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The Effect of Oral Tactile Sensitivity on Texture Discrimination and Mastication

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To the Graduate Council:

I am submitting herewith a thesis written by Grace Evelyn Shupe entitled "The Effect of Oral Tactile Sensitivity on Texture Discrimination and Mastication." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science.

Curtis Luckett, Major Professor

We have read this thesis and recommend its acceptance:

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Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

The Effect of Oral Tactile Sensitivity on Texture Discrimination and Mastication

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Grace Evelyn Shupe
December 2018

Abstract

Texture perception is one of the most important factors in food acceptance. Individual differences between consumers for perception and oral processing techniques makes research on related topics difficult to find overall effects. It is thought that individual differences in texture perception could be caused by oral sensitivity or mastication behavior. The first hypothesis is that the variation in texture perception across populations is dependent on oral tactile sensitivity and masticatory performance. To address this hypothesis, the study was aimed to measure tactile acuity with a battery of tests and quantitate the relationship to masticatory performance. In general, sensitivity and masticatory performance in the younger age groups was superior to that of older adults ($p < 0.0001$). A positive linear trend was also found between bite force sensitivity and masticatory performance with younger participants, a trend not found in older participants. No significant relationship between age groups for bite force sensitivity and masticatory performance was found, suggesting that age-related declines in bite force sensitivity are not a significant cause of altered masticatory performance. The second hypothesis is that as oral sensitivity decreases so will a participant's ability to discriminate texture differences, since there will be less feedback from the oral cavity. We noted that oral sensitivity was not a significant factor when looking at differences in discrimination ability between high and low sensitivity groups. However, the study found that multiple masticatory behaviors were being modulated by oral sensitivity, including overall chewing patterns used ($p < 0.0001$). More specifically, those in the high sensitivity group used more stochastic chewing movements, while those in the low sensitivity group were found to use crescent and crossed-shaped chewing cycles. It was also noted that in the high sensitivity group the jaw moved further distances ($p < 0.0001$) in all phases (opening and closing) and moved at a higher velocity when opening ($p < 0.0001$) but not when closing, when compared to the low sensitivity group. These results help bolster evidence that sensitivity and masticatory performance are related and, as previously reported, both decline as people age (Calhoun, Gibson, Hartley, Minton, & Hokanson, 1992).

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INTRODUCTION

Texture

Texture is how touch is perceived in the oral cavity. Texture is one of the many ways that food is perceived. Other ways include appearance, smell, and flavor. Texture is determined by many parameters including: hardness, springiness, cohesiveness, roughness, etc., underscoring the difficulties in researching this particular aspect of food (Szczesniak, 2002). Texture is often overlooked by consumers, unless there is something unexpected or aversive. But, texture is also indicative of freshness and wholesomeness (i.e. wilted lettuce, stale bread, chunks in milk, stale potato chips). These are all examples of products where quality or possibly safety of a food product is questionable, which is why texture often influences consumer preferences and buying habits (Luckett, Meullenet, & Seo, 2016; Szczesniak, 2002; Wilson, Luck, Woods, Foegeding, & Morgenstern, 2016). These preferences are also based on consumer background as well as familiarity. According to studies conducted by Szczesniak et al. (2002), consumers like to be in full control of the food stuff that they place in their mouth. Meaning the slimy, stringy, hard, cold, or generally hard to manipulate foods are often rejected for fear of gagging or choking. This is more common in lower socio-economic groups and women who are more concisions of how they appear when they eat (Szczesniak, 2002). Foods with these hard to manipulate texture attributes are commonly associated with inedible food stuffs or other bad experiences. While those of a higher socio-economic are constantly learning and trying novel and exotic foods, making them more open to novel texture experiences.

Perceiving Texture

Texture information about a food is collected from the senses of touch, hearing, sight, and even smell; all these factors are used to determine expectations of what attributes a stimulus should possess (crisp/stale potato chips, thin/thick pudding, fresh/wilted lettuce, etc.). Touch is one of the primary senses involved in the perception of texture. Touch is perceived through pressure, vibration, pain, and stretch of the skin (or mucus membrane) (Carlson, 2012). The importance of each of these sensations and how this relates to food texture attributes will be discussed further. Pressure helps to determine the consistency of stimulus. If there is little pressure present between the stimulus and the tongue when a stimulus is manipulated then the stimulus is soft and malleable, but if the stimulus is hard then there will be equal force present when force is applied. Vibration is used to determine the outer texture of a product, rough stimulus cause vibrations while smooth stimulus do not. Pain or discomfort can be signs of sharp edged or other irritations such a slipperiness and stickiness (if force is needed to remove the stimulus). Muscle stretch is used to determine the position of parts of the body, for example when moving jaw muscles up and down it is important to know where teeth are in the oral cavity in order to prevent damage to the oral cavity from clashing of teeth (Carlson, 2012). All of the feedback from each type of touch is transcribed in the central nervous system to produce a complete picture of the texture a product has and determine whether it matches expectations or not through memory or other means.

In the Periphery

There are four cutaneous mechanoreceptors used to perceive touch. Each type is used to perceive one of the four types of texture forces or sensations (Goldstein & Brockmole, 2016; Kenneth O. Johnson, 2001). The first receptor is the slowly adapting type 1 (SA1) afferents that end in the Merkel cells, and are located in the basal layer of the epidermis. This receptor is sensitive to edges, corners, and curvature (Kenneth O. Johnson, 2001). Meissner corpuscles are large cell assemblies that lie just below the epidermis. These structures house the rapidly adapting (RA) afferents. Pacinian (PC) corpuscles reside in the dermis and deeper tissues. This is a large layered structure that helps to shield the single enclosed nerve ending that could be harmed by the stresses of ordinary manual labor. The Ruffini corpuscle, houses the slowly adapting type 2 (SA2) afferents, located in the connective tissue and dermis. The association with connective tissue makes it highly sensitive to skin stretch (Kenneth O. Johnson, 2001).

In the Central Nervous System

There are two different ways the brain communicates with the body, either through spinal nerves or cranial nerves. All cells that receive sensory information are outside of the Central Nervous System (CNS); therefore, these transmissions are called afferent axons, since they are going into the CNS, while efferent axons leaving the CNS control muscles and glands (Carlson, 2012). Once a stimulus comes into contact with the skin/mucus membrane the information has to be transcribed by the CNS. If a stimulus is coming from below the head or neck region then it will come through the spinal nerve, enter the dorsal root ganglia, and transfer up through the spinal cord to the brain. But if a stimulus is from the head or neck region then it will be received through one of the twelve pairs of cranial nerves. Reception occurs in the primary somatosensory cortex of the brain, jaw movement enters the brain through the trigeminal nerve, or the fifth cranial nerve, and tongue movement enters through the hypoglossal, or the twelfth cranial nerve (Carlson, 2012). Information is then processed and relayed back to the oral cavity in what is called the masticatory feedback loop.

Sensitivity Tests

There is no shortage of oral sensitivity tests that have been developed. Although, trigeminal system investigations on humans are very painful; therefore, they are rarely performed. As stated by Jacobs, Serhal, and Steenberghe (1998); other psychophysical approaches are used instead (i.e. asking questions about what the subjects perceive and sense). Most research has been developed specifically towards hands and finger perception. Many tests can be used, but many variables also contribute to a subject's responses; some of these variables are controllable, others are not (these are more difficult). Environmental noises and smells are a controllable variable that can influence a subject's response. Extraneous noises and sounds should be kept to a minimum to ensure no cues are perceived by the subject to change the stimulus. Examiners are also a controllable variable; inter-examiner variability leads to lack of standardization with-in procedures. This includes the standardization of instructions and the need for one examiner to make observations through-out a study. Test and Re-test are another method that can be used to determine the significance of the findings. For example, if retesting a subject does not lead to a similar result (and the difference is not linked to another variable, inter-examiner, environmental, etc.) then the test that is being performed is a poor representation, or measurement, of the desired trait. The following is a brief overview of the common test methods used to determine oral sensitivity.

Oral Tactile Sensitivity

Oral tactile sensitivity is the ability to determine shape, size, and surface texture of food stuffs (Calhoun et al., 1992; Engelen, Van der Bilt, & Bosman, 2004). Various methods have been used to determine oral sensitivity, including oral form recognition, size and weight discrimination tests, and two-point discrimination (Engelen et al., 2004). The last being the most common way of determining subjects' tactile spatial sense. Two-point discrimination testing reflects a subject's ability to interoperate two closely positioned points as two distinct points. There has been new work using monofilaments to test subjects' sensitivity to pressure. These filaments are rated to bend once a certain pressure is applied; the smaller in diameter and the softer the material, the less pressure they exert on the surface being tested. Another common method used is the ability to recognize shapes/objects, or stereognosis (Calhoun et al., 1992). This is done by giving a reference of all possible answers, and sometime unused options as in Engelen et al. (2004), and then administering one shape at a time in random order. The panelist is then given time to identify each object; this method can be used to determine threshold values (based on size) or acuity scores.

Two-Point Discrimination

The Weber's (1835) two-point discrimination test was first performed with a bent paper clip by the hand surgeon Erik Moberg, as published in September of 1978 in *American Society for Surgery of the Hand Journal* (Dellon, 1978). This test is used to determine the threshold at which two distinct points can be distinguished from one point, this is tested by increasing or decreasing the space between two stimuli until either the participant can no longer feel two points and only feels one or vice versa. Since the oral cavity is mainly inaccessible and space is a constraint the test will need to be administered using a novel device. A study was completed by Ringel and Ewanowski inside the oral cavity using a device that allowed for easy manipulation of separation distances and contact times (1965).

This device had two circuits that ensured the force applied was within one to three grams. Below one gram a light would illuminate the oral cavity (a circuit was closed) and above three grams of force was applied a light would also illuminate the oral cavity (a second circuit would be closed). When the light was off the force was between one to three grams which was applied for two seconds. During this time the participant's response of one or two points was recorded (Ringel & Ewanowski, 1965). To ensure consistency of placement for further testing each area was marked with a dye. The distance the points could be separated was adjustable by 0.5 mm increments up to 10 mm, and the force was also adjustable by changing the spring tension (making it harder for the circuit to close, requiring more pressure). The midline tip of the tongue was found to be the most sensitive (1.7 mm, SD 0.46 mm) with the upper lip, soft pallet, alveolar ridge, thenar region, and the fingertip results respectively 2.31mm (SD=0.72 mm), 2.64 mm (1.10), 2.66 mm (1.09), 5.60 mm (1.45), and 2.09 mm (0.57). The midline reading was always the most sensitive with the left and the right side being less sensitive in all cases.

Raised Shape Identification

Several studies have been performed using raised letters to test lingual tactile thresholds (Bangcuyo & Simons, 2017; Essick, Chen, & Kelly, 1999; Lukasewycz & Mennella, 2012). All three studies used the letters A, I, J, L, O, T, U, and W as first described by Essick et al. (1999) The size ranges used and font types were not uniform across all three studies (Table 1), but they all had similar results on acuity and threshold.

