

TACTILE SENSITIVITY and CAPABILITY OF SOFT-SOLID TEXTURE DISCRIMINATION

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KEYWORDS

Tactile sensation, texture discrimination, texture perception, texture sensation, touch sensitivity, two-point discrimination

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Received for Publication December 16, 2014

Accepted for Publication July 8, 2015

Published online Article Accepted on July 15, 2015

doi:10.1111/jtxs.12142

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 related to 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 detection threshold and two-point discrimination threshold) and texture discrimination capability. A range of soft-solid food samples with controlled firmness and elastic moduli were designed for textural discrimination tests. A total of 32 healthy subjects threshold of touch detection 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. 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 slightly more sensitive than the fingertip in discriminating food texture ($P < 0.05$). An expected correlation between individual's capability of texture discrimination and their tactile sensitivity was not observed.

PRACTICAL APPLICATIONS

Texture discrimination capability is a significant factor for food texture preference and appreciation. In order to understand texture perception, it is essential to identify the relevant factors and define characteristics that govern the processes involved. Having a meaningful and reliable texture discrimination indicator is critically important for the food industry in the development and optimization of new food products, and in particular for specific food design for individuals' with special needs, e.g., elderly, dysphagic patients, etc. With this study, we illustrate the differential threshold for soft-solid texture (firmness and elasticity) and also investigate the capabilities of tactile sensation (touch detection and two-point discrimination) and evaluate potential correlations. The results and correlations may provide information about texture sensitivity and also might provide useful information to R&D researchers. Methodologies could also be applied in general food sensory studies and also investigating relationships between sensory psychology and sensory physiology.

INTRODUCTION

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; Kutter *et al.* 2011). Food texture is a somewhat neglected attribute because of the dominating pursuit of understanding taste attributes (Guinard and Mazzucchelli 1996). However, 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). The 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). Food texture was defined as all the rheological and structural attributes of the food perceptible by means of mechanical, tactile, visual and auditory receptors (Lawless and Heymann 1998). In describing a model system of texture perception, multi-parameters are required; it is therefore reasonable to describe texture as a complex property of the food (Engelen and de Wijk 2012). Fundamental concerns related to food are about the textural properties perception and quantification. Guinard and Mazzucchelli (1996) investigated whether texture perception capability is inherent or learnt through experience. This question should be answered with these two perspectives: innate as well as learnt. This is simply because texture is a result of perception series, not only stimuli from basic senses that are inherent capabilities within humans but also by preconceived expectations that we learn by experiencing different foods (Foegeding *et al.* 2011).

In order to understand how the texture is perceived, it is necessary to determine which mechanoreceptors are responsible for creating a sensory experience. An accepted consensus is that texture is sensed by various mechanoreceptors, rather than directly by an associated receptor, unlike taste receptors (Kilcast and Eves 1991). During oral processing, the textural features of the food are 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) have a distinguishable 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 the periodontal ligament and are responsible for two main functions: determination of the level of

the appropriate force applied by teeth in a particular direction during mastication 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 the teeth are not significantly involved in the size reduction process, mechanoreceptors in the periodontal ligament, muscles and tendons, play a minor role where mechanoreceptors in the superficial structures – i.e., tongue – will dictate the major role (Kutter *et al.* 2011). Therefore, the only mechanical force involved in the detection of the texture of gel-like samples is mostly influenced by the tongue, which has receptors that morphologically do not show any significant structural difference from the other cutaneous tissues in the body beside having smaller receptive field and lower force thresholds (Marlow *et al.* 1965; Capra 1995; Trulsson and Essick 1997; 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 somatosensory receptors throughout the whole body shows different sensitivity depending on their location (Guinard and Mazzucchelli 1996). Thus, investigating mechanoreception may offer an improved understanding in texture perception. The sensitivity of the mechanoreceptors throughout the body including the tongue can also provide an indication of the perception mechanism. Even though the action of swallowing has found to reduce the subject's tactile sensitivity in the oral cavity, the threshold of the mechanoreceptors was found to be very sensitive (Trulsson and Johansson 2002; de Wijk *et al.* 2003).

This study aims to test the hypothesis that a relationship exists between individual's capability of texture discrimination of soft-solid foods and the degree of their tactile sensitivities. Experiments were designed to assess the sensitivity of the tongue against the fingertips according to the following parameters:

- (1) Texture discrimination dynamics and thresholds for soft-solid foods firmness and elasticity
- (2) Tactile sensation thresholds including touch detection and two-point discrimination.

These tests were applied on the fingertip and tongue surface. According to the previous studies, fingertips are found to be the most sensitive part of our body, followed by the upper lip, cheeks and nose (Weinstein 1986).

