Video analysis of chewing patterns

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Abstract

The chewing of food is a complex process, involving the physical breakdown of food and mixing it with saliva to form a swallowable bolus, and the release of flavour to produce a pleasant sensory experience. The details of the process vary greatly among people, and interact depending on food types. Using a compact digital camera, video recordings of subjects chewing a range of gel particles have been made. By the use of markers on their chins and noses we have been able to track subjects' chin movements with sufficient accuracy to measure several chewing parameters. This simple technique allows the recoding of a large number of individual chewing profiles, which lends itself to the application of statistical techniques, such as PCA, to look for the relationships between chewing style and sensory perception.

Keywords

Food, chewing behaviour, gel, texture

Introduction

How consumers perceive the texture of food as it is broken down in the mouth by chewing is a key part in determining their liking of the food. Although each individual has their own unique chewing pattern (Yamashita et al. 1999) various authors (Brown et al. 1994; Brown & Braxton 2000; Carvalho-da-Silva et al. 2011; Yven et al. 2012) have been able to group people into a small number of general chewing types. For example Brown & Braxton (2000) grouped their subjects by their masticatory efficiency while chewing brittle or elastic products. The groups exhibited different breakdown patterns for the different samples but there were no significant differences between sensory parameters for the different groups. Conversely Carvalho-da-Silva et al (2011). used cluster analysis on their sensory results for chocolate to look for groups, and found three groups based on time in mouth, chew rate and muscle work. They postulated the chewing behaviours would likely affect the sensory properties the consumers perceive. Further, Yven et al (2012). looked at chewing characteristics of 50 consumers using five model cheeses of different rheological properties. They grouped their subjects into three groups based on how their chewing strategies changed for the different cheese rheological properties. A different approach was taken by Kobayashi et al (2009). who found jaw movement path could be classified into seven patterns. However, the majority (74%) fell into pattern 1 or pattern 3, with no gender difference. This classification required precise measurement of the jaw closing and opening path, which was measured with a mandibular kinesiograph. A more complex analysis used a

multilevel statistical approach which estimated mathematical values, consisting of fixed and random parts for chewing cycle measurements (Buschang et al. 2000). Rather than using all chewing cycles for comparison, cycles that met predefined criteria were selected as representative and included in the model, which used an eight-level polynomial to describe the chewing cycle. Subjects chewed on one side only, producing a more idealised chewing cycle than would be achieved by free chewing.

Various methods have been used to track jaw movement to measure chewing behaviour. Chewing behaviour can be measured using muscle activity measurements (Mioche et al. 1999), electromagnetic induction (Lassauzay et al. 2000), various video filming techniques using rigs attached to the teeth using six cameras (Buschang et al. 2000), or even 12 cameras (Quick et al. 2010), or using skin markers (Gerstner et al. 2005; Green et al. 2007; Chen et al. 2011). The disadvantage of skin markers is that less accurate data on jaw movement is obtained; a variability of 2 mm has been measured (Häggman-henrikson et al. 1998).The more sophisticated the method of measuring jaw movement the more accurate and detailed the information collected about the chewing action, but the more difficult to setup and more time consuming the measurements become. For looking at the prevalence of chewing groups in the general population, and researching the interaction between chewing action and sensory perception a simple method of measuring chewing behaviour is required. By using a single camera with just nose and chin skin markers a significant amount of chewing data can be collected rapidly with little preparation and small cost. This work reports an experiment to look at whether a simple recording system using just chin and nose markers can record sufficient information to categorise chewers into groups. This work is part of a larger study on particle size effects which will be reported elsewhere.

Methods

Subjects

Volunteers, aged 19–30 years, were recruited from Lincoln University (Lincoln, New Zealand) and The New Zealand Institute for Plant & Food Research Limited (Lincoln, New Zealand) through flyers. The volunteers were asked to fill in a screening questionnaire and 12 subjects (9 female and 3 male, mean age 23.5 ± 3.6 years) were selected for this study. The selection criteria were: good general health, a full set of natural teeth, no pain or discomfort during jaw movement, no teeth clenching or grinding, no swallowing problems, no oral piercing, non-smoking, no medication that could influence mastication and salivation, willingness to test foods, and no allergies to any ingredients of the food to be tested. The subjects signed an informed consent form before starting and were compensated for their participation. This study was approved by the New Zealand Health and Disability Upper South A Regional Ethics Committee (Ethics reference no. URA/12/EXP/008).

