to OC and bolus formation of the questionnaire are presented in Figure 2, which shows that both products were highly rated and close to the maximum.

In order to investigate the impact of oral health status in the perception of OC, an ANCOVA model was applied (Table 4). The results show that the stimulated salivary flow rate (SSF) had an influence in the overall comfort score of the sponge-cake, and the participants with a high SSF perceived the product as more comfortable (positive β). Conversely, for brioche neither the dental status (DS), nor the SSF had an influence in the overall comfort score. In this case, the OC seems to be independent from the physiology of the subjects and could be rather explained by the product itself. Indeed, the higher level of fat contained in the brioche may have a lubricating effect which may be responsible for OC perception. Engelen, Fontijn-Tekamp, & Bilt (2005) found that adding butter to Melba toast (approximately 20 g of butter/100 g of Melba toast) reduced significantly the number of chewing cycles and the chewing duration in healthy adults. The same conclusions were obtained by Gavião, Engelen, & Van Der Bilt (2004). Therefore, the addition of fat in some dry foods may compensate for the low moisture content and facilitate the swallowing, leading to high OC scores.

3.5 *Multivariate analysis and overall discussion*

The preceding study of physiological parameters highlighted their impact in the oral processing and the bolus formation process of the elderly. So, in order to consider the simultaneous action of all these variables (physiology, chewing parameters and bolus properties) and their inner relationship with oral comfort (OC) attributes, a PCA was performed. Regarding OC, only the attributes with a significant subject effect were included. For sponge-cake, principal components (PC's) 1 and 3, which together explained 57% of the total variability, were selected for a graphical projection (Fig. 3, left). PC 1 separated the subjects according to their physiology, particularly their stimulated salivary flow rate (SSF) showing a high correlation to the component (R= 0.81). The overall comfort score was also positively correlated to this PC (R= 0.68), as well as easiness (R =0.64). Conversely, PC 3 was driven by the differences in bolus properties, particularly the apparent viscosity, as shown by its correlation to this PC (R= 0.46). This PC was also negatively correlated to the overall comfort score (R= -0.49). From the correlation circle (Fig. 3, left) it can be seen that the overall comfort score was clearly opposed to the apparent viscosity of the bolus, and close to the added saliva. Moreover, the attributes easiness and easy to moisten were depicted together and in the same direction as bolus hydration. These relationships were confirmed by Pearson correlation coefficients, where the overall comfort score positively correlated to the hydration ratio, (r= -0.47, p<0.05) and negatively correlated to the apparent viscosity (r= -0.52, p<0.05). Thus, a sponge-cake bolus with a low hydration ratio and, as a consequence, a high apparent viscosity, will be perceived as uncomfortable. This result confirms an important relationship between physiology and sensory perception that could be quantified and modelled through bolus properties (See section 3.3). These results are in agreement with those of Jourdren, Saint-Eve, et al. (2016), who showed by Multi-bloc Partial Least Squares (MB-PLS) regression that bread bolus properties, and hydration in particular, allow to explain better the perception of texture attributes than the characteristics of the breads themselves.

PC 2 separated subjects according to chewing duration (R= 0.91, data not shown), but no other variable correlated to this PC, meaning that chewing time did not contribute to explain the other variables and in particular OC. This observation was confirmed by Pearson correlation analysis (r= -0.18, p>0.05). Hence, the individuals who took a longer time to swallow did not necessarily find the product uncomfortable and are probably ‘slow chewers’ in a general manner. This supports the theory that there are different chewing strategies according to the consumer preferences (Brown & Braxton, 2000; Jeltema, Beckley, & Vahalik, 2015).

