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REVIEW

A review of assessment methods for measuring individual differences in oral somatosensory perception

Reisya Rizki Riantiningtyas^{1,2,3}  | Anestis Dougkas^{3,4} | Camille Kwiecien⁵ |
Florence Carrouel² | Agnès Giboreau^{2,3} | Wender L. P. Bredie¹ 

¹Section for Food Design and Consumer Behaviour, Department of Food Science, Faculty of Science, University of Copenhagen, Frederiksberg C, Denmark

²Health Systemic Process (P2S) Research Unit UR4129, University Claude Bernard Lyon 1, University of Lyon, Lyon, France

³Institut Lyfe (Ex. Institut Paul Bocuse) Research Center, Ecully, France

⁴Laboratoire Centre Européen Nutrition et Santé (CENS), CarMeN, Unité INSERM 1060, Université Claude Bernard Lyon 1, Pierre-Bénite, France

⁵Danone Global Research & Innovation Center, Utrecht, Netherlands

Correspondence

Reisya Rizki Riantiningtyas, Institut Lyfe Research Center, Chateau Du Vivier, BP 25 – 69131 Ecully Cedex, France.
Email: reisya-rizki.riantiningtyas@institutpaulbocuse.com and rrr@food.ku.dk

Abstract

While taste and smell perception have been thoroughly investigated, our understanding of oral somatosensory perception remains limited. Further, assessing and measuring individual differences in oral somatosensory perception pose notable challenges. This review aimed to evaluate the existing methods to assess oral somatosensory perception by examining and comparing the strengths and limitations of each method. The review highlighted the lack of standardized assessment methods and the various procedures within each method. Tactile sensitivity can be assessed using several methods, but each method measures different tactile dimensions. Further investigations are needed to confirm its correlation with texture sensitivity. In addition, measuring a single textural attribute may not provide an overall representation of texture sensitivity. Thermal sensitivity can be evaluated using thermal-change detection or temperature discrimination tests. The chemesthetic sensitivity tests involve either localized or whole-mouth stimulation tests. The choice of an appropriate method for assessing oral somatosensory sensitivity depends on several factors, including the specific research objectives and the target population. Each method has its unique intended purpose, strengths, and limitations, so no universally superior approach exists. To overcome some of the limitations associated with certain methods, the review offers alternative or complementary approaches that could be considered. Researchers can enhance the comprehensive assessment of oral somatosensory sensitivity by carefully selecting and potentially combining methods. In addition, a standardized protocol remains necessary for each method.

KEYWORDS

assessment methods, chemesthesis, multisensory perception, oral tactile, temperature, texture

1 | INTRODUCTION

Food perception is a complex process involving multimodal interaction of the different sensory systems: gustatory, olfactory, and somatosensory systems integrated along with visual and auditory cues (Small, 2012; Spence, 2016). The mechanism of sensory perception

can be conceptually divided into three stages: stimulation, transduction, and interpretation. Sensory stimuli stimulate various sensory receptors; this process of detecting sensory stimuli is also known as sensation. Taste and smell are detected by various taste and smell receptors (Chen & Engelen, 2012). Texture, in the form of tactile stimulation such as pressure, vibration, slip, and movement, is detected by

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mechanoreceptors (Kutter et al., 2011). Thermoreceptors detect temperature differences, whereas nociceptors detect noxious stimuli, including thermal, chemical, and mechanical stimuli (Engelen, 2012). The stimulus is then transduced by various channels into action potentials and conveyed to the central nervous system via the nerves. Finally, this leads to an encoding process of interpreting the action potential into perception (Chen, 2014). The representations from each sensory modality (taste, smell, somatosensation) are integrated into the multimodal regions, such as the orbitofrontal cortex, to form a complete picture, the perception (Engelen & de Wijk, 2012; Spence, 2016).

While taste and smell perception have been extensively investigated as drivers of food liking, it is crucial to recognize the contributions of somatosensory perception, such as texture, temperature, and chemesthesis, in shaping our preferences. Texture, for instance, plays a significant role in our perception and choice of food (Lukasewycz & Mennella, 2012; Tournier et al., 2007). Engelen and de Wijk (2012) suggested that individuals have specific expectations regarding the texture of different foods. When these expectations are met, there may be less emphasis on texture, yet a discrepancy between the anticipated and actual texture of the food will lead to rejection. Likewise, food temperature can significantly impact our overall perception (Foster et al., 2011; Steen et al., 2017). Additionally, chemesthesis, the perception of chemical or irritant sensations in the mouth, can also influence our preference. For example, the pungency of spicy foods can either enhance or deter our liking of certain foods (Byrnes & Hayes, 2015; Reinbach & Martinussen, 2010). These sensory perceptions become even more crucial in certain populations, such as individuals with food-related sensory impairments or eating difficulties.