Samples

Gelatine-based gel particles were used as a model. Gels were selected for this study because they are (1) highly reproducible between batches, which decreases the risk of a variation caused by the food; (2) easy to produce particles with different sizes and shapes; and (3) easy to colour, which makes it possible to track particles before and after mastication. In order to produce different sized gel particles with the same physical properties, a large slab of gel was prepared. Eighty-five grams of flavoured gelatine (Lemon Jelly, Gregg's®, New Zealand) and 35 g unflavoured gelatine (Davis, New Zealand) were placed in a 500 mL beaker and mixed well. A solution of 123 g water and 2 g food colouring (either red or green, Hansells™, New Zealand) was slowly added to the mixed dry ingredients under stirring. The beaker was then covered and heated to approximately 80^{o}C for 2 h in a shaking water bath (SW20, Gerhardt, Germany) for the gelatine to dissolve. The gelatine solution was poured into a rectangular plastic tray (internal dimension, 210 x 180 x 10 mm) to 5 mm thick and left to cool for 30 min at room temperature for 30 min. After cooling, the large slab of gel was cut into disc-shaped particles (5 mm thick) using cork borers of desired diameter (D). The particles size and colour of the set of samples used are shown in Figure 1. The particles were prepared a day before use. Each sample (approx. 4 g) was placed in a small disposable plastic sauce cup and stored at 10^{o}C until use.

Chew and spit out experiment

Each subject attended four 60-minute chewing sessions spaced 24 h apart (4 consecutive days). The sessions took place in the morning and three subjects were tested in a day. The first session was used to familiarise the subject with the study protocol. Data were collected from the remaining three sessions. During each session, subjects were provided with a full set of 11 samples on a tray, along with a plastic dessert spoon and a plastic teaspoon, and instructed to work from left to right. Each subject received the samples in a different order, following a Latin square design, so that each sample was tested in every position in the order once. Subjects were instructed to carefully transfer each sample from the container on to the dessert spoon using the teaspoon. Subjects were asked to take the whole spoonful into their mouths and chew as naturally as possible until they felt the need to swallow, at which point they expectorated the bolus on a 500 µm sieve. After expectorating the bolus, a cup of water was provided to rinse the mouth. Subjects were asked to rinse their mouths thoroughly and expectorate the rinse again on to the sieve. The experimenter rinsed the bolus particles soon after in running water and collected them on an A4 white paper. The collected bolus samples were dried at room temperature for 4 hours and were analysed by colour image analysis to determine their particle sizes. During the sessions, subjects were also recorded by video camera to measure their chewing behaviour (e.g. total chewing time, number of chew and jaw movement). See below for details.

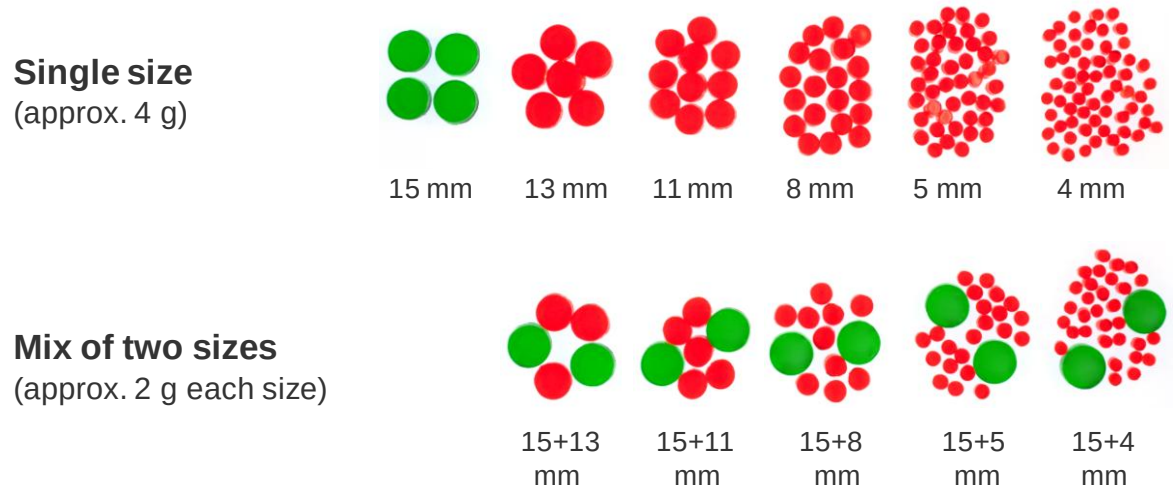

Figure 1. Illustration of particle combinations used in the experiment.