For brioche (Fig. 3, right) PC’s 1 and 2 (61 % of variability) were selected: PC 1 discriminated the subjects in terms of SSF and overall comfort, as shown by their correlations to this PC (R=0.53 and R=0.70, respectively), although they were not depicted close to each other. In fact, unlike sponge-cake, the perception of OC does not seem to be related to physiological variables but rather to sensory attributes describing OC (easy to chew, to swallow and to moisten). Interestingly, the bolus properties appeared to be orthogonal to the OC variables. Although the sticky and pasty attributes were opposed to overall comfort, and thus perceived as uncomfortable, they were poorly explained by the bolus properties or the physiology of the subjects. Previous studies in bread boli have shown a negative correlation between the perceived stickiness and the bolus hydration ratio (Jourdren, Panouillé, et al., 2016; Jourdren, Saint-Eve, et al., 2016). To explain this, the authors hypothesized that a highly hydrated bolus could increase its cohesiveness and thus prevent its adhesion to the palate and teeth. Also, the perception of stickiness seemed to be influenced by the bread density: a higher density led to an increased perception of this attribute (Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014). However in our case, even if the brioche was denser and boli less hydrated, the perception of stickiness did not correlate to any of the studied bolus properties, as confirmed by Pearson correlation analysis (rBHR= -0.17 r□120= 0.2, p>0.05). Also, even if the OC questionnaire does not feature a hedonic dimension, it is interesting to notice that some of the sensory attributes that were related to the perception of OC have shown to influence the liking of similar products in precedent studies (Tarrega, Quiles, Morell, Fiszman, & Hernando, 2017). In this work, participants rated higher the products that were identified as sweet and easy to chew, and lower those that were found to be pasty and dry.

This leads to think such sensory attributes could play an important role in driving consumer preferences, and thus deserve a better understanding and instrumental characterization during oral processing.'

In all, as already seen from section 3.4, neither bolus properties nor physiological variables were related to the overall comfort perception of brioche. PC 3 correlated to chewing duration (R=0.94, data not shown) and did not correlate with other variables.

Additionally, two PCA were performed in order to consider poor and satisfactory dental status (DS) separately. For sponge cake, the obtained projections were similar to those described above on Fig. 3 (left) and led to identical conclusions (data not shown). In contrast, for brioche, PCA performed by DS group highlighted further relationships between physiological variables, oral processing and bolus properties that were not identified previously. For both groups, satisfactory and poor DS, the first two PC's were selected, representing 57 and 63% of the total variability, respectively. A correlation circle including said PC's was depicted for each group (Fig. 4). Some parallels and contrasts between the two groups can be outlined. For instance, in both cases, the overall comfort perception continued to be depicted in opposition to the perceived stickiness and pastiness, as seen in the all-subject results (Fig. 3, right). Also, in both cases, the perceived easiness to swallow and moisten are depicted in the same direction and contribute to discriminate subjects in PC 1, suggesting these attributes are not dependent on the DS. On the other hand, attributes such as easiness and easiness to chew appear to be distinctive between groups. In the case of the poor DS group, they appear correlated positively to PC 1 (R_{chew}=0.8, $R_{easiness}$=0.57), meaning they contribute importantly to discriminate subjects in this dimension, and differences in perception could be higher within this group. It is not the case for the satisfactory DS, where the mentioned variables did not correlate to either of the PC 1 nor PC 2. This result suggests that the perception of these variables is affected by the DS of the subjects and was probably more consensual for the satisfactory DS group. Another important difference resides in the chewing duration, which is depicted contradictorily for each DS group. These results are in agreement with the previous ones (see section 3.2, Table 4), since the bolus apparent viscosity and chewing duration had already shown to be influenced positively by a satisfactory DS.

Finally, the perception of OC was not the same across the two groups. While for the satisfactory DS, the interpretation remains unchanged from the all-subject results (Fig.3, right), for the poor DS group, overall comfort was projected close to the SSF and opposed to the bolus viscosity. Moreover, all of the three variables correlated to PC2 ($R_{Comfort}$= 0.56; R_{SSF}= 0.74; $R_{\eta 120}$= -0.72) even though there was no direct correlation within this group between the bolus apparent viscosity and overall comfort scores, as confirmed by Pearson coefficient (r= -0.17, p>0.05). However, there was a significant one between overall comfort and SSF (r= 0.77, p<0.01). This result suggests that dental status can actually influence the perception of OC, but paradoxically highlights the importance of SSF over DS. These results also suggest that the perception of OC in a product like brioche is more complex and depends on other factors that remain to be studied such as oral lubrication mechanisms (i.e. oral tribology), physiological variables (i.e. in-mouth shear forces), bolus properties (i.e. particle size) or product characteristics (i.e. the amount of fat).