For texture discrimination, particular attributes such as firmness and elasticity were selected for tests. In this work, firmness was defined by the magnitude of the sensation obtained while compressing the sample until the yield point. Similarly, elasticity was defined by the magnitude of the sensation obtained while gently compressing the sample

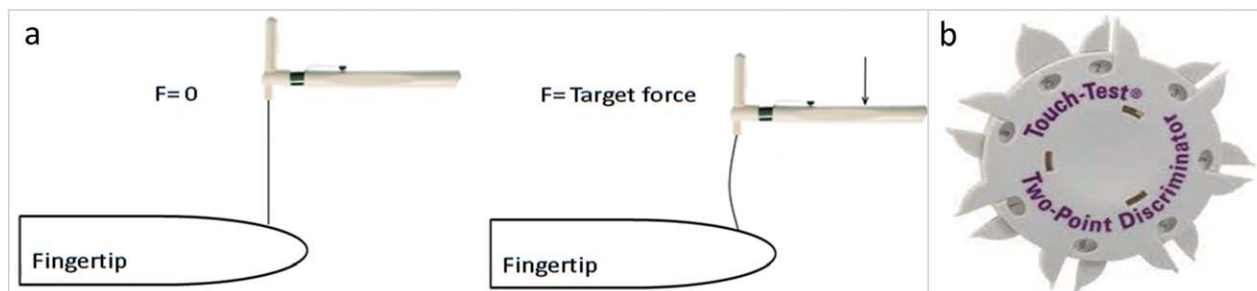


FIG. 1. EQUIPMENT USED IN THE SENSORY ASSESSMENT OF TACTILE SENSITIVITY (a) Illustration of touch sensation test methodology, (b) two-point discrimination tool.

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 detection and the two-point discrimination. Touch detection was measured with Semmes-Weinstein Monofilaments (SWM; Fig. 1a), which is a commonly used technique for tactile sensitivity assessment to determine the minimum force that can be detected by the subject (touch detection threshold) (Wiggermann *et al.* 2012). Two-point discrimination was examined using a disc-shaped instrument shown in Fig. 1b. It evaluates the tactile sensitivity by establishing the narrowest distance between two distinctly perceptible pressure points (Craig and Lyle 2001; Cholewaik and Collins 2003). The findings of this study could provide information about food texture sensation and perception and could be a bridge between oral sensation dynamics from the perspective of food sciences. Also presented, methodologies and results could be of interest to research and development in the food industry where especially improved texture is required (i.e., food producers for patients of dysphagia and vulnerable individuals).

MATERIALS AND METHODS

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), was purchased from a local supermarket and was used to construct soft-solid, gel samples for firmness and elasticity discrimination assessments. Gel powder was stored in a retailer's container at ambient temperature and was 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 (Young's 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 mold to cool down. The gels were cooled down to the ambient temperature for 2 h and then placed at 5C for 12 h. Prior to the sensory tests, gel samples were taken out of the refrigerator and stored at room temperature for 2 h for thermal equilibration.

TABLE 1. PHYSICAL PROPERTIES OF THE SAMPLES INCLUDING THE CALCULATIONS OF THE % FIRMNESS RATIO AND % YOUNG'S MODULUS (*REFERENCE SAMPLE)

Sample number	Firmness			Elasticity		
	Actual firmness (N)	Firmness difference from the reference (N) (Δ)	% Difference firmness ratio (Δ/I)	Actual Young's modulus ($10^4 \times \text{Pa}$)	Young's modulus difference from the reference ($10^4 \times \text{Pa}$) (Δ)	% Difference Young's modulus ratio (Δ/I)
1*	2.58	0	0	2.69	0	0
2	2.81	0.23	9	2.74	0.05	2
3	2.99	0.41	16	2.8	0.11	4
4	3.12	0.54	21	2.85	0.16	6
5	3.31	0.73	28	2.91	0.22	8
6	3.48	0.9	35	2.97	0.28	10
7	3.65	1.07	41	3.03	0.34	13
8	3.81	1.23	48	3.09	0.4	15
9	4	1.42	55	3.15	0.46	17
10	4.61	2.03	79	3.36	0.67	25

Soft-solid edible gels were chosen for texture perception/sensation tests because these are well-known food products all over the world and the textural properties are reasonably easy to control. These samples do not contain taste improvers, colorants and aroma substances so that these factors would not influence the subjects' responses during the sensory testing.