All three studies used an up-down staircase method to determine lingual tactile acuity (threshold) where a reversal was defined as a change in direction (correct response following an incorrect response, or vice versa). A few variations were made to the Essick study. Neither of the other methods blindfolded the participants (unnecessary or thought to be uncomfortable for the test group) and the Bangcuyo group did not present the full alphabet as options during the exercise narrowing their odds of correctly identifying from 3.8% to 46.1% of the time. Even with these changes, the results of these studies were similar. Lukasewycz and Mennella (2012) found the mean lingual tactile threshold among mothers was 3.9 ± 0.2 mm, SD = 1.1 mm, and 4.2 ± 0.2 mm for children. The lower threshold could not be found, as several of the participants correctly identified all of the smallest stimuli (2.5 mm). Therefore there was a floor effect as the threshold was automatically set to 2.5 mm. Bangcuyo and Simons (2017) found the mean lingual tactile threshold was 4.2 ± 0.2 mm, and found a significant difference between the youngest (18-29 – a) and oldest (40-59 – b) age groups, while the middle group differed from neither (30-39 – ab). While there was no significant difference found between sex, there was a correlation with fungiform papillae density on the anterior tip of the tongue (increase in sensitivity was associated with a high density).

In the original Essick, Chen, and Kelly Study (1999) the mean threshold was determined to be 5.1 mm, SD = 1.1 using only the first eight (8) reversals of the session. In this original study, they completed 24 reversals (using ~45 stimulus) total. To ensure that these results were the same as the first eight reversals they completed a second analysis with all 24 reversals. The mean threshold was also 5.1 mm, but the SD was 1.0 mm. This estimation was within ± 0.3 mm of the first estimate using only the first eight reversals, proving that the first eight reversals is adequate to determine the threshold lingual acuity.

Stereognosis

Stereognosis is a measure of a participant's ability to distinguish size, shape, and orientation of stimuli (R. Jacobs, Serhal, & van Steenberghe, 1998). The pieces used during the testing procedure have a great influence on the quality of answers given by the subject. Ease of recognition and ease of confusion are factors to consider when deciding on shapes/letters to use (i.e. easily perceived ratios of length and width (difference between squares and rectangles), concave and convex curves, linear lines, and angles). Shapes with rounded corners are also preferred over those with sharp corners as these can cause discomfort during manipulation of test pieces. Different shapes and sizes should be used, but the optimal thickness of each piece should be between 4 mm and 10 mm. When inserting the stimulus into the oral cavity special care should be taken to not touch the lips or gums; as this could cue the subject to the stimulus size or shape. This could be achieved by inserting a toothpick into the center of each test piece and ensuring the subject does not see the stimulus (Kenneth O Johnson & Phillips, 1981).

There are several methods used to administer stimuli to subjects and evaluate scoring; possible stimulus options can be shown to the subject while testing (with or without extraneous options), or subjects can be left to determine object shape and size without an aid present (Calhoun et al., 1992; Luckett et al., 2016). There are also three methods used to score stereognostic ability: three-point scale, average identification of errors, and average identification time (R. Jacobs et al., 1998). The three-point scale gives credit for correct, incorrect, and partially correct responses; a correct response is when the subjects directly identifies the stimulus exactly as it is, an incorrect response is when a subject identifies an object with no similarities to the stimulus presented, and half-correct is when some similarities are present between the chosen object and stimulus. The scoring for correct, partial correct, and incorrect are as follows: 2, 1, and 0 (respectively) with higher scores being more sensitive or 1, 2, and 3 with lower scores being more sensitive as used by Van Aken in a study comparing oral stereognosis between complete denture wearers (1998). The second method, average identification of errors, just records whether a subject was correct or incorrect in identification. Then an average is calculated of the percentage of correct and incorrect responses. The third method is solely focused on time

Table 1. Summary of oral stereognosis methods and materials from three influential papers.

Author	Font	Letters	Raised Height (mm)	Letter Height (mm)	Letter Font Size
Essick et al.	Letter-Gothic	A, I, J, L, O, T, U, W	2	3, 4, 5, 6, 7, 8	12, 18, 21, 24, 30, 34
Lukasewycz et al.	Arial	A, I, J, L, O, T, U, W	Embossed*	2.5, 3, 4, 5, 6, 7, 8	10, 12, 18, 21, 28, 30, 34
Bangcuyo et al.	Arial & Times New Roman**	A, I, J, L, O, T, U, W	0.8	1.5, 2, 3, 4, 5, 6, 7, 8	6, 8, 12, 18, 21, 28, 30, 34

* Letter height not given, Teflon strips bearing embossed letters of the alphabet.

** Times New Roman was used for the letter "I", while all others were printed in Arial.

required to identify each stimulus. It does not matter whether the response is correct or not. The only important factor is the time consumed not only for each individual piece but the whole trial. As a harder piece will take longer to identify, those with less stereognosis ability (lower sensitivity) will take longer to complete the whole trial than those with high stereognosis ability (1998).

Monofilaments (Pressure Sensitivity)

In a study by the German Research Network on Neuropathic Pain the reliability of intraoral quantitative sensory testing was determined. They looked at thirteen test parameters to quantify one or several aspects of somatosensory functions; mechanical, thermal, chemical, and electrical stimuli have all been used to test nerve functions. But mechanical is the only stimuli that will be used in our study; therefore, mechanical detection threshold reliability is what will be discussed. For their study measurements were made with a standardized set of modified von Frey filaments 0.25 mN to 512 mN (OptiHair$_2$, MARSTOCKnervetest, Marburg, Germany). Five threshold measurements were made (using ascending and descending filament gauges). The mechanical detection threshold ($P < 0.001$) was found to be significantly higher at the gingiva site than the facial site, with the tongue being the most sensitive to mechanical stimulation. But, it was shown that mechanical detection testing with these microfilaments had poor repeatability for inter-examiner and intra-examiner (test-retest). The design of these filaments and the "method of limits" used for the detection threshold determination could explain this. Small differences of force could cause poor repeatability since exact agreement is required. The lowest gauge was 25 mN, which was not low enough to reach the limit of detection (most subjects could feel it every time). Smaller diameter microfilaments need to be used on the face and tongue (low threshold sites).

In researching monofilaments, drastically smaller filaments are commercially available from various sources. Semmes Weinstein measures their filaments in grams of force with the evaluator size being a log of the force exerted upon bending. The smallest size is a 1.65 that exerts 0.008 grams, which is a considerably smaller force than those used in the previous study with the lowest force being 25.45 g (0.25 mN). The filaments that were used previously were straight and would be considered hard to maneuver and place within the oral cavity (Pigg, Baad-Hansen, Svensson, Drangsholt, & List, 2010). Even when monofilaments were perpendicular to the handle panel they were still too long to maneuver effectively in the oral cavity (Komiyama, Gracely, Kawara, & Laat, 2008). Standard Semmes-Weinstein filaments are 38 mm originally. In the Komiyama study the filaments were cut to half their original length (19 mm). The bending force was then re-measured and re-marked using the below formula. The force of the half-length filaments was much higher than the original length filaments. Even with these improvements, monofilaments were not found to be reliable.

$$Filament\ Numbers = log_{10}Force(mg)$$

Foam Compression Discrimination

Since the oral cavity has been determined to be extremely sensitive to discrimination of such small proportions, Stainless Steel 319 coupons of roughness ranging from 0.51 to 22.8 μm were obtained using a micro finish comparator in a study by Linne and Simons (2017). Their results showed that after 8 reversals the roughness detection threshold ranged from 0.190 to 0.238 μm with the average being 0.200 μm. With this information, the threshold of detection cannot expect to be reached by simple means that could be administered in a clinical setting. In light of this, another factor yet researched, the premandible muscle, could be used to determine the pressure threshold using specialty kinds of foams. Which is related to oral sensitivity and masticatory patterns. This research is novel, and foam has never been used for this purpose previously. The foam that has been researched has the same density and appearance, but different compression factors that when squeezed a subject will be able to distinguish a difference between two similar samples.

Pressure vs Vibration

Pressure and vibration are often non-distinguishable for panelists. Vibrations can be conveyed using tuning forks of different pitches to increase or decrease vibrations (Calhoun et al., 1992). Pressure is often conveyed using microfilaments that bend once a specific pressure has been exerted (Pigg et al., 2010). Vibrations are detected using PC, or Pacinian Corpuscles, that are found in deep tissues and the dermis; while slowly adapting type 1 afferents in the epidermis are responsible for feeling pressure (Goldstein & Brockmole, 2016). The deep-set nature of the PC afferents could cause the subject to feel vibrations when there are none.

Mastication

Food textures have been shown to alter mastication patterns (Wilson et al., 2016). Tracking jaw movement is a way to determine differences in these patterns. There are two types of methods for measuring jaw movement, one minimally invasive (video jaw tracking) and the other more invasive with foreign object or wires attached to the teeth. The 3D electromagnetic systems (JT-3D) have been used in the past for studies such as ours. But, with these, systems are much harder to access and require testing larger quantities of panelists in order to use with a sensory study. Each panelist would have a lengthy set up time getting the JT -3D head apparatus functional and magnet adhered to the lower front incisor. The data that would be collected from one of these head apparatuses would also be altered from what they actually perceived since there would be interference from the JT-3D apparatus (Wilson et al., 2016). Not to mention the man hours needed in order to process and analyze the data since data is captured at a rate of 5000 times/second. Minimally invasive jaw tracking includes a plane of reference around the panelist's head and a black and white dot on the panelists jaw that is monitored by a video camera. This creates a 2D plane that can then be recognized by the software used in data analysis. This procedure will increase the comfort for the panelist and require much less set up time, therefore reducing the time to complete each session. The video monitoring has been shown to be accurate measurement of the chewing time, number of chews, chewing cycle times and chew frequency. But, the video system does overestimate the lateral movement of the jaw. Which can result in differences in the specific values found by the video monitoring and the 3D electromagnetic tracking. Even with these differences in magnitude, the order of characteristics is found to be the same with 3 of the 4 product types tested, enough information for the large quantity (100+ participants) of testing that needs to be done in a sensory study.

Chewing Efficiency

Chewing efficiency, or masticatory efficiency, is normally evaluating the distribution of particle sizes of any given food after a specified number of chewing cycles (Olthoff, Van Der Bilt, Bosman, & Kleizen, 1984). This distribution is determined by using fracturable foods, such as peanuts, that would then be run through a series of sieves to determine the amount in each level as defined by Gaudenz in 1900. But in recent studies, new food choices have been used that are more cost effective and consistent. Examples of these are hardened gelatin, silicone, and chewing gum (Hayakawa, Watanabe, Hirano, Nagao, & Seki, 1998; Liu, Wang, Chen, & van der Glas, 2018). In one particular study, using two-color chewing gum (Hubba-Bubba Tape Gums, The Wrigley Company Ltd, Plymouth, Devon, PL6 7PR, England) a baseline was determined using 20 “healthy chewers” at 0, 5, 10, 20, 30, and 50 chews. Once the gum bolus had been chewed the specified number of times, it was then placed into a clear bag and the mixing was visually assessed. The bolus was then flattened into a disk 1 mm in thickness and scanned on both sides to make an electronic assessment using Adobe Photoshop Elements 2.0® to select the unmixed pixels and determine the total number of unmixed over the total pixels (Schimmel, Christou, Herrmann, & Muller, 2007). A scale of unmixed gum was also included with each picture to ensure accurate selection of the chosen color as shown below in Figure 1. “Healthy chewers” – were defined as fully dentate, having an Angle class I occlusion with less than four decayed or filled teeth and were free of temporomandibular joint dysfunction (TMD) symptoms, and perceived their masticatory efficiency as normal (Schimmel et al., 2007).

