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A HUMAN-LIKE CHEWING MEASUREMENT SYSTEM FOR THE ASSESSMENT OF THE PERCEPTION OF FOOD CONSISTENCE

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Consistence and crispiness are key textural qualities capable to significantly increase the desirability of food, as proved by the 40% growth of market share of "crispy" products since 1994. To match this demand and improve the quality there is a strong need for an instrumental method for assessing these parameters. Most works reported in literature only focus on the rheological properties of food, completely ignoring the perceptive aspect. In this work a device capable to assess consistence of food is presented. A mechanical system composed of a joint jaw/mandible set and a dental prosthesis was designed to emulate the main movements of chewing. An array of strain gauges allowed the indirect measurement of the instant pressure acting upon the teeth. A consistency index was derived from the features extracted from the sensor signals and calibrated with the results of a differential test carried out by ten untrained panellists. A high degree of correlation was obtained, suggesting that the system might be used to predict the consumer perception of consistence.

1. Introduction

In the human history, as soon as the living conditions have raised beyond the level of the bare survival, the food consumption has always ceased to be just a basic biological need, assuming hedonistic, symbolic and ritual features.

Nowadays, the food market in western countries is highly competitive, and many companies struggle to gain and widen market shares. Many factors drive the consumers' preference for food, some related to its intrinsic features (nutritional properties, safety, preservability and other biological properties, price, packaging, easiness of use), some related to the market and the society (corporate advertising, dietary habits, life style) [1]. Organoleptic properties have a primary role, and for this reason sensory evaluation methodologies have

been studied and standardized [2]. Food sensory features can be grouped in three interacting categories: appearance, taste and consistence [3]. Appearance is defined as the sensory features perceived by the sight, but it has been proved that other senses, olfaction in particular, can have an influence. A combination of gustative, olfactory, tactile and thermic sensations produces the taste perception, while consistence is a sensorial characteristic related to the perception of the theological properties of food during chewing [4,5]. This perception is influenced by the absorption of saliva into the food, while the sound produced during biting is related to the crispiness. Such sounds the consumer learned to associate with a particular food and they thus have an important role on his satisfaction. In this work, a device capable to assess consistence of food is presented. The performance of the device was tested on one type of biscuits at four different ageing levels, and the results were compared with those obtained by a panel test. The good correlation between the two sets of data suggests that similar devices may replace expensive and low throughput human panels in the near future for this particular analysis.

2. Experimental

The chewing device was designed to emulate the human mastication, both from a cinematic and dynamic point of view.

The human mastication results from complex bicondylar movements of the mandible: opening and closing in the sagittal plane, protraction and retraction in the horizontal plane and lateral movements in the horizontal and frontal planes. A typical masticatory cycle can be divided in three phases: an opening phase (duration 250-300 milliseconds), consisting in a slow movement at the beginning and a quick movement at the end; a closing phase, in which the mandible is raised quickly to grasp the bolus; an occlusal phase, in which the elevators muscles of the mandible slowly apply an increasing pressure on the bolus, up to the complete closure of the lower and the upper dental arch. The mean length of this phase is about 200 milliseconds and the maximum force (~27 kg) is applied for approximately 120 milliseconds.

A whole chewing cycle lasts about 700 milliseconds; the maximum vertical and lateral displacements are about 16-22 millimeters and 3-5 millimeters, respectively. The prototype consists of a jaw/mandible set capable to emulate the human chewing cycle (opening, closing and lateral movements of the mandible). During the opening and closing phase, a pneumatic piston (Norgren RT/57232/M/50) rotates the mandible by 20 ± 2° in the sagittal plane. The lateral movements (1 ± 0.01° rotation in the horizontal and frontal planes) are obtained passively, thanks to the deformations induced by the food in two silent

blocks placed at both ends of the mandible, in the points where it is bound to the structure. The combination of these movements allows the mechanical mandible to describe trajectories similar to those of the human analogue. A proportional pump, whose output pressure can be controlled by an input voltage, was used to drive the piston. The upper and lower part of a dental prosthesis, made with stainless steel teeth dipped in a rigid resin, were fixed on foils screwed respectively on the mandible and the jaw. Two strain gauges (Measurement Group EA-06-125BT-120) were symmetrically glued on the opposite sides of each foil, so that any bending induced an increase of resistance in the upper strain gauge and a decrease of resistance in the lower strain gauge. These resistance variations were detected by means of a Wheatstone bridge, in which the two sensors were connected symmetrically on the opposite paths of the bridge to double the signal relevant to the bending of the foil and avoid common mode noise due to temperature variations or voltage fluctuations. Data were collected by a data acquisition card (National Instrument PCI-6025E).

3. Materials and Methods

Several batches of the same brand of Italian biscuits named Savoiardi were stored for one, two and three weeks in controlled air conditions (23°C temperature, 50% R.H.).

