A review on oral tactile acuity: measurement, influencing factors and its relation to oral texture perception and preference

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Abstract

Texture perception is one of the most important factors in food acceptance. Despite the contribution of oral tactile sensitivity to perception of food texture, it has been understudied. This review of oral tactile sensitivity concentrated on measurement methods, factors that influenced such sensitivity, and its association with texture perception and preference. Notably, the advantages and disadvantages of different testing methods were discussed, including the two-point discrimination task (or two-pin test), a grating orientation task, the letter-identification task, pressure sensitivity by filaments, and discrimination tests for specific aspects of texture. The effect of age, sex, fungiform papillae, ethnicity and pathological changes on oral tactile sensitivity were also reviewed. Regarding the association between oral tactile sensitivity and texture perception/preference, it was suggested that the sensitivity measured by techniques such as the two-point discrimination task or a grating orientation task, typically represent a single dimension of texture perception and thus are difficult to link directly to perception of other texture dimensions. However, one could examine sensitivity to specific texture attributes in order to investigate texture perception.

Keywords

Individual variation; oral sensitivity; lingual tactile acuity; texture perception; texture preference

1. Introduction

The somatosensory system encompasses nerves under the skin's surface that conduct information to the central and peripheral nervous systems sub serving the sensations of touch, pain, pressure, temperature and proprioception (Carlson, 2012; Haggard & de Boer, 2014; Kohyama, 2015). Presso-receptors, mechanoreceptors and thermo-receptors in oral cavity sensory cells are responsible for the oral touch sensations, while receptors localized in the mucosa, jaw and teeth act in the perception of the granulometry and consistency of foods, respectively. Information about the shape, size and texture of foods during oral exploration by the tongue are provided by the proprioceptive system (Carlson, 2012; Haggard & de Boer, 2014; Kohyama, 2015).

Much of scientific knowledge related to the perception of texture in the mouth is derived from findings in the hands where four major classes of mechanoreceptors have been identified (Abraira & Ginty, 2013; Foegeding et al., 2015; Roudaut et al., 2012). Two classes are slowly adapting (SA) receptors - identified as SAI (associated with Merkel's disks) and SAII (associated with Ruffini endings) - and respond to sustained static stimulation, particularly to edges and points or skin stretch. The other two classes are rapidly adapting (RA) receptors - identified as RAI (associated with Meissner corpuscles) and RAII (associated with Pacinian corpuscles) - which respond primarily to changes in stimulation, such as general skin motion and vibration. The surface of the oral cavity is innervated by the same nerve fibres as the non-hairy skin of the hands and fingers, with the possible exception of RAII mechanoreceptors which are yet to be found in oral surfaces (Bukowska et al., 2010; Johansson et al., 1988; Trulsson and Essick, 1997; Trulsson & Johansson 2002). One type of mechanoreceptor type does not directly code for a specific texture modality, rather each modality is likely to be coded by a combination of signals (Foegeding et al., 2015; Linne & Simons, 2017). Thus, the specific textural modalities perceived during the consumption of foods, such as viscosity, roughness or smoothness, are result from the integration of signals registered by SA and RA during higher processing in the brain.

In summary, texture is determined by various parameters which are combined together, underscoring the difficulties in researching this particular aspect of food (Szczesniak, 2002). Therefore, a single method to measure texture sensitivity is unlikely to prove sufficient. It is likely that a suite of effective and repeatable tests to evaluate a variety of texture modalities is needed.

2. Methodology in measuring oral tactile sensitivity

2.1 Two-point discrimination task

Various methods have been used to determine oral tactile acuity to gain further insight into its contribution to food texture perception. A two-point discrimination task has been one of the primary measurement techniques (Ringel & Ewanowski, 1965). This method has been a standard since the 1860s and commonly used for determining the tactile spatial resolution in a subject. The task requires that 2 punctiform stimuli (e.g., two pins) that can be recognized as two distinct points, are lightly pressed onto the anterior part of the subject's tongue. The separation of the pins ranged from 0 to 8 mm, using the staircase method, with steps of 1 mm (Engelen & Van Der Bilt, 2008). This method determines a spatial threshold at which the two distinct punctiform stimuli can be distinguished from one. At each presentation, the subject is asked to indicate whether 1 or 2 stimulus points are perceived (Engelen, van der Bilt, & Bosman, 2004). However, it has been questioned whether the two-point discrimination task really characterises tactile spatial resolution. van Boven & Johnson (1994) suggested that the subject might use non-spatial cues (i.e. movement of the probe or oral surface) to distinguish one from two points, and in such circumstances the subject's performance could exceed their true spatial resolution limit.

