Description of oral behaviour during the oral processing of heterogeneous apple purees. An application of the temporal check-all-that-apply method

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Description of oral behaviour using TCATA

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/jtxs.12634

Abstract

The objective of this study was to assess the potential of the temporal check-all-that-apply (TCATA) method to describe oral behaviour from the introduction of products into the mouth until swallowing. In particular, we wanted to test the feasibility of the task, the ability to show differences between composite products, and the possibility of segmenting the panel based on the data collected.

Terms referring to actions performed during Food Oral Processing (FOP) were used instead of classical sensory descriptors. The evaluation consisted, for a panel of 54 subjects, of checking the boxes corresponding to the actions in progress throughout the consumption of the products. The five products studied were an apple puree and four heterogeneous mixtures that were obtained by adding gel pieces varying in size (two sizes) and firmness (two levels of firmness).

The participants did not encounter any particular difficulty in describing in real time the actions in progress during the consumption of the products. Data collected made it possible to describe the sequences of actions carried out during the FOP and to determine the influence of the presence of pieces of gels, their size and their firmness. We highlighted two groups of subjects presenting different behaviours. The subjects in the first one exhibited little difference in processing between the four samples containing the gel pieces, while the subjects in the second group adapted their behaviour according to the firmness of the gel pieces.

Overall, this exploratory study suggests the ability of TCATA in describing oral behaviour during FOP. Future studies should aim at validating it with objective measurements of FOP.

Key words

TCATA, food oral processing, heterogeneous foods, oral behaviour, individual variability

1. Introduction

The appreciation of foods during consumption is largely guided by the simultaneous perception of flavour, aroma, texture and trigeminal sensations. The quality and intensity of perceived sensory stimuli depends on the initial physical and chemical characteristics of the food and how it progresses from bite to swallow (Salles, 2011, Devezeaux de Lavergne, 2017). The oral mechanical actions performed and the gradual incorporation of saliva are at the origin of the physical and chemical transformations undergone by the food and therefore of the evolution of perceived sensations and their appreciation. The perceived sensations can, in turn, impact on the oral mechanical actions to be carried out to maximize the pleasure of tasting and obtain a food bolus that is safe to swallow (Chen, 2009).

The initial characteristics of foods can be understood by instrumental measurements of many structural, physicochemical, rheological or tribological variables. Many sensory methods make it possible to provide a qualitative or quantitative description of the perception of sensory stimuli generated by the food throughout its passage through the oral cavity as well as of the resulting appreciation. In this context, so-called "dynamic methods" naturally seem more suitable than traditional methods, such as the conventional sensory profile, based on tasting experience as a whole (integration of sensations perceived during the tasting). There are many methods in this field, but the following methods can be cited in particular: time intensity (Dijksterhuis & Piggott, 2000), temporal dominance of sensations (Pineau et al., 2009), and temporal check-all-that-apply (Castura et al., 2016). All of these methods have already been used to describe texture characteristics (Duizer et al., 1996, Lenfant et al., 2009, Fuentes et al., 2014, Panouillé et al., 2014, Devezeaux et al., 2015, Lorido et al, 2015, Makame et al., 2019, Sharma et al., 2019). There are therefore many techniques available to describe both the physical and chemical properties of foods as well as their perception, and they provide useful information for understanding FOP. However, they do not directly provide information on the exact nature of the actions that occur in the mouth during the consumption of food. The techniques used to study the nature and sequence of actions performed in real time during the FOP are relatively few. These include video fluoroscopy (Matsuo et al, 2016), kinematic and electromyography techniques (Peyron et al., 1997, Carvalho-da-Silva et al., 2011, Yven et al., 2012), and visual observation of masticatory movements (Hutchings et al., 2011, Larsen et al., 2016, Iizumi et al., 2018, Aguayo-Mendoza et al., 2020). These techniques require specific equipment and/or skills and involve individual evaluations limiting the size of the groups of subjects studied.

The interactions between the actions carried out, the sensations perceived and the dynamic aspect of FOP make this first stage of the ingestive phase relatively difficult to understand, especially since the underlying mechanisms are influenced by individual factors linked to consumers (physiological factors, physiology of the oral cavity, psychological factors, etc.). For the same food, the oral behaviour during FOP, sensations perceived, and resulting pleasure may therefore vary from one consumer to another. This variability has been the subject of several studies, which have made it possible to propose behavioural typologies based on the actions carried out during FOP. For example, Carvalho-da-silva et al. (2011) identified, within a panel of 40 subjects, three possible behaviours during chocolate tasting. The subjects were divided into three groups: "fast chewers", "thorough chewers" and "suckers". In another study conducted with 23 consumers of sausage, two groups of subjects characterized as "long duration eaters" and "short duration eaters" were identified Devezeaux et al. (2015). Following a different approach, Jeltema et al. (2015) proposed a tool (JBMB typing tool) to classify consumers based on their preferences for four types of commercial foods with very different textures and involving specific mouth behaviours. Based on their preferences for these four types of foods, consumers could be classified into one of the following groups: "chewers", "crunchers", "smooshers" and "suckers". Wilson et al. (2018) were able to partially predict (68%) subjects' membership in the JBMB type from a set of 19 variables describing their chewing sequence in a lab experiment.

Taking into account the variability of behaviours due to individual factors requires working with a large number of subjects. As suggested above, the current techniques used to study the nature and sequence of actions performed in real time during FOP involve individual assessments limiting the size of the groups of subjects studied. Thus, alternatives to existing methods are required. The description by a human subject of his/her oral actions during the course of FOP seems to be an interesting alternative approach that has rarely been addressed thus far. Saint Eve et al. (2018) proposed for the first time to study oral processing using the temporal sensory method called 'temporal dominance of motions' (TDM, which is inspired by the TDS method), which consists of a real-time description of the sequences of oral actions and elementary physiological actions during oral processing. The method was found to be relevant to discriminate the oral processing of homogeneous products presenting large texture differences. The objective of the present study was to explore the potential of temporal check-all-that-apply method (TCATA) for describing oral behaviour during FOP. The potential of the method was evaluated according to two criteria, i) the ability to discriminate between products with different textures, ii) the ability to distinguish behavioral patterns of FOP actions sequences between individuals.

It builds on the evaluation of the relevance of dynamic sensory methods for describing FOP. It completes previous work from Saint-Eve et al. (2018) by the method used as well as by the products studied. Indeed, we have chosen to study heterogeneous products (fruit purees with pieces), presenting less important differences in texture, based only on the size and firmness of the pieces included in the homogeneous phase. In addition, this work goes further by investigating interindividual variability in oral processing for these types of foods.

