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Bolus rheology of texture adjusted food—Effect of age

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Abstract

Swallowing disorders, or dysphagia, affect a large part of the population due to factors such as degenerative diseases, medication side effects or simply age-related impairment of physiological oropharyngeal function. The management of dysphagia is mainly handles through texture-modified foods of progressively softer, smoother, moister textures, depending on the severity of the disorder. Rheological and physiological-related properties of boluses were determined for a group of five older persons (average age, 74) for a set of texture-modified foods: bread, cheese and tomato and the combination into a sandwich. The softest class was gel food, after which came a smooth timbale; both were compared to boluses of regular food. The subjects chewed until ready to swallow, at which point the bolus was expectorated and measured regarding saliva content, linear viscoelasticity and shear viscosity. The results were compared to those of a previously studied younger group (average age, 38). The general physiological status of the subjects was determined by hand and tongue strength, diadochokinesis and one-legged standing and showed that all subjects were as healthy and fit as the younger group. Age-related properties such as one-legged standing with closed eyes and salivary flow plus bolus saliva content were lower for the older group, but the average chews-until-swallow was surprisingly also lower. Consequently, bolus modulus and viscosity were higher than for the younger group. Overall, the intended texture modification was reflected in bolus rheological and physiological-related properties. Bolus modulus, viscosity, saliva content and chews-until-swallowed all decreased from regular food to timbale food to gel food.

KEYWORDS
bolus, dysphagia, rheology, swallowing, texture-modification

1 | INTRODUCTION

Aging affects various aspects of human health, including the ability to chew and swallow. Food oral processing and swallowing involve a complex interplay of different muscles, nerves and tissues in the mouth, pharynx and esophagus. One main factor affecting chewing and swallowing with aging is decreased overall muscle strength and mass. Similar to saliva, as salivary gland function declines with age, the activity and quantity of the enzymes (amylase, lipase) in the saliva may also decline, leading to a decrease in the breakdown of food particles in the mouth and a decrease in the content of food boluses.

Even in "healthy" aging bite force, tongue activity and unstimulated salivary flow rate decrease with age (Bakke et al., 1990; Navazesh et al., 1992). To adapt to such age-related changes, the

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average number of masticatory cycles required before swallowing a specific food increases progressively with age (even if there is considerable individual variation) (Peyron et al., 2004; Peyron et al., 2017). Additionally, muscular contraction amplitude is adapted to maintain chewing efficiency (Yven et al., 2012).

More serious effects of aging are various types of swallowing disorders (dysphagia) and, consequently, lack of proper food intake, that is, insufficient intake of energy, protein and other nutrients. This form of malnutrition all too often leads to negative feedback of further weight loss, falling accidents and disabilities. At this stage, older people might be admitted into nursing homes or hospitals, or they may even die. There is seldom a cure for dysphagia, and it needs to be managed by thickening liquid food and texture-modifying solid food (Ekberg, 2019).

A set of "model" foods ranging from normal to timbale to gel food have previously been characterized regarding rheological and mechanical properties (Stading, 2021b). The recommended levels for texture modification vary from country to country, and these three foods follow the Swedish scale (Möller, 2007; Wendin et al., 2010). Timbales are homogenized food restructured by starch and egg to create a soft, moist texture. The gel food is similarly homogenized food with an added gelling thickener. This set of foods was previously served to a group of young subjects (average, 38 years) who were asked to chew until feeling comfortable to swallow, at which point boluses were expectorated and analyzed regarding rheological properties and saliva content (Stading, 2021a). The texture modification was reflected in both bolus rheology and physiology-related properties in that bolus storage modulus, viscosity, saliva content and chews-until-swallowed all decreased from regular food to timbale food to gel food. The same set of model foods was used in the present study.

The aim of the present study was to determine rheological and physiological characteristics of boluses of normal and texture-adjusted, solid foods for healthy older people (70+) compared to young, healthy persons. The texture-modified foods represented texture classes of solid foods from previously studied normal foods to gel foods (Stading, 2021a, 2021b).

2 | MATERIALS AND METHODS

2.1 | Ingredients

Strained tomatoes without skins and kernels, produced in Italy were obtained as "Coop Passerade Tomater" (COOP Sweden, Stockholm). Gelatin from pigskin, Tørsleffs Favorit Gelatin was sold by Haugen-Gruppen (Norrköping, Sweden). A starch-based thickener, "Thick&-Easy" (Hormel Health Labs, GA, USA) was kindly provided by Findus Special Foods (Malmö, Sweden).

