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Tactile sensitivity and the capability of soft-solid texture discrimination

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Abstract

The sensation and perception of food texture is regulated by tactile-dominated mechanisms and therefore it is believed that one's capability in discriminating food textural properties could be influenced by one's tactile sensitivity. However, evidence to support this hypothesis is currently not available. This work aims to test this hypothesis by examining tactile sensitivity of individuals' (touch sensitivity and two-point discrimination) and texture discrimination capability. A range of food gel samples with controlled firmness and elastic moduli were designed for textural discrimination tests. A total of 32 healthy subjects (15 females, 17 males; mean age 34 ± 9 years old; mean body mass index 23±3 kg/m^2) participated in this study. Mean population threshold of touch sensitivity was found to be 0.028 g for the fingertip and 0.013 g for the tongue. Similarly the mean threshold of two-point discrimination was 1.42 mm and 0.62 mm for the fingertip and tongue respectively. Population threshold for firmness discrimination (compressing until yielding) of the gel samples was 13.3 % for the fingertip and 11.1 % for the tongue. However, the elasticity discrimination threshold (by gentle pressing) of the population was found to be much smaller at 2.3 % and 1.2% for the fingertip and the tongue respectively. Results show that tongue is more sensitive than the fingertip in discriminating food texture ($p<0.05$). However, surprisingly no correlation was observed between individual's capability of texture discrimination and their tactile sensitivity.

Keywords

Texture perception, Texture discrimination, Texture sensation, Tactile sensation, Touch sensitivity, Two-point discrimination

Practical Applications

Texture discrimination capability is significant factor for food texture preference and appreciation. In order to understanding the texture perception limitations and characteristics the underlying factors are essential to be determined. These basics of the texture discrimination is critically important for the food industry in development of new food products, and in particular for specific food design for individuals' with special needs, e.g. elderly, dysphagia patients, etc. With this study we illustrate the differential threshold for soft-solid texture (firmness and elasticity) and also investigate the sensations of touch sensitivity and two-point discrimination. These results and correlations could provide new perspective for researchers in the food industry and in food development. Methodologies could also be applied for general food sensory studies in establishing relationships between sensory psychology and sensory physiology.

1. Introduction

With no doubt, taste perception has been studied widely and the dynamics of flavor release and perception are reasonably well understood (Capra, 1995, Engelen and Van Der Bilt, 2008). However, in contrast to flavour studies, the questions regarding the mechanisms of food texture perception remained to be answered (Capra, 1995, Engelen and Van Der Bilt, 2008, Kutter et al., 2011). Food texture is a forgotten attribute due to biased attention to the taste attributes (Guinard and Mazzucchelli, 1996). As a matter of fact, food texture is a very important attribute influencing a consumers' preference and attitude toward a food and therefore, questions about food texture and characteristics must be addressed (van Vliet, 2013). Main difficulties surrounding textural approaches and investigations are the multidimensional nature of texture itself and the complexity of its sensation mechanisms (Kutter et al., 2011). Texture in material sciences refers to surface characteristics and appearance of an object given by the size, shape, density, arrangement, proportion of its elementary parts (Urdang, 1968). The first investigation into texture attempted to describe the visual and tactile characteristics of fabrics (Guinard and Mazzucchelli, 1996). This approach was followed by other materials including foods (Richardson and Booth, 1993). One of the earliest definitions of food texture was given by Szczesniak in 1963 (Szczesniak (1963), who defined the textural properties of food as the sensory manifestation of the structure of food and the manner in which this structure reacts to the forces applied during handling and, in particular, during the consumption process. Lawless and Heymann (1998) later defined food texture as all the rheological and structural attributes of the food perceptible by means of mechanical, tactile, visual and auditory receptors. All of these definitions underlines that texture is a physical property perceived by tactile, visual and auditory senses during contact with the food. Due to the involvement of many parameters in texture perception, it is reasonable to describe texture as complex property of the food (Engelen and de Wijk, 2012).