Materials and methods

a. Products

i. Sample preparation

The five products studied were a commercial apple puree (Carrefour® brand, ingredients: apple puree, 98.5%, concentrated apple juice, 1.4%, added sugar) and four heterogeneous mixtures obtained by adding gel pieces varying in size (two sizes) and firmness (two levels of firmness) to the commercial apple puree. The two levels of firmness were obtained by using two different gelling agents exhibiting different gelling properties (agar-agar and gelatine). The gel pieces were made from a mixture of apple puree (the commercial product described above) and apple juice (pure juice, Joker®) supplemented with either agar-agar (NAT-ALI, Rezé, France) or bovine gelatine (Kalys gastronomie, Bernin, France). For each session, they were prepared by mixing 595 g of apple puree, 105 g of apple juice, and 21 g of agar-agar or 28 g of gelatine (Table 1). Agar-agar powder was added at ambient temperature, and then, the mixture was heated to 90 °C. Gelatine powder was added when the temperature was 60 °C, and the mixture was then heated to 80 °C and kept at this temperature for 30 s. Preparations were made under constant stirring in a closed mixing bowl using a food processor (Vorwerk Thermomix TM5). Mixtures were then poured in 22x22 cm silicone moulds in a quantity necessary to obtain 3- or 6-mm-high gel plates after cooling. After covering them, gel plates were placed in a cold room (4 °C) for a maximum of 72 h. Preliminary rheological measurements demonstrated the stability of gel hardness during this period. Microbiological analyses, performed by an independent laboratory, confirmed that the samples were consumable for at least 72 hours after manufacture. On the day of the experiment, 3- and 6-mm-high gel plates were cut into 6x6- or 12x12-mm pieces using a manual vegetable cutter equipped with a suitable cutting grid. Finally, the sampling operation consisted of placing 2 g of gel pieces into plastic spoons and 10 g of apple puree on top. After covering them, all samples were stored at 10 °C for 2 h before the session and then served and evaluated at room temperature under red light. The spoons were coded using a three-digit code.

[Insert Table 1]

Agar-agar and gelatine gels were prepared in cylinders 23 mm in diameter and 11 mm in height. Uniaxial single compression tests were performed at room temperature using a TA. XT*plus* Rheometer

(Stable Micro Systems, Surrey, UK). Samples were compressed with a plate probe (45 mm diameter) with a constant deformation speed of 1 mm/s to 80% initial height. The maximum peak force was 55.2 N (SD=5.4) for the agar-agar gel and 25.8 N (SD=3.0) for the gelatine gel.

ii. Texture characterization of the products with pieces

Before the main measurements intended to study oral behaviour during FOP with the TCATA method, a simplified texture profile was carried out to ensure that the differences between the products with pieces were well perceived. The four heterogeneous samples were compared according to three characteristics: perceived number of particles ('none' to 'a lot'), particle size (from 'small' to 'big'), and particle hardness ('soft' to 'hard'). Linear scales were used, giving rise to scores ranging from 0 to 10. The simplified texture profile was performed using 10 subjects (different from those who performed the TCATA) without previous experience in quantitative descriptive analysis. Considering that the descriptors were very few and simple, the authors considered that the task was realizable without previous training. The samples were evaluated under the same conditions as for the main study (product manufacturing, sampling, and tasting). The measurements were performed in three replicates (three different sessions). During each session, the order of presentation of the products was balanced according to a Williams Latin square design. Subjects had to take a 30 s break between each sample, during which they rinsed their mouths with water.

b. *Subjects*

Fifty-four panellists were recruited from Dijon (France) and surrounding areas. To be included, participants had to be older than 18 years old, accept consuming the study products, present a normal dentition (no dental apparatus and no orthodontic treatment) and have no known allergy. Thirty-three women (mean age: 37.2 years, min/max = 21/50) and 21 men (mean age: 36.7 years, min/max = 22/49) were included. Some of them may have participated in the past in consumer tests and possibly, in basic sensory analysis tests, but none had recent extensive experience in descriptive analysis. They all signed an informed consent form before the start of the study and were compensated for their participation.

c. *Dynamic characterization of FOP (TCATA)*

The sequence of actions carried out during the consumption of the samples was studied using TCATA, a dynamic method for describing the multidimensional sensory properties of products as they evolve over time (Castura et al., 2016). The selection and deselection of attributes are tracked continuously over time, permitting panellists to characterize the evolution of sensory changes in products. The originality of the present study lies in the fact that the panellists did not have to select/deselect sensory attributes corresponding to their perceptions but instead selected actions describing FOP in real time.

When choosing which temporal method to use, the TI method was eliminated because we were not interested in the intensity of the actions but just in their sequence. In addition, of the three main temporal methods, TI is the most precise but also the most complicated to implement, especially with several attributes. The TDS method was not retained for the present study because we considered that the concept of dominance seemed difficult to transpose to actions such as chewing, moving, swallowing, etc. In contrast, the use of terms describing actions instead of perceived sensations did not pose any problem with TCATA. In addition, this method had the advantage of allowing the subjects to simultaneously select several actions.

A preliminary study made it possible to select five essential actions when consuming the products studied. These five actions were "chewing", "crushing against the palate", "moving with the tongue", "separating liquid from solid" and "swallowing". These five actions were presented to the panellists before the start of the measurements. Considering the simplicity of the terms, no complicated explanation was necessary. However, subjects were informed that they could ask for explanations if certain terms appeared to be ambiguous to them.

All measurements were conducted in individual sensory booths at ambient temperature (21 °C +/- 2 °C) and under red light. TCATA data were collected using TimeSens software (INRAE, Dijon, France). First, the panellists were familiarized with the procedure on two products considered training samples. Then, the five products described above were evaluated successively during the same session. One of the products, Aga-small, was doubled to assess the repeatability of measurements. Overall, after the two training samples, the panellists evaluated six samples whose order was balanced according to a Williams Latin square design. A 30-second break allowed subjects to rinse their mouths with Evian water between each sample. Panellists were instructed to click a Start button concurrently with putting the whole sample (12 g of product presented on a spoon) into their mouth and to immediately commence tracking changes in the sample by checking and unchecking actions occurring at each moment during oral processing for a maximum of 120 s. Over this period, the end of the evaluation of the product was determined by observing, for each subject, the time of the last box checked (swallowing). At any time between clicking Start and the end of the evaluation time, panellists were free to check any unselected action or to uncheck any selected action. In accordance with the usual instructions for TCATA (Castura et al., 2016), panellists were informed that it was possible that some actions were never checked, that other actions were checked but never unchecked, and that other actions were checked and unchecked one or more times, ending in either the checked or unchecked state. However, no instruction was given regarding the way participants should eat and swallow the products. The entire list of attributes was displayed on the screen. The attribute positions on the screen were balanced across participants but were consistent for a given participant across all samples. The whole session lasted between 45 min and 1 H.

d. Data analysis

Data were analysed using XLSTAT (Addinsoft, Paris, France). A significance threshold of 0.05 was considered for all of the statistical analyses.

i. Sensory evaluation (simplified texture profile)

ANOVA (model: descriptor = subject + size + gelling agent + size*gelling agent + err.), performed on the four products with gel pieces, made it possible to study the influence of the size of the pieces and the nature of the gelling agent on the perceptions of the panellists (number, size and firmness of the pieces of gels). A post hoc multiple comparison test (Tukey HSD) was used to determine if means were significantly different from each other.