2.2 Grating orientation task

Another task to measure a subject’s tactile spatial acuity is the grating orientation task. This task was developed and validated by Van Boven and colleagues (1994b) to provide clinicians and researchers with an alternative means to assess spatial acuity that overcame the limitations of the two-point discrimination task. The task consists of blocks engraved with ridges (gratings) on their surface. Gratings have equal groove and bar widths, e.g. 0.2, 0.25, 0.5, 0.75, 1.00 and 1.25 mm; (Appiani et al., 2020) or 0.35, 0.5, 0.75, 1.00, 1.25, 1.5, 2.00 and 3.00 mm for the JVP domes, (Stoelting Co, Wood Dale, IL, USA). The block has an overall size of 1 cm^2, which allows to cover an area of the tongue with multiple receptor sites; this is quite different to the two-point discrimination test. The blocks are positioned on blindfolded subject’s tongue, who is asked to recognize the orientation (horizontal *vs*. vertical) of the ridges. To avoid cognitive difficulties in articulating the possible orientation of the grooves, the subjects could use his/her hand to indicate the orientation.

The task has been used to assess lingual spatial resolution both in a group of adults (Van Boven et al., 1994) and recently in children (Appiani et al., 2020). However, also in this case some authors raised concerns about the feasibility of test, since cognitive confounds may affect the answers given by subjects when they are asked to recognize grating orientation, as well as non-spatial cues (e.g. lateral movement of the tongue) on which subjects based their responses could be generated.

2.3 Letter-identification task

In order to overcome some of the limitations in two-point and grating tasks, Essick and colleagues developed in 1999 a letter-identification task, asking subjects to use their tongues to identify letters of the alphabet of varying sizes embossed onto Teflon strips (Essick et al., 1999). The identification of a 3-D sub-set of the Latin alphabet letters (printed or embossed) may also assess aspects of oral stereognosis, the ability to distinguish size, shape, and orientation of stimuli (Boliek et al., 2007, Jacobs et al., 1998). The letter recognition task is thought to provide stimuli that are still identifiable on the basis of shape, while limiting at the same time the use of non-spatial cues in discrimination. Although stereognosis tasks do assess tactile acuity, there is also a cognitive component associated with letter/shape identification (Miles et al., 2020). Variability identified in subjects' tactile acuity or the quality of answers given by the subjects, may not necessarily be attributable to tactile differences alone. Indeed, this task is inappropriate to use in countries that do not use the Latin alphabet (Cattaneo et al., 2020). However, these tasks have been used in a number of studies designed to evaluate tactile acuity and how it relates to a variety of factors (Bangcuyo & Simons, 2017; Essick, et al., 2003; Steele, et al., 2014; Lukasewycz & Mennella, 2012). For example, it has been used to study possible connections between lingual tactile acuity and responsiveness to the bitter compounds 6-n-propylthiouracil (PROP) as well as fungiform taste bud density in Asian women, demonstrating a positive relationship between PROP bitter sensitivity and tactile acuity (Essick et al., 2003). Letter-identification has also been used to investigate possible connections between oral tactile acuity and age (Bangcuyo & Simons, 2017; Steele, et al., 2014), and more specifically between food texture preferences of children and their mothers (Lukasewycz & Mennella, 2012) as discussed further in section 3.1. It has been investigated alongside tongue strength where an age-related reduction in lingual tactile acuity was not explained by variations in tongue strength (Steele et al., 2014).