Texture Analyses

Textural properties of the jelly samples were examined by using TA-XT Plus texture analyzer (Stable Micro Systems Ltd., Surrey, U.K.). Tested textural attributes were firmness (breaking hardness) and elasticity (Young's modulus). Textural profile measurements were conducted at room temperature (25°C) using flat-ended 40-mm diameter cylindrical aluminum probe. Gel firmness (breaking hardness) was measured with a compression test at 2 mm/s speed and the highest force (in Newton) required for yielding was noted as firmness value of the sample. Similarly, elasticity of the gel samples was obtained by the calculation of the Young's modulus during the compression test with a test speed of 2 mm/s speed. The initial slope of stress and strain at viscoelastic region (20% strain) was noted down as the Young's modulus (in Pascal) of the samples. Elastic moduli of the samples were calculated as force per area (geometric mean area) calculated using the dimensions of the gel mould ($1.8 \times 1.5 \times 1.5$ cm). Identical tests were carried out five times of each formulation and the average of these was calculated.

In order to establish the discrimination threshold of the textural properties, % difference ratio of each sample was calculated based on the magnitude of the reference sample. Table 1 shows the steps and the results of the calculations and the % difference values for each sample.

Sensory Test Descriptions

Subjects. Thirty-two assessors (15 females, 17 males) were recruited in this study. All subjects were nonsmokers and healthy individuals. Subjects reported no medical complications related to skin and oral conditions which might have influenced the results of the tests. Subjects were aged from 21 to 62 years old with a mean age of 34 ± 9 years and mean body mass index of 23 ± 3 kg/m². All subjects were recruited from the campus of the University of Leeds, and were either students or staff of the university. Written consents were obtained from each assessor prior to the test. During the initial introduction, assessors were instructed about the procedure of the test. However, they were not told of the purpose of the investigation. Ethical permission was obtained from the faculty ethic committee (MEEC 12-013) and all test procedures followed the ethical rules and regula-

tions as set by the University of Leeds, U.K. All sensory tests were conducted in a purposely designated sensory lab, within the food science building at the University of Leeds.

Tactile Sensitivity Tests. In the present study, tactile sensitivity was examined by two different methods: touch detection and two-point discrimination. Those tests were applied on the dominant hand index fingertip and on 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. Touching point was selected at the front central position, about 1.5 cm from the front tip. During the tests, subjects were blindfolded in order to prevent them from gathering any visual cues.

Touch Detection Tests. SWM Touch-Test[®] sensory evaluators (illustration shown in Fig. 1a) were used for touch detection tests. The test kit was purchased from North Coast Medical Inc. (Gilroy, CA). The set consists of 20 monofilaments designed to provide a noninvasive evaluation of cutaneous sensation levels throughout the body. Deliverable forces have a range from 0.008 g up to 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 detection the Touch-Test[®] monofilament was pressed perpendicular against the surface until the filament bowed for approximately 1.5 s and then removed (Fig. 1a). Tests were started with a monofilament which applies a force of 0.008 g force and then continued in an ascending order toward the highest available force of 300 g if necessary. Tests stopped when subject started to feel the touch for two consecutive monofilaments touches. First detected force was then taken as the threshold of touch detection. Between each test the monofilament fiber was cleaned with an antibacterial wipe.

Two-Point Discrimination Tests. Touch-Test[®] two-point discriminator sensory evaluator (Fig. 1b) was used for determination of two-point discrimination sensitivity. The test kit was purchased from North Coast Medical Inc. (Gilroy, CA). The two-point discriminator was designed to measure the narrowest distance that can be sensed as two distinct pressure points and may be applied to particular body areas. The measurement distances were ranged from 0.25 to 15 mm.

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

Texture Discrimination Tests of Soft-Solid Foods.

The present experiments dealt mainly with texture perception in gel food samples. The aim of the study was to obtain the just noticeable difference (JND) threshold with % differences of each sample that was calculated for both; firmness (breaking) and elasticity (by compressing). For this purpose, a set of sensory tests was conducted with series of gel samples (of different concentrations) in a pair-wise comparison procedure with fingertip and tongue. Samples were arranged in an ascending order of concentration (firmness and elasticity) and no prior knowledge was offered to subjects'. Tests ceased when a subject gave three affirmative consecutive detection assessments of textural difference. Between these reported three detections, the sample with the lowest concentration was noted down to be used as the reference for JND value. Cumulative population was then tabulated against the logarithmic stimulus levels and the median (50%) JND value was taken as the population average threshold.

Firmness Discrimination Tests. Firmness is the sensory feeling obtained from compressing the sample until yielding (Brown *et al.* 2003). Participants were asked to assess the firmness of the samples by breaking the gel with their fingertip and tongue. They were required to make a pair-wise comparison for each sample against the reference sample and assess whether the firmness of the two gel samples were the same or different. Between each sample, subjects' were asked to clean with wet tissue paper and dry their fingertip. Water was provided for mouthwash between the samples.

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 compared with the reference by using their fingertip and tongue to assess whether the elasticity of the two samples were the same or different from each other as a discrimination task.