A fundamental concern relating to food is how the textural properties are perceived and quantified. Guinard and Mazzucchelli (1996) investigated whether texture perception capability is inherent or learned through experience. This question should be answered with these two perspectives: innate as well as learnt. This is simply because texture perception is a result of a series of not only stimuli from basic senses that humans are inherent capabilities within but also by preconceived expectations that we learn by experiencing different foods (Foegeding et al., 2011).

In order to understand how texture is perceived it is necessary to determine which mechanoreceptors are responsible to create the sensory experience. Researchers are already in a consensus that the texture is sensed by various mechanoreceptors, rather than directly by an associated receptor, like taste receptors (Kilcast and Eves, 1991). During oral processing, the textural features of the food is perceived by three different modalities: Mechanoreceptors in the superficial structures (hard and soft palate, tongue and gums), mechanoreceptors in the periodontal membrane (root of the teeth) and mechanoreceptors of the muscles and tendons that are involved in mastication (Guinard and Mazzucchelli, 1996, Fujiki et al., 2001). Mechanoreceptors on the superficial structures of the mouth (hard and soft palate, tongue, and gums) has a distinguished ability from the other receptors to deform under mechanical responses during the oral processing by being highly dependent on the deformation and mechanical resistance of the food (Peleg, 1980, Guinard and Mazzucchelli, 1996). Mechanoreceptors that are found in periodontal ligament are responsible for two main tasks: achieving the maximum possible response to the force applied by teeth in a particular direction and detecting the thickness of objects between opposing teeth (Boyar and Kilcast, 1986). Mechanoreceptors of the muscles and tendons have various receptors to monitor their activities, such as velocity of stretching and responding to the changes in tension (Gordon and Ghez, 1991). Consumption of soft solid foods, where teeth does not involve in size reduction process, mechanoreceptors in the periodontal ligament and muscles and tendon plays a minor role where mechanoreceptors in the superficial structures, especially the tongue, will instead play the major role (Kutter et al., 2011). Therefore, the only mechanical force involved in the detection of the texture, is caused by the tongue which has receptors that morphologically does not show any significant mechanical difference from the other cutaneous tissues of the body (Capra, 1995, Marlow et al., 1965, Trulsson and Johansson, 2002). Additionally, according to Kutter et al. (2011), tactile senses are the only reason one can perceive texture. However, the sensitivity of the somatory receptors throughout the whole body show a different sensitivity depending on their location (Guinard and Mazzucchelli, 1996). Thus, investigating the mechanoreceptors perception and sensation may offer a better understanding in texture perception. The sensitivity of the mechanoreceptors throughout the body including the tongue can also give us an indication of the perception mechanism. Despite the fact that swallowing movement reduces the subject’s tactile sensitivity in the oral cavity, the sensitivity threshold was found to be very low threshold (de Wijk et al., 2003, Trulsson and Johansson, 2002).

Texture perception is a dynamic sensory process because the physical properties of the food change continuously during oral processing (Guinard and Mazzucchelli, 1996). Since texture is a multimodal sensory feature, the mechanical tests performed using the instruments are unlikely to reflect the human experience of the texture. The relationship between the instrumental texture assessments and sensory tests are still contentious for food scientists (Foegeding et al., 2011, Karel, 1997). Therefore, even the most developed instruments such as a texture analyser or a rheometer cannot represent the process of eating. A possible way of investigating the texture sensation is by doing carefully selected analytical sensory tests with distinct applications and also with robust, reproducible results with a required sensitivity for a specific target (Foegeding et al., 2011, Guinard and Mazzucchelli, 1996, Lawless and Heymann, 1998, Meilgaard et al., 2011). However, designing of a sensory test with all these conditions has never been a simple task (Foegeding et al., 2011).