Chewing efficiency was measured in a study of older adults (Wada, Kawate, & Mizuma, 2017) by using a color changeable gum, instead of mixing colors as in the previous study. This study uses Masticatory Performance Evaluating Gum XYLITOL (Lotte, Tokyo, Japan), which is very popular in Asia for the belief that better chewers are healthier and is not specifically designed for research purposes, as shown in Figure 2. This could be administered anywhere from a patient’s home to a clinical laboratory setting. For their procedure, participants were asked to chew the gum for 120 seconds then spit it out, the sample was then immediately flattened (1.5 mm thickness) and tested five times for color using a colorimeter (center and ~5 mm above, below, left, and right of the center). Using the L*a*b* scale, the a* values were used to determine the degree of mixing (positive a* more red, negative more green) as shown in Figure 3.

The color change found in this gum is due to a pH sensitivity of the yellow and blue dyes. Citric Acid is added to the gum to help maintain a low internal pH, therefore making the color stable. Once chewing begins the pH changes from acidic to neutral or alkaline as the citric acid is dissolved by the saliva. The blue and yellow dyes then seep into the saliva leaving the red color behind.

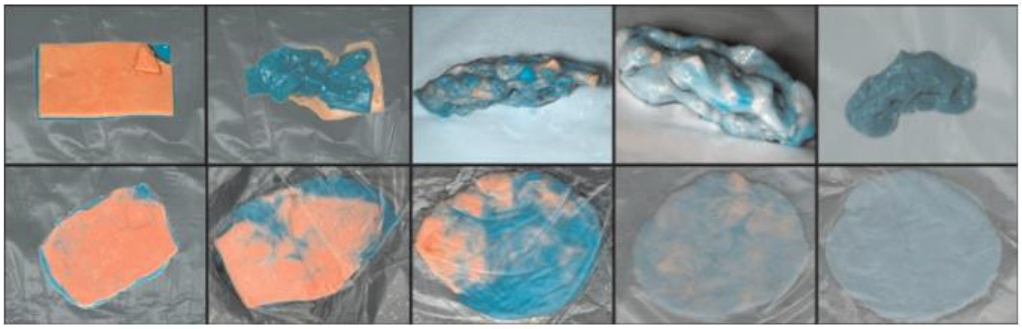

Figure 1. Example of a subjective assessment of unmixed (left) to well mixed (right) of before and after flattening.

Figure 2. Lotte XYLITOL gum color scale and actual representation of color change upon through chewing.

*Figure 3. L*a*b* Scale showing the range of possible colors, L* Lightness, a* Green to Red, and b* Blue to Yellow.*

Objectives

The purpose of the first study is to better understand the relationships between oral sensitivity and masticatory performance (by measure of chewing efficiency). A battery of tests will be used to quantify oral sensitivity across age groups and relate this to mastication performance. The purpose of the second study is to build off the knowledge gained in the first study. By looking at differences in mastication behavior between high and low oral sensitivity participants, to better understand the relationship between mastication and oral sensitivity. Sensitivity to texture changes will also be measured in the second study.

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CHAPTER I

CHARACTERIZATION OF ORAL TACTILE SENSIVITY AND MASTICATORY PREFORMANCE ACROSS ADULTHOOD

A version of this chapter has been previously published by Grace E. Shupe, Zoe N. Resmondo, and Curtis R. Luckett:

Shupe, G. E., Resmondo, Z. N., & Luckett, C. R. (2018). Characterization of oral tactile sensitivity and masticatory performance across adulthood. *Journal of Texture Studies.*

Abstract

Texture perception is one of the most important factors in food acceptance, yet population-wide differences in texture sensations are not well understood. The variation in texture perception across populations is thought to depend on oral tactile sensitivity and masticatory performance. To address this hypothesis, we aimed to measure tactile acuity with a battery of tests and quantitate the relationship to masticatory performance. The study was performed on 98 participants, in three age groups (20-25, 35-45, or over 62). Two main measures of oral sensitivity were performed. To assess bite force, subjects were asked to discriminate between foam samples of varying hardness. Secondly, to assess lingual sensitivity the subjects were asked to identify 3D printed shapes using their tongue, as well as identify confectionary letters. Additionally, masticatory performance was measured through assessing each participants ability to mix two-colored chewing gum. In general, we found that sensitivity and masticatory performance in the younger age groups was superior to that of older adults ($p < 0.0001$). We also found a positive linear trend between bite force sensitivity and masticatory performance with younger participants, a trend not found in older participants. We found no significant relationship between age groups for bite force sensitivity and masticatory performance, suggesting that age-related declines in bite force sensitivity are not a significant cause of altered masticatory performance. These results help bolster evidence that sensitivity and masticatory performance are related, and as previously reported declines in both as people age.

Introduction

While food texture perception is multisensory in nature, involving sight and hearing, it is mainly routed in touch (Nishinari, Kohyama, Kumagai, Funami, & Bourne, 2013; Szczesniak, 2002). Touch is perceived through pressure, vibration, pain, and stretching (Carlson, 2012). Tactile sensitivity in the mouth, often termed, oral sensitivity, is the ability to determine shape, size, and surface texture of food stuffs (Calhoun et al., 1992; Engelen et al., 2004). Oral sensitivity has been shown to be dependent on several factors, such as gender, but especially age and dental status (Bangcuyo & Simons, 2017; Calhoun et al., 1992; Trulsson, 2005). With age, oral sensitivity decreases along with other physiological measures like fungiform papillae density and dental health (Bangcuyo & Simons, 2017; Calhoun et al., 1992). Along those lines, dental health is also of significance since when an implant or prosthetic replaces a natural tooth, the nerves that would otherwise carry feedback to the brain disappear (Trulsson, 2005; Trulsson & Johansson, 2002). This loss of sensitivity/oral ability may result in discomfort or an inability to adequately prepare a bolus and potentially lead to problems with swallowing. This could lead to dysphagia in older populations, and therefore a lack of use, resulting in an overall decreased sensitivity (Wada et al., 2017).

Various methods have been used to determine sensitivity in the oral cavity, these have included oral form recognition (Essick et al., 1999), size and weight discrimination tests (Kenneth O Johnson & Phillips, 1981), stereognosis (R. Jacobs et al., 1998), two-point discrimination (Engelen et al., 2004), force perception (Pigg et al., 2010), and other physiological measures (Bangcuyo & Simons, 2017; Calhoun et al., 1992; Linne, 2017).

While there is no shortage of methods to assess oral tactile sensitivity, few studies have directly attempted to relate oral sensitivity to elements related to food/beverage intake, most importantly texture perception and oral processing. Recently, Linne et al. (2017) investigated the relationship of astringency perception and roughness perception, finding that astringency is related to oral roughness sensitivity for some compounds, but not others. Additionally, Engelen et al. (2004) found the ability of individuals to discriminate sizes of steel spheres to correlate to their masticatory performance. However, performance on a two-point discrimination task was not correlated to masticatory performance, suggesting certain forms of oral tactile sensitivity are more important for oral processing than others. Furthermore, a recent study by Schimmel et al. (2017) found that oral sensitivity by a battery of tests and masticatory performance was significantly less for stroke patients than for their healthy counterparts. Maximum bite force was similar between healthy and stroke patients.

There are also multiple methods used to evaluate mastication performance: this can include measuring the mixing ability of a gum (Halazonetis, Schimmel, Antonarakis, & Christou, 2013; Schimmel et al., 2007; Schimmel et al., 2017; Wada et al., 2017) or measuring the particle size of a foodstuff (Engelen et al., 2004; Liu et al., 2018). Generally, the golden standard is using model foodstuffs and measuring the distribution in particle size by multiple sieves. But, this is a messy and time-consuming process. Chewing (rhythmic movements) is controlled by a brainstem central pattern generator, which receives feedback from oro-facial receptors such as the periodontal ligament and muscle spindles (Avivi-Arber, Martin, Lee, & Sessle, 2011; Lund, Kolta, Westberg, & Scot, 1998). With this being said, mixing tasks are very easy and can be performed automatically without feedback, since there is very little resistance from the food product itself (Avivi-Arber et al., 2011; van der Glas, van der Bilt, Abbink, Mason, & Cadden, 2007).

One area that has yet to be explored is the use of a person's bite as a physiological measure to characterize masticatory performance. Masticatory performance and bite force sensitivity have been explored separately, but have not been studied together to determine the relationship to one another (Carlsson, 1974). Bite force measurements are often used in dentistry. As force is applied to an object by the teeth, the many nerve endings innervating the periodontal ligament give the ability to distinguish small changes in pressure. In order to determine jaw placement and avoid discomfort while chewing due to an unintended collision of teeth feedback from these nerve endings about location of the jaw, speed, and information about particles in the mouth is utilized during mastication (Desislava & Mariana, 2016). Previous research has been done using anesthetized rabbits to show that the periodontal ligament is not the only source of feedback from the oral cavity by eliminating sensory feedback from specific areas and testing the response when rhythmic jaw movements were obstructed (Hidaka et al., 1997; Lavigne, Kim, Valiquette, & Lund, 1987; Morimoto, Inoue, Masuda, & Nagashima, 1989). Morimoto et al. showed using foam strips that muscle spindles are also responsible for sensory feedback used in jaw closing (1989).

It has been suggested that methods being used to determine sensitivity, should focus on how texture (shape, force, size, orientation, etc.) is perceived then relayed back into the masticatory feedback loop (Chen, 2014). The sensitivity to bite force would be expected to be closely related to the mastication feedback loop. As mentioned earlier, these questions have not been extensively addressed in the oral cavity. However, studies investigating grip force have detailed the extreme precision in which healthy subjects use enough grip to prevent accidental slips, but not induce muscle fatigue or damage to the object (Johansson & Westling, 1984). Interestingly, the application of topical anesthesia significantly reduces the ability of subjects to use precise grip forces, suggesting that tactile sensitivity is key to this skillset (Johansson & Westling, 1984). Translating this to the oral cavity, sensitivity to bite force may be a key factor in explaining the variation in masticatory performance.

The purpose of this study is to better understand the relationships between oral physiology and masticatory performance. More specifically, we look to quantify the relationship of bite force sensitivity, oral stereognosis, and lingual tactile sensitivity to masticatory performance. Secondarily, we seek to look for changes in both oral sensitivity and masticatory performance across the adult lifespan. More specifically, we set out to provide evidence against the possibility that there are no differences in masticatory performance or oral tactile sensitivity between age groups. Hence, we hypothesize the following:

H_1 Age will influence mastication performance.

H_2 Age will influence oral sensitivity.

H_3 Dental status will influence oral sensitivity and mastication performance.

H_4 Mastication performance will influence oral sensitivity.

H_5 Certain measures of oral sensitivity will correlate better with mastication performance.

Materials and Methods

Participants

Ninety-eight participants were recruited for this study. Participants reported a good sense of smell, had no allergies or food restrictions and were not pregnant. Participants were also asked to self-report common dental procedures such as root canals, crowns, partial or full dentures (see Table 3). Participants were grouped by age as either young (20-25, n=34), middle (35-45, n=31), or old (>62, n=28); see Table 2 for participant demographics. All participants were living independently at the time of the study.

Table 2. Demographics of participants by age group.

Demographics		Age Group		
		Young	Middle	Old
Age	N	34	31	28
	Mean	22.5 ± 1.6	40 ± 3.1	73 ± 6.1
	Max	25	45	87
	Min	20	35	63
Gender	Female	22	18	16
	Male	12	13	12
Ethnicity	White	26	29	28
	African American	3	1	-
	Asian/Pacific Islander	3	1	-
	Latino	2	-	-

* Mean values have SD as the error term.

Table 3. General dental status of participant, self-reported common major procedures.