Despite the significance of somatosensory perception in shaping our food preferences, it remains the least understood of the three sensory systems (Lundström et al., 2011). Somatosensation is composed of different sub-modalities (tactile involved in texture perception, thermal perception, and chemesthetic perception) and various methods have been developed to measure these individual sub-modalities. Unlike taste and smell perception, which have been extensively studied and have standardized assessment methods such as the taste strips and sniffin' sticks (Hawkes, 2021; Riva et al., 2015), there is currently no clear consensus on assessing somatosensory responses. Assessing and measuring individual differences in oral somatosensory perception remains challenging for researchers aiming to understand and address issues related to oral somatosensory perception.

Appropriate assessment methods will not only contribute to the advancement of research on individual differences in oral somatosensation but also guide the development of products for specific populations and new food products following the current trend of using sustainable alternative ingredients. Furthermore, it can help identify individuals who may experience difficulties with certain food textures, temperatures, or chemesthesis. This knowledge can guide nutrition interventions aimed at enhancing the overall food acceptance and quality of life for individuals with sensory-related challenges or eating difficulties. Therefore, this review aimed to describe the various assessment methods used in the field, including the variations in procedures, and to evaluate their strengths and limitations. The present

review complements the works of Liu et al. (2022) by providing a critical and up-to-date comprehensive evaluation of the available methods covering all aspects of oral somatosensory, including chemesthetic and thermal sensitivity, in addition to tactile sensitivity.

2 | EXISTING SENSORY METHODS TO MEASURE ORAL SOMATOSENSORY PERCEPTION

Various methods have been utilized to assess individual differences in the different sub-modalities of oral somatosensory perception (tactile and texture sensitivity, chemesthetic sensitivity, and thermal sensitivity), each with its distinct procedures. This section describes how these methods are employed to measure oral sensations related to food perception. To facilitate comparison and comprehension, a summary of the different methods and their variations in protocols is presented in Table 1. This compilation shows the heterogeneity of procedures and allows for an overview of the assessment methods currently employed in the field.

2.1 | Tactile and texture sensitivity

Mechanoreceptors in the oral cavity play a crucial role in the perception of tactile sensations, which provide sensory feedback for important oral functions such as tongue positioning, chewing, manipulating food, and swallowing (Moayedi et al., 2021). Consequently, assessments of oral tactile function have been conducted in clinical studies to investigate the physiological functioning of the elderly or populations susceptible to eating difficulties (Elfring et al., 2012; Furukawa et al., 2019; Loewen et al., 2010). In addition, these mechanoreceptors are also responsible for the perception of food texture (Engelen et al., 2004; Kutter et al., 2011). Whereas tactile sensitivity represents the sensation that arises when a mechanical stimulus is detected by a mechanoreceptor, texture sensitivity encompasses sensory and functional aspects related to the structural, mechanical, and surface characteristics of objects/foods resulting from the integration of signals registered by several mechanoreceptors during higher processing in the brain (Foegeding et al., 2015; Szczesniak, 2002). Further, food texture perception also involves interaction with teeth, saliva and tactile receptors in the oral cavity (Tournier et al., 2007). Tactile and texture sensitivity can be measured using several different measures, including point-pressure sensitivity, spatial acuity, stereognosis ability, and texture discrimination ability.

2.1.1 | Point-pressure sensitivity

Oral tactile sensitivity can be assessed with the point-pressure test using von Frey filaments. The tool consists of a single filament that exerts light tactile stimulation at varying forces. Two existing procedures can be used for the test, the threshold procedure and the signal detection procedure. In the threshold procedure, a stimulus of different filament thicknesses is always presented until the participant can

TABLE 1 Summary of the different methods measuring oral somatosensory responses.