Video recording and tracking

Circular 14 mm white adhesive labels with 5 mm black centre dots were placed on the subjects' chins and nose tips. A Canon HS115 compact digital camera was used to record video of the subjects chewing at a resolution of 640x480 pixels at 30 frames per second. The video was tracked using Kinovea (http://www.kinovea.org/) to measure the 2D position (x,y) of the two markers in pixel units in each frame. The position data were saved in a spreadsheet file for further analysis

Video analysis

The position data were then analysed using a custom-written Labview (www.labview.com) program to measure the chin position relative to the nose. This corrected for any translation movement of the head in the plane of the image (Zafar et al. 2000). To further compensate for out of plane movement or rotation in or out of plane a moving average position was subtracted from each image position. A three–chewing cycle average position was used for the vertical movement, with a 10-cycle average for the horizontal position. A longer time was used for horizontal position as subjects sometimes chewed only on one side of the mouth. No attempt was made to calibrate the pixel coordinates to real distances so the data reflect only the relative movement in vertical and horizontal directions.

The chin movement program summarises the relative chin movement in four ways:

- Vertically by time
- Horizontally by time
- Chin position intensity plot
- Individual chewing cycles.

The vertical chin movement versus time was analysed to extract the chewing frequency (seconds per chew), total chewing time, and number of chews. A chew is defined as the time between the mouth being open, then closed, then open again.

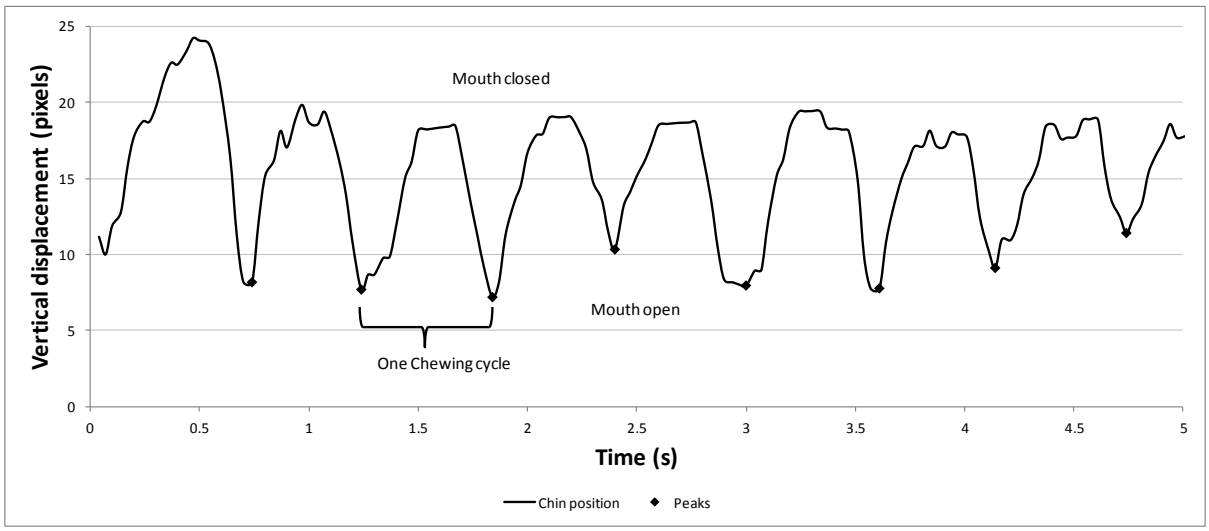

Figure 2. Vertical chin displacement versus time showing determination of chewing cycle parameters.