CONCLUSIONS

Our results have shown remarkably that for soft aerated cereal foods, stimulated salivary flow rate is the most important physiological variable that impacts the food bolus properties and the perception of oral comfort in elderly, priming over the dental status. However, increasing the amount of fat seems to lower the role of the stimulated flow rate and bolus hydration, likely by increasing lubrication. This highlights the importance of the hydration and lubrication mechanisms in the oral processing and enjoyment of eating for this type of products in the elderly. Additionally, it was seen that two products with different composition and structure show similar chewing behavior and oral comfort perception but different bolus properties and oral mechanisms. Moreover, it has been found that the evolution of bolus viscosity can be predicted through the stimulated saliva flow rate of the individual independently of the dental status. Since viscosity has been shown to influence significantly the oral comfort, this relationship could be a good basis for modelling oral processing and designing foods with the desired oral comfort for the elderly.

In this study, salivary role has been only considered in terms of resting and stimulated flow. However, other salivary properties may influence bolus properties and sensory perception of cereal products, in particular salivary alpha-amylase and/or viscosity (Joubert et al., 2017). Knowing that salivary composition evolves significantly with age, (Nagler & Hershkovich, 2005) influence of salivary composition on oral processing, food bolus properties and sensory perception of cereal products in elderly will be the subject of further investigation.

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Figure 1. Bolus apparent viscosity η ($\dot{\gamma}$=120s^{-1}) as a function of the theoretical amount of saliva in mouth. ▲=Sponge-cake, ●=Brioche, Full symbols= C1, Mid-filled symbols=C2, Empty Symbols=SP.

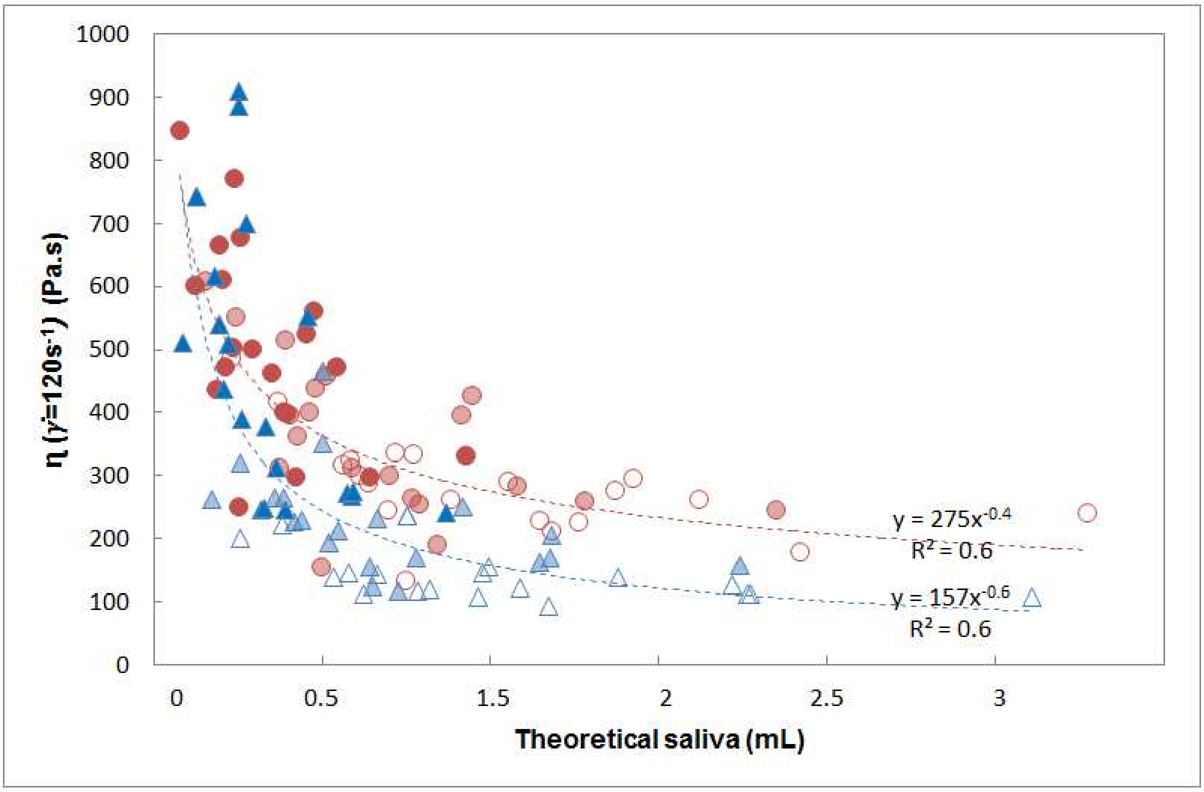
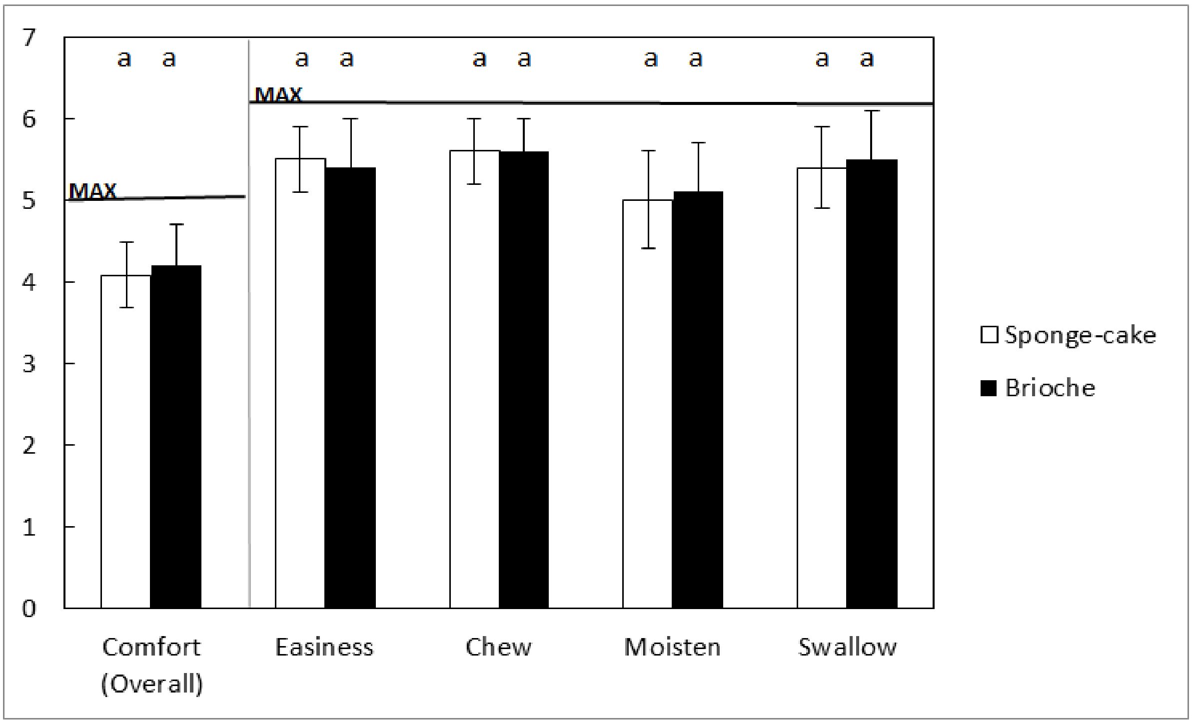