The reference sample was repeatedly sensed as the first sample of the pair 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 mouthwash between the samples.

Statistical Analysis

Obtained data from the touch sensation, firmness perception and elasticity perception were 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.

RESULTS AND DISCUSSION

Tactile Tests

Touch Detection Tests. SWM is a popular technique to measure touch detection. Despite reliability concerns of the technique for neurological examinations, it is commonly used as a general method to assess the effect of the nerve treatments because of its noninvasive and user-friendly 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 touch detection thresholds (Bell-Krotoski and Tomancik 1987; Jerosch-Herold 2005).

Touch detection of subjects were plotted in Fig. 2. Cumulative distribution (population percentage) is shown as a function of logarithmic touch detection of the fingertip (a) and tongue (b). For general applications, the population threshold was given by the cumulative median (50%) of the cumulative population distribution (Lawless and Heymann 1998). According to this approach, the threshold of the fingertip touch detection 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). Therefore, on average, any touch force smaller than those values is not expected to be detected or sensed by the fingertip and the tongue respectively by half of the population, which can be accepted as population threshold. 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 have been reported as follows: from 0.008 to 0.07 g according to Gillenson *et al.* (1998) and 0.008 to 0.6 g according to

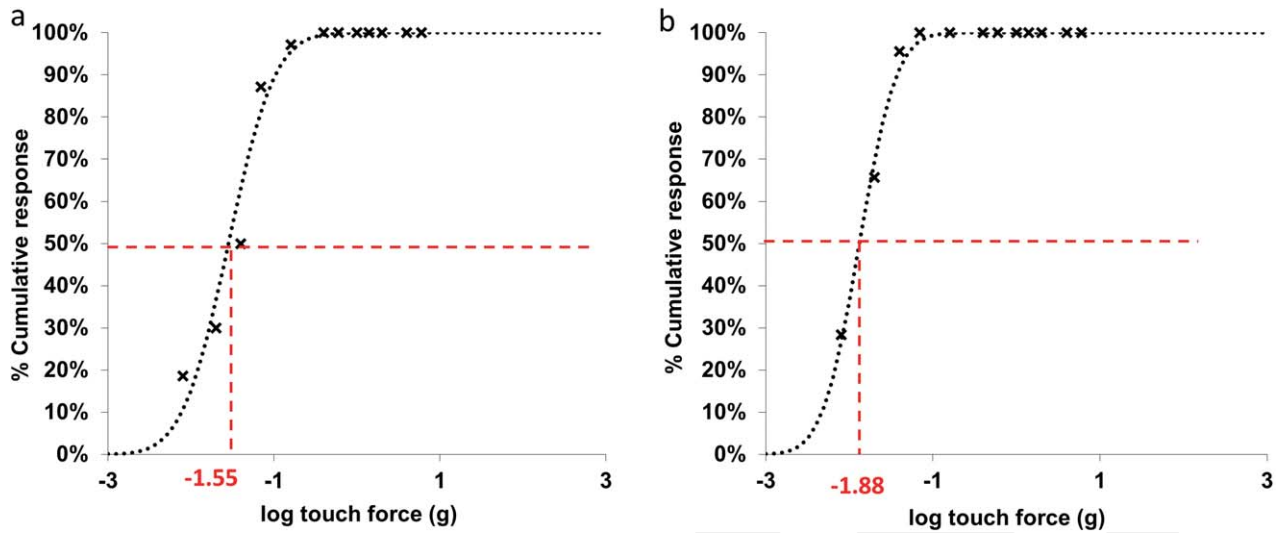


FIG. 2. LOG-NORMAL FITTING (PROBIT ANALYSIS) OF THE CUMULATIVE POPULATION PERCENTAGE VERSUS THE TOUCH SENSITIVITY (G): (A) THE INDEX FINGERTIP (MEDIAN: $10^{-1.55} = 0.028$ g [BETWEEN 0.026 AND 0.031 g]); (B) THE TONGUE (MEDIAN: $10^{-1.88} = 0.013$ g [BETWEEN 0.012 AND 0.014 g])

Joris Hage *et al.* (1995). The thresholds obtained from this experiment offer comparable estimates.