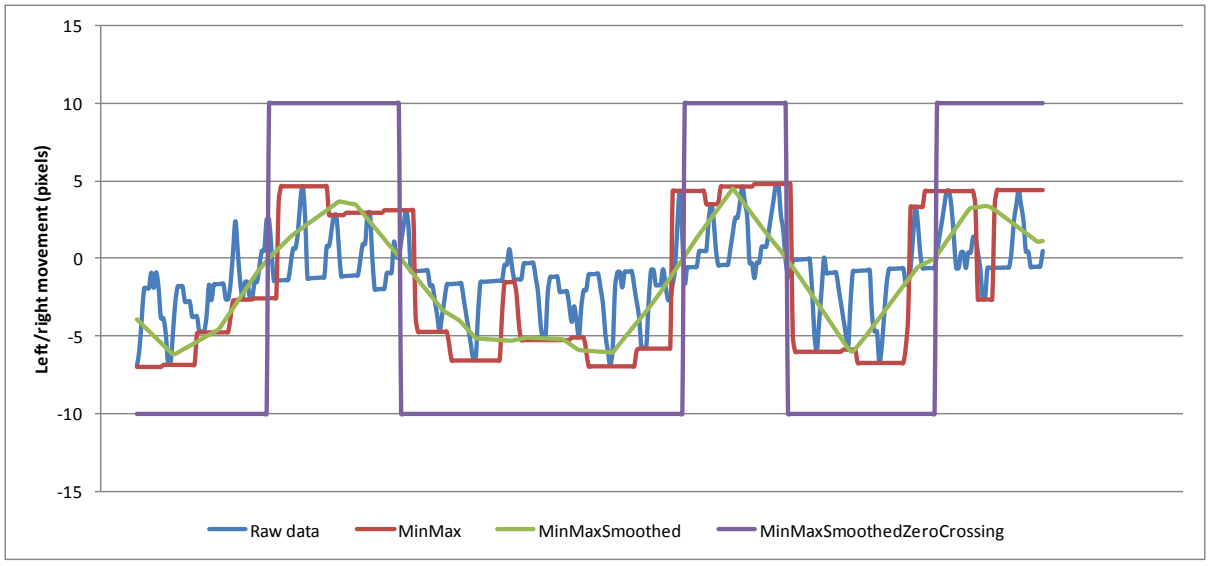

Figure 3. Plot of left/right chewing showing results of intermediate filtering calculations.

The horizontal movement with time was analysed to look for the proportion of time spent chewing on each side. Because of the inaccuracies caused by only using chin and nose markers with one camera, significant filtering of the horizontal position data was required to differentiate between left and right chewing. The first pass calculates the maximum absolute value of the minimum and

maximum value in a window length of one chew. This is then filtered using a three-chew length moving average, and the zero point crossings were taken as the change from one side to the other.

Then the vertical and horizontal movement of the chin was analysed, giving a 2d picture of chin movement with time (Figure 4).

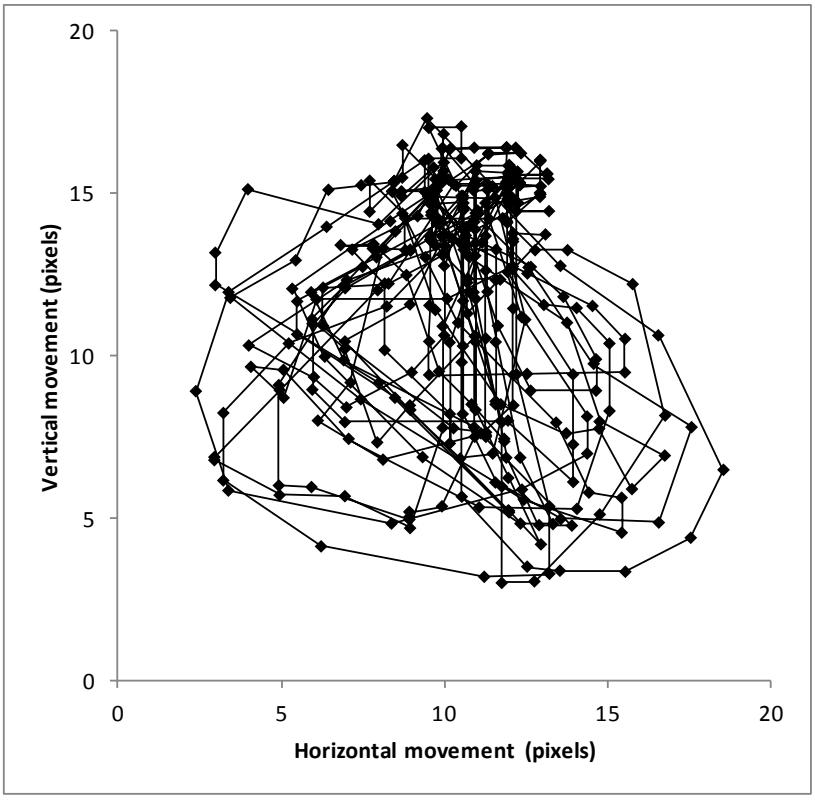

Figure 4.Plot of chin position with time for an example chewing sequence.

From the 2d plot an intensity plot was calculated (Figure 5). Using the vertical and horizontal positions the chewing area was divided into a 20x20 grid and the number of times the chin was in each position was summed to produce an intensity matrix. The mapping of pixel coordinates to grid position was normalised for each subject using the maximum of seven times the standard deviation of the vertical and horizontal position as the range of the grid centred on the mean position. Smoothing was applied in two dimensions by averaging the four horizontally and vertically adjacent points in the intensity matrix. Thus the matrix simply represented the relative time spent in the horizontal and vertical positions.