Figure 2. Mean scores for general comfort and bolus formation sections of the comfort questionnaire for all subjects and both products.



Different letters indicate means that significantly differ between products with p<0.05 (Student-Newman-Keuls test).

Figure 3. PCA correlation circle for oral health status, bolus properties, chewing duration and in-mouth comfort variables. Left= Sponge-cake, Right=Brioche.

Comfort=*Overall oral comfort perception score;* ***Chew=****Perceived as easy to chew;* ***Moisten=****Perceived as easy to moisten;* ***Swallow=****Easy to swallow;* ***Easiness=****Perceived as easy to eat;* ***Pasty=****Perceived pastiness;* ***Sticky=****Perceived stickiness;* ***BHR=****Bolus hydration ratio or added saliva;* η***120=****Bolus apparent viscosity at 120s*$^{-1}$*;* ***SSF=****Stimulated salivary flow rate;* ***SP=****Swallowing point or total chewing duration.*

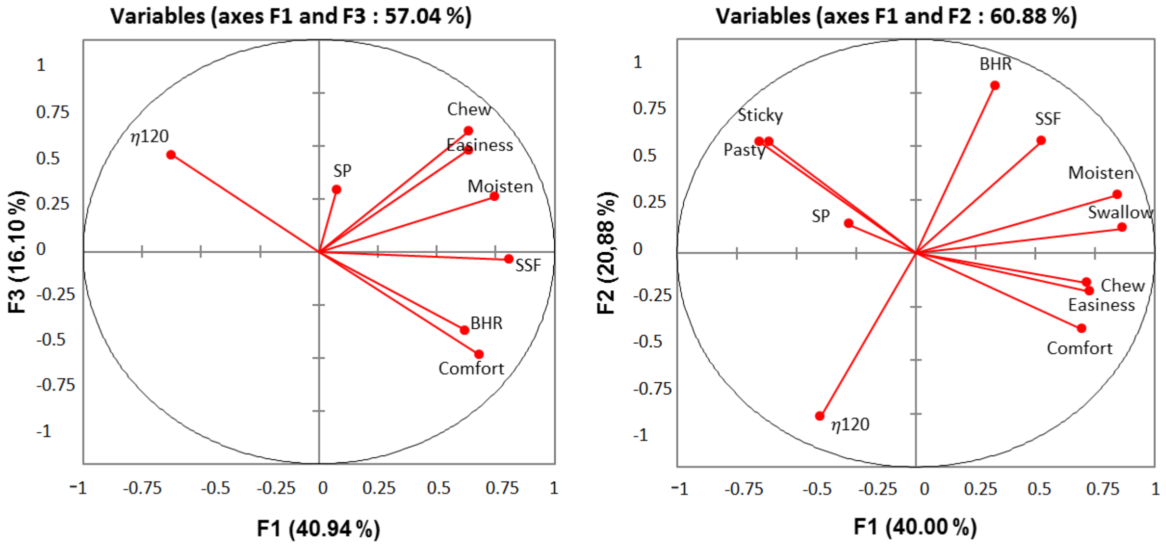


Figure 4. PCA correlation circle for oral health status, bolus properties, chewing duration and in-mouth comfort variables by dental status group for Brioche. Left= Satisfactory DS; Right= Poor DS

***Comfort=**Overall oral comfort perception score; **Chew=**Perceived as easy to chew; **Moisten=**Perceived as easy to moisten; **Swallow=**Easy to swallow; **Easiness=**Perceived as easy to eat; **Pasty=**Perceived pastiness; **Sticky=**Perceived stickiness; **BHR=**Bolus hydration ratio or added saliva; **η120=**Bolus apparent viscosity at $120s^{-1}$; **SSF=**Stimulated salivary flow rate; **SP=**Swallowing point or total chewing duration.*

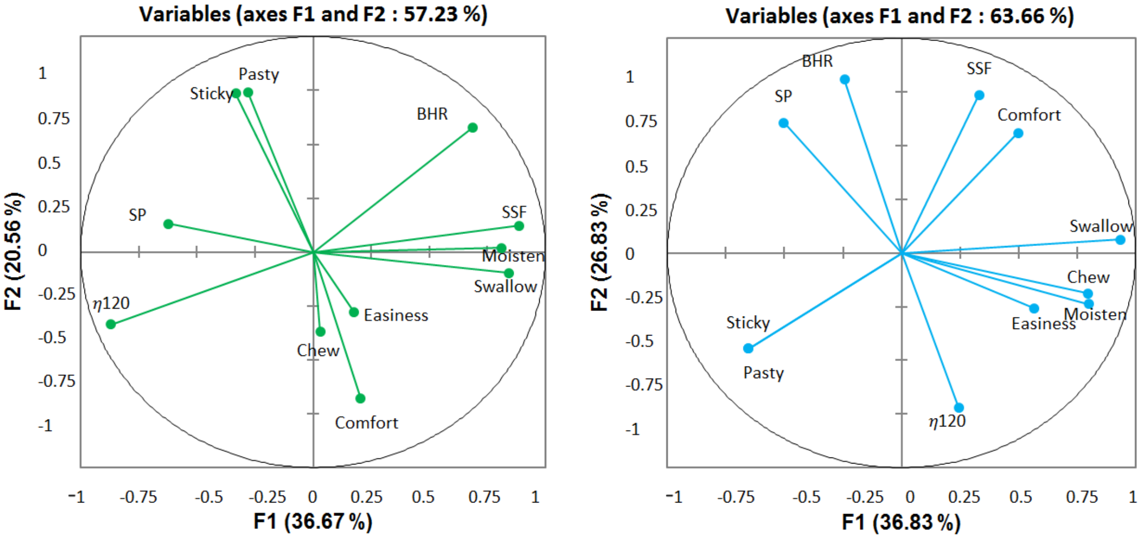


Table 1. Subjects characteristics.