2.2 | Food products

Regular foods were obtained from the local supermarket.

- Bread: Kavring (Skogaholm, Sweden), a dark brown homogeneous bread without any seeds. The bread is sold pre-sliced in 8 mm thick slices.
- Fresh tomatoes: The skins, interior fluid and seeds were removed before serving.
- Cheese: "Grevé," 17% fat (COOP Sweden, Stockholm), a Swedish semi-soft cheese similar to the Swiss Emmental or British Cheddar.

Timbale foods were kindly provided by Findus Special Foods (Malmö, Sweden) as bread timbales and tomato timbales. Timbales are made from puréed food reconstituted with modified starch and egg to create a soft, moist texture similar to an omelette texture. Timbales are distributed frozen and were thawed at room temperature (21°C) before measurements were taken. In the Swedish system, processed cheese spread is used for both the timbale and gel food classes, and a processed cheese spread with 17% fat was used here ("Fjällbrynt Storsjö," Foodmark AB, Sundbyberg, Sweden).

The gelled bread was prepared according to a typical recipe in elderly and clinical care facilities. For 30 min, a piece of bread was soaked in 100 mL water with oil (15 mL rapeseed oil and thickened with 7.5 mL Thick & Easy first heated to 80°C and then cooled to 20°C). The gelled tomato was prepared from 100 mL strained tomatoes heated above 80°C, to which 1–8 g gelatine was added and incorporated into the solution. The solution was cooled and kept at 8°C overnight before serving. The set of food products has been evaluated in detail in a previous paper regarding mechanical and rheological properties (Stading, 2021b).

2.3 | Subjects

Five healthy older subjects, one woman and four men aged 70–76 years participated in the study. The subjects all had good dental status with no dentures. The experiments reported here were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and the participants gave their informed consent to participate in the study prior to the start of the experiment.

2.4 | Bolus sampling procedure

Six samples were prepared for each food, 4 g each. The subject was instructed to chew and swallow the two first samples and count the number of chews before swallowing. The following four samples were chewed one by one until the subject felt comfortable to swallow and the bolus was then expectorated on a small plate. About 0.5 mL of each sample was immediately applied in the rheometer and the rest weighed and placed in an oven at 105°C over night for at least for 18 h for gravimetric determination of moisture content (MC). Evaporation of other components at 105°C was assumed negligible.

Journal of Texture Studies

2.5 | Physical and oral status of the subjects

The general status of the subjects' physical and oral strength was evaluated with a set of well-established tests used previously to predict frailty (Kito et al., 2019).

2.5.1 | Physical strength

Hand grip strength: Measurements were carried out in triplicate for each hand with a digital hand dynamometer (Jamar Plus Dynamometer, Jamar, Cedarburg, WI, USA). The mean maximum grip strength for each hand was used for the analysis.

One-foot balance: The subjects were asked to balance on 1 foot at a time with eyes both open and closed for as long as they could, but for a maximum of 60 s.

2.5.2 | Oral function

Tongue pressure: A tongue pressure sensor balloon probe connected to a digital tongue pressure meter (JMS, Hiroshima, Japan) was placed on the dorsal tongue surface. Participants were asked to press up against the probe with the tongue toward the hard palate at maximum strength for 3 s (Kito et al., 2019). After several practice movements, tongue pressure was assessed three times to calculate mean values.

Tongue and lip motor function: Oral diadochokinesis tests were used. Participants were instructed to say the syllables "pa," "ta," or "ka" as many times as possible for 5 s. The number was counted by a digital counter (Kenkokun Handy, Takei Scientific Instruments Co., Ltd, Japan) and used for analysis (Yamada et al., 2015).

Salivary flow: The flow of stimulated saliva was obtained by chewing on a piece of tasteless Parafilm (0.3 g; Parafilm "M"1, American National CanTM, Chicago, IL, USA). Mechanically stimulated saliva was collected over a period of 3 min. Before collection, the mouth had been emptied by an initial swallow. At 30 s intervals, saliva was expectorated into a pre-weighed container, and flow rates (ml/min) were calculated. The weight of saliva in grams was assumed to equal the milliliters of saliva secreted, as the specific density of saliva is close to 1.0 (Richardson & Feldman, 1986).