ii. FOP duration

The FOP duration is the period of active oral actions and was determined by determining the duration elapsing between the time of the first checked action and the time just after the last checked action (swallowing), as shown in Appendix 2. Two analyses of variance (ANOVA) were carried out to study the influence of gel pieces on the FOP duration (nonstandardized data). The first was carried out with the aim of comparing the product without pieces and the four products with pieces (model: FOP duration = subject + product + error). The second aimed to specifically study products with gel pieces and to determine if the size and nature of the gel (the firmness) influenced the duration of the FOP (model: FOP duration = subject + gelling agent + size + gelling agent * size + error). Both analyses were followed by a post hoc multiple comparison test (Tukey HSD) to determine if means were significantly different from each other.

iii. TCATA analyses

As we wanted to compare individual on their FOP behaviour, TCATA data were standardised using the TimeSens software. Example of standardization of dynamic data can be found in Lenfant et al., 2009 on DTS data. In our case, only the active FOP period was considered (i.e. period between when the first action is checked until the last action is unchecked (Appendix 2). TCATA standardized data were in binary format, which means for each row (product/subject/action combination) a binary vector with a size of 100 characterizes the combination with 1 if the attribute is selected at time t and 0 otherwise. T=1 corresponds to the beginning time where the first click occurs (first action checked) and T=100 corresponds to the end time corresponding to the last action unchecked.

Three types of graphs resulting from the TCATA analysis were used within the framework of this work.

- Product trajectory: A factorial correspondence analysis was performed to define the product trajectory. Each row corresponds to a product/time combination, and the columns contain the attributes. The factorial coordinates of the lines (product/time) are linked together, and thus, the trajectories of the products over time are displayed on the factorial plane (smooth curves). The initial point (start of the evaluation) of each trajectory contains the label with the name of the product. An arrow shows the direction of the evolution of the position of the product over time.

- Citation proportion curves: For each product, the citation proportion curves for each of the attributes are displayed as a function of time (smooth curves). A reference curve is displayed for each action. For a given product, this reference curve corresponds to the average proportion of citations for all of the other products combined. To test the difference between the curve of an action and its reference curve, a chi-squared test was performed. To avoid overloading the graph, the reference curves are displayed only if the difference is significant for a given time. When a significant reference curve is displayed, the curve for the attribute is displayed in bold.

- Differences between products: a graph is displayed for each pair of products for comparison. For each attribute, a chi-squared test was performed to determine whether the difference in quotation proportions was significant. When the difference is significant for a given time, the curve of the difference in proportions is displayed. Preliminary comparison of both replicates collected for the same product revealed no significant differences in quotation proportions at any moment of the evaluation (data not shown), suggesting reproducibility of the data; thus, only the first replicate was further considered in this manuscript.

iv. *Clustering of subjects*

Agglomerative hierarchical clustering (AHC, Euclidean distance, Ward's method) was carried out to study the possibility of grouping subjects according to the FOP duration observed for each product. The TCATA data were then analysed separately to compare the product trajectories of groups formed using AHC. A t-test by product was carried out to compare the mean FOP duration of the groups. A t-test was carried out to determine whether the two groups of subjects obtained from the AHC presented differences in terms of age. A chi-squared test was performed to determine whether the sex ratios of the two groups were equivalent.

2. Results

a. *Texture characterization of the products with gel pieces (simplified texture profile)*

As expected, the results showed that the number of pieces perceived in the mixture depended on the size of the pieces ($F(1, 106) = 299.39$, $p < .0001$). The pieces of gels were added at a constant mass (2 g, regardless of the size), hence small pieces were more numerous than the large pieces. The type of gelling agent did not influence the perceived number of pieces ($F(1, 106) = 0.59$, $p < .44$). The agar-agar pieces were perceived to be firmer than the gelatine pieces ($F(1, 106) = 253.15$, $p < .0001$). This result confirms the rheological measurements performed. The size of the pieces did not influence their perceived firmness ($F(1, 106) = 3.48$, $p = .06$). More surprisingly, the analysis showed that the perceived size depended both on the actual size ($F(1, 106) = 138.85$, $p < .0001$) and on the firmness of the pieces (gelling agent, $F(1, 106) = 7.2$, $p = .01$). The multiple comparison of the means (Tukey test, threshold set at 5%) showed that, at equivalent size, the pieces of agar-agar gel were on average perceived to be larger than the pieces of gelatine gel. The "size×gelling agent" interaction was not significant for the three descriptors ($p > 0.05$).

Overall, these results confirm the relevance of the choices made concerning the size and firmness of the added pieces of gels. Indeed, the four heterogeneous mixtures studied were consistent with real foods (apple purees with pieces), and the differences between the four types of pieces were clearly perceptible.

b. *Dynamic characterization of oral behaviour during FOP (TCATA)*

i. *FOP duration*

The first ANOVA showed that the FOP duration differed between products ($F(4, 212) = 82.41$, $p < .0001$). Tukey's test (Fig. 1) revealed that the products with firm pieces (agar-agar gel) implied a longer FOP duration than products with softer pieces (gelatine gel). In addition, for the same gelling agent, the duration of FOP did not differ significantly as a function of the size of the pieces. Finally, apple puree without pieces was the product that involved the shortest duration of FOP (approximately 6 s). Compared to the product without pieces, the duration of the FOP was on average multiplied by 2.2 for the soft pieces and 2.7 for the hard pieces. The second ANOVA, performed only on products with pieces, confirmed the first ANOVA by showing that the FOP duration was influenced by the gelling agent and therefore by the firmness ($F(1, 159) = 56.03$, $p < .0001$), but not by the size of the gel pieces ($F(1, 159) = 2.78$, $p = .10$). The gelling agent*size interaction was not significant ($F(1, 159) = 0.03$, $p = .85$).

[Insert Figure 1]

ii. *Global description of oral behaviour during FOP (product trajectory map)*

Biplot representation of the correspondence analysis (Fig. 2) shows the sequence of the actions observed throughout the oral processing. The product trajectories were based on the citation frequencies of the different actions over time. The black diamonds represent the extremity of the vectors of the studied variables. The variables studied in our case are the actions carried out during the FOP. For each product, the more a point on the trajectory approaches a black diamond, the more frequent the corresponding action is within the panel for the product.

The positions of the beginnings and ends of the trajectories indicate that the left side of the representation is associated with actions that tend to occur early in the evaluation, whereas the right side is associated with actions that tend to be elicited later in the evaluation. The opposition "chewing" and "swallowing" actions mainly define the first axis (F1). "Moving" and "crushing" actions and their opposition to "separating" action mainly define the second axis (F2).

We can observe that all of the trajectories logically end in the direction of the "swallowing" action. The greater the oral process accomplished, the more frequent this action occurs, and all evaluations end with this action. The map also shows that it is essentially the starting points of the trajectories that make it possible to differentiate the oral processes of the different products. At the starting points of the trajectories, a clear separation can be observed between apple puree without gel pieces (lower right quadrant), products containing pieces of gelatine gel (lower left quadrant), and products containing pieces of agar-agar gel (upper left quadrant).