2.4 Pressure sensitivity by filaments and aesthesiometers

Recently, various laboratories have used monofilaments that measure pressure sensitivity to gain further insight into lingual tactile acuity. This tool has been commonly used in the medical field to assess the tactile sensitivity of hands and feet, to diagnose diseases such as hypesthesia (i.e., abnormally decreased sensitivity to touch stimuli) and dysesthesia (i.e., abnormally increased sensitivity to touch stimuli). Different types of monofilaments are commercially available from various sources. A number of studies have used von Frey/Semmes-Weinstein monofilaments to measure punctate pressure detection on the tongue (Appiani et al., 2020; Breen et al., 2019; Cattaneo et al., 2020; Etter et al., 2017; Liu et al., 2021; Pigg et al., 2010; Santagiuliana et al., 2019; Yackinous & Guinard, 2001; Zhou et al., 2020). Both Semmes Weinstein and von Frey instruments provided in a range of different thickness filaments that exert a set force upon bending. In both cases the smallest filament exerts a force of 0.008 g (0.08 mN). However, several of the aforementioned studies highlighted that these filaments might not be a sufficiently sensitive tool to evaluate oral tactile sensitivity, as the lowest available force (0.08 mN) is higher than the reported sensitivity level of the tongue mucosa (Trulsson & Essick, 1997). Thus, more recent studies used the Luneau Cochet-Bonnet aesthesiometers to obtain a more sensitive measurement that was not possible in past studies. Compared to monofilaments, aesthesiometers have various benefits: i) they can provide an increased number of extremely low-force stimuli (the lightest measured force is 0.0044g); ii) they can reduce the inter-device variability due to the force adjustability being from a single device; and iii) they can reflect sensitivity to mechanical pressure (force per unit area) unambiguously since the filament's surface area remains constant as mechanical force is varied (Miles et al., 2018).

2.5 Discrimination tests for specific aspects of texture

In addition to punctate pressure sensitivity, the evaluation of fine surface roughness offers another type of tactile stimulus that is free from cognitive confounds. However, unlike the monofilaments or aesthesiometers, there is not an established and validated instrument for the evaluation of this attribute. Previous studies on the fingertip have utilized commercially available products, such as abrasive papers and fabrics (Bensmaïa & Hollins, 2005; Miyaoka et al., 1999), while others have recently used polymer custom-made stimuli, directionally roughened (Skedung et al., 2013) to evaluate fine surface roughness. Only a single study focuses on the oral cavity using directionally roughed metal bars, having small but discrete changes in roughness (Linne & Simons, 2017). Few studies have been conducted using real food to measure such specific aspects of texture (Breen et al., 2019; Puleo et al., 2019). In particular, Breen and colleagues (2019) studied the perception of grittiness, using chocolate as a model food. They measured subjects' discrimination thresholds for oral point pressure using von Frey filaments and the discrimination of particle size in chocolates by means of just-noticeable-difference (JND) thresholds. Subjects were classified according to their discrimination thresholds for oral point pressure using Von Frey filaments, and tested for their ability to discrimination between two commercial chocolates of difference particle sizes. The group with better oral acuity were more able to discriminate between the chocolates. Similarly, Puleo and colleagues (2019) developed a methodology to investigate individual discrimination sensitivity to different levels of graininess in cocoa-based creams, obtained by changing refining time. Subjects were clustered into three groups in terms of perceived graininess (high, moderate and low sensitivity) and the relationship between sensitivity and liking was investigated. The results showed that the three groups, even if significantly differs in term of sensitivity to perceived graininess, presented little differences in terms of liking scores. Nevertheless, a significant trend was observed for the subjects characterized by high sensitivity, who liked more the most refined samples.

3. Factors influencing oral tactile sensitivity

3.1 Effect of age

There is limited scientific evidence of differences in oral sensitivity across lifespan, or more specifically comparing children and adults. Recent studies (Appiani et al., 2020; Lukasewycz &