Modalities	Assessment methods	Variation in methods	Application	Comments	Reference
Oral tactile	Point pressure test	Tools: von Frey or Semmes Weinstein monofilament, aesthesiometer Procedures: threshold, signal detection	NC: adults, children C: patients with HNC, BMS	Suitable for measuring nerve impairment; location of stimulation need to be specified	Appiani et al. (2020), Bearely et al. (2017), Bodin et al. (2004), Elfring et al. (2012), Kimata et al. (1999), Liu et al. (2021), Loewen et al. (2010), Santagiuliana et al. (2019)
	Two-point discrimination	Tools: caliper, 2-point discriminator wheel, tweezers, drawing compass Stimuli presentation: static, moving Evaluation procedures: threshold, signal detection	NC: adults C: patients with HNC	Questionable validity in measuring spatial acuity, but maybe a useful assessment tool for nerve impairment	Aviv et al. (1992), Boliek et al. (2007), Elfring et al. (2012), Essick and Trulsson (2008), Furukawa et al. (2005), Furukawa et al. (2019), Kimata et al. (1999), Loewen et al. (2010)
	Grating orientation task	Tools: grating size Evaluation procedures: threshold, signal detection	NC: adults, children C: none	It was only used for cutaneous sensitivity, and only recently used to evaluate oral sensitivity.	Appiani et al. (2020), Chaffee et al. (2023), Lee et al. (2022), Mani et al. (2022)
	2D-Letter recognition	Tools: acrylic resins with different letters, modified version uses different shapes instead of letters	NC: adults, children C: patients with taste dysfunction	There are some disagreements about whether the task measures tactile spatial acuity or stereognosis ability	Bangcuyo and Simons (2017), Bogdanov et al. (2021), Essick et al. (1999), Lukasewycz and Mennella (2012), Shupe et al. (2018)
	Stereognosis test	Tools: confectionary alphabets, steel spheres of different sizes, acrylic resins with different shapes, discs with different hole sizes	NC: adults, children C: patients with HNC	Suitable for measuring sensitivity to whole-mouth oral sensation	Bodin et al. (2000), Elfring et al. (2012), L. Engelen et al. (2004), Kremer et al. (2007), Luckett et al. (2016), Shupe et al. (2019)
Oral texture	Discrimination test- non-edible stimuli	Tools: acrylic resin, metal bars	NC: adults C: patients with HNC	Suitable for investigating sensitivity to oral roughness	Boliek et al. (2007), Linne and Simons (2017)
	Discrimination test- edible stimuli	Dimensions of texture: hardness, particle size, thickness Food models: edible hydrogels, cream, quark, cream cheese, chocolate	NC: adults C: none	Suitable for investigating specific texture sensitivity, but results may not be easily interpolated to other aspects of texture	Breen et al. (2019), Furukawa et al. (2019), Puleo et al. (2020), Santagiuliana et al. (2019)
Chemesthesis	Localized testing	Tools: cotton swabs, filter paper, pipette Stimuli: capsaicin, menthol	NC: adults (including elderly) C: none	Suitable for investigating thermal threshold sensitivity	Furukawa et al. (2005)
	Whole-mouth testing	Stimuli: capsaicin, piperine, menthol; either as aqueous solution or mixed in food models Stimuli presentation: sip-and-spit, sip-and-swallow Evaluation procedures: detection threshold, difference testing, intensity rating	NC: adults (including elderly) C: none	A simple and rapid method to screen for severe impairment in oral sensation	Roukka et al. (2021), Yang et al. (2022)
Temperature	Thermal-change detection test	Tools: temperature-controlled thermodes	NC: adults C: patients with BMS, oro-facial pain	Suitable for investigating regional variation in case of localized damage in oral sensation	Baad-Hansen et al. (2015), Rolke et al. (2006)
	Temperature discrimination	Tools: dental or pharyngeal mirror, test tube, water, metal rolls Temperatures: 10 and 50°C; 3 and 55°C; 28 and 44°C	NC: adults C: patients with HNC	Suitable for investigating food perception during normal eating/drinking	Bodin et al. (2004), Boliek et al. (2007)

Abbreviations: BMS, burning mouth syndrome; C, clinical population; HNC, head and neck cancer; NC, non-clinical population.

detect the tactile stimulation. Depending on the participant's ability to detect the touch, a thicker or thinner filament would be given on the following stimulation (Santagiuliana et al., 2019). On the other hand, the signal detection procedure is based on the signal detection theory, developed to examine an observer's behavior in the presence of ambiguous stimuli. The observer must determine whether there is a stimulus or not. Participant's sensitivity is determined by their ability to distinguish signal from noise (Green & Swets, 1966). Using this procedure, participants are asked to indicate whether the stimulus is present or absent and their degree of certainty (certain/uncertain) (Cattaneo et al., 2020; Liu et al., 2021).

2.1.2 | Spatial acuity

Spatial acuity measures an individual's sensitivity to spatial difference, with higher acuity indicating a greater ability to detect fine details, which depends on the density of the sensory innervation (Essick et al., 1999; Tong et al., 2013). Unlike point-pressure sensitivity, which assesses mechanical sensitivity at one point in the oral region, spatial acuity involves a wider area of stimulation and a more complex innervation of several types of mechanoreceptors. It can be assessed using a two-point discrimination test and grating orientation task.