The homogeneous apple puree (i.e., without pieces) is the only product whose trajectory begins on the right-hand side. "Chewing" and "separating" actions were not required during the oral processing of this product. The oral processing of this product seems to be determined by the following sequence: "crushing" and "moving" actions quickly followed by the "swallowing" action. The trajectories of two products containing pieces of gelatine gel start almost from the same place on the map and follow a similar course. These products are first chewed, moved in the mouth, crushed against the palate, probably alternately, and then swallowed. Finally, the starting position and the trajectories of the two products containing pieces of agar-agar gel seem to indicate that these products first require chewing and separation of the pieces, and then, they are moved and crushed against the palate before being swallowed. A detailed description of oral behaviour is presented in Appendix 1.

[Insert Figure 2]

iii. Comparison of oral behaviour as a function of product properties

The TCATA difference curves show pairwise product differences (Figs. 3, 4, and 5). These curves allow the visualization of differences in TCATA action citation frequencies at each moment of the evaluation. The curves are shown only for the time slices during which the difference between the citation frequencies of both products was significantly different from zero.

The global effect of the pieces of gels on the oral behaviour during FOP can be inferred from the comparison of the curves of the apple puree without pieces with those of the four other products. Fig. 3 shows that the addition of pieces of gels implied an increase in the citation frequency of the chewing action over the entire evaluation in all cases, with the exception of the very last moments. Conversely, swallowing action was more frequent for apple puree without gel pieces during most of the evaluation (80%). The addition of pieces of gel therefore generally delayed the swallowing action, even if the individual curves (Appendix 1) show that this action occurred periodically during the evaluation (but less frequently than for apple puree without pieces). The addition of pieces of gels also involved an increase in the frequency of citations of the separation action. Overall, this difference relates more to the first half of the evaluations. More episodically, the addition of pieces of gels increased the frequency of citation of the moving action (second part of the evaluation) and crushing action (variable moment depending on the products).

The effects of products properties on FOP can be inferred from the comparison curves, where only significant differences at a given time point were drawn. Fig. 4 shows the effect of the size of the pieces of equal firmness: Aga-small versus Aga-big and Gel-small versus Gel-big. Fig. 5 shows the effect of the firmness of the gel pieces of equal size: Aga-small versus Gel-small and Aga-big versus Gel-big. It can be observed from Fig. 4 that gel pieces size hardly induced any difference in oral behaviour, in agreement with the individual curves showing a great proximity between products containing pieces made with the same type of gel (Appendix 1). Significant differences were observed depending on the type of gels (and thus firmness levels) (Fig. 5). These differences relate in particular to the chewing action. Indeed, the frequency of chewing action was higher for products containing pieces of agar-agar gel (firmer) than for products containing pieces of gelatine gel (softer). In addition, for larger pieces, the separating action was more frequent for the product containing the firmer pieces (Aga-big) than for the product containing the softer pieces (Gel-big). This difference is visible in the first part of the evaluation. It can also be observed that the crushing action was slightly more frequent at the very start of the evaluation for the products containing the pieces of gelatine gels than for the products containing the pieces of agar-agar gel. However, this phenomenon is ephemeral.

[Insert Figure 3, Figure 4, and Figure 5]

c. *Clustering of subjects*

The AHC performed suggests clustering into two groups of subjects (cluster 1: n = 32, cluster 2: n = 22, see dendrogram in Appendix 3). Comparison of the FOP durations of the two groups showed significant differences for all products (Table 2). The durations of cluster 2 are systematically higher than those of cluster 1, even for the sample without pieces (ref.).

[Insert Table 2]

The oral processes of the two clusters thus obtained were compared using their respective product trajectory maps (Fig. 6). The comparison of the two maps clearly reveals that the subjects of cluster 1 made very little difference between the four samples containing the pieces of gel, while the subjects of cluster 2 adapted their behaviour according to the firmness of the pieces of gel.

Indeed, for cluster 1, the trajectories of the four products containing pieces of gel are similar, i.e., very close starting and end points and parallel trajectories. This reveals the same treatment applied to these samples. They were chewed, moved, and then swallowed. The citation proportion curves (not shown) revealed that the chewing action was the most frequently cited action for all samples containing pieces of gel throughout most of the evaluation.

The subjects of cluster 2 did not apply the same oral treatment to the samples depending on the firmness of the pieces of gels. In addition, the oral processing of samples with pieces of gelatine and apple puree was quite similar. The trajectories of the products containing pieces of agar-agar gel (firm) and gelatine (soft) differ mainly in their starting point and in the distance between them on axis 2 in the first part of the evaluation. Axis 2 of AFC is mainly explained by the chewing action, in opposition to the crushing and moving actions. Thus, for cluster 2, the samples containing the pieces of agar-agar involved a greater chewing action than for the samples containing the pieces of gelatine gel. Conversely, crushing moving action was more frequent for the samples containing pieces of gelatine gel. The citation proportion curves (not shown) confirmed that chewing action was the most frequent for the samples containing pieces of agar-agar gel, while the most frequent action for the products containing pieces of gelatine gels was crushing action. In addition, separation action was more frequent for samples containing pieces of agar-agar at the beginning of the evaluation.

The average age of the subjects did not differ from one group to another ($t(52) = 0.36$, $p < .72$). The sex ratios of the two groups were equivalent ($\chi^2(1, N = 54) = 0.78$, $p < .41$).

[Insert Figure 6]

3. Discussion

The objective of this exploratory study was to assess the potential of the TCATA method to describe oral behaviour during FOP, that is, the sequence of actions carried out from the introduction of the product to the mouth until swallowing of the bolus. This potential was evaluated from different perspectives: the relevance and convenience of the method, the ability to differentiate between products, and finally the possibility of using the data collected for a further analysis intended to determine groups of subjects based on their oral behaviour during FOP.

Relevance and convenience

On the basis of to the preliminary work of Saint-Eve et al. (2018), we knew that the TDS method could be useful in describing the actions carried out during FOP. Considering that the concept of dominance was difficult to transpose to actions, we chose to use the TCATA method. In the present study, the TCATA procedure applied to actions made it possible to characterize the sequence of actions performed from the introduction of the product in the mouth until swallowing of the bolus in a single measurement. The measurements were carried out on 54 subjects in a relatively short time due to the ability of working with 10 to 16 participants simultaneously (this number was limited by the reception capacity of our facilities). The participants did not encounter any particular difficulties in applying the TCATA procedure. Indeed, after the training products, the subjects had the opportunity, at the request of the facilitator, to express themselves. No questions or comments suggesting that the task was difficult were noted.