2.5.3 | Saliva content in bolus

The saliva content of each bolus was calculated from the moisture content (MC) of the bolus and the MC of the individual foods (Stading, 2021b) as previously published by Drago et al. (Drago et al., 2011) as

$$\text{Saliva content} = \frac{MC_{bolus} - MC_{food}}{1 - MC_{food}} \tag{1}$$

where MC_{bolus} is the moisture content of the bolus and MC_{food} is the moisture content of the food.

2.5.4 | Rheometry

Small Amplitude Oscillatory Shear (SAOS) and viscometry were performed using an ARES-G2 and an HR 30 rheometer (TA Instruments, New Castle, DE, USA) equipped with a 20 mm, 25 mm or 40 mm diameter parallel plate system. The bottom plate was temperature controlled, and the measuring system was enclosed in a solvent-trap enclosure with water to humidify the air surrounding the sample. Bolus measurements were performed at 37°C. A measuring sequence was performed with a mechanical spectrum (SAOS) for 0.1–20 Hz at 0.5% strain, followed by a flow curve for 0.01–1 s^{-1}. An amplitude sweep, 0.05%–10% strain, was performed for one of the samples after the mechanical spectrum. The measurements were optimized to give results as quickly as possible as the rheological properties of the bolus changes with time (Stading & Röding, 2020).

2.5.5 | Statistical evaluation

Measured values are presented as mean values with error bars denoting the standard deviation. Samples were compared pairwise using a two-sample *t*-test.

3 | RESULTS AND DISCUSSION

The general and oral physiological state was determined for the five subjects by a set of established tests (Kito et al., 2019). The tests for general status included hand strength and one-legged standing. The oral physiological state was characterized by tongue strength and oral diadochokinesis tests. Table 1 shows the results, demonstrating that all subjects were remarkably healthy, fit and had excellent oral strength. This group of older Swedes (average age, 74) were on par with the previously examined group of younger subjects (Stading, 2021a) (average age, 38) and scored even better in the diadokinesis tests. The only test that signaled their age was their inability to sustain one-legged standing with closed eyes for an extended period, an exercise known to become more difficult with age.

Similarly, average salivary flow rate decreases with age (Mioche et al., 2004; Navazesh et al., 1992).This can also be seen when comparing the groups of older and younger subjects; see Figure 1b, where the older subjects have a statistically significant lower salivary flow rate ($p < .05$). The individual variations were not so significant, as shown in Figure 1a.

In conclusion, the studied group of older Swedes could be defined as "young old" for whom no strong causal relationship exists between age and impaired mastication (Peyron et al., 2017). The decline in one-legged standing and salivary flow rate is rather an inevitable effect of

TABLE 1 Physiological status of the subjects

	Median	Average	Standard deviation	Average young subjects (Stading, 2021a)
Age [years]	74	74	3	38
Tongue pressure [kPa]	40	42	7,5	44
Hand strength				
Left hand [kg]	37	37	6,5	35
Right hand [kg]	41	38	7,0	39
Diadochokinesis				
/Pa-pa-pa/ per 5 s	33	33	1,3	34
/Ta-ta-ta/ per 5 s	33	33	1,9	34
/Ka-ka-ka/ per 5 s	31	31	2,7	32
One-leg-standing				
Left foot, open eyes [s]	60	46	22,6	60
Right foot, open eyes [s]	60	59	1,8	60
Left foot, closed eyes [s]	4	3	1	54
Right foot, closed eyes [s]	3,2	4	1,4	59

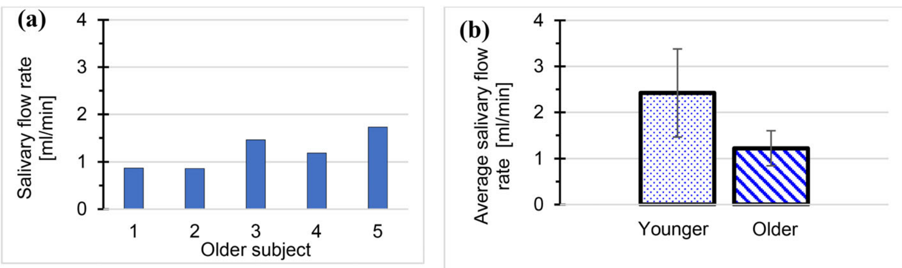

FIGURE 1 (a) Salivary flow rate for the five subjects, one to five from left to right, and (b) average salivary flow rate of young subjects from the previous study (left) (Stading, 2021a) and the older subjects in this study (right).

growing old, even in healthy aging, rather than a sign of weaker physical functions (Mioche et al., 2004).