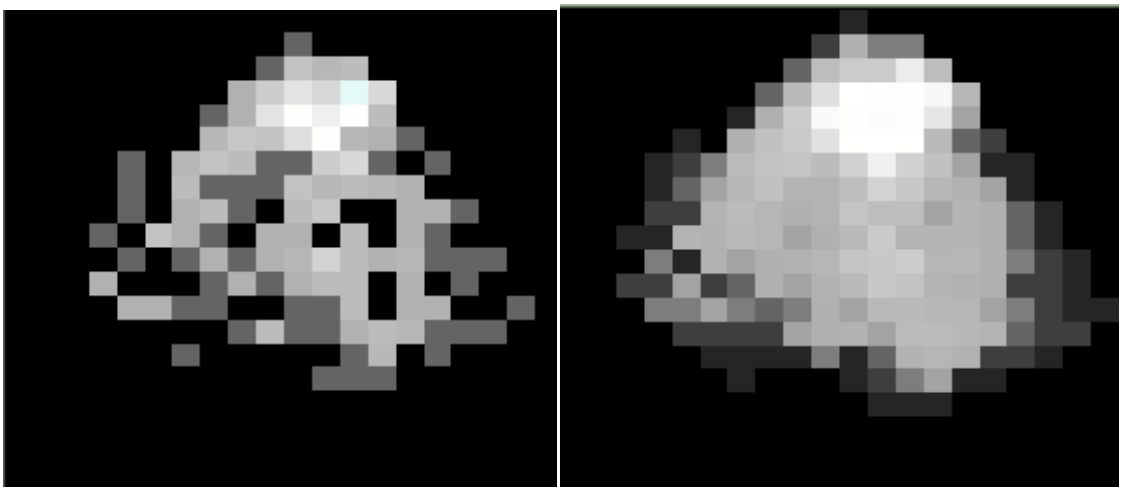

Figure 5. Intensity plot showing the relative time the chin spent in each of the positions in the 20x20 grid. Left side raw data, right side smoothed data.

Individual chewing cycle

Chewing cycles are defined as the time between the mouth being fully open, then closed, then fully open again. Because not every mouth closing and opening movement is a chew, filtering was applied to attempt to automatically remove movements that were swallows or food manipulations. Chew cycles that took longer than 1.5 times the average chewing cycle time were discarded from the analysis.

Because the video is captured at a constant frame rate, but chewing time can vary, the number of data points for each chewing cycle can also vary. For statistical comparison it is preferable to have the same number of data points in each chewing cycle. To achieve this, the original data were fitted with a B-spline using seven control points. Then a 15-point curve was interpolated from the B-Spline using fractional interpolation so the step size follows the step size of the original data (equally spaced in time but not in (x,y) position.

As a simplified way of viewing each chewing cycle the following calculations were applied to each cycle:

- 1^{st} order polynomial
- 2^{nd} order polynomials
- Area of closed curve

- Convex hull approximation
- Circle approximation.

The following rules were then applied to categorize the chewing cycle:

- If the 2nd order polynomial residual was less than 1.5*(the 1st order polynomial residual) then the cycle was crescent shaped.
- If 2*(area of closed curve) is less than the convex hull length* convex hull width then the chewing cycle is crossed.
- If area of closed curve is greater than 0.7*(area of circle) and (convex hull length divided by convex hull width) is less than 3 then it is circular.

These rules produced five possible classifications:

- Circular
- Crescent
- Crossed
- Crescent and crossed
- Unclassified.

Circular and crossed are mutually exclusive as are circular and crescent. For each subject by sample by rep the data were expressed as the percentage of each chewing type in the total number of chews.