Previous works on the FOP of heterogeneous products have mainly focused on chewing behaviour (upward vertical movements of the lower jaw), duration of consumption and number of swallowing events (Aguayo-mendoza et al., 2020; Hutchings et al. 2011, Larsen et al 2016). In the present study, five essential actions for the consumption of heterogeneous semisolid products were considered, and the data collected allowed us to determine the sequence of these actions for each of the products in a single measurement. The TCATA method has the advantage of allowing subjects to select several actions simultaneously. The data collected indeed enabled us to observe that for certain periods of the evaluation, several actions were selected simultaneously. For example, the “chewing” action (movement of the jaw) has frequently been cited at the same time as “separating” or” moving” actions (movement of the tongue). The TCATA method is therefore well suited to the description of a process involving several actions that take place at the same time in the mouth. It should be noted that actions linked to the movement of the tongue ("moving" and "separating") are major in the FOP of semisolids (de Wijk et al. 2011) and difficult to study in natural conditions and with a large number of subjects.

In general, this study shows that the TCATA method is suitable for the dynamic description of oral behaviour during FOP, which may involve simultaneous actions, and that it is an efficient response to the need to work with a large number of subjects.

Ability to describe and discriminate between products

We intentionally chose to study products with heterogeneous textures that were relatively close to each other. Indeed, the differences between the hardness and the size of the pieces included in the apple puree were noticeable but modest. This relative proximity between products and the diversity of actions involved in their FOP defined an ideal framework to test the ability of the method to describe and discriminate between products.

The data collected showed that without pieces, the apple puree was just quickly pressed against the palate and moved to be swallowed. "Chewing" and "separating" actions were not required. This result is in agreement with the fact that tongue movements and saliva are the main contributors to oral processing in semisolid foods (Aktar et al., 2019).

The consequences of including gel pieces in the apple puree were visible both in terms of the actions performed (frequency and sequences) and in terms of the total duration of FOP. The two aspects are somewhat related since the duration of the FOP depends in part on the number of actions to be carried out to swallow the products without risk.

Adding gel pieces generally induced an increase in "chewing" and "separating" actions, a time lag of the "swallowing" action, and an increase in the FOP duration. This can be explained by the need to chew the composite products to breakdown the gel pieces; consequently, the oral processing time is prolonged, and swallowing is delayed. Moreover, it is not surprising to observe an increase in the "separating" action because to chew the pieces, it is necessary to regularly bring the pieces back to the cheeks and molars. Aguayo-Mendoza et al. (2020), in similar products, also found that the addition of peach gel particles to yogurt, regardless of characteristics, caused an increase in the number of chews and consumption time. A narrative review by van Eck & Stieger (2020) cites several other studies that also show that the addition of particles increases the number of chews and FOP duration.

We observed that the firmness of the pieces was a determining parameter for the duration of the FOP. On the other hand, for the same level of firmness, the FOP duration did not depend on the size of the pieces. Aguayo-mendoza et al. (2020) also reported that the size of the peach gel particles added to yogurt (cubes of 3 × 3 × 3, 7 × 7 × 7, and 10 × 10 × 10 mm) did not affect oral behaviour. The two sizes chosen for the present study may not have been large enough to cause differences in oral behaviour. It would be interesting to study products with even larger pieces to know if oral behaviour changes above a certain size.

We have shown that the increase in the firmness of the gel pieces causes changes in oral behaviour, resulting in a particular increase in the "chewing" and "separating" actions. This means that the method seems sufficiently sensitive to allow us to observe differences in behaviour for this difference in firmness. The difference in firmness of the two gels was approximately 20 N. It would be interesting to know what minimum difference in firmness is necessary to generate differences in terms of oral behaviour. Furthermore, the "crushing" action is slightly more frequent for products containing softer pieces. We think that the softer and more melting texture of the gelatine gels (Devezeaux et al., 2016) encouraged the subjects to crush the pieces against the palate more than to chew them.

Overall, the TCATA method made it possible in a single measurement to describe the sequences of actions carried out during the FOP of the different products and to show differences between products in accordance with our expectations and the results of the literature.

Clustering individuals based on oral behaviour

Individual variability is an important factor to take into account in the study of oral behaviour. The duration of the FOP is an interesting variable for researching oral behaviour patterns because it is partly linked to the number of actions performed and the time spent performing these actions. If differences in behaviour exist, it is likely that they are visible with this variable. Based on this hypothesis, we proposed clustering into two groups of subjects, and then we observed and compared their oral behaviour.

Our results showed that the two clusters had different oral behaviours during the FOP of the heterogeneous purees. The first group has the same behaviour as all of the products containing gel pieces. Regardless of the firmness of the pieces, they started by separating the gel pieces from the rest of the product and then chewed them before swallowing them. Unlike the subjects of this first group, the subjects of the second group adapted their oral behaviour to the firmness of the pieces. For the products with the firmest pieces, their oral behaviour was close to the general behaviour of the subjects of the first group. However, for products with softer gel pieces, the subjects of the second group chose to crush them against the palate rather than chewing them. This type of difference in oral behaviour has already been observed in previous work on other types of products. For example, Yven et al. (2012) showed interindividual heterogeneity in the adaptation of masticatory behaviour following a change in cheese textural properties. Among 43 participants, 70% showed an adaptation of chewing activity to product properties, whereas little change was observed for 30% of them.

In the present study, it is difficult to explain with certainty the origin of this difference in strategy between the two groups. We have shown that it does not depend on the sex or the age of the subjects. The subjects of the second group were perhaps more attentive to the sensory signals generated by the texture of the pieces of gels and, in particular, to their firmness. A difference in sensitivity to firmness is also possible. It would be interesting to study these two hypotheses. Another possible explanation would be that the subjects who did not adapt their behaviour according to the samples had more difficulty using the method, without however expressing this difficulty. It is a possibility that we cannot rule out.

It is important to understand the origin of these strategies because the properties of the bolus depend on the oral processing of foods. Indeed, Yven et al. (2012) demonstrated that individual chewing strategies impact bolus properties. Moreover, it has been previously shown that variation in the oral movements engaged during FOP influences both bolus properties and sensory perception (De Wijk et al., 2011) and that interindividual differences in oral processing explain differences in perception in the case of sausages (Devezeaux et al. 2015) and chocolate (Carvallo da Silva, 2011). Relating the detailed description of oral processing as obtained in our study to bolus properties and sensory perception would be of interest for future studies.

It should be noted that the subjects of the second group took on average 1.7 times longer than those of the first group to consume the products (including the reference products without pieces). This result should be taken into account because it may reveal a difference in general behaviour when consuming food. This notion is to be compared with previous work, which made it possible to distinguish "long/short duration eaters" (Devezeaux et al. 2015).

The results of this study show that the TCATA method makes it possible to obtain relevant data for the study of the variability of oral behaviour during FOP.

Interest of the method and potential applications

Overall, this study demonstrated the ability in TCATA in describing oral behaviour during FOP and distinguish behavioral patterns. The method proposed here has promising development potential. Indeed, the method being relatively simple to implement with a large number of consumers, it must be possible to quickly accumulate data sets, at least on certain categories of products, then to use them with the objective of predicting oral behaviour applied to food products according to their initial characteristics. In addition, the collection of data relating to the hedonic appreciation of products (before the TCATA task), would make it possible to study the links between the actions required during the FOP and preferences. Therefore it may provide interesting information for future products development as well as evaluation of FOP behaviours, for example in the context of dysphagia.