Two-point discrimination test

The two-point discrimination test is performed using an adjustable caliper or a specialized set of tools with two points that can be adjusted to varying distances (Furukawa et al., 2019). The test measures the minimum separations at which an individual can discern the two points of physical contact (Essick & Trulsson, 2008). Two different procedures can be used: the threshold procedure and the signal detection procedure. The threshold procedure involves adjusting the distance between the two points until the participant can certainly perceive them as two distinct points. Meanwhile, the signal detection procedure involves stimulating the tongue of blindfolded participants with either one or two points and asking them to indicate how many points are perceived. Based on the participant's response, the distance between the two points is adjusted on the next stimulation (Boliek et al., 2007; Fukunaga et al., 2005).

Grating orientation task

The grating orientation task uses a square grid engraved with evenly spaced ridges/grooves ranging from 1.25 to 0.20 mm (Appiani et al., 2020). The grids are applied vertically or horizontally on the tongue of the blindfolded participant. The participant is asked to indicate the orientation of the ridges and their degree of sureness to calculate the R-index (Appiani et al., 2020; Chaffee et al., 2023; Lee et al., 2022). A study used the 3-down/1-up staircase protocol to calculate the threshold (Mani et al., 2022). Participants were asked to indicate the orientation of the grooves, starting with the highest groove (1.25 mm width). Three correct answers of the same groove resulted in a presentation of the next lower groove, whereas an incorrect answer resulted in a presentation of the next higher groove (Mani et al., 2022).

2.1.3 | Stereognosis ability

Stereognosis is the ability to perceive and recognize the form (shape, size) of an object in the mouth using tactile cues in the absence of visual and auditory information. It measures the function of the entire oral cavity rather than the tongue alone. An individual's oral stereognosis abilities serve as an indicator of functional sensibility, encompassing the integration of multiple sensory inputs within higher brain centres (Spence & Piqueras-Fiszman, 2016). The stereognosis ability can be assessed using different tools of two-dimensional and three-dimensional objects, varying in shapes, sizes, and materials. Two-dimensional tools such as those used for the letter recognition task involve the use of acrylic strips with a letter embossed on one side (A, I, J, L, O, T, U, or W) with different heights of 2–8 mm. The strips are applied on the tongue, and participants are instructed to indicate the letter that they perceive (Essick et al., 1999). The presentation of sizes is adjusted based on the participant's response. Three-dimensional objects, including edible stimuli such as confectionary alphabets and non-edible stimuli such as acrylic with different shapes, steel spheres with different sizes, and acrylic discs with different hole sizes, have been used (Bodin et al., 1999, 2000; Engelen et al., 2004; Shupe et al., 2019). Participants are presented with the tool and are instructed to indicate the shape or size. These studies measured stereognosis ability in healthy adults (Chuang et al., 2019; Kremer et al., 2007; Luckett et al., 2016; Shupe et al., 2018) and cancer patients (Bodin et al., 1999, 2000; Engelen et al., 2004).

2.1.4 | Texture discrimination ability

Studies focused on understanding how individuals perceive and respond to certain textures in relation to eating behavior often directly assess the individual texture discrimination ability. This assessment involves providing stimuli varied in one textural dimension, for example, stimuli with different levels of hardness, thickness, or particle size. Several other forms of stimuli have been documented, and examples include non-edible physical tools such as spheres of textured resin attached to small rods (Boliek et al., 2007), as well as edible stimuli such as hydrogels made of agar or xanthan solution (Furukawa et al., 2019); model food such as cocoa-based cream (Puleo et al., 2020), quark and cream cheese (Santagiuliana et al., 2019), and chocolate (Breen et al., 2019). The evaluation procedures used in the studies include intensity scaling (i.e. evaluating the intensity of the given sensory attribute on a visual scale) and paired comparison (i.e. identifying which of the pairs have a higher intensity of the given sensory attribute).

2.2 | Chemesthetic sensitivity

Chemesthetic sensations arise from the chemical stimulation of receptors associated with pain and mechanotransduction. Within the oral cavity, each of these chemesthetic sensations is detected by nociceptors and transduced into the nervous system through a combination of various molecular channels and receptors present on trigeminal

nerve fibers (Simons et al., 2019). The chemical compounds that have been used to investigate chemesthetic sensitivity are capsaicin, menthol, ethanol, cinnamaldehyde, and aluminum sulfate (Green, 2001; Piochi et al., 2021; Prescott & Swain-Campbell, 2000; Roukka et al., 2021). The sensation exhibited by these chemical compounds can be described with several qualities, including heat, pungency, burning, stinging, cooling, tingling, and numbing (Nolden & Hayes, 2017; Simons et al., 2019; Viana, 2011). Oral chemesthetic sensitivity, the sensory response to direct chemical irritants, can be assessed using the localized test and the whole-mouth test.