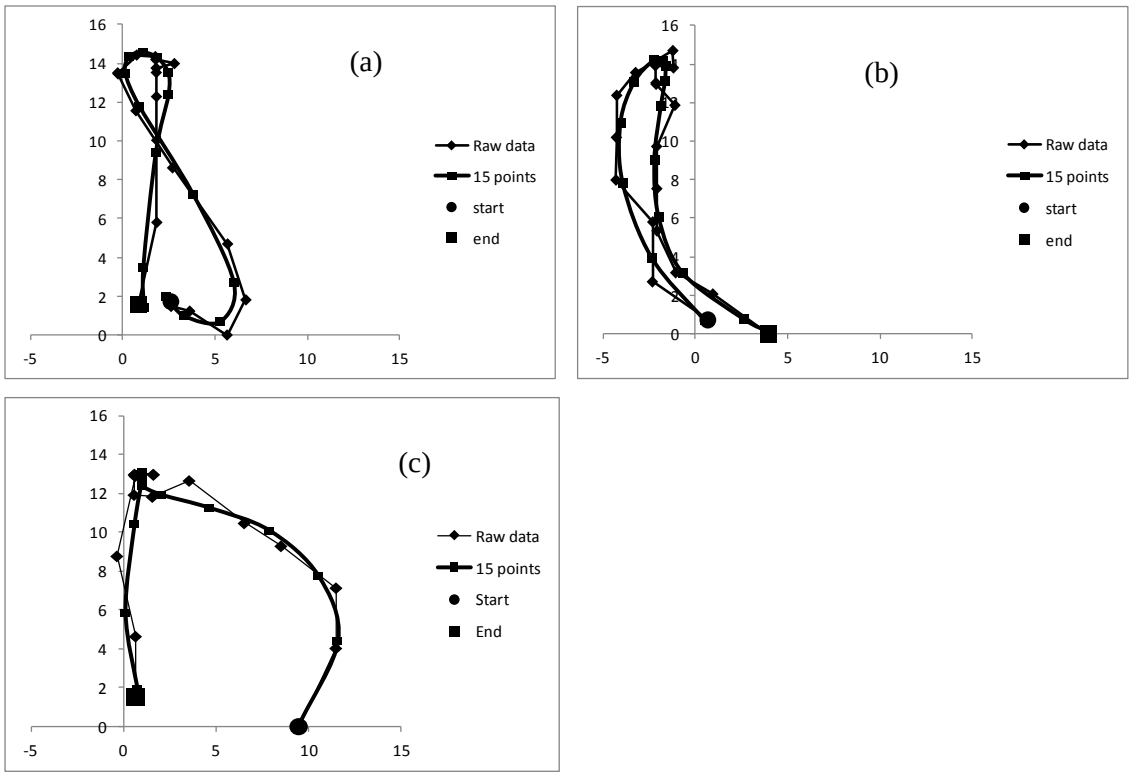

Figure 6. Examples of chewing cycle types (a) crossed cycle, (b) crescent cycle, (c) circular.

Results and Discussion

Simple chewing parameters

Using principal component analysis (PCA) of the simple chewing parameters (number of chews, chewing time, and chewing frequency) to reduce the dimensionality of the data, a plot of the two principal components separates out the 12 subjects (Figure 7). The plot of the correlations of the attributes in Figure 7 shows that the first principal component separates on chewing time and the second on chewing frequency. Although there is no clear clustering of the subjects into groups, they are separated out with subjects 1and 3 at one end of the distribution and 6 and 7 at the other. Thus the chewing style of each of the subjects is consistent for the different samples. The chewing parameters analysed here are time-based and say nothing about the chewing trajectory or force applied.

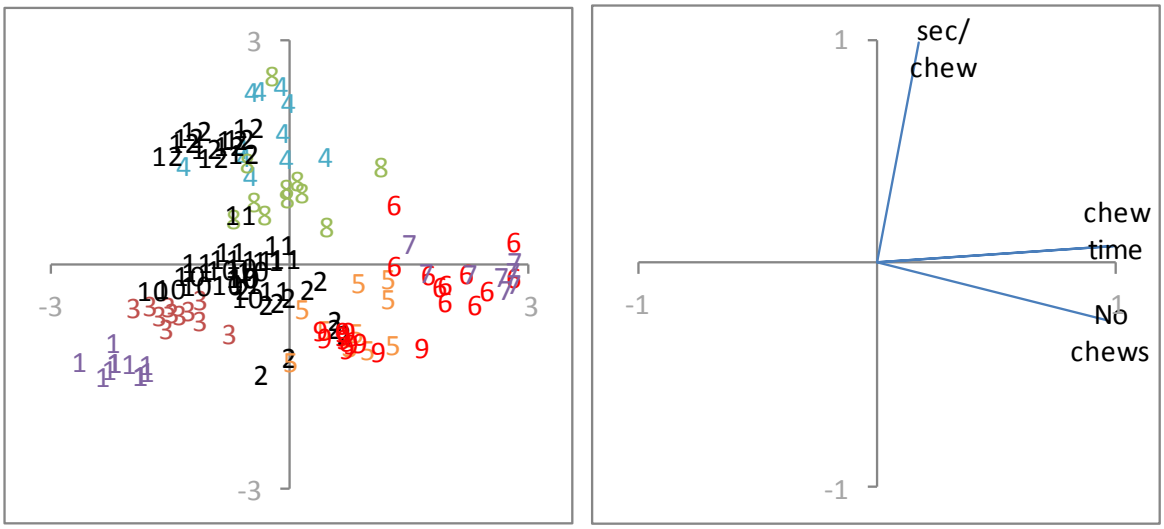

Figure 7. PCA biplot of simple chewing parameters where number indicates subject id (left), and correlation of the attributes (right). First principal component (x axis) accounts for 65% of variance; second (y axis) for 35%.