Dental Status	Age Group		
	Young	Middle	Old
Healthy (Fillings Only)	32	22	4
Crowns	1	6	13
Root Canals	1	2	6
Multiple Crowns and Root Canals	-	1	5
Partial or Full Dentures	-	-	*4
Minimal natural teeth with no prosthetics	-	-	*1

* These participants were considered compromised and were excluded from the main elements of data analysis.

Procedure

Upon arrival each participant was familiarized with each stimulus and the general tasks to be completed. The presentation of stimuli within each test was randomized, with the overall order of presentation maintained between participants to reduce fatigue. Participants completed one (1) approximately hour-long session with the following serving order; gummy letters (3), shapes, gum, shapes, gummy letters (3), gum, foam, gummy letters (3). Participants were asked to verbally respond with all answers, which were then recorded by members of the research team. Participants also filled out demographics upon completion and were compensated ten dollars for time participating.

Oral Stereognosis

Based on Calhoun et al. (1992), confectionary alphabet letters (Haribo Alphabet Letters Gummy Candy, Haribo of America, Inc., Rosemont, IL) were used to determine stereognosis ability. Letters displaying physical signs of unconformity in letter shape were not used. Stimuli were matched for letter geometry; therefore, each participant received the same amount of straight to curved letters. Each participant received nine (9) confectionary letters with no letters being repeated.

Prior to samples being administered participants were instructed that all 26 capital letters of the alphabet were an option. Letters were in Arial font. Once participants were ready to proceed, they were blindfolded to ensure letters would not be visualized and metal forceps were used to place samples in the mouth. Participants were given as much time as needed to identify the sample. No answer key was given. Once a participant had an answer, they would verbally respond, and answers were recorded by administering personnel.

Shape Identification

Stimuli were based on Essick et al. (1999), an applicator and 10 different shape stimuli (of 4 different sizes in both raised and recessed orientations, see Table 4) were used to determine lingual sensitivity. Geometric shapes were chosen as to refrain from assuming that participants have a familiarity with the Latin alphabet. Sizes were optimized by a pilot study to guard against possible ceiling/floor effects. All materials were 3D printed using a uPrint SE Plus® printer (Stratasys, Eden Prairie, MN) (See Figure 4). The ten shapes consisted of a variety of geometric shapes of varying difficulties and were as follows: square, rectangle, triangle, star, hexagon, circle, half circle, diamond, cross, and heart. The longest axis was used to determine the size in millimeters for each stimulus, and across all four sets the orientation of each shape was not altered and appeared exactly as pictures on the provided answer bank in order to prevent confusion.

Participants were familiarized with both orientations (raised and recessed) and shown multiple shapes in different sizes until they were confident in their understanding of the task. Participants were presented with an answer key of all possible shapes. Participants were instructed that each shape would only be used once per size (four sizes), but that they could use the same answer multiple times if desired. Size and order of shapes was randomized, only one size was presented at a time.

Masticatory Performance

Using the method defined by Schimmel et al. (2007), two different colors (blue and pink) of Hubba Bubba® tape chewing gum (The Wrigley Company Ltd, Plymouth, Devon, England) were used to measure masticatory performance.

Participants were given a gum sample and instructed to chew normally and would be told when to stop and place samples in a plastic bag. Each participant was allowed to chew for 10.0 seconds. We chose not to limit the masticatory performance measurement by number of chewing cycles due to compensatory strategies exhibited by older adults (K. Kohyama, Mioche, & Bourdiol, 2003; K. Kohyama, Mioche, & Martin, 2002; Mioche, Boundial, & Peyron, 2004). Each participant completed this task in duplicate.

Table 4. Shape stimuli presented to participants showing all orientation and size combinations.

Stimulus	Orientation	Size (mm)
■ ⬣ ✚ ▲ ▬ ● ◓ ♥ ◆ ★	Raised	3 and 5
	Recessed	4 and 8

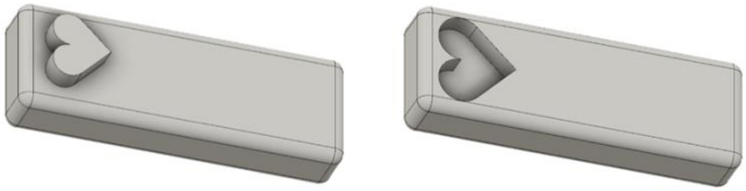

Figure 4. Vector drawing of stimuli: 5 mm raised and 8 mm recessed heart.

Sensitivity to Bite Force

Several foam samples with multiple hardness levels (or compression factors), and similar densities were used in this study. Foam was cut into 1 cm cubes and attached to an applicator to allow for the placement of each sample between the molars. Hardness levels were verified using a TA.XT Plus Texture Analyzer and Exponent software (Texture Technologies Corp. and Stable Micro Systems, Ltd., Hamilton, MA) and are shown in Table 5.

A 2-AFC forced-choice paradigm was used to assess sensitivity to pressure. Each 2-AFC consisted of two samples: a reference and another sample of varied firmness. For each test, one sample was always firmer than the other, if participants correctly chose the firmer sample this was considered a point, while if they chose incorrectly they received a zero. The total score for all comparisons was used for analysis. All sample pairs were presented in duplicate. Prior to samples being administered participants were familiarized with materials and given a visual demonstration by administering personnel. Panelists were asked which side of the jaw they would prefer testing be performed on (the side with the most natural teeth or dominate chewing side). Panelists were then blindfolded and samples places between the back molars of the preferred side monadically with as little time between samples as possible (ensuring that stimuli were correctly oriented and placed between the molars). Participants were allowed to retest if necessary, sample order was maintained.

Table 5. Hardness of 1 x 1 cm foam samples using a TA.XT Plus Texture Analyzer.

Foam #	Mean ± SD (N)
1	1.25 ± 0.23
2	1.45 ± 0.08
3*	1.88 ± 0.12
4*	2.21 ± 0.06
5	2.25 ± 0.32

*References

Data Analysis

Data was structured as the number of correct responses each panelist gave for each oral sensitivity measures and masticatory performance was reported as a percentage (averaged over both trials). In order to determine overall oral sensitivity, the sum of correct responses for lingual sensitivity, stereognosis, and bite force sensitivity tasks was used. Dental status was collected from the participants. For data analyses, dental statuses were assigned a numeric value ranging from zero to five, zero and one were considered notably compromised during analysis, as shown in Table 3.

Gum samples were flattened into a 1 mm thick disk, and pictures taken of both sides using an 8.0-megapixel camera (2448 × 3264). The samples were analyzed using Adobe Photoshop Creative Cloud® (Adobe Systems Inc., San Jose, CA). A reference of un-chewed gum was used to determine the hex code 237a88 for selecting pixels of the desired blue color, which was then used to calculate pixel counts at three fuzziness settings (60, 75, and 90 to account for slight color variation in chewed samples) using the color range selection and the measurement tool (Figure 5). These measurements were averaged for each side and trial.

All results were analyzed using JMP Pro 13.1 (SAS Institute, Cary, NC), with statistically significant defined as $p < 0.05$. Differences in lingual sensitivity, stereognosis, bite force sensitivity, and masticatory performance were examined across age groups by multiple analysis of variances (ANOVAs). Specific LS means contrasts and linear regression was performed for the categorical variable dental status. Pairwise post-hoc comparisons were performed using Tukey’s HSD adjustment and Pearson’s correlations were used to determine associations between measures. To compare oral sensitivity scores, an ANOVA was run, using age group as the sole factor. Each sensitivity task was analyzed separately as well with lingual sensitivity, stereognosis, and bite force sensitivity each compared across the age groups. To compare masticatory performance ratings, a one-way ANOVA was run, using age and masticatory performance as fixed factors.

Results

Since major disturbances of dental status were only found in the older participants (Table 2), those participants that were considered compromised were excluded from the majority of the analysis (n=5, mean age =70, SD 6-year, 2 Female).

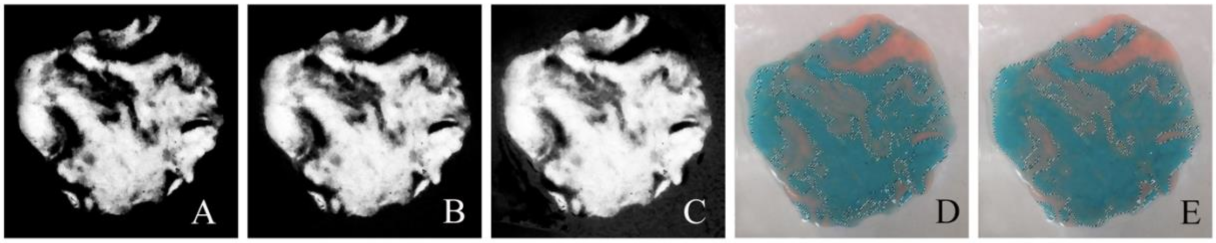

Figure 5. Representation of blue pixels selected by 60 (A) 75 (B) 90 (C) tolerance, D and E show color selections of 60 and 90.

Age

Oral sensitivity was different across the age groups, with the older age group having lower total scores than both the young and middle age groups ($F_{2,90} = 11.78$, $p < 0.0001$). In looking at specific oral sensitivity measurements, both lingual sensitivity and stereognosis differed across the age groups ($F_{2,90} = 8.96$, $p = 0.0003$ and $F_{2,90} = 13.53$, $p < 0.0001$, respectively), as shown in Figure 6. Conversely, bite force sensitivity did not differ by age group ($F_{2,90} = 0.57$, $p = 0.57$).

Masticatory performance was found not to differ across age groups ($F_{2,90} = 0.46$, $p = 0.63$). However, in observing the distributions of masticatory performance by age group, it can be noted that a bimodal distribution is observed in the older age group, as shown in Figure 7.

Gender

There was not a significant difference between gender for all three age groups ($T_{1,91} = 0.16$, $p = 0.88$). Gender was also not a significant predictor for any of the individual oral sensitivity measures (stereognosis $T_{1,91} = -0.03$, $p = 0.97$; lingual tactile sensitivity $T_{1,91} = -0.42$, $p = 0.67$; bite force sensitivity $T_{1,91} = -0.22$, $p = 0.82$) or the total oral sensitivity score ($T_{1,91} = -0.40$, $p = 0.69$). Furthermore, gender was not significantly related to masticatory performance ($T_{1,91} = 0.37$, $p = 0.71$).

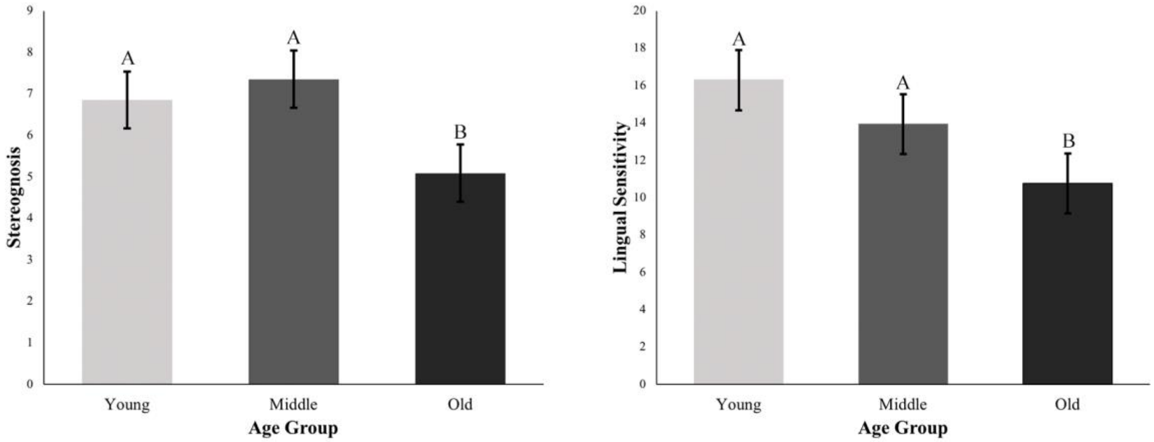

Figure 6. Mean values of letters and shapes correctly identified by age group, letter groupings specify significant difference (p<0.05) using Tukey's adjustment.