Texture is a major determinant of consumer acceptance and preference of a food product and it is also the main indicator for swallowing initiation (Foegeding et al., 2003, Kutter et al., 2011, Guinard and Mazzucchelli, 1996). The consumers attitude to the food texture depends on physiological, social, cultural, economic and psychological conditions (Szczesniak and Khan, 1971). It is very clear that when the experienced texture of the food does not meet with the expectation, the acceptability of that food will be reduced (Lillford, 1991).

This study aims to best the hypothesis that a relationship exists between individual's capability of texture discrimination of soft solid food and the degree of their tactile sensitivities against the null hypothesis of having no correlation between the tactile sensitivity and texture discrimination. Experiments were designed to assess the sensitivity of the tongue against the fingertips. Fingertips are the most sensitive part of our body, followed by the upper lip, cheeks and nose (Weinstein, 1986). Little is known so far about the tactile sensitivity of the tongue, though it is critical for food texture sensation.

For texture discrimination, particular attributes such as firmness and elasticity were selected for tests. In this work firmness was defined as the feeling obtained while compressing the sample until it yields. Similarly elasticity was defined as the feeling obtained while gently compressing the sample without breaking the structure and assessing how the sample restores to original shape (Brown et al., 2003). Tactile sensitivity of the fingertip and tongue were tested with two different methods: touch sensitivity and the two-point discrimination. Touch sensitivity was measured with Semmes-Weinstein Monofilaments (SWM) (figure 1) which is a common technique for tactile sensitivity assessment to determine the minimum force that can be detected by the subject (touch sensitivity threshold) (Wiggermann et al., 2012). Two-point discrimination was examined using a disc shaped instrument shown in figure 3. It evaluates the tactile sensitivity by establishing the narrowest distance between two pressure points (Cholewaik and Collins, 2003 , Craig and Lyle, 2001). Findings of this study will improve our fundamental understanding of food texture sensation and perception, providing a new perspective. In particular, the findings should provide new insight for food formulation to improve the design of food structure to meet desired food texture related expectations from various consumer groups.

2. Materials and Methods

2.1. Food Samples

The food system used in this study was soft solid jelly samples. Instant gel powder which consists of carrageenan and locust bean gum (Vege-gel, Dr.Oetker Ltd. Bielefeld, Germany) purchased from a local supermarket and was used to construct a jelly samples as for firmness and elasticity discrimination assessments. Gel powder was stored in its original box at ambient temperature and used prior to the indicated best before date. Test samples were reconstituted into a series of concentrations (Table 1) for required firmness (breaking hardness) and elasticity (elastic modulus) range by simply mixing different amount of the powder with cold distilled water and bringing up to boiling point. Then the liquid solution was poured into cubic gel mould to cool down. The gels were cooled down to the ambient temperature for 2 hours and then placed into the refrigerator of 5 ^{o}C for 12 hours. Prior to the sensory tests gel samples were taken out of the refrigerator and kept at room temperature for 2 hours for thermal equilibration.

Edible vege-gels were chosen for texture perception/sensation tests because it is well-known food product all over the world and is reasonably easy to control the textural properties.

These samples do not contain flavour improvers, colourants and aroma substances so that these factors would not influence subjects' responses during the sensory testing.

2.2. Texture Analyses

Textural properties of the jelly samples were examined by using TA-XT Plus texture analyser (Stable Micro Systems Ltd., Surrey, UK). The textural attributes tested were the firmness (breaking hardness) and the elasticity (elastic modulus). The textural profile measurements were conducted at room temperature (25 ^{o}C ± 0.3) using flat ended 40 mm diameter cylindrical aluminium probe. Gel firmness (breaking hardness) was measured with a compression test at 2 mm/s speed and the highest force (in Newton) required to break the gel structure was noted as the representative firmness of the sample. Similarly elasticity of the gel samples was measured by the compression test with a test speed of 2 mm/s speed. The initial slope of stress and strain at viscoelastic region was calculated as the elastic modulus (Pascals) of the samples. Elastic moduli of the samples were calculated as force per area (geometric mean area) calculated using dimensions of the gel mould (1.8×1.5×1.5 cm). Identical tests were carried out 5 times of each formulation and the average of these was calculated.