3.1 | Physiological properties

The measured physiology-related properties of chews-until-swallow and the bolus saliva content are shown in Figure 2 for the individual subjects and the averages are shown in Figure 3. As expected, there are individual variations although less so than for the younger group (Stading, 2021a). Figure 3 shows averages for the older subjects as compared to the those of the previously examined younger subjects. Both chews-until-swallow and the bolus saliva content, in general, decreased from regular food → timbale food → gel food for both age groups, as was also intended by the texture modification (Chen, 2009; Stading, 2021a).

All but one parameter (out of 22) in Figure 3 shows a decrease going from younger to older subjects. For 12 out of 22 the decrease is statistically significant ($p < .05$). As we age, there is a gradual decrease in the number and function of salivary glands, which can lead to a reduction in the volume and composition of saliva produced as exemplified in Figure 1 (Bakke et al., 1990; Navazesh et al., 1992). This reduction in salivary flow rate and composition also manifests itself in the decreased bolus saliva content of the older subjects as compared to the previously examined younger subjects.

Due to this salivary age effect, chews-until-swallow generally increase with age to compensate for the typically diminishing saliva production and impaired oral strength (Woda et al., 2006), but this older subject group illustrates the opposite behavior. One possible explanation for this discrepancy could be that, on average, these two groups eat at different speeds. When asked, "On a scale of 1–9 (very slow–very fast, respectively), how fast do you believe you eat?" the older group responded with an average of 5.6 and the younger group with a 5.4, but the difference was not statistically significant. There could nevertheless exist differences as self-reported eating speed has only fair agreement with objective measures (Woodward et al., 2020).

There is a relationship between chewing ability and physical fitness, as shown, for instance, in a cohort of 1282 community-dwelling 80-year-old Japanese adults (Takata et al., 2004). The researchers measured several factors for physical fitness, such as oral strength, hand strength and one-legged standing and then correlated them with the ability to chew different foods. In the present study, the subjects all showed excellent fitness, which could have influenced the chewing ability in general and required a number of chewing cycles before