2.2.1 | Localized test

A localized test involves stimulation on a distinct part of the tongue either with a filter paper disk, or cotton swabs impregnated with a chemesthetic compound (Cliff & Green, 1996). Another procedure is to apply chemesthetic solutions on distinct parts of the tongue using a pipette (Epstein et al., 2019).

2.2.2 | Whole-mouth rinse test

The whole-mouth test involves participants sipping aqueous solutions and holding them in their mouth for a few seconds, then they are instructed to expectorate (sip and spit procedure) or swallow, depending on the study design (Green & McAuliffe, 2000). Commonly used evaluation procedures are the detection threshold procedure (i.e. identifying the lowest concentration for which the participant reported the existence of stimuli), the difference testing procedure (i.e. comparing stimuli with control), and the intensity-rating procedure (Fukunaga et al., 2005; Roukka et al., 2021; Yang et al., 2022).

2.3 | Thermal sensitivity

Thermal sensitivity refers to the ability to perceive and detect temperature changes. Thermoreceptors have free nerve endings responsible for detecting temperature variations and are activated over a specific temperature range (Engelen, 2012). Generally, both warm and cold receptors are active at moderate temperatures, such as 35°C, but stop firing altogether at a noxious temperature range (<5°C and >50°C) (Engelen, 2012). In the range of noxious temperatures, the nociceptor transient receptor potential (TRP) TRPA1 activates at temperatures below 17°C, whereas TRPV1 and TRPV2 activate at temperatures above 43°C (Schepers & Ringkamp, 2010). The methods to assess thermal sensitivity are the thermal-change detection method and the temperature discrimination test.

2.3.1 | Thermal-change detection test

The thermal-change detection test is part of the Quantitative Sensory Testing (QST), a standardized protocol to assess somatosensory

function in a clinical setting (Rolke et al., 2006) developed by the German Research Network on Neuropathic Pain. In the thermal-change detection test, a temperature-controlled thermode is used to stimulate the tongue. The surface temperature of the tongue can be transiently increased or decreased with a square Peltier thermode. The test starts with a baseline temperature of 32°C (the center of the neutral range), and then the temperature is increased or decreased between 0 and 50°C until the participant perceives a noticeable change in temperature (Rolke et al., 2006).

2.3.2 | Temperature discrimination test

The second method is the temperature discrimination test, which involves the use of tools submerged in two different water temperatures (hot or cold). The tool is applied on the tongue and blindfolded participants are instructed to discriminate whether the stimulus is hot or cold. The tools used were metal rolls, test tubes, or dental mirrors, and the water temperatures used in previous studies are reported to be 55–60°C for hot and 3–4°C for cold (Bodin et al., 2004; Boliek et al., 2007).

3 | CHOOSING THE PROPER ASSESSMENT METHOD FOR MEASURING ORAL SOMATOSENSORY PERCEPTION

Several factors should be considered when selecting a method to measure oral somatosensory perception. The method should demonstrate good validity to measure the intended objective or specific research question. The differences in procedure among the various methods should be considered, as this may impact the reliability and feasibility of the assessment. Furthermore, it is important to consider the characteristics of the target population, as some methods may be more suitable for certain age groups or specific populations. The following section compares the different methods and procedures to guide choosing the most appropriate assessment method by considering the aforementioned factors.

3.1 | Tactile and texture sensitivity

Overall, the methods to measure oral tactile sensitivity are generally practical as the tools do not require complex set-up, do not demand laborious preparation, and are affordable for routine use. It is important to note that each method measures different aspects of oral tactile sensitivity. The point-pressure and the two-point discrimination tests only stimulate distinct parts of the tongue, so does not represent whole-mouth sensation. They are associated with the slowly adapting superficial mechanoreceptor (SA1, Merkel cells) (Tong et al., 2013).

The point-pressure test is among the most widely used methods to measure tactile sensitivity and has been tested with healthy adults and children (Appiani et al., 2020; Bearely et al., 2017; Cattaneo et al., 2020), as well as in clinical investigations among cancer patients

to measure orosensory reinnervation following surgical reconstruction of the tongue or the oral cavity (Bodin et al., 2004; Elfring et al., 2012; Kimata et al., 1999; Loewen et al., 2010). Regarding the choice of procedure, a study using the threshold procedure observed a floor effect even with the thinnest available monofilament of 0.008 g (Santagiuliana et al., 2019). This suggests that the procedure may not accurately represent the absolute detection threshold, the lowest magnitude the participant can detect. To overcome the limitation, an aesthesiometer can be used to provide forces as low as 0.0044 g (Liu et al., 2022). Alternatively, the signal detection procedure offers an alternative approach. In the threshold procedure, participants have the option to respond “yes” to perceiving a touch even if they did not perceive it. Including mock touches in the signal detection procedure reduces this response bias. An R-index is then calculated to estimate the likelihood of participants accurately identifying a real touch versus a mock touch (Appiani et al., 2020; O'Mahony, 1992).