2.3. Sensory Test Descriptions

2.3.1. Subjects

A total of 32 assessors (15 females, 17 males) were recruited for this study. All subjects were non-smokers and had good health status. Subjects reported no medical complication, no eating disorders, not on a special diet, no oral diseases, no skin problems, and no other known health problems which may influence the results of the test. Subjects were aged from 21 to 62 years old with a mean age of 34 ± 9 years. They had a mean body mass index of BMI of 23±3 kg/m^2. All subjects were recruited from the campus of the University of Leeds, and were either students or university staff. Written consents were obtained from each assessor prior to the test. During the initial introduction, assessors were informed of the procedure involved in the test. However, they were not told of the purpose of the investigation. Permission was obtained from the faculty ethic committee (MEEC 12-013) and all test procedures followed the ethical rules and regulations as set by the University of Leeds, UK. All sensory tests were conducted in a purposely designated sensory lab, within the food science building at the University of Leeds.

2.3.2. Tactile Sensitivity Tests

In the present study tactile sensitivity was examined by two different methods: touch sensitivity and two-point discrimination. Those tests were applied at the hand index fingertip of the dominant hand and the tongue. Before the test, subjects were asked to have their hand and mouth washed and to sit comfortably in a pre-arranged soft seat. For fingertip test, subjects were asked to rest their hand on the bench and release fingers in a relaxed manner. For touch tests involving the tongue, subjects were asked to open their mouth and gently extend their tongue outside the mouth in a manner that they found most convenient. The touch point was selected at the front central position, about 1.5 cm from the front tip. During the tests subjects were blind folded to prevent them from gathering any visual clues.

2.3.2.1. Touch Sensitivity Tests

Semmes-Weinstein Monofilaments (SWM) Touch-Test® sensory evaluators (shown in Figure 1) were used for touch sensitivity tests. The test kit was purchased from North Coast Medical Inc. (Gilroy, CA 95020 USA). The set consists of 20 monofilaments designed to provide a non-invasive evaluation of cutaneous sensation levels throughout the body. The touch force ranges from values as low as 0.008 g up to ones as high as 300 g, in logarithmic intervals. According to the manufacturer's specifications, each Touch-Test® sensory evaluator monofilament is individually calibrated to deliver its targeted force within an accuracy of 5 % of the given value (North Coast Medical Inc., 2013).

During the assessment of touch sensitivity the Touch-Test® monofilament was pressed perpendicular against the surface until the filament bowed for approximately 1.5 seconds and then removed (figure 2). Tests were started with a monofilament which applies a force of 0.008 g force and then continued in an ascending order towards the highest available force of 300 g if necessary. Tests stopped when subject started to feel the touch for two consecutive monofilaments touches. The first detected force was then taken as the threshold of touch sensitivity. Between each test the monofilament fibre was cleaned with an antibacterial wipe.

2.3.2.2. Two-Point Discrimination Tests

Touch-Test® two-point discriminator sensory evaluator (figure 3) was used for determination of tactile sensitivity. The test kit was purchased from North Coast Medical Inc. (Gilroy, CA 95020 USA). Two-point discriminator was designed to measure the narrowest distance that is sensed as two separate pressure points and may be applied to particular body areas. The measurement distances were ranged from 0.25 mm to 15 mm.

During the tests the Touch-Test® two-point discriminator was pressed perpendicular against the test surface for approximately 1.5 seconds in a static manner. Tests were started with a two point distance of 8mm and then continued in a descending order towards the smallest separation distance of 0.25 mm. Participants were asked to report if they could sense 1 or 2 distinct pressure points. Tests stopped when subject started to feel only 1 pressure point and the lowest detected 2 pressure points were then taken as the threshold of two-point discrimination for that individual. Between each test the discriminator was cleaned with an antibacterial wipe.