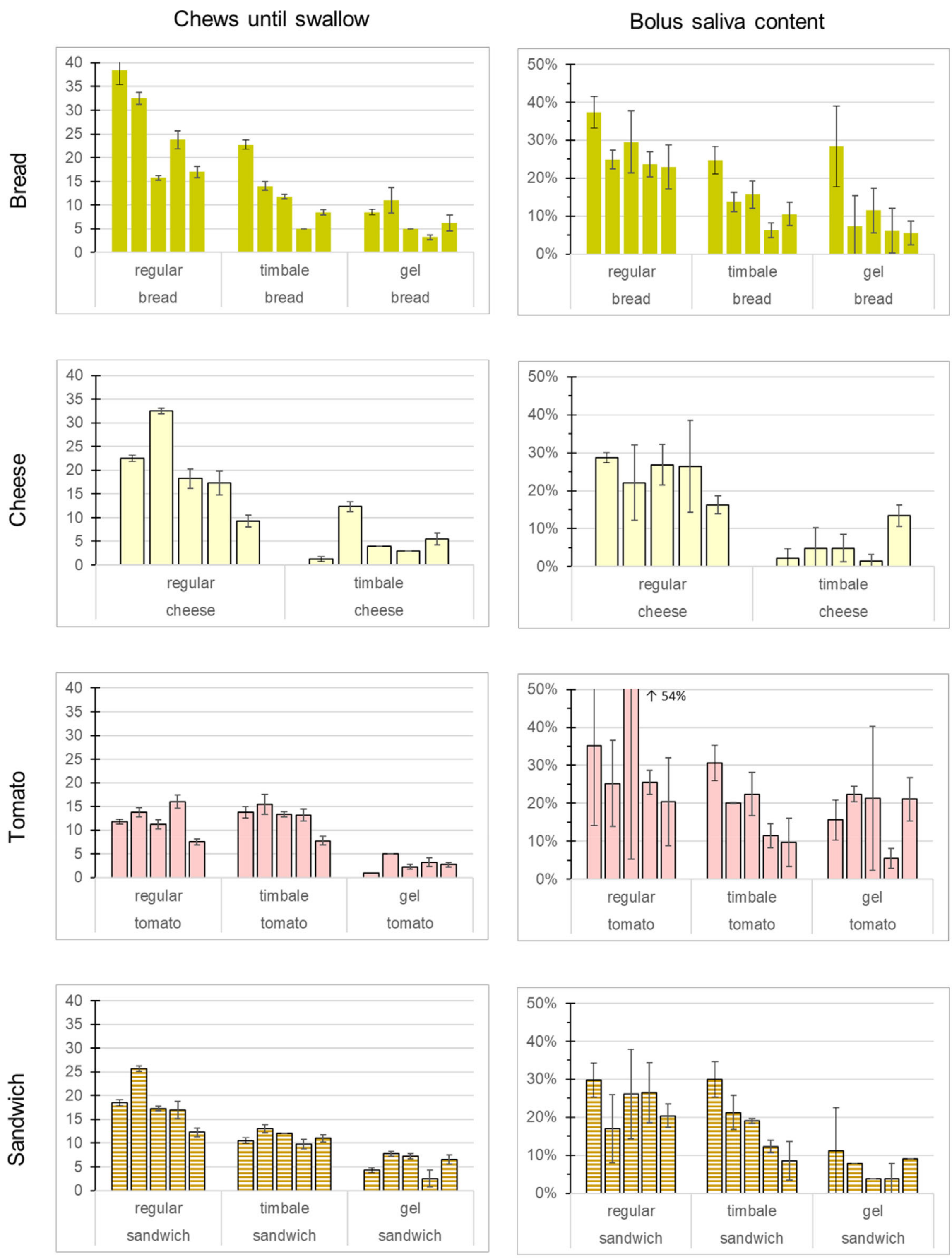

FIGURE 2 Physiological properties of the boluses for the five subjects. The first row shows results for bread, 2nd for tomato, 3rd for cheese and 4th for the combination into a sandwich. The first column is the required chews until swallow and the 2nd column is the calculated bolus saliva content. Each group shows bars ranging from subject one to subject five from left to right.

swallowing in particular. This effect could be more dominant in the older group than the younger one.

In a separate study, a high level of competence in daily living correlated with objective masticatory function (OMF) (Takagi et al., 2017). The competence in daily living was assessed from a questionnaire and the OMF using a Masticatory Performance Evaluating Gum, a standard chewing gum that changes color proportionally to the amount of chewing. In the present study, the subjects have