A large amount of fresh biscuits, i.e. contained in their sealed package, was also available for the measurements. Tests were carried out with an untrained panel and the chewing device to calibrate this latter and make it capable to predict the panel judgement. The international standard ISO 6658-1985 [3] was considered for the sensory analysis, and in particular a combination of paired comparison test and scoring test was chosen as the most suitable for our purpose. The paired comparison test is used to determine whether a difference exists between two products, while scoring is recommended for evaluating the intensity of one or more attributes. In our experiment, pairs of Savoiardi biscuits were offered to each panellist, i.e. one sample and a reference (a fresh biscuit). Panellists were asked to bite once either into the sample and the reference, then to rate the difference of consistence in a nine step numerical scale ranging from –4 to + 4. The 0 value was by definition attributed to the reference, negative values were hence to be attributed to samples less consistent than the fresh biscuit. The choice of a paired comparison was made to increase the reliability of the untrained panellists, while scoring was needed to have results comparable with the chewing device. Ten samples were tested in random order by each of the ten panellists for each of the four ageing levels as to have a sufficient number of repetitions.Using the prototype, the same number of measurements

was carried out following the same procedure (single bite), but no reference sample was used in this case. The proportional pump was supplied with a pressure of 0.5 bar and driven by a sinusoidal voltage (period 0.7 sec), resulting in low velocities at the changes of direction and the good correlation with the closing phase of the human chewing cycle.

4. Results

Panel test results are summarised in table 1, in which the number of responses collected for each scale interval and the average consistence value relevant to each ageing level are reported.

It can be noted that Savoiardi undergo a progressive hardening with an almost linear trend.

Table 1 – Panel test results: total number of responses collected for each scale interval and average consistence value relevant to each ageing level

Aging	Consistence value									Average
	-4	-3	-2	-1	0	1	2	3	4	
Fresh	0	0	0	0	93	7	0	0	0	0,1
One Week	0	0	0	0	10	67	23	0	0	1,3
Two Weeks	0	0	0	0	0	27	50	23	0	2,2
Three Weeks	0	0	0	0	0	0	10	80	10	3,3

A typical signal obtained by two coupled strain gauges is showed in figure 1a: overshoot, settling time and steady state amplitude were selected as the most significant features.

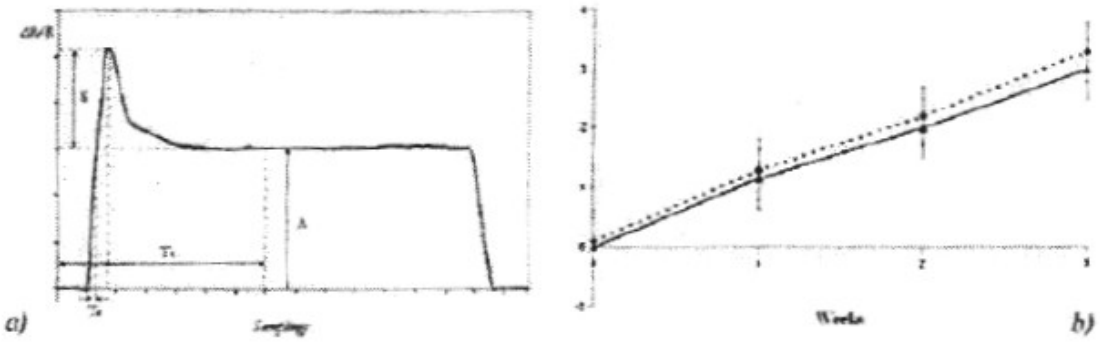

Figure 1 – a) Typical relative resistance variation in the coupled strain gauges due to the bending of the foil during the occlusal phase: overshoot (S), settling time (Ts) and steady state amplitude (A); b) Consistency index (rhombi, continuous line) and average consistence value (triangles, dashed line) obtained by the sensory analysis

A consistency index C_I was defined as:

$$C_I = \sum_{i=1}^{n} A_i \Phi_i = \sum_{i=1}^{n} A_i \frac{S_i}{Ts_i}$$

where n is the total number of teeth, S the overshoot, T_S the settling time, Φ the S/T_S ratio and A the steady state amplitude. The range of variation of the consistency index and that of the test panel were normalized by range scaling, which is equivalent to calibrating the instrument on the panel results. The graph in figure 1b shows that there is a very good agreement between the panel and the instrument results within the experimental errors.

5. Conclusions

A device capable to emulate the main movements of mandible during the mastication and to assess the consistence of food was developed.

An array of strain gauges was used to get an indirect measurement of the pressure exerted on the teeth during chewing. The features extracted from the sensor signals were combined to derive a consistency index related to the rheological properties of food. The prototype was tested on Italian biscuits Savoiardi at four different ageing levels. A sensory analysis was carried out by ten untrained panellists, and results were used to calibrate the system. The linear hardening of Savoiardi with time was pointed out by the system and the panel with a good agreement, but further measurements on different types of food are needed for a better estimate of reliability and resolution of the system. Also, the use of a microphone will permit in the near future to take into account crispiness and increase performances.

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