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 perceptible 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 accepted as 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 3 shows the two-point discrimination test results with the cumulative response of the population percentage as a function of two-point distance (mm). Evidently, most healthy individuals are capable of detecting the narrowest two points available from this technique. The data profiles

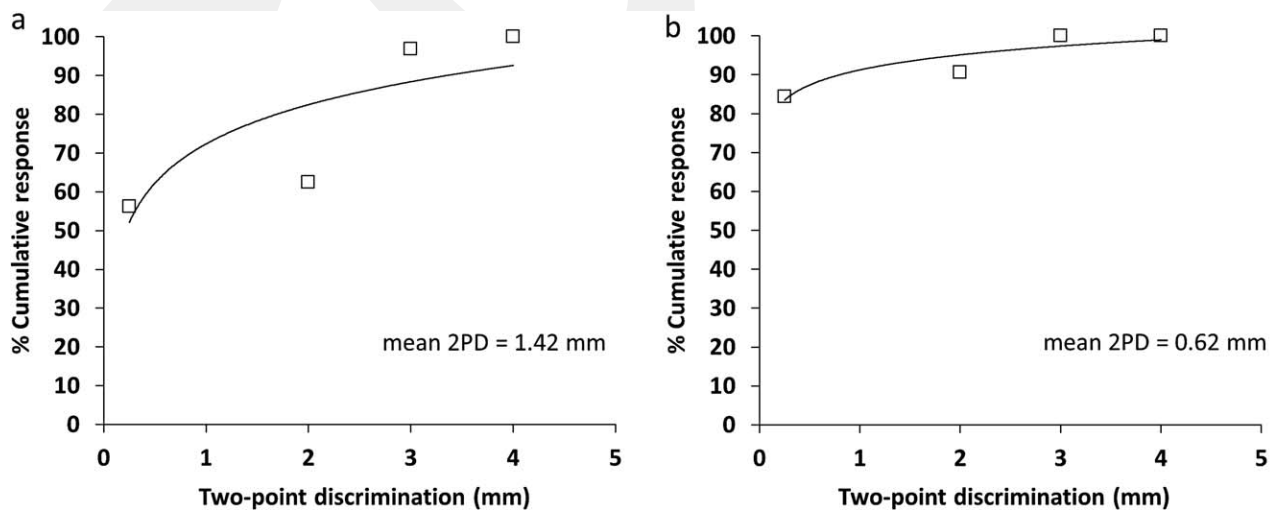


FIG. 3. CUMULATIVE RESPONSES OF SUBJECTS SHOWN AS POPULATION PERCENTAGE AGAINST THE DISTANCE (MM) BETWEEN THE TWO POINTS: (A) THE INDEX FINGERTIP (MEAN TWO-POINT DISCRIMINATION = 1.42 mm); (B) THE TONGUE (MEAN TWO-POINT DISCRIMINATION = 0.62 mm) (WITH GUIDE TO EYE LINES)

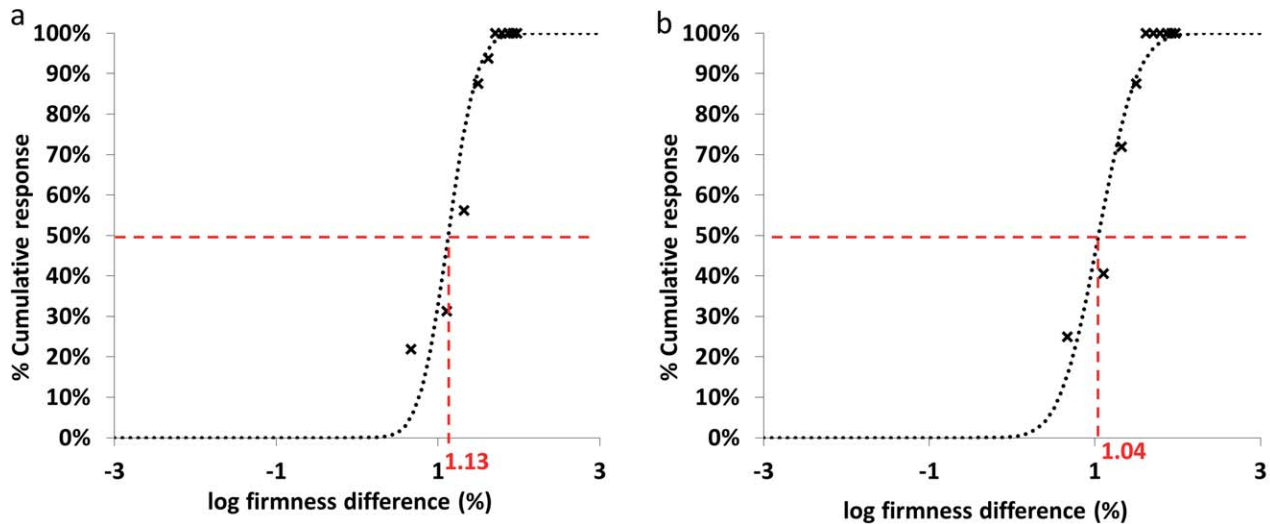


FIG. 4. LOG-NORMAL BEST FITTED (PROBIT ANALYSIS) CUMULATIVE RESPONSES OF SUBJECTS SHOWN AS POPULATION PERCENTAGE AGAINST THE LOGARITHMIC FIRMNESS DIFFERENCE (%); (A) THE FINGERTIP (MEDIAN: $10^{1.13} = 13.3\%$, [BETWEEN 12.1 TO 14.7%]); (B) THE TONGUE (MEDIAN: $10^{1.04} = 11.1\%$, [BETWEEN 10.0 TO 12.3%])