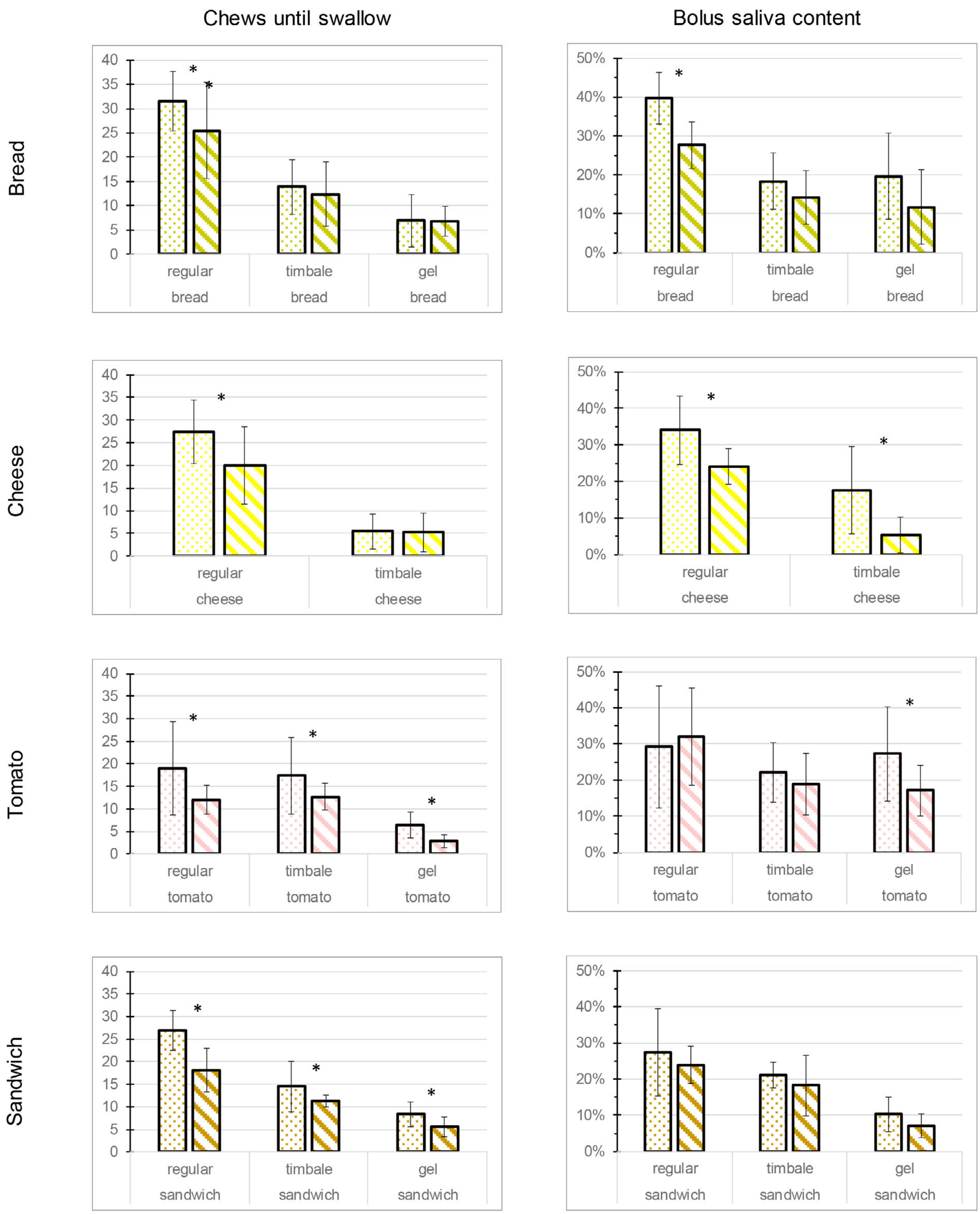

FIGURE 3 Average physiological properties of young subjects from previous study (Stading, 2021a) (left, dotted bar) and the older subjects (right, striped bar) of this study. The first column shows average chews until swallow and the second the average saliva content in the bolus. A statistically significant difference ($p < .05$) between the two groups is indicated by an *.

extensive social interactions, and some even have part-time academic employment despite exceeding retirement age. The correlation with OMF could also be extended to masticatory efficiency and required chews-until-swallow, even if there are no established direct links.

A further explanation of the observed difference could possibly be found in the composition of the groups of subjects. The younger group consisted of three women and two men whereas the older consisted of one woman and four men. Men in general have higher chewing frequency and eat faster (Park & Shin, 2015; Youssef et al., 1997).

In conclusion, there is only speculation as to why this group of older subjects all required fewer chews-until-swallow compared to the younger group (or why the younger group required more chews-until-swallow). Individual variations are known to be significant (Jeltema et al., 2020; Kim & Vickers, 2020; Lassauzay et al., 2000) and, as the two groups of subjects are small, the unexpected fewer chews-until-swallow for the older group could be attributed to individual variations. Nevertheless, even though both groups were considered "normal," it is an interesting observation that a group of healthy, fit older persons may very well have physical status on par with a younger group and fewer chews-until-swallow. To establish the cause, we would need further research and more subjects, which would also assist in determining whether or not this is a general observation for healthy "young-old" Swedes.

3.2 | Rheological properties of the bolus

The rheological properties of boluses, storage modulus, phase angle and viscosity after expectoration are shown in Figure 4, individually for the five subjects, and in Figure 5, as an average for the group. The latter figure also compares the averages with the previously studied younger group and, where possible, with the rheological properties of the foods (Stading, 2021a, 2021b). As expected, there are individual variations, but similarly to the younger group, these variations are smaller for the phase angle than for storage modulus and viscosity.

FIGURE 4 Rheological properties of the boluses for the five subjects in shear. Each group shows bars ranging from subject one to subject five from left to right.