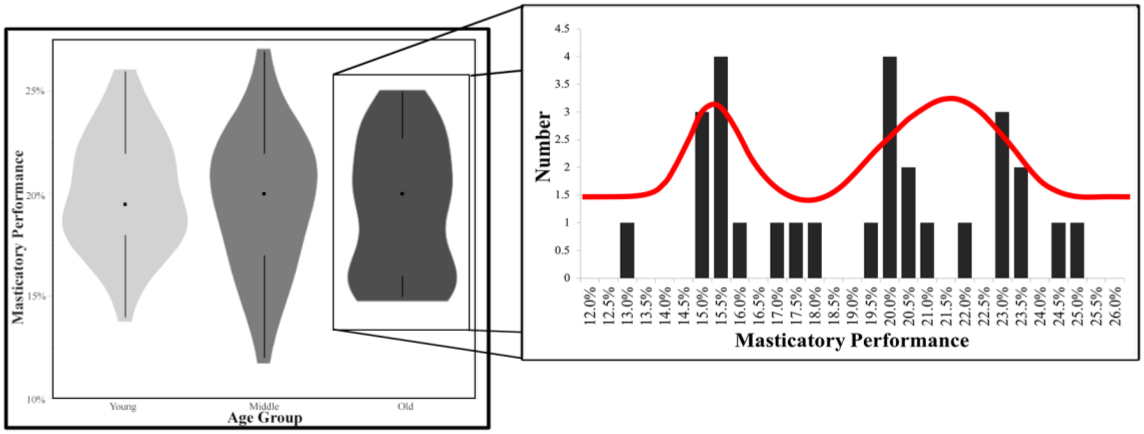

Figure 7. Distributions of chewing efficiency values for each of the three age groups.

Dental Status

There was a significant effect on masticatory performance by dental status, such that as dental status declines so do the observed masticatory performance ($r^2 = 0.13$ p=0.0268). When comparing those with notably compromised dental status (i.e. partial and full dentures) to participants with a healthy dental status, a significantly lower masticatory performance was found in those with missing teeth ($F_{1,92} = 8.59$, p=0.0043). Alternatively, with lingual sensitivity and stereognosis measures there was no significant relationships found with masticatory performance (p= 0.2396 and 0.1820, respectively).

Further investigations into dental status were performed by including the previously excluded participants with notably compromised dental status. This analysis focused on the older adult population, since there were not a sufficient number of participants with notably compromised dental status in the younger age groups. Within the older adult group, it was revealed that there was no significant effect of dental status on bite force sensitivity between those with a healthy dental status and compromised participants ($F_{1,27} = 4.1237$, p=0.0522). Although, it was found that masticatory performance was significantly lower in those older adults with a compromised dental status ($F_{1,27} = 5.60$, p=0.0254).

Relationship Between Measurements

As shown in Table 6, increases in age were not found to be significantly correlated with masticatory performance (r = 0.1037, p = 0.3226). Even after the older subjects with severe compromises in dental status were removed, a significant correlation between age and dental status was still found (r = -0.5859, p < 0.0001). In looking at the specific associations of the test methods used, stereognosis showed a moderate negative correlation with age (r = -0.3978, p < 0.0001) and a weaker positive correlation with dental status (r = 0.2364, p = 0.02). Lingual sensitivity was also moderately correlated with age (r = -0.3881, p = 0.0001). Both lingual sensitivity and stereognosis scores were strongly correlated with each other (r = 0.4648, p < 0.0001).

Further investigation into the different relationship that sensitivity tests were having with masticatory performance, among the older age group, bite force sensitivity (r = -0.4943, p = 0.0035) as well as dental status (r = 0.4144, p = 0.0165) were both significantly correlated with masticatory performance. These findings highlight the multifaceted nature of oral sensitivity/processing and the need for multiple methods to comprehensively characterize oral tactile sensitivity. Among the two youngest groups, increases in bite force sensitivity was shown to significantly associate with higher masticatory performance ($r^2 = 0.0729$, $p = 0.0297$); and, in the older age group a significant association between masticatory performance and bite force sensitivity was also found ($r^2 = 0.1397$, $p = 0.05$). However, the relationship between bite force sensitivity and masticatory performance is in the opposite direction for the older age group (i.e. as bite force sensitivity decreases, masticatory performance increases), therefore canceling out any effect seen across the whole participant pool (Figure 8). Total oral sensitivity relates to masticatory performance similarly in young and middle age groups, but older adults show a different relationship.

Discussion

The present results showed that as the population ages, there are different rates of sensitivity and proficiency decline with one group showing minimal sensory decline and another displaying notable declines. This phenomenon is also observed in other food-related sensory systems. For example, olfactory sensitivity remains normal in portions of the aging population, while others exhibit a drastic loss (Murphy et al., 2002). The finding that sensitivity decreases as the population ages agrees with previous findings (Bangcuyo & Simons, 2017; Calhoun et al., 1992; Linne, 2017; Wada et al., 2017). Masticatory performance of younger participants is not significantly different than those ranging from >62 years of age. The lack of difference in masticatory performance could be linked to the ease of the gum chewing task. A mastication task that requires more bite force capacity would be more likely to find differences that exist in masticatory performance. Additionally, while the study controlled for how long the gum sample was to be chewed, the older adults could have used compensatory strategies. These strategies such as performing more chewing cycles have been previously documented in older adults (K. Kohyama et al., 2002; Mioche et al., 2004). However, degradation of dental status linked to aging is not the main factor of oral sensitivity, as measured through oral lingual sensitivity testing. These findings reinforce that a host of oral sensory processing factors must be used in order to measure oral sensitivity. Even in older participants with a dental status ranging from minimal natural teeth without prosthetics to full dentures, they performed well at pressure discrimination while they scored lower on all other tests.

Table 6. Pearson’s correlation coefficients (r) among the oral sensitivity and masticatory performance tasks.

	Age	Dental Status	Masticatory Performance	Stereognosis	Lingual Sensitivity	Bite Force Sensitivity
Age	-	-0.5859**	-0.1037	-0.3978**	-0.3881**	-0.0593
Dental Status		-	0.1193	0.2364*	0.2244*	0.0485
Masticatory Performance			-	0.0429	0.0657	0.0771
Stereognosis				-	0.4648**	0.0027
Lingual Sensitivity					-	0.0030
Bite Force Sensitivity						-

* Significant at the 0.05 level.

** Significant at the 0.0001 level.

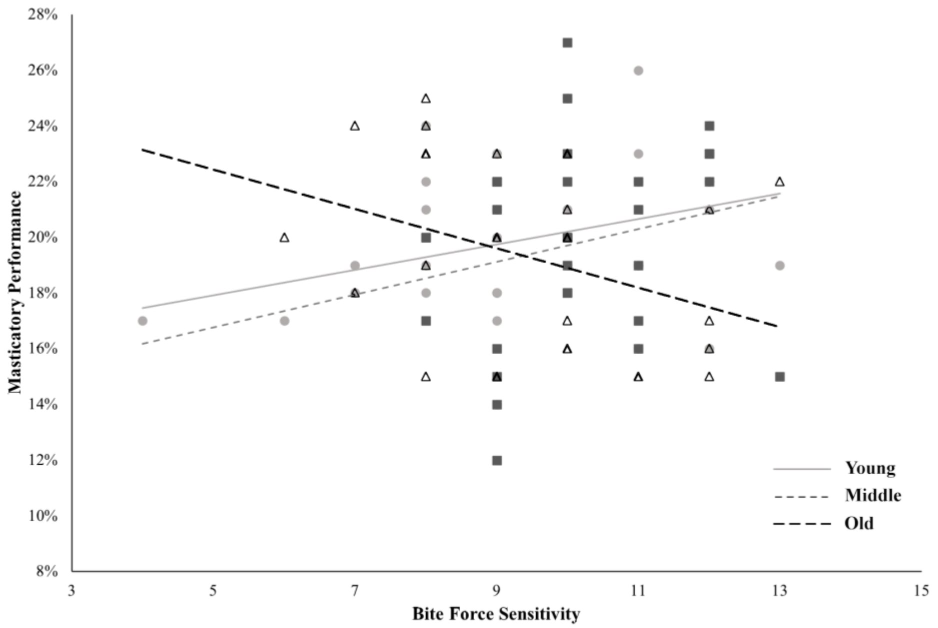

Figure 8. Linear regression of chewing efficiency by pressure sensitivity, grouped by age (Young •, Middle ■ , Old Δ), showing an inverse trend as age increases.

Previous attempts to relate mastication performance to oral sensitivity have shown a stronger link between pressure-related measures of oral tactile sensitivity in comparison to those measures of surface sensitivity (Engelen et al., 2004). This study did not find bite force sensitivity to be significantly related to mastication performance or significantly different by age group, which is in agreement with similar findings in stroke patients (Schimmel et al., 2017). Furthermore, bite force sensitivity is conserved as teeth are removed, showing that muscle spindles are providing important feedback on mechanical events in the oral cavity since the periodontal receptors can no longer signal information (Trulsson, 2005). This measure of bite force sensitivity would therefore be expected to show more of a relationship with tongue movement elicited by oral stereognosis, but this is not the case since it was the least correlated of all comparisons.

We showed that the influence of other sensory sensations on masticatory performance is small, suggesting that, regardless of age, the chewing process is largely automatic when using a soft bolus as test food (Lund et al., 1998; Ottenhoff, van der Bilt, van der Glas, & Bosman, 1992; van der Glas et al., 2007). More, specifically, it was hypothesized that oral sensitivity would be linked to masticatory performance through its tactile feedback. However, as mentioned earlier, this relationship may be muted by the ease of the mastication task as it has been reported that sensory feedback becomes more important as the motor task becomes more difficult (Lund et al., 1998; Ottenhoff, van der Bilt, van der Glas, & Bosman, 1992; van der Glas et al., 2007). Although no strong correlations were not found between sensitivity tests and mastication performance it was noted that dental status is a significant factor in explaining the variance within masticatory performance even with compromised participants removed.

Of the three oral sensitivity tests, stereognosis would be the best predictor of masticatory performance as shown by Pearson's correlations. This indicates that the tongue proprioceptive ability, which is crucial in orienting and identifying stereognosis stimuli, may be a determining physiological factor in masticatory performance. Further research is needed to determine the oral physiology and the masticatory feed-back loop inputs. Tongue pressure has been measured with gels of varying initial consistency using measurements of force exerted on the hard pallet and how this relates to particle size reduction, and therefore mastication, using multiple oral processes (Yokoyama et al., 2014). The tactile modalities used in this study showed a relationship with oral sensitivity and masticatory performance, while novel techniques such as those measuring bite force sensitivity of the periodontal muscle through bite failed to show a significant relationship.