are not sufficiently wide to cover the whole range of population distribution, which shows the limitation of the present methodology. Likewise, in the literature, the two-point discrimination thresholds were usually reported as the mean value rather than the cumulative median. Using this measure, the two-point discrimination threshold distance of the fingertip was found to be 1.42 ± 1.39 mm and for the tongue 0.62 ± 0.89 mm. The tongue was found to be more sensitive than the fingertip statistically ($P < 0.05$).

Previous research involving two-point discrimination tests are mostly used for monitoring the degree of patient's postoperative recovery and treatment. Results obtained from this work show good agreement with some previously reported literature results, e.g., 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).

Texture Discrimination Tests of Soft-Solid Foods

Firmness Discrimination Tests. Figure 4 summarizes the firmness discrimination capability of the index fingertip (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 Eq. 1):

$$\% \text{ Firmness difference} = \frac{N_1 - N_0}{N_0} \times 100 \quad (1)$$

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 suggests that a change of 13.3% in the breaking hardness from the reference sample will be the minimum change for detectable firmness change for 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 implies that a minimum change of 11.1% is needed for a detectable difference for the tongue (with confidence intervals of 9.97% to 12.32%). The findings of this experiment show that the tongue has similar sensitivity to the fingertip. Additionally, further statistical analysis shows that fingertip and tongue has no difference between their firmness discrimination sensitivity ($P > 0.05$).

Elasticity Discrimination Tests. Figure 5 illustrates the elasticity sensation of 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 Eqn. 2):

$$\% \text{ Young's modulus difference} = \frac{E_1 - E_0}{E_0} \times 100 \quad (2)$$

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

Elasticity discrimination threshold for the fingertip was found to be 2.3%; in other words, it is essential to increase the elastic modulus of the sample by at least 2.3% in order to create detectable difference for fingertip (confidence

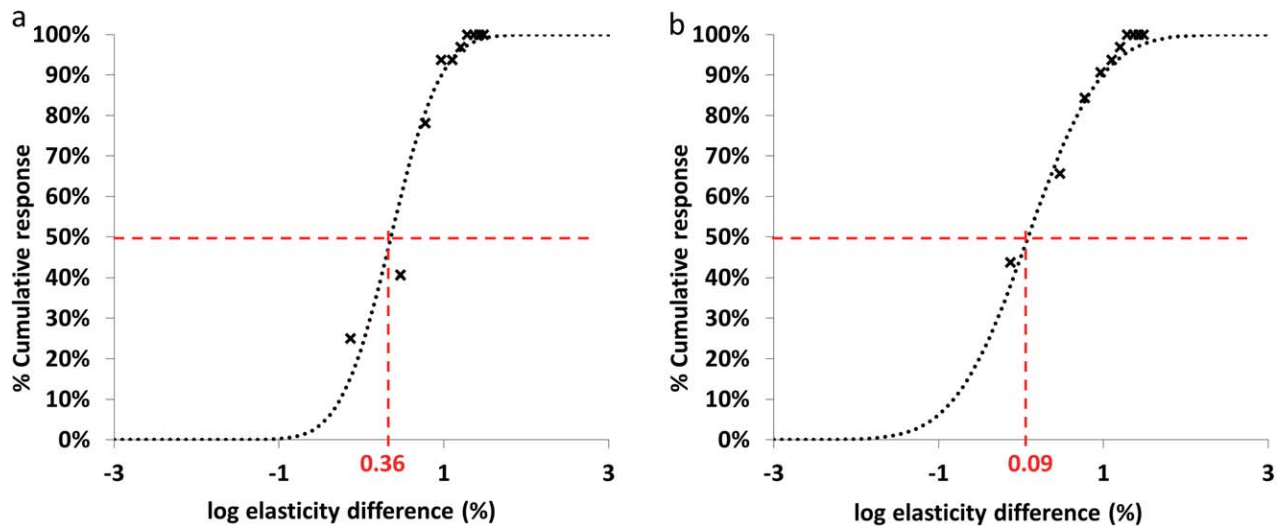


FIG. 5. LOG-NORMAL BEST FITTED (PROBIT ANALYSIS) CUMULATIVE RESPONSES OF SUBJECTS SHOWN AS POPULATION PERCENTAGE AGAINST THE LOGARITHMIC ELASTICITY DIFFERENCE (%); (A) THE FINGERTIP (MEDIAN: $10^{0.36} = 2.7\%$, [BETWEEN 2.0 TO 2.6%]); (B) THE TONGUE (MEDIAN: $10^{0.09} = 1.1\%$, [BETWEEN 0.97 TO 1.5%])

intervals from 1.97% to 2.64%). With similar approach, elasticity discrimination threshold of the tongue was found to be 1.2% (with confidence intervals of 0.97% to 1.53%). This means that minimum sensible difference in elasticity requires 1.2% change 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 different sensitivity values. 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 – 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 recognize or appreciate the delicacy of texture differences.