2.3.3. Texture Discrimination Tests of Soft-Solid Foods

The present experiments dealt mainly with texture perception in jelly food samples. Just noticeable difference (JND) threshold was used for both firmness (breaking) and elasticity (by compressing) assessments. For this purpose, a set of sensory tests was conducted for a series of gel samples (of different concentrations) in a pair-wise comparison procedure with either fingertip pressing or tongue pressing. Samples were arranged in an ascending order of concentration (firmness and elasticity) without any prior knowledge for the subject. Tests ceased when a subject gave three affirmative consecutive detection assessments of textural difference. The sample with the lowest concentration was used as the reference for the determination of the JND value. Cumulative JND against population was then tabulated and the median (50 %) JND value was taken as the population average threshold.

2.3.3.1. Firmness Discrimination Tests

Firmness is the sensory feeling obtained from compressing the sample until breaking (Brown et al., 2003). Participants were asked to assess the firmness of the samples by breaking the gel with either the fingertip or the tongue. They were required to make a pairwise comparison for each sample with the reference sample and test sample and answer whether the firmness of the two gel samples were the same or different from each other. The same procedure was repeated for each pair of sample by repeating the reference sample to ensure that the subjects did not lose the sensation of the reference firmness. Between each sample the fingertip were cleaned with a wet tissue paper and then dried with a paper towel. Water was provided for mouth wash between the samples.

2.3.3.2. Elasticity Discrimination Tests

Perceived elasticity is defined by Brown et al. (2003) as the sensation obtained from gently compressing the sample without breaking and assessing how the sample recovered to its original form. Subjects were asked to compress the test sample and the reference sample by using the dominant index fingertip and the tongue to assess whether the elasticity of the two samples were the same or different from each other. The reference sample was repeatedly sensed throughout the test to ensure that the subject did not lose the sensation of the reference elasticity. Fingertips were cleaned with a wet tissue paper and then dried with a paper towel and water was provided for mouth wash between the samples.

2.4. Statistical Analysis

The data obtained from the touch sensation, firmness perception and elasticity perception was plotted to log-normal best fitting lines with probit analysis with the confidence intervals by Microsoft Office Excel 2010 (v14.0). Statistical analysis was conducted in XLSTAT (Microsoft, Mountain View, CA) including the Pearson correlations, average and standard deviation values and Mann-Whitney tests in 95% significance level.

3. Results and Discussion

3.1. Tactile Tests

3.1.1. Touch Sensitivity Tests

Semmes-Weinstein Monofilaments is a popular technique to measure touch sensitivity. Even though some researchers still question the reliability of the technique for neurological examinations, it is commonly used as a general method to assess the effect of the nerve treatments, due to its easy applicability and non-invasive approach (Lundborg, 2000, Schreuders et al., 2008). The technique has been reported in literature by a number of researchers as a standard method to assess the touch sensation thresholds (Jerosch-Herold, 2005, Bell-Krotoski and Tomancik, 1987).

Touch sensitivity of all subjects are plotted in figure 4. The logarithmic normal cumulative distribution response (population percentage) is shown as a function of logarithmic touch sensitivity of the fingertip (a) and tongue (b). For general applications, the population threshold was given by the cumulative median (50 %) of the population distribution (Lawless and Heymann, 1998). According to this approach, the threshold of the fingertip touch sensitivity in the present study is found to be 0.028 g force (with confidence intervals of 0.026 g to 0.031 g). The threshold for the tongue is determined to be 0.013 g with the similar approach (confidence intervals of 0.012 g to 0.014 g). This means on average any touch force smaller than those values will not be detected or sensed by the fingertip and the tongue respectively. Based on these data, one can infer that the tongue is more sensitive to the touch than the fingertips and this finding was statistically significant ($p < 0.05$).