The two-point discrimination test has been used in adults and in clinical investigations with cancer patients to assess sensory innervation (Aviv et al., 1992; Elfring et al., 2012; Kimata et al., 1999; Loewen et al., 2010). However, the threshold procedure of this method has been scrutinized in terms of test–retest reliability due to inconsistencies over repeated testing on the same individuals (Craig & Johnson, 2000). Furthermore, investigations on cutaneous sensations observed that the signal detection procedure induced nonspatial cues that enabled participants to discriminate between one and two points. For example, one can easily distinguish one point from two points as the former feels sharper. Hence, it is posited that the two-point discrimination test is not a valid measure of spatial acuity, and advised alternative method, such as the grating orientation task (Craig & Johnson, 2000).

The grating orientation task activates both rapid and slowly adapting mechanoreceptors over a wider area (Appiani et al., 2020; Lee et al., 2022). Historically, its application has been limited to evaluating cutaneous sensitivity but has recently been adapted for measuring the sensitivity of the oral region among the general population (Appiani et al., 2020; Chaffee et al., 2023; Lee et al., 2022; Mani et al., 2022). The grating orientation task addresses the limitations of the two-point discrimination test by using stimuli with identical spatial structures, thus avoiding possible nonspatial cues (Craig & Johnson, 2000). However, it is argued that lateral scanning and exploratory movements are necessary to assist participants in extracting relevant spatial cues, yet this method limits these actions and relies on static evaluation (i.e. participants are not allowed to move the tongue) (Essick et al., 1999). An alternative method to address this limitation is using the 2D-letter recognition task, where participants are encouraged to examine the stimuli dynamically.

The 2D-letter recognition task has been used to assess the spatial acuity of healthy adults, children, and patients with taste dysfunction (Bangcuyo & Simons, 2017; Bogdanov et al., 2021; Essick et al., 1999; Lukasewycz & Mennella, 2012). Nonetheless, issues were raised that the 2D-letter recognition task may be unsuitable for those unfamiliar with the Latin alphabet (Liu et al., 2022). Moreover, it was argued that not all letters would be equally identifiable, for instance, the letter ‘l’

would be relatively easier to identify than ‘w’ (Lukasewycz & Mennella, 2012). An adaptation using 2D-geometrical shapes instead of letters may potentially address these limitations and has been tested among healthy adults and the elderly (Shupe et al., 2018).

While the aforementioned methods are useful measures for indicators of physiological function, they may not be suitable for measuring tactile sensitivity as a proxy measure of food texture sensitivity. Texture perception involves innervation of the entire oral cavity, whereas the stimulated area of these methods is isolated on the tongue. The stereognosis test can potentially reflect texture sensitivity as it innervates the entire oral cavity. It has been tested among healthy adults, children, and cancer patients (Bodin et al., 1999, 2000; Engelen et al., 2004; Shupe et al., 2019). However, no conclusive evidence has supported the correlation between stereognosis ability and food texture sensitivity. Moreover, the heterogeneity of tools used in different studies led to varying results (Bodin et al., 1999, 2000). Furthermore, age and dental status have significant effects on oral stereognosis ability and should be considered as confounding factors (Jacobs et al., 1998).

The more valid method that may reflect food texture sensitivity is to measure the texture discrimination ability directly. However, the use of texture discrimination tests with non-edible stimuli is relatively rare and limited only to roughness sensitivity (Elfring et al., 2012; Loewen et al., 2010). It is unclear whether the measurements using these non-edible stimuli are representative of food roughness sensitivity, let alone other dimensions of food texture sensitivity (Liu et al., 2022). However, using non-edible stimuli has its advantages, namely its practicality and ease of use for routine assessments, as the tools can be reused and do not require additional preparation. Using the texture discrimination test with edible stimuli allows full manipulation of the stimuli and thus may be the closest representation of food texture perception and an individual's food texture sensitivity. The versatility of the stimuli allows each experimenter to develop their prototype of food models suited to their study objectives. However, this creates heterogeneity in study designs, thus there is no standardized stimuli for comparison between studies. Another limitation concerns the limited number of samples that can be tested due to fatigue and post-ingestive effects.