Correlation of Tactile Sensitivity and Soft-Solid Discrimination Capabilities

Having built up the population profiles of tactile 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 (touch detection

and two-point discrimination) for both fingertip and tongue. The assumption behind this was that, since food texture is a sensory property observed via the tactile mechanism, an individual's tactile sensitivity could play a critical role to their capability in texture discrimination. However, results were not in line with our initial hypothesis and we were unable to reject our null hypothesis of no correlation between tactile sensitivity and soft-solid texture discrimination. Figure 6 plots the individual firmness discrimination capability against the tactile sensitivity tests (touch detection and two-point discrimination) for fingertip (a) and tongue (b). It can be seen from those graphs that experimental data were largely scattered, low correlation between these capabilities for both fingertip and tongue is indicated. With similar approach, Fig. 7 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 capability of texture discrimination and tactile sensitivity.

The reason of having no direct correlation between one's capability of texture sensation and tactile sensitivity is still not certain. But the complex nature of texture perception could be a possible cause for no direct correlation. Additionally, 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.

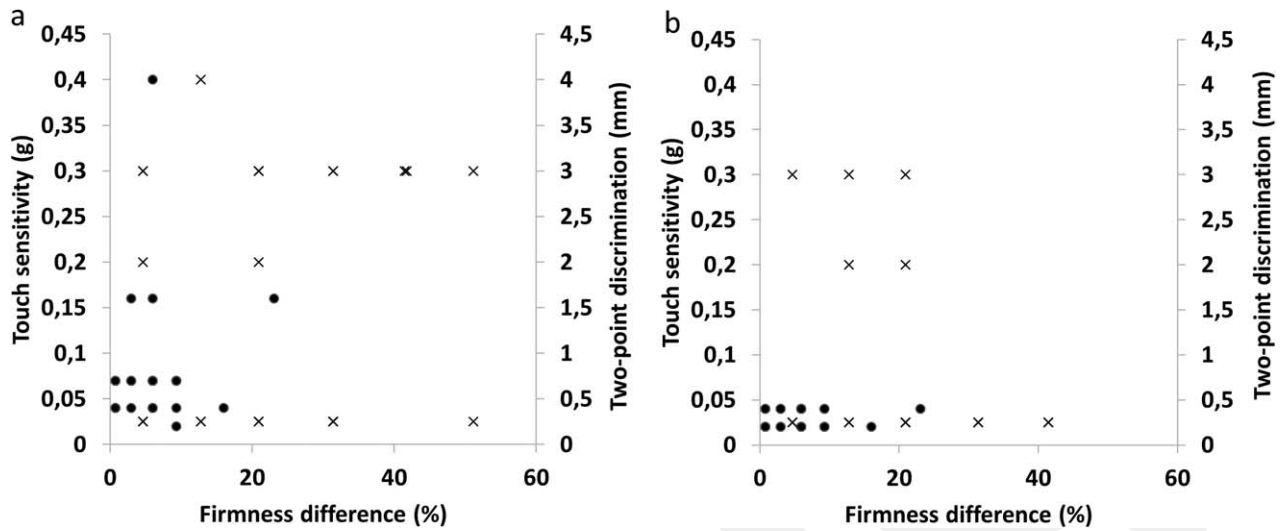


FIG. 6. INDIVIDUAL'S CAPABILITY OF FIRMNESS DISCRIMINATION AND TOUCHING SENSITIVITY (●) AND TWO-POINT DISCRIMINATION ABILITY (×): (A) BY THE INDEX FINGERTIP; (B) BY THE TONGUE

Previous laboratory based testing of the tactile sensations showed greater sensitivities with active touch compared with those done with static manner (Srinivasan and LaMotte 1995). It is very likely that tactile sensitivity has an impact on texture appreciation and that texture discrimination could be learnt experience improved by culture and knowledge.