In the literature fingertip touch sensation thresholds has been reported as follows: between 0.008 g to 0.07 g according to Gillenson et al. (1998) , 0.008 g to 0.6 g according to Joris Hage et al. (1995). The thresholds obtained from this experiment offer comparable estimates. However, there is no literature data illustrating the touch sensitivity threshold of the tongue. To our best knowledge, the data reported in this work could be the first quantitative indication of the touch sensitivity of human tongue.

3.1.1.1. Two-Point Discrimination Tests

Two-point discrimination test was the main measure of the acuity in most of the early research on touch (Goldstein, 2010). Capability to discriminate the two closest points reflects the degree of sensation or sometimes the degree of sensation loss (Periyasamy et al., 2008). It has been reported in the literature that this test can be applied in a static and dynamic manner, though the dynamic test is not a routine practice (Periyasamy et al., 2008). In this study the static two-point discrimination method was used because of its reported feasibility and reliability for the determination of the nerve integrity (Ferreira et al., 2004).

Figure 5 shows the two-point discrimination test results with the cumulative response of the population percentage as a function of two-point distance (mm). It seems that most healthy individuals are capable of detecting the narrowest two points available from this technique. The data profiles are not wide enough to cover the whole range of population distribution, showing a limitation of the present methodology. However, in the literature the two-point discrimination thresholds were usually reported as the mean value rather than the cumulative median. With this perspective mean two-point discrimination threshold of the fingertip was found to be 1.42 ± 1.39 mm and for the tongue 0.62 ± 0.89 mm distance. The tongue was found to be more sensitive than the fingertip and this finding was statistically significant ($p<0.05$).

Previous researches of two-point discrimination test are mostly used for monitoring the degree of patient recovery after treatment and operations. Results obtained from this work seem to agree well with some previously reported literature data. Previously observed mean threshold for the two-point discrimination of the finger was found to be 1.66 ± 0.09 mm by Chandhok and Bagust (2002) and 2.2 mm by Menier et al. (1996). Meanwhile mean threshold for the two-point discrimination of the tongue was as follows: 1.09 ± 0.35 mm by Minato et al. (2009), 1.7 ± 0.1 mm by Okada et al. (1999).

3.2. Texture Discrimination Tests of Soft-Solid Foods

The texture of the soft solid food gel samples were tested in this task. There were 9 different test samples and 1 reference sample. Participants were asked to do pairwise comparison between each sample and the reference and to report if the texture of the two samples were the same or different from each other. The results obtained from the experiment were illustrated as a cumulative response of population in order to represent the population threshold by finding the cumulative median (50 %) response.

The texture perception test was conducted for two different textural parameters: the firmness and the elasticity. As noted earlier, during firmness assessment, subjects were asked to compress to yield point the two samples while for the elasticity perception they were asked to compress and sense the textural features. Texture discrimination tests were conducted by both the fingertip and the tongue.

3.2.1. Firmness Discrimination Tests

Figure 6 summarises the firmness discrimination capability of the index finger (a) and the tongue (b). Cumulative response as shown in population percentage was plotted against the logarithmic percentage of firmness difference to the reference (see equation 1):

$$\% \text{ Firmness difference} = \frac{N_1 - N_0}{N_0} \times 100 \qquad equaion\ 1$$

where, N_1 is the firmness of the sample and N_0 is the firmness of the reference sample.

Population threshold (cumulative median) of firmness detection was 13.3 % for the fingertip, which means that a change of 13.3 % in the breaking hardness from the reference sample will be the minimum change for firmness discrimination by the fingertip (confidence intervals of 12.1 % to 14.7 %). Meanwhile the threshold of firmness discrimination by the tongue was found to be 11.1 %, which again means that a minimal change of 11.1 % is needed for a detectable difference perceivable by the tongue (with confidence intervals of 9.97 % to 12.32 %). The findings of this experiment show that the tongue is more sensitive than the fingertip. Further analysis of these data shows that this finding is statistically significant ($p < 0.05$).