Unlike taste and smell perception, which have been directly attributed to specific gustatory and olfactory receptors, the neurological principles of translating information detected by various mechanoreceptors into texture perception are considerably less understood (Engelen & de Wijk, 2012). Texture perception involves a multifaceted nature and dynamic process integrating a multitude of neural inputs from the receptors spread over the entire oral cavity (Engelen & de Wijk, 2012; Furukawa et al., 2019; Liu et al., 2022). Therefore, assessing a single dimension of tactile function or a single textural attribute may not fully represent overall food texture sensitivity. Combinations of the methods and assessment of several textural attributes should be done to obtain a comprehensive depiction. Measurement techniques, individual variability (sex, age, fungiform papillae density, physiological and pathological factors), and the dimension of texture are the contributing factors to the variability in oral tactile sensitivity and

its relation to texture perception and preference (Liu et al., 2022). To fully understand texture perception, measurements of oral processing ability, such as salivary function, chewing ability, and bite force, should also be considered.

3.2 | Chemesthetic sensitivity

There are no standardized chemical compounds and concentrations for the chemesthetic sensitivity tests. However, the most commonly used chemical compounds are menthol and capsaicin, which exhibit sensations of cooling and spiciness/warming, respectively (Cardello & Wise, 2008; Prescott, 1999; Rentmeister-Bryant & Green, 1997; Roukka et al., 2021). The localized method limits potential irritations to the stimulated area. Moreover, the choice of methods largely depends on the study objectives. The use of localized testing would benefit studies whose objectives are to (1) screen possible neural damage as stimulation can be limited to a specific region and (2) investigate the regional variation of oral sensitivity, as differences in spatial patterns have been reported. For instance, the tip of the tongue was most sensitive to capsaicin, followed by the lip, palate, and cheek (Lawless & Stevens, 1988). Within the tongue region, capsaicin burn was perceived strongest on the fungiform region (front of the tongue) and weakest on the circumvallate papillae. In contrast, the cooling sensation of menthol was highest perceived in circumvallate papillae and least in the fungiform region (Green & Schullery, 2003). Due to the spatial difference, precise and consistent placement of stimuli is necessary for all participants to ensure reliability, requiring experimenter training.

For studies aiming to replicate real eating or drinking experiences, the whole mouth testing method is recommended. Lower concentrations of the sample should be used when using this method, as it was shown that 0.6 ppm of capsaicin delivered via whole-mouth rinse had an equivalent burn intensity as 3 ppm of capsaicin delivered via localized filter paper method (Prescott, 1999). In studies where the chemesthetic compounds are dissolved in a food model (Lyu et al., 2021; Piochi et al., 2021), swallowing the stimuli may present a post-ingestive effect and difficulty in removing residual sensation. To limit these effects, the sip-and-spit procedure is preferable (Green, 2001). For the same reason, the choice of evaluation procedure is also crucial. The threshold and discrimination testing procedure would require several samples to be tested. Therefore, it should be conducted over multiple sessions. On the other hand, the intensity-rating procedure does not require many samples to be evaluated but may require precise instruction on the use of scale.

Both the localized and whole-mouth stimulation methods have been performed in healthy adults and the elderly (Fukunaga et al., 2005; Roukka et al., 2021; Yang et al., 2022), but applications in the clinical setting have not been documented. Temperature control is critical for testing with chemesthetic compounds due to the overlap of TRP channels for temperature and chemesthesis (Simons et al., 2019), which may result in an 'interaction' effect (Green, 1985). To prevent this interaction effect, chemesthetic solutions should ideally be served at the resting temperature of the mouth, between

35 and 37°C. A serving temperature below this will cool the oral temperature and reduce the sensitivity to chemesthetic compounds (Green, 2001).

Due to the slow onset and decay of chemesthetic compounds, it is necessary to provide sufficient rating time and interstimulus interval (ISI) between different samples (Green, 1991). A rating time of 10–30 s after stimulation was employed in previous studies (Green, 1989; Nolden & Hayes, 2017; Roukka et al., 2021; Yang et al., 2022). The greater depth of somatosensory receptors compared to gustatory receptors, along with the tendency for lipophilic substances to stay in the epithelium, results in prolonged sensations compared to taste sensations. While most sensory systems typically exhibit a diminishing sensitivity with constant or repetitive stimulation (adaptation), this pattern does not consistently apply to chemesthesis. Continuous or recurring stimulation can lead to a heightened (sensitization) or reduced (desensitization) sensitivity depending on the ISI between samples (Green, 2001). The sensitization and desensitization phenomena were observed both in localized and whole-mouth methods (Prescott, 1999). Through a series of experiments, it was demonstrated that an ISI of <3.5 min leads to sensitization, whereas desensitization occurs at an ISI of 5.5–14.5 min (Lyman & Green, 1990). However, as considerable individual difference was observed in previous studies, a tailored ISI for each individual may be required (Cliff & Green, 1996; Green, 2001; Prescott, 1999). Measurement of the temporal characteristic of the sensations can be of added value to compare between individuals. Different temporal methods can be performed, such as the time-intensity, temporal check-all-that-apply, progressive profile, and temporal dominance of sensation methods (Esmerino et al., 2017; Green & Rentmeister-Bryant, 1998).