LIMITATIONS

While research findings from this work are significant, limitations of the study should also be noted. Even though the

method for touch detection was sensitive enough for this study, the two-point discrimination test was not sensitive enough to cover the whole population profile. Most participants were able to detect the minimal distance available in the technique. The technique of two-point discrimination test used in this work was initially designed for the patients who are in nerve recovery process and therefore, may not be appropriate for healthy individuals. An alternative technique is needed for more precise discrimination of two-point. Additionally two-point discrimination is considered to be a confounded measure of spatial resolution acuity; therefore, the findings of two-point discrimination tests

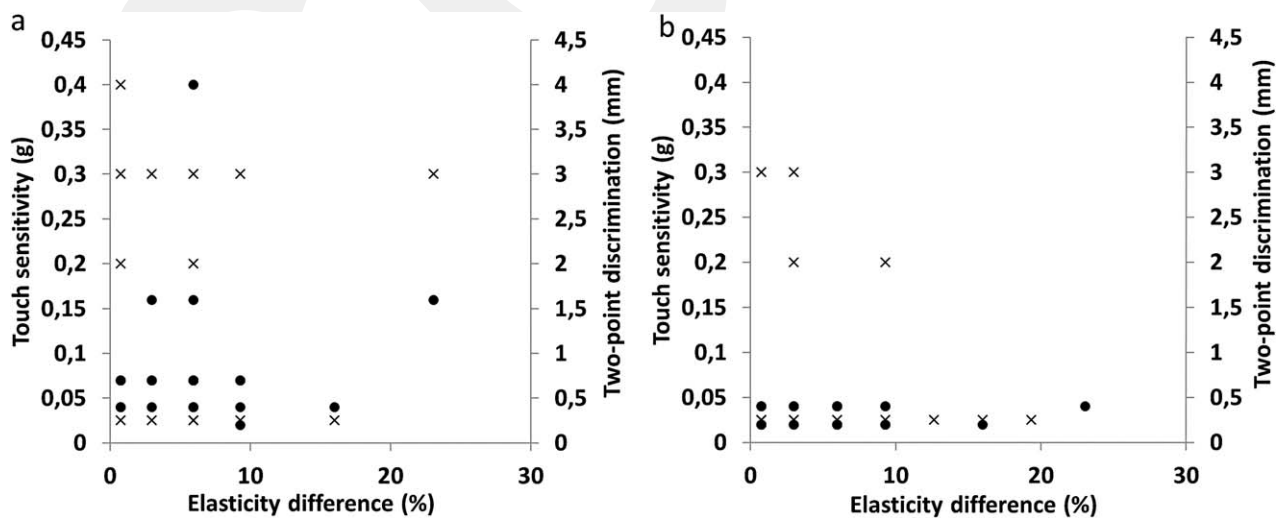


FIG. 7. INDIVIDUAL'S CAPABILITY OF ELASTICITY DISCRIMINATION AND TOUCHING SENSITIVITY (●) AND TWO-POINT DISCRIMINATION ABILITY (×): (A) BY THE INDEX FINGERTIP; (B) BY THE TONGUE

should be stated as a subjective form of threshold (Johnson *et al.* 1994; van Boven and Johnson 1994). Moreover, the tactile assessments are only possible to supply punctate pressure to a particular point, where the gel texture assessment were applied over a larger area, rather than distinct points.

Another obvious limitation of the experimental design is the temperature control. It is well known that textural properties of gel samples could be highly dependent of the temperature. In this work, all gel samples were characterized for their firmness and elasticity at a constant temperature of 25°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 are available to show the real temperature of the food in both cases, this work simply adopts 25°C as standard but of course, temperature change of the gels during finger or tongue contact, was expected to cause limitation.

During the assessment of texture perception (firmness and breaking), there were some limitations caused by the sensory test nature. The variance between the individuals were reduced by including two blind samples prior to the test to prepare the participants for the upcoming tasks and make them familiar with what they need to do and how to assess the texture of the samples (firmness and elasticity).

The experiments involved in this study showed threshold values that were limited to the nominal values obtained from the available stimuli. Therefore, future investigations on this topic could focus on the biological aspects of such claims in order to avoid effects of variance between the assessors.

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 the tongue is tactually more sensitive than the fingertip. Touch detection threshold of the population was found to be 0.028 and 0.013 g for the fingertip and the tongue, respectively. Mean threshold of two-point discrimination was observed as 1.42 and 0.62 mm for fingertip and tongue correspondingly. Additionally, the firmness discrimination measured by the just noticeable difference (JND) of the gel samples was found to be 13.3% for fingertip and 11.1% for the tongue. Elasticity discrimination threshold level was 2.3% for the fingertip and 1.2% for the tongue. In contrast to our initial hypothesis, there was not any evidence to reject the null hypothesis of having no correlation between individual's tactile sensitivity and the capability of texture discrimination.

ACKNOWLEDGMENTS

One of the authors (Tugba Aktar) would like to thank the Turkish Ministry of Education for their financial support and sponsorship of her PhD.

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