Bite force sensitivity was not correlated with either oral tactile measures, masticatory performance, age, or dental status, demonstrating that bite force sensitivity measurements are likely measuring a different physiological ability from the lingual sensitivity and stereognosis measurements. These findings are in line with previous studies looking at relationships between different measures of oral sensitivity. Engelen et al. (2004) found no correlation between oral spatial acuity and oral size acuity, creating consistent evidence that oral sensitivity is multidimensional and cannot be comprehensively characterized by a single physiological assessment.

This study highlights that many factors must be taken into consideration when understanding the abilities, regardless of task, of older populations. Jaw muscles have been shown to fatigue and bite forces decline, leading to compensatory strategies such as more mastication cycles and longer mastication sequences(K. Kohyama et al., 2003; K. Kohyama et al., 2002; Mioche et al., 2004)

Limitations

Participants with a compromised dental status were not tested across all three age groups. It would have been preferable for compromised participants to have been tested across all age groups, but the lack of availability of participants in the low and middle age groups with compromised dental status prevented the authors from comprehensively addressing this factor. Additionally, while this study only included independently living participants, the presences of other health conditions and medication was not measured. It is possible that some of the participants had confounding health issues that could alter their mastication performance or oral sensitivity.

The masticatory performance task used in this study, can be considered to be relatively easy and has been used to create a baseline measurement in stroke patients (Schimmel et al., 2017). While this study represents a valuable first step in showing that bite force sensitivity does not depend on age, and the minimal influence of factors such as age and oral sensitivity on masticatory performance, future studies should be performed with more difficult chewing tasks. A more difficult chewing task will likely be able to distinguish more differences amongst people of varied oral sensitivity and age. Similarly, masticatory performance measurements were also found to be very similar, leading to possible range restriction when attempting to build relationships relating measures of oral sensitivity to masticatory performance. Future work should be vigilant of condensed values for masticatory performance, which are likely a byproduct of the ease of the task. Also, the presence of increased number of chewing cycles as a compensatory strategy could not be verified because quantitating the number of chewing cycles during the masticatory performance task was not performed.

It was noted that even though masticatory performance photos were taken in a controlled environment throughout the study, there were color temperature differences in the final photographs; which resulted in varying selections of blue pixels. This limitation was mediated by the use of multiple tolerances, yet room for improvement still exists. The lack of a relationship between the bite force sensitivity and masticatory performance may be due to the fact that the foam used in this study can undergo oxidation when exposed to light for prolonged periods of time, which could have resulted in a change of observed hardness over the course of the study. Oxidation of samples was mitigated by using colored containers to store samples prior to being prepped; prepped samples were used within a week and were discarded if discoloration was observed. Samples were kept in opaque containers to prevent prolonged exposure to UV light. In future studies, different types of foams could be used that have been engineered to be more resistant to oxidation from many common sources such as heat and light (Christopher, 2015).

Conclusion

Our results show that multiple factors contribute to masticatory performance, but when a soft test food is used, there is a relatively small relationship between physiological factors and masticatory performance; highlighting the automaticity of the chewing process. Lingual acuity and stereognosis showed the highest correlation with masticatory performance and appear to be the most reliable measurements, while bite force sensitivity did not show any relationship and did not differ with age. Further research is required to quantify the relationship between physiological measures and oral sensitivity and Mastication performance utilizing a harder chewing task. While some methods such as monofilaments and periodontal muscle sensitivity testing have not shown promising results, modifications to these concepts may still lead to viable research. Furthermore, the tongue’s contribution to mastication performance appears to be highly correlated, showing that tongue movements or force may be a key physiological measure in future studies.

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CHAPTER II

THE EFFECT OF ORAL SENSITIVITY ON TEXTURE DISCRIMINATION AND MASTICATORY BEHAVIOR

Abstract

Mastication behavior is a notable source of interindividual variation in texture perception and could be linked to oral sensitivity. As oral sensitivity declines so does the amount of tactile feedback relayed to the brain, resulting in less effective manipulation of food and a reduced ability to discriminate differences. To address these hypotheses, we measured masticatory behavior and related this to texture discrimination and oral sensitivity. The study was performed on 41 participants in two groups, with high ($n = 20$) or low ($n=21$) sensitivity. Oral sensitivity was measured using a battery of tests that included: oral stereognosis, lingual tactile acuity, and bite force sensitivity. Sensitivity to texture changes was measured using a series of triangle tests with confectionaries of different hardness levels, with masticatory patterns and behaviors being video recorded and analyzed using jaw tracking software. Overall, there was no significant difference between high and low sensitivity participants and their ability to distinguish texture changes. But, there were significantly different trends found between the groups based on their masticatory behaviors including chewing pattern and overall number of chews. It was found that multiple masticatory behaviors were being modulated by oral sensitivity, including overall chewing cycles used ($p < 0.0001$). More, specifically those in the high sensitivity group used more stochastic chewing movements, while those in the low sensitivity group were found to use crescent-shaped chewing cycles. It was also noted that in the high sensitivity group the jaw moved further distances ($p < 0.0001$) in all phases and moved at a higher velocity when opening ($p < 0.0001$) but not when closing, when compared to the low sensitivity group. These results help bolster evidence that mastication and oral sensitivity are related.

Introduction

Texture perception is a dynamic process that is constantly changing during oral processing; therefore, mastication and texture perception are thought to be linked (Hutchings & Lillford, 1988). During mastication, the first step in the digestive system, a product is broken down in the oral cavity and its texture properties are continuously changing (e.g. particle size reduction, saliva lubricating and softening, mixing) (Hutchings & Lillford, 1988; Szczesniak, 2002). As feedback on these textural properties is received from the oral cavity, adjustments are made to maximize the efficiency of chewing, altering masticatory patterns as well. This feedback from the oral cavity to the brain creates a loop that modulates force, energy, speed, etc. required to properly masticate and form a bolus (Lund et al., 1998; van der Glas et al., 2007). The action of chewing is controlled by a central pattern generator located in the brainstem, modulating peak amplitudes, force loads and rhythmic movements (Avivi-Arber et al., 2011; Lund et al., 1998; Widmer & Morris-Wiman, 2018). Furthermore, people eat differently and have different mechanism for chewing, resulting in notable differences between consumers making it difficult to collect and compare behavior results. Because of this complexity, relatively few published papers have been published investigating the relationship of masticatory behavior and texture perception. In addition, many of the most comprehensive findings on the relationship between masticatory behavior and texture perception were primarily concerned with age related changes in either variable (Forde & Delahunty, 2002; Kremer, Mojet, & Kroeze, 2007). A recent preliminary study by Pedroni-Pereira et al., looking at objective and subjective (by means of a questionnaire) measures of masticatory function but found no correlation with subjective measures. The objective measures of masticatory function was maximum bite force and two measures of masticatory performance, all of these measures were moderately correlated (2018).

Oral sensitivity has been well documented to decrease with age, along with other forms of mastication performance such as chewing efficiency (Calhoun et al., 1992; Essick et al., 1999; Murphy et al., 2002; Shupe, Resmondo, & Luckett, 2018; Trulsson, 2005; Wada et al., 2017). Uniquely mastication, is key to many food sensations such as texture perception (Brown, Langley, Martin, & MacFie, 1994; Wilkinson, Dijksterhuis, & Minekus, 2000), flavor release (Taylor & Roozen, 1996), flavor perception (Luckett et al., 2016), and bolus formation (Devezeaux de Lavergne, Derks, Ketel, de Wijk, & Stieger, 2015). All of this requires the active breakdown and manipulation of a food product in the oral cavity (Brown et al., 1994; Forde &

Delahunty, 2002). It is thought that as oral sensitivity declines there will be less feedback from the oral cavity to the brain resulting in a less efficient and longer masticatory process. This could result in the use of compensatory strategies used by older populations, such as chewing longer or chewing more in a specified amount of time (K. Kohyama et al., 2002; Mioche et al., 2004).

In general, people have different chewing styles and chewing efficiencies which can lead to different chewing times and swallowing thresholds (Brown et al., 1994; Devezeaux de Lavergne et al., 2015). The reproducibility of mastication measurements obtained is relatively low due to intra-individual differences exhibited by participants, in a study by Remijn et al. chewing duration and chewing frequency showed the best reproducibility while chewing side and other measures were not reproducible when using 3D kinematics and sEMG (2016). It has been shown that chewing time can change a consumer's perception of a food product. Since it is not manipulated for a long duration a soft product will be perceived as harder due to the breakdown process not being fully completed (Brown et al., 1994). The first characteristics of a product would be used for judgements by a fast eater, since later sensory information that a slow eater would have is unavailable to a fast eater (Brown et al., 1994). When comparing slow and fast eaters using soft and hard sausages, it was noted that there was difference in bolus properties at the end of mastication for these two groups (Devezeaux de Lavergne et al., 2015). However, using Temporal Dominance of Sensations (TDS), the first dominate attribute was not different between the fast and slow eaters. Conversely, the attributes did become different between the two groups towards the end of the mastication sequence.

Work has been going on for years on how to link subjective measures (such as those received from a sensory panel during Qualitative Descriptive Analysis (QDA) or TDS) to objective instrumental measurements of food texture properties (James, 2018; Le Révérend, Saucy, Moser, & Loret, 2016). In a study by Révérend et al., seven cereal products were used that had similar fracture force, all of which were perceived differently due to the internal structure (low density/high porosity) of each product (2016). This is why it is so important to use a human observation to translation sensory perception to physical information such as that obtained from texture profile analysis (TPA)(James, 2018; Nishinari et al., 2013). Even using a model food stuff such a gel or agar, there will be melting and saliva incorporation during the end of oral processing and these factors cannot be recreated during TPA.

It would be logical for some of the individual variation in texture perception to be explained by differences in oral sensitivity. Kremer et al. (2007) reported a mild association between oral tactile sensitivity and texture perception, using chewing efficiency of two-color gum, oral stereognosis, and particle size discrimination; olfactory ability was also characterized for the elderly group only. Elderly participants were found to preform significantly worse at the chewing and oral stereognosis tasks but were not different in their ability to distinguish particle size when given two samples and asked to identify the finer sample. However, this study was not solely designed to characterize the relationship between oral sensitivity and texture perception. Therefore, several confounding factors make definitive conclusions difficult. For example, flavor preferences were based on participants olfactory acuity. The participants groups were split at the median, and the experimental groups had a relatively small *n=10* and *12* for good and poor performers, respectively (Kremer et al., 2007). Forde and Delahunty (2002) showed that texture attributes were more important for liking in older participants than in younger participants when looking at liquid, semi-solid, and solid foods. Kremer et al. (2007) investigated the relationship of texture and flavor manipulation with sweet and savory waffles in young and old populations. It was found that older populations had a decreased sensitivity to oral stereognosis but not when discriminating particles sizes, and older populations also exhibited lower chewing efficiency. This agrees with previous research, that not all sensations are influenced the same way during aging. Calhoun et al. (1992) found that vibration and thermal sensations were intact in older populations while two-point discrimination and oral stereognosis showed declines. In a study looking at the effects of mastication on food intake, where chewing cycles was modified to 100%, 150% and 200% of participants normal chews, younger participants had a 10% and 14% decrease in food intake but older participants had no such decline (Hollis, 2018; Zhu & Hollis, 2014).

The purpose of this study is to better understand the relationships between masticatory behavior and oral sensitivity. More specifically, to look for changes in masticatory behavior with differences in oral sensitivity. Secondarily, to quantify the relationship of texture perception and oral sensitivity. Hence, we hypothesize the following:

H_1 High oral sensitivity participants will be more sensitive to texture differences between samples.

H_2 Oral sensitivity will modulate masticatory behavior.