4. Limitations

This study was exploratory; therefore, some limitations should be considered for future studies.

The first limitation is linked to the TCATA method itself and has already been mentioned several times. People tend to forget to uncheck the boxes when the perceived sensation or the performed action is no longer relevant. This defect has been particularly highlighted for the swallowing action, which is supposed to be brief. For future studies, it would be interesting to use the fading option provided by the authors of the TCATA method (Ares et al., 2016). Besides, measuring FOP using

TCATA may not be suitable for food products having a very short residence time in the mouth or which require a succession of very short actions, as it takes some time to participants to check and uncheck the boxes. This need to be further explored.

Furthermore, we observed that a few subjects selected the “chewing” action for homogeneous apple puree. This action is not a priori suitable for a product such as apple puree without pieces. This behaviour perhaps makes it possible to increase the circulation of the aromas in a retronasal way and therefore to better perceive the aromas. However, if in doubt, it would be interesting to increase the duration of training for the TCATA task. This also suggests that future studies should aimed at validating the reliability of the method by carrying out objective measurements, at least with a few dozen subjects, to find out whether the actions declared with the TCATA method as well as their duration are real. For example, it would be possible to check that jaw movements actually take place when the "chewing" box is checked.

Finally, we do not know to what extent the FOP duration and oral behaviours in general may have been influenced by the TCATA task. Indeed, asking participants to focus on their actions may have induced a more pronounced FOP behaviour than it would have been natural. This is inherent to the method, but controlling that the observed durations are within the same range as observed in a natural eating context is advisable.

5. Conclusion

The TCATA method applied to the study of oral behaviour during FOP has interesting potential. The method was well accepted by the subjects, and they were able to perform the requested task without reporting any particular difficulty. We were able to collect data in a single measurement and in a relatively short time, which allowed us to observe the influence of the presence and firmness of pieces in a heterogeneous product and the sequences of actions carried out during their FOP. Finally, the TCATA method allowed us to work with a large number of subjects and therefore to take into account interindividual variability by studying groups of subjects with different oral behaviour patterns. This exploratory study calls for more research on the potential of sensory dynamic methods to study FOP. Future studies should aim at validating the method against objective measurements of FOP and further explore how food textural properties influence on individual variability of FOP behaviours.

6. Ethical statements

The authors declare that they do not have any conflict of interest. Written informed consent was obtained from all study participants.

7. Contributions

CM, VD and CT designed the experiment and analysed the data. CM and CT developed the recipes, and VD collected the data. CM and CT wrote the manuscript with input of VD.

8. Acknowledgements

The authors warmly thank Anne Saint-Eve (UMR SayFood) for sharing information on their previous work (TDM) and for valuable discussions before the building of this study and Michel Visalli (UMR CSGA, Chemosens platform) for discussion on TCATA data analysis. The authors also thank the participants of the study.

9. Funding

This work was financially supported by the AIC TactiPhy project funded by the INRAE TRANSFORM department.

10. Data sharing

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Tables

Table 1: Product/sample characteristics

Product (code)	Gel pieces						Sample[1] (mixture)		
	Apple puree (%)	Apple juice (%)	Agar-Agar (%)	Gelatine (%)	Size (mm)	Volume (cm^3)	Gel pieces (g)	Apple puree (g)	Total (g)
Aga-big	82.5	14.6	2.9	-	6x12x12	0.864	2	10	12
Gel-big	81.7	14.4	-	3.8	6x12x12	0.864	2	10	12
Aga-small	82.5	14.6	2.9	-	6x6x6	0.216	2	10	12
Gel-small	81.7	14.4	-	3.8	6x6x6	0.216	2	10	12
Ref	-	-	-	-	-	-	0	12	12

[1]All samples were presented on a spoon containing 12 g of product

Table 2: Comparison of the FOP durations of the two clusters for the five products.

Product	Cluster 1	Cluster 2	t	ddl	p value
Aga-big	12.57	20.71	-8.12	52	<0.0001
Gel-big	10.30	15.71	-4.34	52	<0.0001
Aga-small	12.74	21.87	-8.86	52	<0.0001
Gel-small	9.96	17.58	-6.24	52	<0.0001
Ref.	3.91	8.13	-3.25	52	0.002

Figures

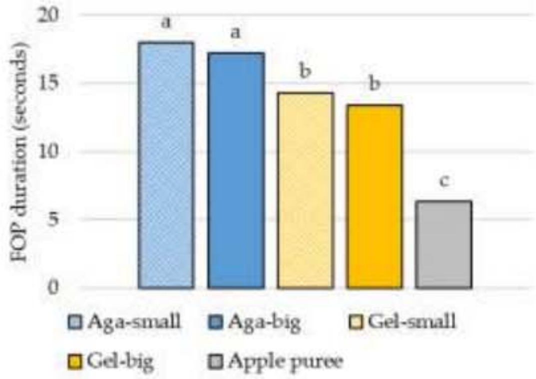

Figure 1: FOP duration(s) for the five products studied. Products with the same letter have nonsignificantly different FOP durations (Tukey's post hoc test, $\alpha = 5\%$).

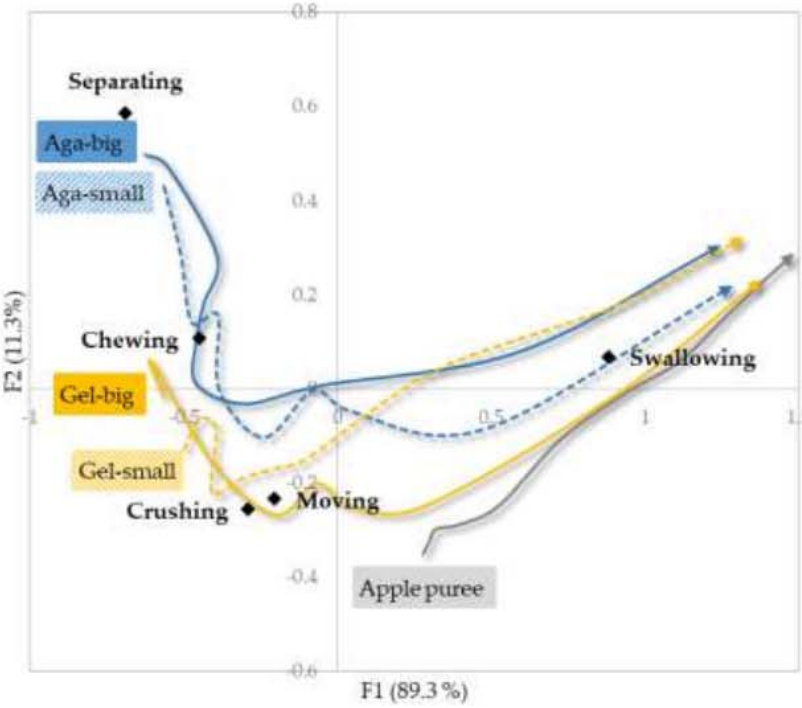

Figure 2: TCATA product trajectories. Biplot representation of the correspondence analysis.