Mannella, 2012) did not find any age-related differences between children and adults. The Appiani study (2020) compared lingual tactile sensitivity between children and adults by using von Frey filaments and a gratings orientation test, while Lukasewyc study (2012) used a letter identification task. However, some earlier studies had conflicting findings. A study from 1976 (Thach & Weiffenbach) evaluated oral tactile sensitivity in pre- term and term neonates and compare results to adults. The tongues of both infants and adults were stimulated with filament esthesiometers with different intensities. Small pre- term infants (31-35 weeks gestation) and infants born near term (37-40 weeks gestation) were more sensitive to tactile stimulation compared to the intermediate group (35-37 weeks gestation). Moreover, the tactile sensitivity in the adult group was superior compared to the sensitivity of infants. However it is arguable as to whether the results from the infants and adults were comparable as different methods of evaluating the sensory function were used: reflex responses were used for the infants, whilst a voluntary response measurement was used for the adults. Another study by Crary, Fucci, & Bond (1981) compared the oral sensory and temporal articulatory function in children and adults. Each subject participated in four experimental conditions: normal condition, exposure to binaural auditory masking during speech, topical application of anaesthesia to the lingual dorsum prior to speech, and combined masking and anaesthesia. Children had lower lingual sensory thresholds than adults in all conditions and they were more sensitive to the disruption of auditory feedback. Threshold values obtained from children significantly increased in the masking only condition.

It is worth mentioning the study of Shupe, Resmondo, & Luckett (2018) that investigated oral tactile sensitivity in three age groups of adults (20–25, 35–45, or over 62) through 3D printed shapes and gummy candy alphabet letters. It was found that oral sensitivity in the younger groups was superior to that of older adults. Finally, Bangcuyo and Simons (2017) tested lingual threshold sensitivity through a modified letter identification task, and found that lingual tactile thresholds were significantly impacted by age groups; participants older than 40 years had higher thresholds than those in their 20s.

3.2 Effect of sex

In the few studies specifically addressing sex differences in lingual mechanosensation, results are controversial. No differences between males and females were found by Shupe (2018) in oral tactile sensitivity assessed by 3D printed shapes and gummy candy alphabet letters. Moreover, using the stereognostic letter identification task, tactile acuity was not affected by sex, although the study was underpowered due to a small sample size of only ten women and ten men (Essick et al. 1999). Similarly, whole mouth stereognostic testing has revealed no differences in oral mechanosensitivity of men and women (Jacobs et al., 1998; Kawagishi et al. 2009).

However, in a study by Michon et al. (2009), females were found to have a higher ability to identify letter shapes in their mouth. Using the grating test, Appiani (2020) found significant differences in lingual tactile sensitivity only for the greatest grating size, where adult women performed significantly worse than adult men.

3.3 Effect of fungiform papillae density (FPD)

In the anterior tongue, neuroanatomical studies have shown that somatosensory trigeminal neurons terminate as a network of fibres in the perigemmal tissue (des Gachons et al., 2011; Suemune et al., 1992; Whitehead, Beeman, & Kinsella, 1985). Mechanical stimuli are likely to activate some receptors of the trigeminal nerve endings, which surround taste buds in the FP and terminate in the papilla apex (des Gachons et al., 2011). It has been suggested that papillae density, and hence the number of the activated trigeminal fibres, underpins the intensity of trigeminally mediated qualities (Prescott, Soo, Campbell, & Roberts, 2004).

Previous studies have examined the relationship between fungiform papillae density (FPD) and oral tactile sensitivity. Several researchers found that lingual thresholds using the letter recognition task were significantly associated with FPD, such that higher densities resulted in greater tactile acuity (Bangcuyo & Simons, 2017; Essick, Chopra, Guest, & McGlone, 2003). The positive correlation between FPD and tactile sensitivity was also observed in a more recent study using point pressure by von Frey filament (0.008g, r=0.41) on the tongue surface (Zhou et al., 2020). However, Nachtsheim and Schlich (2013) found that FPD was not related to tactile sensitivity of pressure stimulated by von Frey filaments. The converse findings in tactile acuity by von Frey filaments might be attributed to stimulation areas in the tongue, e.g. whether touching the filaments to the fungiform papillae. The extent to which other modalities of lingual mechanosensitivity (e.g., a gratings orientation test) are influenced by fungiform papillae density remains to be explored.