Chewing cycle type

The PCA of chewing cycle type, using the average of the reps, also gave some separation of the subjects. The axes for the different chewing types are also shown in Figure 8. One axis splits Crossing Crescent chews (left) and unclassified chews (right); the other splits Circular chews (lower right) and Crossing chews (upper). Subject 5 is quite distinct, with a high proportion of unclassified and circular chews; subject 9 has a high proportion of unclassified chews but a more typical proportion of circular ones. Subjects 8 and 12 have more typical proportion of Crossing-Crescent and Unclassified chews, but a higher proportion of Circular chews than is typical. Subjects 1 and 10 have a higher proportion of Crossing-Crescent chews and fewer Unclassified, but a typical balance of Circular and Crossing chews.

The chewing parameters analysed here are trajectory-based and include no information about the number of chews or speed of chewing. As for the simple chewing parameters, the subjects can be separated out, with the samples being similar within each subject. However, the position of the subjects relative to each other in the PCA plot is different.

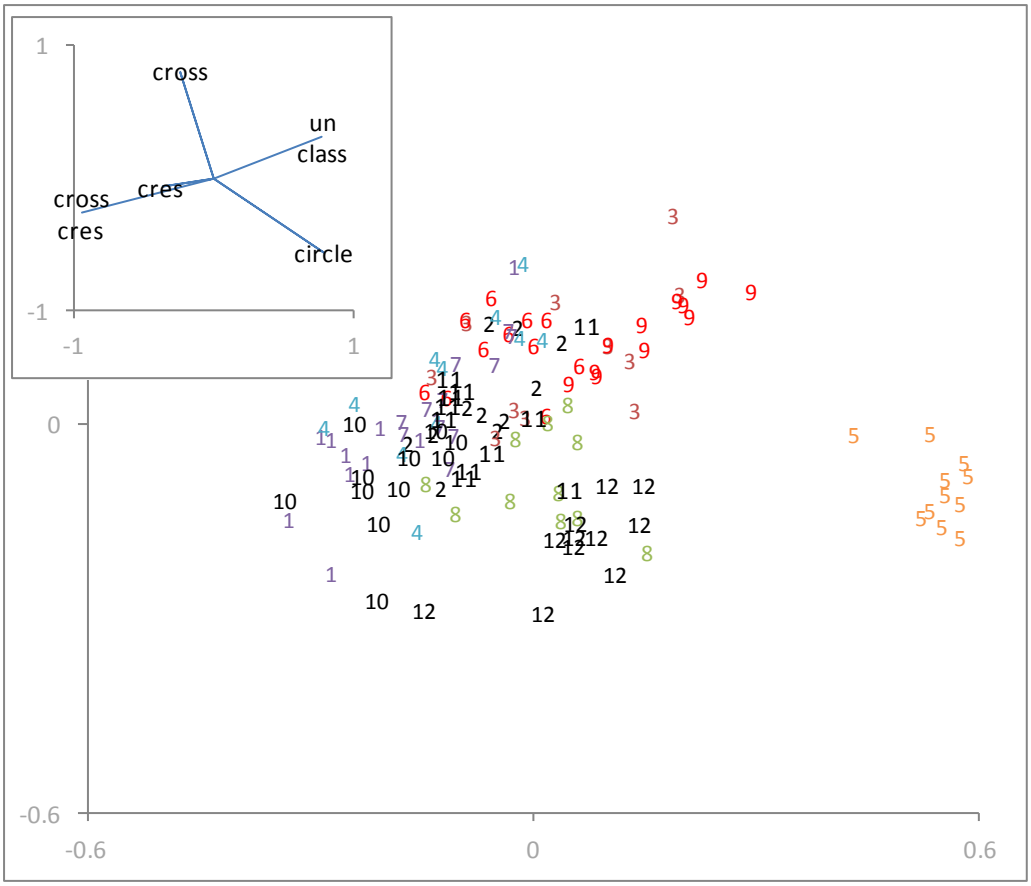

Figure 8. PCA biplot of chewing cycle analysis by subject for all samples with the axes of the different chewing types. Number is subject id. First principal component (x axis) accounts for 62% variance; second (y axis) accounts for 22% of variance. Inset indicates how classifications correlate with principal components.