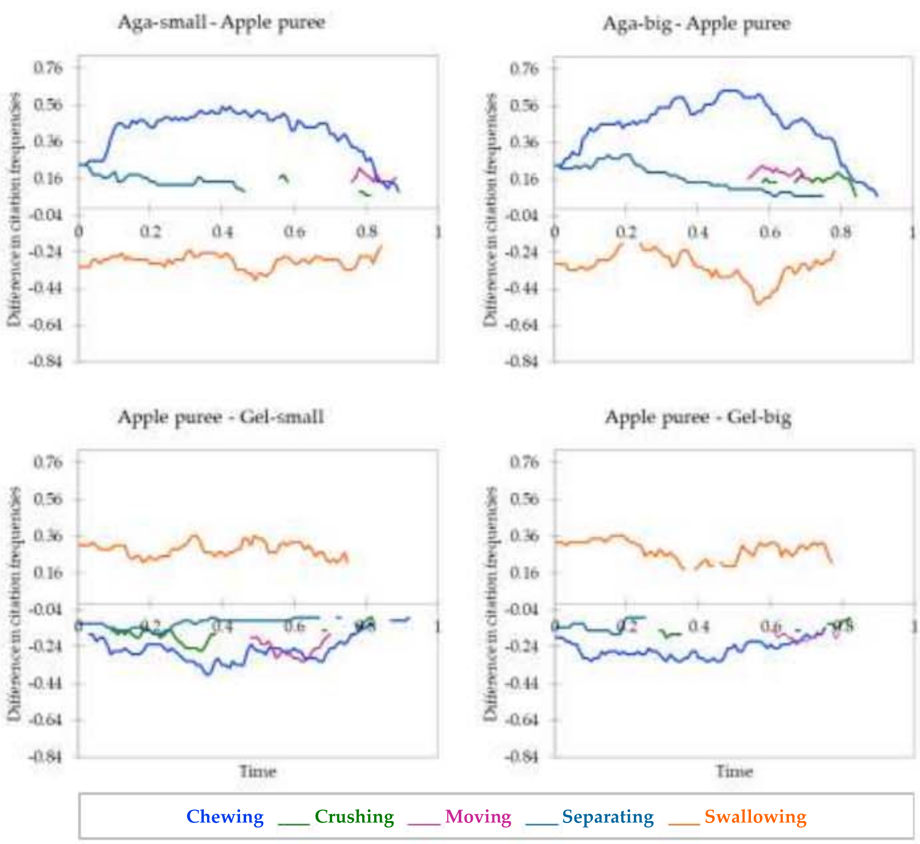

Figure 3: Impact of adding gel pieces on oral behaviour during FOP (standardized time)

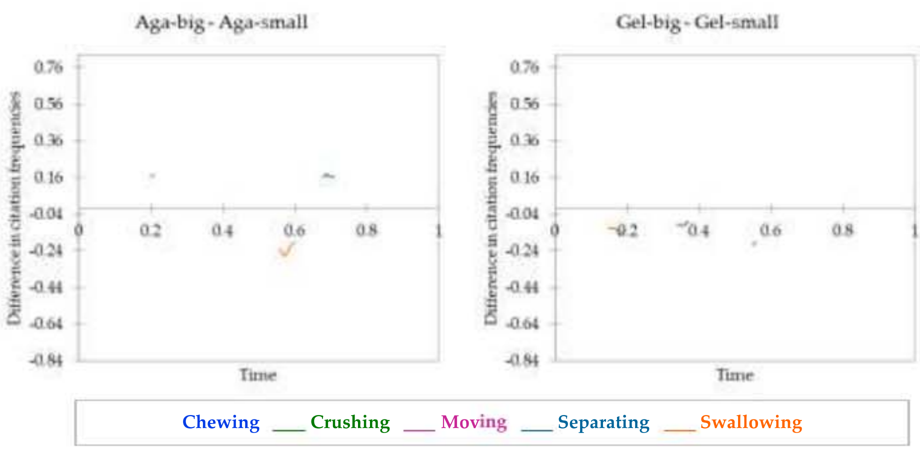

Figure 4: Impact of the size of the gel pieces on oral behaviour during FOP (standardized time)

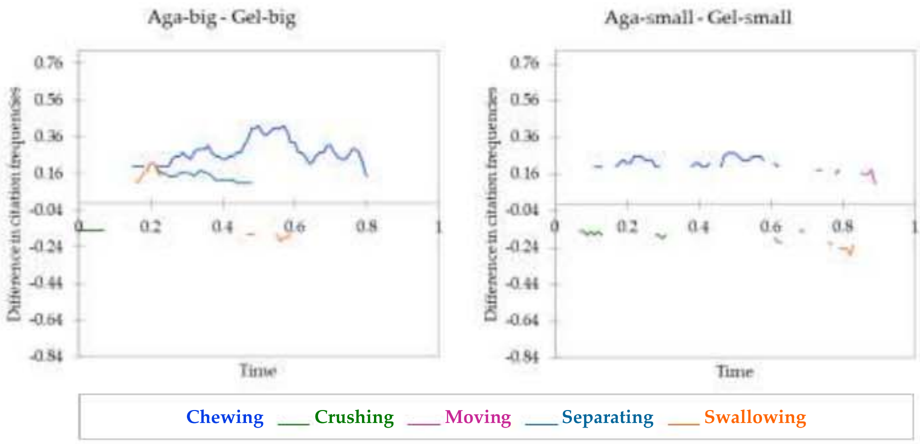

Figure 5: Impact of the firmness of gel pieces (gelatine/agar-agar gel) on oral behaviour during FOP (standardized time)

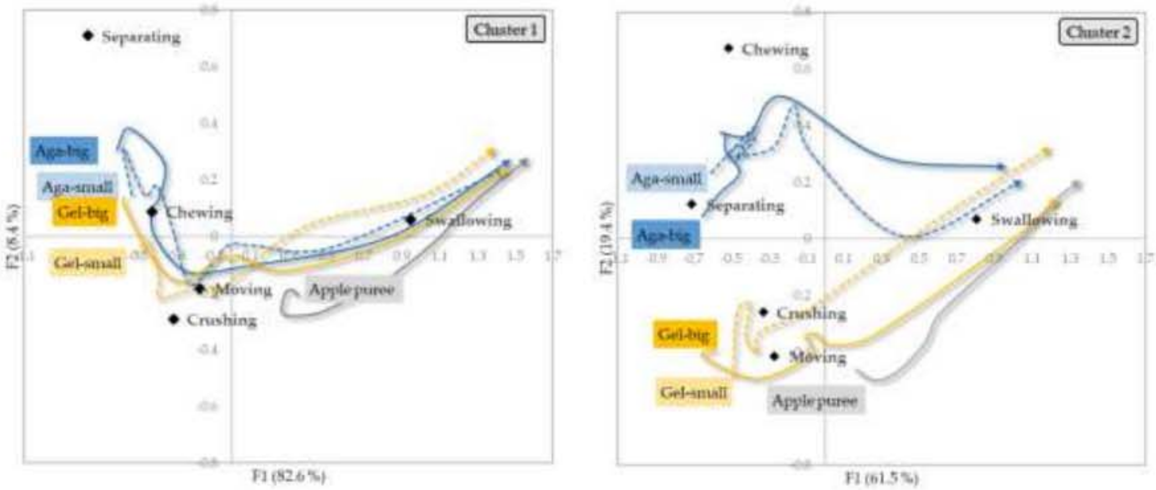

Figure 6: Product trajectory map for cluster 1 (left side) and cluster 2 (right side).