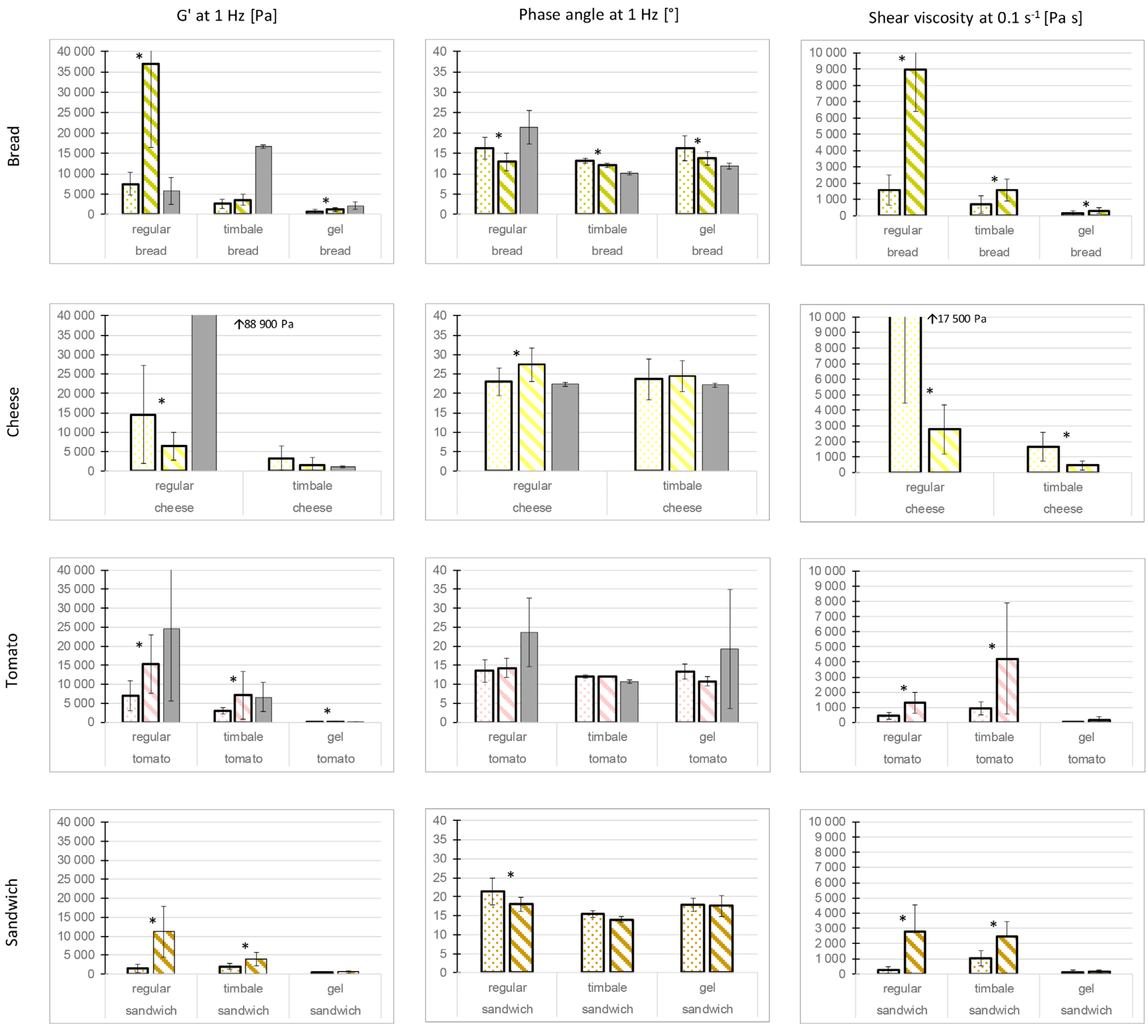

FIGURE 5 Average rheological properties of boluses from the previous study's younger subjects from previous study (Stading, 2021a) (first, dotted bar) and boluses from the present study's older subjects in this study (second, striped bar), as compared to rheological properties of the food (third, gray bar) where available. The first column shows the storage modulus at 1 Hz, the second column the phase angle at 1 Hz and the third column shear viscosity at 0.1 s^{-1}. A statistically significant difference ($p < .05$) between the two groups is indicated by an asterisk (*).

The storage modulus and viscosity, in general, decrease from regular food → timbale food → gel food for both age groups, as is intended with texture modification.

Small Amplitude Oscillatory Shear (SAOS), and especially the phase angle, can be interpreted as describing the bolus' character in contrast to viscosity that describes flow. The phase angle depicts the degree of solid versus viscous on a scale from solid (0°) to viscous (90°). As the phase angle was relatively constant for all subjects, this could indicate a certain required structure for swallowing (Chen & Lolivret, 2011; Hutchings & Lillford, 1988). A bolus has to be sufficiently viscous and cohesive to be swallowed (Coster & Schwarz, 1987; Loret et al., 2011; Lorieau et al., 2018; Prinz & Lucas, 1997), but there are no clear general correlations between specific rheological properties and swallowing threshold. Product characteristics have, for example, been observed to affect the swallowing threshold to a greater extent than oral physiology (Engelen et al., 2005). However, when comparing the rheological properties of boluses with that of the foods in Figure 5, there is no clear correlation. The mastication process is simply too complex to draw direct correlations (Woda et al., 2006).