3.3 | Thermal sensitivity

The thermal-change detection test is primarily used for cutaneous sensations and has limited application in oral sensations. Due to its constant yet subtle changes in temperature, it measures thermal sensitivity at a higher resolution. In this context, resolution refers to the smallest detectable change or difference that a test or instrument can measure. The use of the test has been documented for osteoarthritis and neuropathic patients, in comparison with healthy subjects, and to understand complex pain mechanism (Suokas et al., 2012; Walk et al., 2009). The duration of the test was 8 min, during which requires a constant level of concentration and a higher level of cognitive processing (Rolke et al., 2006), which may cause fatigue for children, elderly, or clinical populations. As there are no simple devices to conduct the test, the thermode may not be affordable, especially if it is not meant for routine or repeated use. For assessing cutaneous sensations, simpler devices have been developed, such as the Lindblom roller and Minnesota thermal disks, which utilize the thermal conductivity of metals to create a cooling sensation when applied to the skin (Walk et al., 2009). However, their use for measurement in the oral cavity has not been documented.

On the contrary, the temperature-discrimination test offers a lower resolution as it measures the supra-threshold level, with only

two extreme temperatures (hot/cold) tested. The purpose of this test is to screen for neural damage or severe disturbances in the oral sensations, particularly in patients with orofacial pain, head and neck cancer, or burning mouth syndrome (Bodin et al., 2004; Grushka et al., 1987) rather than comparing individual sensitivity in the general healthy population. Compared to the thermal-change detection method, it is a rapid, simple, and affordable tool. Despite its simplicity, this method was able to identify clinical populations with severely altered thermal sensitivity (Bodin et al., 2004; Elfring et al., 2012; Kimata et al., 1999; Loewen et al., 2010; Riantiningtyas et al., 2023). To improve the discrimination and resolution of the test, it is suggested to include more temperature intervals between the two extremes, rather than relying solely on the two temperatures. This method has been performed among cancer patients to assess sensory re-innervation function following surgical procedures in the oral cavity (Bodin et al., 2004; Kimata et al., 1999; Loewen et al., 2010).

4 | CONCLUSION AND PERSPECTIVES

This review identified the absence of a method for assessing oral somatosensation in its entirety as it comprises multiple sub-modalities, although various methods exist for measuring the individual sub-modalities (tactile and textural sensitivity, chemesthetic sensitivity, and thermal sensitivity). However, even the assessment methods for those sub-modalities are not standardized, and procedures vary across studies. Tactile sensitivity can be assessed using different methods, but it is essential to note that each method measures different dimensions of tactile function. Similarly, texture perception is multi-faceted, thus, measuring a single textural attribute may not comprehensively capture overall texture sensitivity. Thermal sensitivity can be evaluated using thermal-change detection or temperature discrimination tests, while the chemesthetic sensitivity tests involve either localized or whole-mouth stimulation tests.

The review highlighted that there is no one-size-fits-all approach for evaluating oral somatosensory sensitivity, as each method has its own intended purposes, strengths, and limitations. Researchers must carefully evaluate these aspects alongside factors such as validity, reliability, and feasibility and choose the most appropriate assessment method for their specific research objectives and target population. They can also explore alternative or complementary methods proposed in this review to overcome limitations of the chosen method. Standardized protocols for each method should be established, or researchers should document a concise and comprehensive protocol to facilitate the replication of the experiment and enable comparison of the results among other researchers.

AUTHOR CONTRIBUTIONS

Reisya Rizki Riantiningtyas: Conceptualization; writing – original draft; writing – review and editing; investigation. **Anestis Dougkas:** Conceptualization; writing – review and editing; supervision. **Camille Kwiecien:** Conceptualization; writing – review and editing; supervision. **Florence Carrouel:** Conceptualization; writing – review and

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

ORCID

Reisya Rizki Riantiningtyas  <https://orcid.org/0000-0001-8115-6135>

Wender L. P. Bredie  <https://orcid.org/0000-0001-5145-4131>

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