Appendices

Appendix 1: Detailed description of the FOP behaviour (product TCATA curves)

The citation proportion curves (Fig. A1) show the evolution of the citation frequency of each action over time in thin solid lines. Thicker solid sections indicate time intervals during which the difference between citation frequencies of a given product and the other products is significantly different from zero. In this case, dotted reference lines (same colour) are shown to indicate the action citation proportion based on pooled results for the other products. In summary, product specificities can be inferred from thicker continuous lines compared to the corresponding dotted lines.

The two products containing pieces of agar-agar gel have relatively similar profiles. For these two products, the predominant action was chewing. During most of the evaluation, this action was significantly more frequently mentioned than for other products. The separation action was also cited more than for other products, especially for the product containing the larger pieces of agar-agar gel (Aga-big). The separation action was also cited for the product containing the smallest pieces of agar-agar gel (Aga_small), but the significant differences with the other products were more episodic.

The profiles of the two products containing pieces of gelatine gel are quite similar. The three major actions were chewing, crushing and moving. However, the citation frequencies for these three actions did not differ significantly from those for the other products, except for the product containing the smallest pieces of gelatine gel (Gel-small), for which the actions of crushing and moving were, over short periods, more cited than for other products.

As expected, the profile of the apple puree without pieces is the one that stands out the most from the others. The swallowing action was predominant. Unlike the other products, swallowing action occurred very quickly after the sample entered the mouth and was significantly more frequent than for other products throughout the evaluation, with the exception of the final part, where all of the products were swallowed. It can also be noted that the displacement action was significantly less frequent than for the other products in the second part of the evaluation. Finally, this product also stands out from others by the chewing action, which is significantly less cited than for other products.

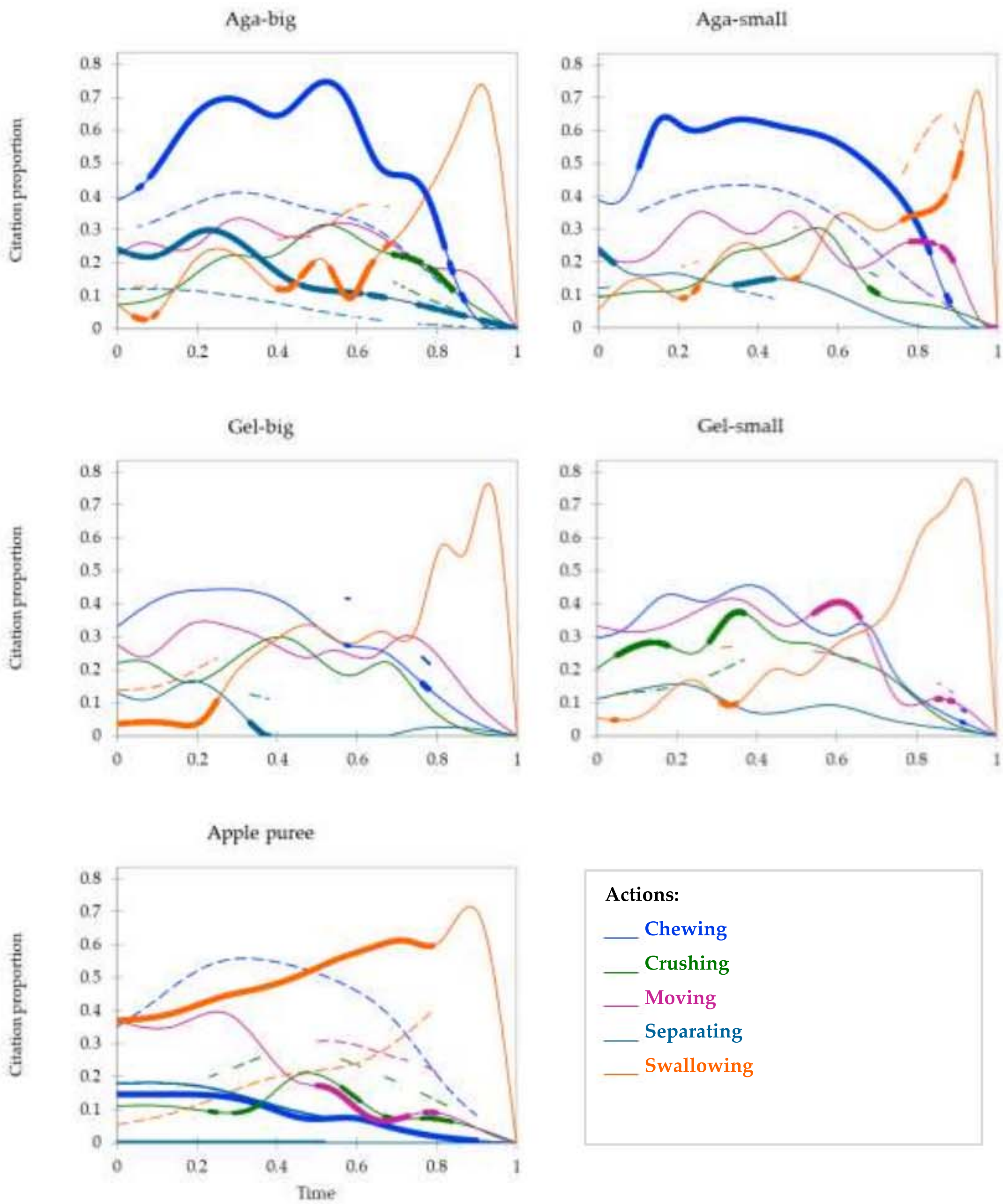

Figure A1: Citation proportion curves (standardized time). For each action, thicker parts of the curves indicate the time intervals during which the citation frequencies were significantly different from the average frequency observed for the other products (the average is symbolized by a dotted line of the same colour).

Appendix 2 : Examples of raw (non-standardized data) for one subject and one product

Product	Subject	Action	Time (0 - 120 s)																																								
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	...	120
Gel-big	xxx	Swallowing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Gel-big	xxx	Crushing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Gel-big	xxx	Moving	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Gel-big	xxx	Chewing	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Gel-big	xxx	Separating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0

FOP duration

Appendix 3 : Dendrogram of the ACH performed on FOP duration