Materials and Methods

Participants

Forty-one participants were recruited for this study. Participants were screened to ensure that they reported a good sense of smell, had no allergies or food restrictions and were not pregnant. Participants were asked to self-report common dental procedures such as root canals, crowns, partial or full dentures. Participants were recruited by their oral sensitivity. Using the test battery outlined in Shupe et al. 2018, in which participants were characterized by oral sensitivity using oral stereognosis, raised and recessed shape identification, and bite force sensitivity. The results of these three measures were compiled and a total score was calculated. This study recruited subjects that scored in the upper 25% of oral sensitivity and those that scored in the lower 25% of oral sensitivity, based on results from Chapter 1. The high sensitivity group contained 20 participants, while the low sensitivity group was comprised of 21 participants (see Table 7 for participant demographics). All participants signed an informed consent and were compensated for their time. This experiment was conducted according to the Declaration of Helsinki for studies on human subjects and approved by the University of Tennessee IRB review for research involving human subjects (IRB #18-04466-XP). The authors declare that they do not have any conflict of interest.

Table 7. Demographics of participants by sensitivity group.

Demographics		Sensitivity	
		Low	High
Age	N	21	20
	Mean	47.8 ± 20.0	37.1 ± 13.4
	Max	70	67
	Min	20	21
Gender	Female	43%	50%
	Male	57%	50%

* Mean values have SD as the error term.

Stimuli

Oral Sensitivity

Oral sensitivity stimuli were previously defined in Shupe et al. (2018), and consisted of oral stereognosis, lingual tactile sensitivity, and bite force sensitivity stimuli.

Confectionaries

Texture stimuli were made using, sucrose (Domino Foods Younkers, NY), glucose syrup (Caulet, Erquinghem-Lys, France), sorbitol (4mular, Irvine, CA), citric acid (SAFC, Switzerland), and water were mixed together and heated using a double boiling system until forming a homogenous solution (Table 8). Three different gelatin bloom strengths (170, 200, and 230 bloom) were used to create texture differences and all were type A gelatin (PerfectaGel, Germany). Gelatin sheets were cut into inch wide stripes and submerged in room temperature water until fully bloomed (approximately two minutes). Then the gelatin was drained, added to the sugar solution, and stirred using a stirring rod until completely dissolved, approximately two minutes. The solution was brought to room temperature (23°C) and strawberry flavoring was incorporated. Then 4.0 g of the solution was poured into each oil coated, hemi-spherical silicone mold (11.2 cm^3) and allowed to harden in a refrigerator (4°C) overnight. Confectionaries were verified for hardness using a TA.XT Plus Texture Analyzer and Exponent software (Texture Technologies Corp. and Stable Micro Systems, Ltd., Hamilton, 102 MA) shown in Table 9.

Table 8. Ingredients used to make confectionary texture stimuli.

Ingredient	**Amount**
Sucrose	200 g
Glucose Syrup	300 g
Sorbitol	15 g
Citric Acid	6 g
Water	232 g
Gelatin [a]	7.5 g
Flavor [a]	112 µl

[a] Gelatin and flavor were both added to 1/8 (75 ml) of the sugar solution, in order to reduce variability of samples.

Jaw Tracking Apparatus

A polycarbonate face-shield (3M^{TM}, Saint Paul, MN) was transformed into an open front clear polycarbonate reference frame, similar to that used by Wilson et al. (2016). A quarter inch black reference line with a white boarder was visible from the front, and a 1/8-inch diameter black dot surrounded by a white boarder was applied to each participant's chin. This would allow software to track jaw movements (Figure 9).

Pre-Screening

The pre-screening process was completed as defined in Shupe et al. 2018, with participants receiving three different tests of oral sensitivity: oral stereognosis, raised and recessed shape identification, and bite force sensitivity. Mastication performance was excluded from this study as discrimination ability and jaw movements were the result of interest. The results from Chapter 1 were used to determine high and low sensitivity, based on the distribution obtained from previous tests the upper and lower quartiles were used. Only those participants that were in the upper or lower quartile continued on to the jaw tracking exercise.

Dental status was self-reported by participants, categorized by 6 levels (*healthy or having filling(s)*, *singular crown*, *singular root canal procedure, multiple crowns and root canal procedures*, *dentures,* and minimal natural teeth with no prosthetics). Those subjects who reported *dentures* or *minimal natural teeth with no prosthetics* were considered notably compromised and were excluded from the study as dental status was not a factor of interest.

Table 9. Hardness and springiness of confectionary samples using a TA.TX Plus Texture Analyzer.

Gummy	Bloom Strength	Hardness (N) ± SE	Springiness (%) ± SE
A	170	2.54 ± 0.23	65.98 ± 4.23
B	190	2.10 ± 0.25	70.03 ± 2.73
C	200	1.68 ± 0.10	77.38 ± 2.53
D	230	1.75 ± 0.09	78.88 ± 2.29

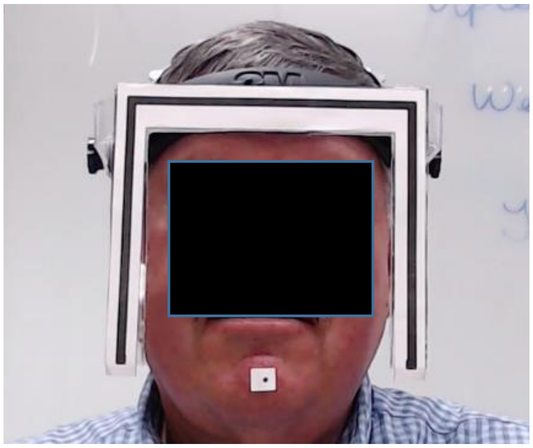
[redacted]

Figure 9. Example of head apparatus and chin marker used to track jaw movements.

Procedure

During the first session, each participant was familiarized with each stimulus and the general tasks to be completed. The presentation of stimuli within each test was randomized, with the overall order of presentation maintained between participants to reduce fatigue. Participants completed one (1) approximately hour-long session with the following serving order; gummy letters (3), shapes, gummy letters (3), shapes, foam, gummy letters (3). Participants were asked to verbally respond with all answers, which were then recorded by members of the research team.

During the second and third sessions, participants were familiarized with video equipment used by the jaw tracking software and the discrimination task they would be completing. Participants were also familiarized with the head apparatus that would be worn during testing and were instructed to place the entire sample in the mouth before chewing. They were also informed of the location of the camera and to look directly into it while chewing samples. Participants were then outfitted with the head apparatus and the chin dot before testing began. Participants were given three triangle discrimination tests, in order to determine sensitivity to texture changes. Through-out testing, participants filled out demographics and a survey about snacking preferences and consumption. Upon completion of the three sessions they were compensated for time participating.

Data Analysis

Data was structured as the number of correct responses each panelist gave for all oral sensitivity measures. In order to determine overall oral sensitivity, the sum of correct responses for lingual sensitivity, stereognosis, and bite force sensitivity tasks was used (Shupe et al. 2018).

Jaw tracking videos were recorded using a Logitech HD Pro Webcam C920. Each video consisted of the chewing sequence of a single sample from the discrimination task. Therefore, each participant produced nine (9) mastication sequences for analysis. The videos were then analyzed using the method defined by Wilson et. al (2016). This method converts a 2D plane into a 3D matrix that will allow for measurements such as vertical and horizontal distances, speeds, velocities, angles, and slopes (see Table 10 for a list of all variables). Instead of the standard 30.0 frame/sec being used to calculate all secondary measures, each individual frame rate from each video was used to calculate distance, speeds, and velocities of jaw movements. These could be specified as jaw opening and closing. Also, chewing cycle shapes (circular, crossed, crescent, and no shape) were also determined as shown in Figure 10. These results of the video analysis were used to determine differences between groups. Two participants were excluded for masticatory behavior analyses due to the poor video quality, these two participants were included in discrimination analyses.

Results were analyzed using R and JMP Pro 13.1 (SAS Institute, Cary, NC), with statistically significant defined as $p < 0.05$. Differences in jaw movement and chewing parameters were examined across sensitivity level and sample by multiple analysis of variance (ANOVAs). In order to verify the assumptions of a T-test for high and low sensitivity groupings, variance was compared using Brown-Forsythe test of unequal variance. Two of the fourteen variable had unequal variance between high and low sensitivity groupings, and a Welch's t-test was preformed to account for the assumptions not being met. Pairwise post-hoc comparisons were performed using Tukey's HSD adjustment, and simple correlations were used to determine associations between measures. To compare masticatory behavior, multiple ANOVAs were run using sample and sensitivity group (high or low) as fixed factors. A multiple logistic regression model was run to identify which mastication behaviors lead to texture discrimination.

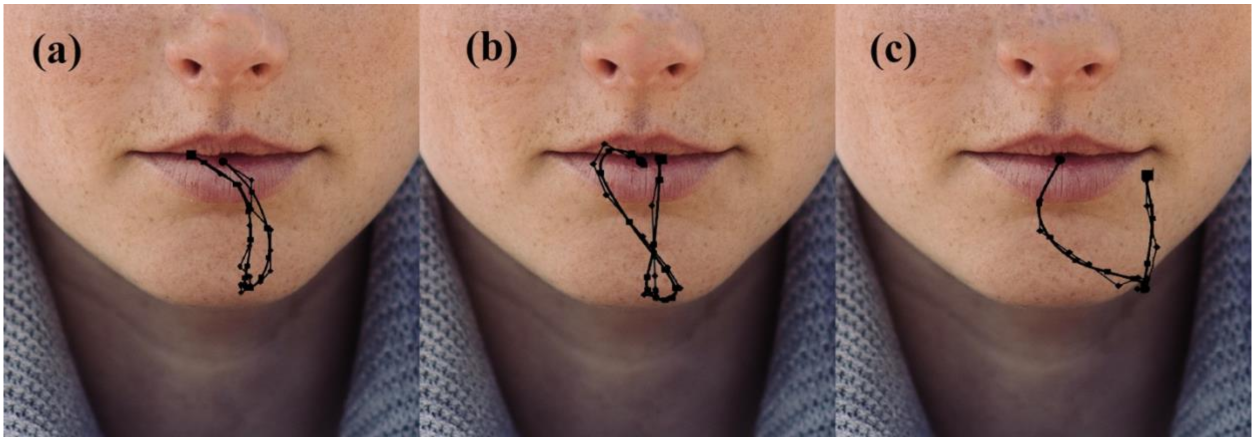

Figure 10. Examples of different known chewing patterns (a) crescent (b) crossed and (c) circular.

Table 10. List of variables extracted from video clips.

Variable Name	**Description**	**Units**
Chews	Total number of chews	chews
Chew Time	Total chewing time	Seconds
Frequency	mean inverse of seconds per chew	chews/second
Close	mean closing distance	mm
CloseV	mean closing speed	mm/second
Open	mean opening distance	mm
OpenV	mean opening speed	mm/second
Width	mean width of chew	mm
Height	mean height of chew	mm
Perimeter Length	mean distance of chew	mm
Crossed Cycle	proportion of crossed shaped chews	-
Crescent Cycle	proportion of crescent shaped chews	-
Circle Cycle	proportion of circular shaped chews	-
No Shape Cycle	proportion of chews with no shape	-

Results and Discussion

Age and Gender

There was not a significant difference in age between sensitivity groupings (X^2_1= 3.31, p = 0.07). There was also not a significant difference in sensitivity groupings between gender (X^2_1= 0.21, p = 0.65).