The rheological properties of the bolus of the older group as compared to those of the food differed, as shown in Figure 5. This is expected when the food is masticated and mixed with saliva. When masticating porous bread without adding a surplus of saliva, the

TABLE 2 Probability of data for younger subjects being equal to older subjects for all determined parameters.

Food	Class	G' at 1Hz	Phase angle at 1 Hz	Shear viscosity at 0.1 s^{-1}	Chews-to-swallow	Saliva content
bread	regular	0%	0%	0%	1%	0%
bread	timbale	14%	0%	1%	49%	7%
bread	gel	3%	1%	2%	77%	92%
cheese	regular	1%	0%	0%	1%	0%
cheese	timbale	32%	59%	0%	70%	6%
tomato	regular	0%	36%	0%	2%	63%
tomato	timbale	2%	98%	0%	3%	12%
tomato	gel	2%	38%	14%	0%	2%
sandwich	regular	0%	0%	0%	0%	19%
sandwich	timbale	0%	45%	0%	2%	12%
sandwich	gel	26%	68%	39%	0%	24%

Note: Framed values show a decrease from younger to older, the remainder an increase. Red cells contain a statistically significant difference ($p < 0.05$).

storage modulus may increase, as shown in Figure 5, due to compacting the bread. The older group had reduced salivary flow and lower saliva content in the bread boluses than the younger group, which explains the difference in storage modulus. For the other foods, where the storage modulus could be measured, the bolus had a lower or same-range storage modulus as the corresponding food.

Similar reasoning explains why the storage modulus and the viscosity were higher for the older group than the younger one, see Figure 5. The older group, on average, chewed fewer times, had a lower salivary flow rate and had reduced saliva content in the boluses, giving rise to higher modulus and viscosity. This has also been observed for meat boluses (Mioche et al., 2002) and the hardness of a number of foods (Chen et al., 2013). Table 2 shows the probability of measured parameters for younger subjects being equal to older subjects, that is, a low probability means they are different. The red numbers show a probability $p < .05$, which for storage modulus and viscosity are 17 out of 22 measured foods, that is, the boluses of most foods have different rheological properties depending on age, and for these two groups of subjects, storage modulus and viscosity increased from young to old. However, this effect was not observed for the cheese boluses.

Despite the observation that chews-until-swallow and the saliva content were lower for the older group than for the younger one, viscosity still decreased from the younger to the older group, both for regular and timbale cheese. This particular group of older people chewed less before swallowing and had less saliva than the younger group, as discussed above, which also rules out an effect of enzymes in the saliva affecting the cheese due to prolonged exposure. Fat, as in the cheese, has been shown to facilitate bolus formation and reduce oral duration (Lorieau et al., 2018; van Eck et al., 2019), but the relation to lower bolus viscosity and storage modulus for the older group is still not apparent.

The previous study's younger group showed lower storage modulus and viscosity for the boluses comprised of the three foods, that is, a sandwich instead of individual components (Stading, 2021a). This was not as obvious for the older group, see Figure 5, much due to the cheese boluses having lower values than the younger group.

4 | CONCLUSIONS

The group of older people studied (average age, 74) were to be considered as fit and healthy "young old" (Peyron et al., 2017), managing the physical tests on par with the previously studied group of younger subjects (average age, 38) (Stading, 2021b). Tests of one-legged standing with eyes closed matched the appropriate age, which was also reflected in lower salivary flow rate and reduced bolus saliva content. Contrary to previous findings, the older group had lower chews-until-swallow than the younger group.

Due to the lower chews-until-swallow and bolus saliva content, the older group displayed higher storage modulus and viscosity of boluses than the younger group.

The texture modification of the foods functioned as intended, as displayed by chews-until-swallow, bolus saliva content, storage modulus and viscosity, in general, decreasing from regular food → timbale food → gel food for both age groups.

The phase angle indicated a similar structure or slightly more solid character for the older group as compared with the younger group.

The exception in all measured rheological properties was the one for cheese, both regular and timbale. We cannot find any specific explanation for this effect, and further research would be needed on a vast number of subjects.

Overall, when comparing this older group with the younger group, it is interesting to note that there are differences with age, but as the older group was healthy and fit, the differences are relatively small. However, an expanded study would be necessary to draw more general conclusions.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they do not have any conflict of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

ETHICS STATEMENT

This study does not involve any human or animal testing.

INFORMED CONSENT STATEMENT

The experiments reported here were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and the participants gave their informed consent to participate in the study prior to the start of the experiment.

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