3.4 Effect of ethnicity

In a study conducted by Skinkai (2004), European Americans demonstrated greater sensitivity compared with Mexican Americans (*p*=0.048) on the soft palate when stimulated with Semmes-Weinstein filaments. A more recent study (Cattaneo et al., 2020) noted a trend in tactile acuity between ethnicities, where Asian Chinese subjects exhibited higher tactile acuity than Caucasian Danish subjects as assessed by Semmes-Weinstein filaments; however, the difference was not significant (*p*=0.08). Another study using von Frey monofilaments found no evidence that tactile acuity differed between Asian Chinese and Caucasian Dutch participants (Santagiuliana et al., 2019). Nevertheless, a ceiling effect was observed in their work as most participants could detect the smallest stress used. More evidence is needed in the investigation of ethnicity and tactile acuity. If differences do exist between ethnic groups, then consideration needs to be made whether these stem from cultural gastronomic or genetic differences.

3.5 Effect of pathological changes

Along with the facial nerve damage, studies have shown that the somatosensory system may be disrupted after pathological changes. Perez et al. (2006) and Sakaguchi et al. (2013) reported that the trigeminal sensitivity of the anterior tongue was significantly diminished in patients with clinical tongue symptoms after middle ear surgery, using the Semmes-Weinstein filament test. Schimmel et al., (2017) found that intra oral tactile sensitivity on the contra-lesional side was significantly impaired in stroke patients compared to their healthy counterparts. Such pathological changes may be due to impairment of nerves that result in both taste and tactile disturbance.

4. Association between oral tactile sensitivity and food texture perception/preference

4.1 Relating oral tactile sensitivity to food texture perception/preference

Whereas mechanosensation underpins texture perception, few studies have linked the oral tactile sensitivity to perception of food textures. Recently, several studies reported no significant correlations between individuals' tactile sensitivity and food texture perception/preference (Aktar, Chen, Ettelaie, & Holmes, 2015; Furukawa, Ito, Tanaka, Ito, & Hattori, 2019; Shupe, Wilson, & Luckett, 2019). It has been suggested that food texture preferences are more influenced by factors such as culture and experience, but are little influenced by one’s oral tactile sensitivity (Aktar et al., 2015; Liu, et al., 2021). However, it is worthwhile noting that the cited studies measured detection or recognition thresholds which may not fully reflect the real perception of food texture; they did not directly measure sensory sensitivity to texture presented by real products. Breen, Etter, Ziegler, & Hayes (2019) observed a significant relationship between chocolate particle-size discrimination and pressure point sensitivity on the centre tongue, though a similar relationship was not seen for data from the lateral edge of the tongue. Their study results suggest that the relationship between texture perception and oral somatosensory acuity may depend on the part of the oral cavity assessed.

Furthermore, the methodology used to assess oral tactile sensitivity should be considered (Section 2). In a study assessing lingual tactile sensitivities by von Frey filaments and a gratings orientation test in children, a clear relationship was not found between lingual tactile sensitivity and texture preference (Appiani et al., 2020). Moreover, the reliability of testing techniques in different laboratories across countries should also be considered. Further investigations are required which combine different methods to assess tactile sensitivity in real food products when correlating to texture perception and preference.

4.2 Relating discrimination ability of specific texture attributes to texture preference

Oral texture perception sensitivity can be evaluated using discrimination tests for specific aspects of texture, by using appropriate test foods (Furukawa, et al., 2019). It has been suggested that food texture preference might be more related to these discrimination abilities compared to lingual tactile acuity. Puleo and colleagues (2019) investigated individual sensitivity to discrimination of different levels of graininess in cocoa-based creams; a significant trend was observed for the highly sensitive subjects who liked more the most refined samples, although all the samples were equally liked for both the moderate and low sensitivity groups. In a more recent study, it was found that individuals with different levels of hardness sensitivity differed in hardness perception and liking of jellies (Puleo, Valentino, Masi, & Di Monaco, 2021). Future research is needed to investigate relationships between texture preference and the capability of discriminating texture attributes.