Chewing intensity plots

Using PCA analysis of the intensity plots we can again separate out the subjects (Figure 9). In this case subject 6 is separated out with subjects 1and 7 at one extreme, and 9 at the other extreme of the distribution of the remaining subjects. This analysis includes data on both trajectories, from the position in the 2d intensity plot, and number of chews, from the values in the 2d intensity plot. However, the trajectory data is different from the trajectory analysis as it uses a normalised 20x20 grid rather than the absolute pixel coordinates. Again as for the simple chewing parameters and trajectory analysis, the subjects can be separated out, with the samples being similar within each subject. There is also a different distribution of subjects relative to each other.

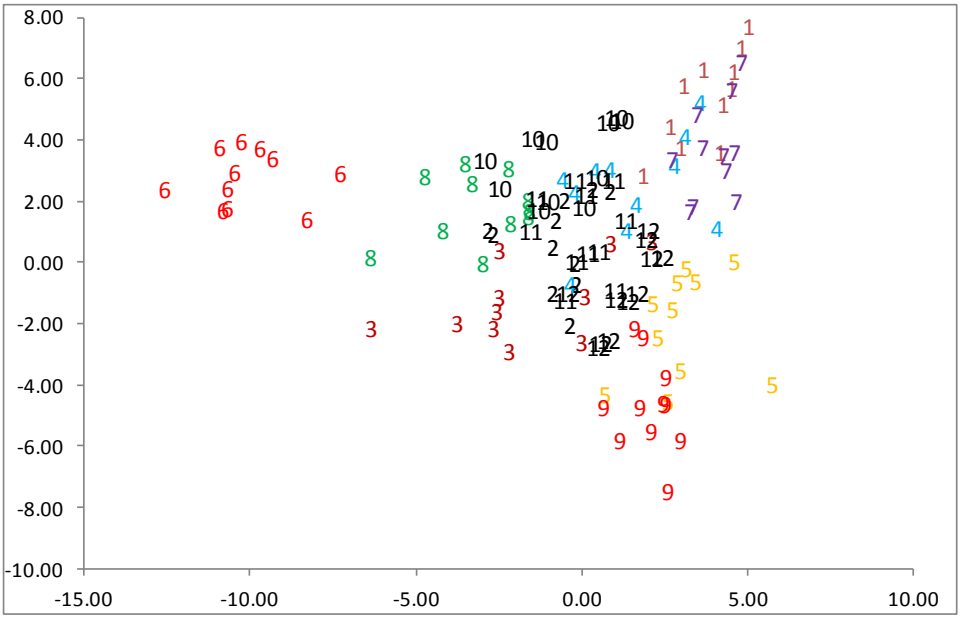

Figure 9. PCA biplot of chewing intensity by subject by sample with the number indicating the subject id.

Summarising the three methods of separating subjects using PCA, each gives different separations, with only subjects 1, 6 and 7 possibly different from the others in two of the methods. However, in each case the samples are clustered together within each subject, indicating a consistent chewing style is used by each subject even though they are chewing a large range of different particle sizes and mixtures of particle sizes. The difference in the order of the subjects according to the different analysis methods highlights different aspects of their chewing style. The first method, being time-based, was relatively insensitive to inaccuracies in the position data as all that needed to be detected was whether the mouth was open or closed. Thus the simple camera and skin marker method works well. The second method requiring measurement of chin trajectory is much more sensitive to position accuracy to distinguish one trajectory shape from another. However, consistent results within each subject were still obtained, indicating that the method was sufficiently accurate to pick up differences in individual subjects' chewing trajectories. The final method, which combined trajectory and number of chews, is also sensitive to position measurement accuracy. By using a normalised 20x20 grid the trajectory data are different from the trajectory analysis method and are likely to be less sensitive to position errors.

Using this simple video recording and analysing techniques it is a simple task to record the chewing patterns of a large number of consumers. By combining this with sensory data it will be possible to look in some detail at the influence of chewing style on sensory perception in consumers in general.

Conclusions

Using video recordings of chin and nose markers it is possible to record chin movement and from this extract information about chewing behaviour. Application of this technique to chewing of gel particles has allowed separation of subjects based on their chewing style as measured from a range of chewing parameters using PCA on time-based measurements (number of chews, chewing time, chewing frequency), trajectory measurements(chewing cycle type), and trajectory and number of chews (chewing intensity plots). The three different ways of analysing the data gave three different distributions of the subjects, highlighting different aspects of their chewing styles. Combining these techniques with sensory data may help explain how chewing behaviour can influence sensory perception.

Acknowledgements

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