3.2.2. Elasticity Discrimination Tests

Figure 7 expresses the elasticity sensation of the participants by index fingertip (a) and tongue (b). Cumulative response as population percentage was plotted against the logarithmic percentage elastic modulus difference of the reference sample (see equation 2):

$$\% \text{ Elasticity difference} = \frac{E_1 - E_0}{E_0} \times 100 \qquad equaion\ 2$$

where E_1 is the elastic moduli of the sample and E_0 is the elastic moduli of the reference sample.

Elasticity discrimination threshold of the population was found to be 2.3 % elastic modulus difference, in another words it is essential to increase the elastic modulus of the sample by at least 2.3 % in order to create a fingertip detectable difference (confidence intervals from 1.97 % to 2.64 %). With similar approach elasticity discrimination threshold for the tongue was observed at only 1.2 % elastic modulus difference (with confidence intervals of 0.97 % to 1.53 %). This means that only 1.2 % change in elasticity will be perceivable by gentle pressing by the tongue. This information again reveals that the tongue is more sensitive than the fingertip and again this finding was statistically significant ($p < 0.05$).

Both the elasticity and the firmness are the textural properties closely associated with the mechanical nature of the food material. However, it seems that different sensing mechanisms for the two textural properties lead to very different sensitivity. By comparing elasticity discrimination against firmness discrimination, one can clearly see that individuals are much more capable in differentiating textural properties by applying gentle touch or compression for elasticity perception than by destructive yielding for firmness sensation. The reason behind this difference is not yet clear, but one could speculate that an excessive force might be applied during structure breaking, which may make texture detection less precise and therefore not able to appreciate the delicacy of texture differences.

3.3. Correlation of Tactile Sensitivity and Soft-Solid Discrimination Capabilities

Having built up the population profiles of the touch sensitivity and textural discrimination capability, this study moved further to examine the possible correlation between the individual capabilities of texture discrimination (firmness and elasticity) and the tactile sensitivity (the touch sensitivity and the two-point discrimination) for both fingertip and tongue. The assumption behind this was that, since food texture is a sensory property via the tactile mechanism, an individual's tactile sensitivity could play a critical role to their capability in texture discrimination. However, results were largely surprising and not in line with our initial expectation and we were therefore unable to reject our null hypothesis of no correlation between tactile sensitivity and soft-solid texture discrimination. Figure 8 plots the individual firmness discrimination capability against the tactile sensitivity tests (touch sensitivity and two-point discrimination) for fingertip (a) and tongue (b). It can be seen from these graphs that experimental data are largely scattered, low correlation between these capabilities for both fingertip and tongue is indicated. With similar approach, Figure 9 shows the data of individual elasticity discrimination capability against the tactile sensitivity (touch sensation and two-point discrimination) for fingertip (a) and tongue (b). Again the elasticity perception shows a low correlation with the tactile sensation. Based on these results, one may conclude that there is no direct correlation between one's tactile sensitivity and soft-solid texture discrimination (firmness and elasticity) capabilities.

The reason of having no direct correlation between one's capability of texture sensation and tactile sensitivity is not yet certain. But the complex nature of texture perception could be a possible cause for no direct correlation. It is very likely that tactile sensation has an impact on the texture appreciation, and texture discrimination could be a learned experience improved by culture and knowledge. The lack of correlation between one's capability of tactile sensitivity and texture discrimination could be due to the fact that tactile sensitivity was assessed in a static manner while texture sensation was a dynamic process. This of course will be another interesting topic for future studies.

4. Limitations

While research findings from this work are significant, limitations of the study should also be noted, in particular the limitations of the methodologies that were used to determine the tactile sensitivity (touch sensitivity and two-point discrimination) and texture discrimination (firmness and elasticity) capabilities. Even though the method for touch sensitivity tests was sensitive enough for this study, the two-point discrimination test was not sensitive enough to cover the whole population profile. Most participants were capable to detect the minimal pressure point distance available from this method. The technique of two-point discrimination test used in this work was initially designed for the patients who are in nerve recovery process and may not be appropriate for healthy individuals. An alternative technique is needed for more precise discrimination of two-point.