5. Conclusion and perspectives

This work has reviewed methods used to test oral tactile sensitivity, including the two-point discrimination task, grating orientation task, letter-identification task, and pressure sensitivity by filaments and aesthesiometers. These methods normally represent a single dimension of texture perception and thus are not directly linked to perception of other texture dimensions. The discrimination sensitivity to specific texture attributes seems more likely to predict texture perception and/or preference of specific foods. As shown in Figure 1, several factors such as age, sex, FPD (fungiform papillae density), ethnicity, and pathological changes affect oral tactile acuity. Evidence of the effect of age, sex and ethnicity on oral tactile acuity is contradictory within the scientific literature. The testing technique, the area of the tongue stimulated, and the operator's skill must also be considered when investigating factors which may influence oral tactile acuity. For example, higher sensitivity (as measured by a lingual point pressure method) on the midline of the tongue corresponded to better particle-size discrimination in chocolate (Breen et al., 2019). However, the same measure on the lateral edges of the tongue did not correspond to differences in texture discriminatory ability (Breen et al., 2019). Future studies should also consider monitoring the repeatability of the operators over time. The relationship between discrimination tests of specific texture attributes and texture preference are also recommended in order to examine the nature of texture perception and preference. Having a meaningful and reliable texture discrimination and preference indicator is critically important for the food industry in the development and optimization of new food products, and in particular for design foods for individuals with special needs, such as elderly people and dysphagic patients.

Declaration of competing interest

The authors declare no conflicts of interest.

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Table 1 Summary of different methodology in measuring oral tactile sensitivity

Methodology	**Determination**	**Methodological Challenges**
Two-point discrimination task	Subject's tactile spatial resolution	- subject might use non-spatial cues (i.e. movement of the probe or oral surface) to distinguish one from two points - the tool might not be sufficiently sensitive - poor test retest reproducibility
Grating orientation task	Subject's tactile spatial resolution	- cognitive involvement - subject might use non-spatial cues (i.e. movement of the probe or oral surface) to distinguish vertical or horizontal grating - require specialized pre-constructed stimulus objects, which span a fixed spatial range
Letter-identification task	Subject's tactile acuity	- spatial properties and ability to cognitively understand the letter - not necessarily just spatial recognition - less suitable for cross-cultural studies
Pressure sensitivity by filaments and aesthesiometers	Subject's pressure sensitivity and acuity	- presence or absence rather than resolution of patterns - the tool might not be sufficiently sensitive (e.g., von Frey filaments) - inter-device variability (e.g., von Frey filaments)

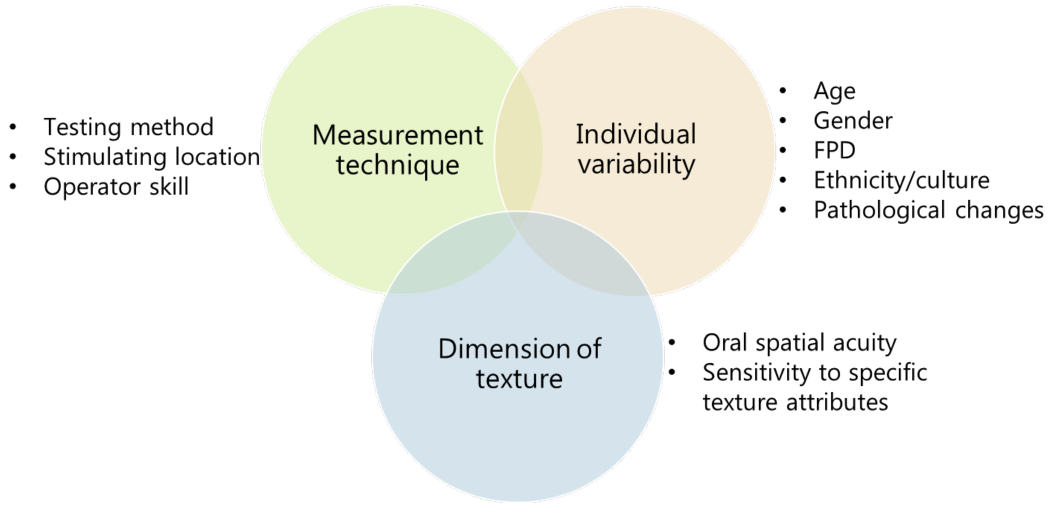

Figure 1. Factors contributing to variability in oral tactile acuity and its relation to texture perception and preference.