	Poor Dental Status (PFU ≤ 4) n=10	**Satisfactory Dental Status (PFU ≥ 7) n=10**	**Whole group n=20**
Age (years)	75 ± 4	69 ± 5	72 ± 5
Sex			
Number of Male	5	4	9
Number of Female	5	6	11
Unstimulated Salivary Flow Rate (mL/min)	0.41 ± 0.19 Min 0.18 Max 0.75	0.33 ± 0.18 Min 0.03 Max 0.67	0.37 ± 0.18 Min 0.03 Max 0.75
Stimulated Salivary Flow Rate (mL/ min)	1.76 ± 0.89 Min 0.84 Max 3.70	2.05 ± 0.98 Min 0.30 Max 3.84	1.91 ± 0.92 Min 0.3 Max 3.84

Table 2. Product properties and composition (wet basis).

	Sponge-cake	**Brioche**
Proteins (g/100 g)*	11	7
Fat (g/100 g)*	6	17
Carbohydrates (g/100 g)*	55	46
Sucrose (g/100 g)	27	14
Starch (g/100 g)	18	30
Others (g/100 g)	10	2
Density (g/cm^3)	0.21 ± 0.02	0.33 ± 0.02
Water content (g/100 g)	28 ± 2	30 ± 2

**Theoretical values based on individual ingredients composition (USDA database).*

Table 3. Chewing parameters and bolus properties for all subjects by product and chewing stage (C1, C2 and SP).

Product	Sponge-cake	Brioche	Sponge-cake	Brioche	Sponge-cake	Brioche
Chewing stage	*C1*	*C1*	*C2*	*C2*	*SP*	*SP*
Chewing parameters						
Chewing duration (s)	11±4*	11±3*	23±8*	21±7*	34±11^{a}	33±9^{a}
Chewing cycles	13±5*	13±4*	27±9*	27±8*	41±13^{a}	41±11^{a}
Chewing frequency (Hz)	1.2±0.3*	1.3±0.2*	1.2±0.3*	1.3±0,2*	1.2±0.3^{a}	1.3±0.2^{a}
Bolus Properties						
Hydration ratio Added saliva (%)	31±12^{a}	23±7^{b}	55±21^{a}	35±9^{b}	79±25^{a}	45±11^{b}
Apparent viscosity η ($\dot{\gamma}$=120s^{-1}) (Pa.s)	464±216^{a}	505±159^{a}	227±83^{a}	358±120^{b}	145±44^{a}	284±79^{b}

*Different letters indicate means that significantly differ between products for each chewing stage with p<0.05 (Student-Newman-Keuls test); Values with a * were not measured but calculated from the SP (measured) value (C1=1/3SP or C2=2/3SP).*

Table 4. ANCOVA model coefficients (Type III sum of squares) for chewing duration, bolus properties and oral comfort by product Sponge-Cake (SC) and Brioche (B). *; **F=** Fisher ratio; **p=** p-value; **β =**normalized regression coefficients, for dental status only the Satisfactory coefficient is given (**S**).*

			Chewing duration (SP)		**Hydration ratio**		η_{120}		**Overall Comfort**	
			SC	*B*	*SC*	*B*	*SC*	*B*	*SC*	*B*
Dental Status (DS)	F		**4.87**	**8.25**	0.15	1.54	0.41	**7.76**	2.11	2.34
	p		**0.03**	**0.006**	0.70	0.22	0.53	**0.007**	0.17	0.15
	β	S	**0.67**	**0.86**	-0.08	-0.28	0.03	**0.62**	0.67	0.82
Stimulated Salivary Flow (SSF)	F		3.33	1.56	**21.17**	**17.75**	**12.10**	**23.35**	**7.89**	0.47
	p		0.07	0.22	**0.0001**	**0.0001**	**0.001**	**0.0001**	**0.01**	0.51
	β		0.01	0.20	**0.37**	**0.34**	**-0.25**	**-0.20**	**0.80**	0.41
DS*SSF	F		3.70	**7.60**	0.17	1.76	0.95	**7.10**	1.54	0.30
	p		0.06	**0.008**	0.69	0.19	0.33	**0.01**	0.23	1.13
	β	S	-0.72	**-1.02**	0.09	0.34	-0.26	**-0.70**	-0.67	-0.66

Significant values (p<0.05) highlighted in bold