Another obvious limitation of the experimental design is the temperature control. It is well known that textural properties of gel samples could be highly temperature dependent. In this work, all gel samples were characterised for their firmness and elasticity at a constant temperature of 25 ^{o}C, despite the fact that gel samples experienced varying temperature during the sensory discrimination tests either inside the mouth or under the fingertip. Since no literature data is available to show the real temperature of the food in both cases, this work simply adopts 25 ^{o}C as standard. Though temperature difference is a possible influence on gel samples, it is expected to be systematic and it is anticipated the effect would not be significant on the ranking of the textural properties.

During the assessment of texture perception (firmness and breaking) there were some limitations due to the sensory test nature. The variance between the individuals were reduced by including 2 familiarisation samples prior to the test to prepare the participant and make them familiar with what to do and how to assess the samples texture (firmness and elasticity).

5. Conclusions

The main aim of this study was to examine the tactile sensitivity and texture discrimination of the fingertip and tongue and to examine whether correlations exist between the two processes. Our results suggest that tongue is tactually much more sensitive than the fingertip. Touch sensitivity threshold of the population was found to be 0.028 g and 0.013 g for the fingertip and the tongue respectively. Mean threshold of two-point discrimination was observed as 1.42 mm and 0.62 mm for fingertip and tongue correspondingly. Additionally the firmness discrimination measured by the just noticeable difference (JND) of the gel samples were assessed as 13.3 % for fingertip and 11.1 % for the tongue. Elasticity discrimination threshold was 2.3 % of the fingertip and 1.2 % for the tongue. In contrast to our initial hypothesis, there was no clear evidence to reject the null hypothesis of having no correlation between individual’s tactile sensitivity and the capability of texture discrimination.

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Legends

Equation 1. % firmness difference

Equation 2. % elasticity difference

Table 1. Properties of constituted jelly test samples (*reference sample)

Figure 1.Touch sensation test kit consisting of 20 Semmes-Weinstein Monofilaments

Figure 2. Illustration of touch sensation test methodology. The monofilament pressed perpendicular to the target surface. The pressing force continues to increase until it reaches a maximum when the filament starts to bend and apply a target force.

Figure 3. Two-point discrimination tool to assess the narrowest distance that could be sensed as two pressure points.

Figure 4. Log-normal fitting (probit analysis) of the cumulative population percentage vs the touch sensitivity (g): (a) the index fingertip ($10^{-1.55}$ = 0.028 g); (b) the tongue ($10^{-1.88}$ = 0.013 g).

Figure 5. Cumulative responses of subjects shown as population percentage against the distance (mm) between the two points: (a) the index fingertip (mean two-point discrimination = 1.42mm); (b) the tongue (mean two-point discrimination = 0.62 mm) (with guide to eye lines)

Figure 6. Log-normal best fitted (probit analysis) cumulative responses of subjects shown as population percentage against the logarithmic firmness difference (%); (a) the fingertip ($10^{1.13}$ = 13.3 %); (b) the tongue ($10^{1.04}$ = 11.1 %)

Figure 7. Log-normal best fitted (probit analysis) cumulative responses of subjects shown as population percentage against the logarithmic elasticity difference (%); (a) the fingertip ($10^{0.36}$ = 2.7 %); (b) the tongue ($10^{0.09}$ = 1.1 %)

Figure 8. Individual's capability of firmness discrimination and touching sensitivity (●) and two-point discrimination ability (×): (a) by the index fingertip; (b) by the tongue.

Figure 9. Individual's capability of elasticity discrimination and touching sensitivity (●) and two-point discrimination ability (×): (a) by the index fingertip; (b) by the tongue.