Sensitivity to Texture Changes

There was not a significant difference in sensitivity to texture changes between high and low sensitivity groupings (p = 0.486), showing that oral sensitivity does not have an effect on the texture discrimination of gummy confections (as shown in Figure 11). Overall participants performed well on this discrimination task, with approximately 40% of all participants correctly identifying the odd sample regardless of sensitivity grouping.

The present results show that as oral sensitivity increases there is no corresponding increase in discrimination ability. It was expected that oral sensitivity would modulate a participant's sensitivity to texture changes. As oral sensitivity increases, the potential for textural information from the oral cavity to the brain also increases, which can be clearly seen when prosthetics are used, since the removal of natural teeth drastically limits the information available to the masticatory feedback loop by excluding the tactile feedback from the periodontal ligament (the main provider of mechanical feedback in the oral cavity) (Trulsson, 2005). It has also been shown that even when physiological declines are present, there is not always a corresponding decline in sensory perception, especially when dealing with dynamic systems.

In the work by Kremer et al. (2007), it was noted that even when sensory declines of oral sensitivity are present in older populations there was not a related perception decrease of texture attributes. Furthermore, this was not the case when there was an olfactory sensitivity decline. This resulted in a decrease in flavor intensity ratings for sweet and savory waffles. It has also been documented that chewing behaviors can influence flavor and texture perception (Brown et al., 1994). Specifically, foods that are firm or rubbery were rated significantly different by groups that exhibited fast and slow eating behaviors (Brown et al., 1994).

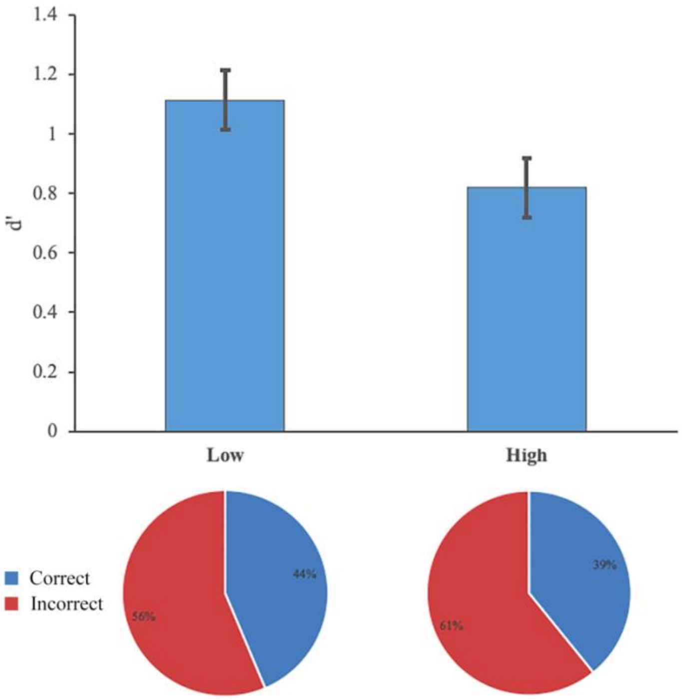

Figure 11. d' for discrimination task for low and high sensitivity groups.

The masticatory process is largely automatic when the task is easy. Similarly, to when you are walking through a familiar area and no extra thought is needed to know where you need to go (Lund et al., 1998; Ottenhoff et al., 1992; van der Glas et al., 2007). But, when you are asked questions about a food product, there is more thought that goes into analyzing the components than normal masticatory patterns, providing enough difficulty in the discrimination task. However, the difference between each sample was too obvious to obtain clear separation based on oral sensitivity levels of each group. A harder discrimination task would give a wider range of ability between participants. Although no relationships were found between oral sensitivity level and sensitivity to texture changes, it was noted that oral sensitivity is a significant factor in explaining the variance between masticatory behavior and chewing patterns.

Mastication Behavior

We were able to verify that the texture modifications received different oral processing and were different enough to extract different parameters despite the ease of the discrimination task. As shown in Figure 12, as the hardness of the confectionary increases so does the total number of chews prior to swallowing ($F_{4,654} = 2.99$, $p = 0.0304$).

Overall masticatory behavior was different across the sensitivity groups with many of the variables having significant differences between the groups. In looking at specific chewing patterns used, crescent and crossed chewing patterns were significantly used more by the lower sensitivity group ($F_{1,656} = 11.86$, $p = 0.0006$ and $F_{1,633} = 11.12$, $p = 0.0009$, respectively), as shown in Figure 13. The high sensitivity group was significantly more likely to use no shape chewing patterns ($F_{1,656} = 22.16$, $p < 0.0001$). Conversely, circular chewing patterns did not differ by age group ($F_{1,656} = 0.04$, $p = 0.84$). This shows the high sensitivity participants, when compared to low sensitivity participants, are much more likely to use novel or unpredictable chewing patterns based on the feedback that is received during chewing.

Further investigations into chewing parameters showed that there were significant differences between sensitivity group's physiological measure of chewing, such as opening and closing distances. High sensitivity participants had a significantly larger opening and closing distance ($F_{1,656} = 12.96$, $p = 0.0003$ and $F_{1,656} = 9.17$, $p = 0.0026$, respectively), as shown in Figure 16. This results in a significantly larger average height and width of chew distance than the lower sensitivity group ($F_{1,656} = 11.72$, $p = 0.0007$, and $F_{1,656} = 8.09$, $p = 0.0046$, respectively).

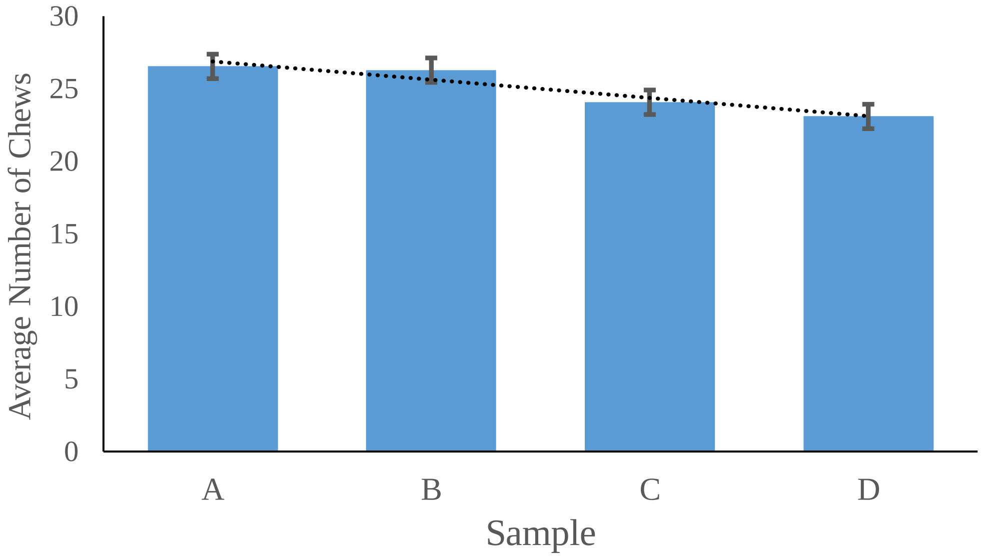

Figure 12. Total chews prior to swallowing for each sample.

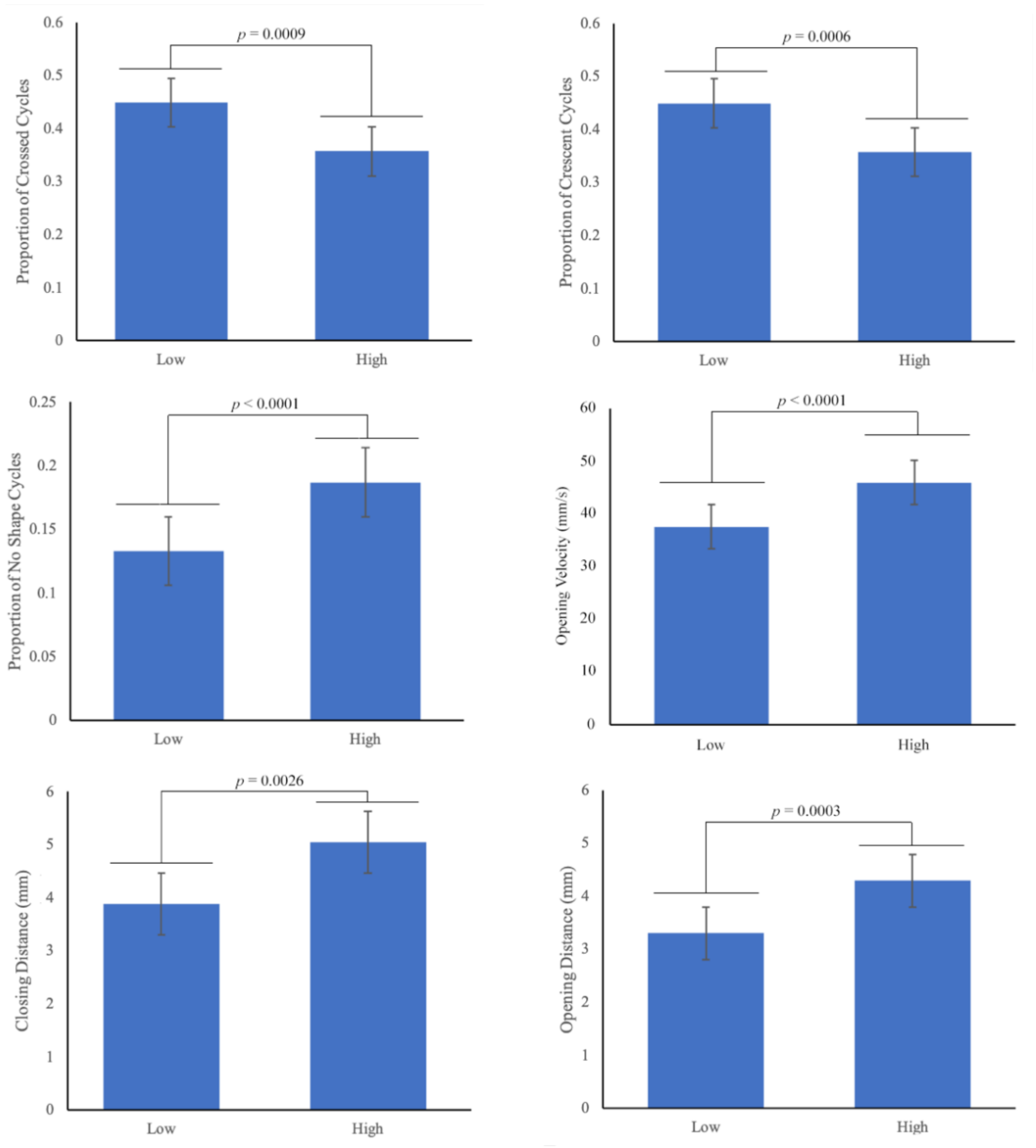

Figure 13. Mean values when comparing low and high oral sensitivity groups.

Overall, the frequency at which high and low sensitivity participants chew (chews/second) was not significantly higher for high sensitivity participants ($F_{1,556}$= 0.68, p = 0.41). The mean opening and closing velocities noted for high sensitivity participants is significantly faster for opening, but not for closing, than that of the low sensitivity participants ($F_{1,657}$ = 28.2, p < 0.0001 and $F_{1,657}$ = 0.74, p = 0.39, respectively). On average a high sensitivity participant's chewing would be described as more exuberant than low sensitivity participants, who have a slower paced more rhythmic chewing cycle, which can be confirmed by the higher proportion of known chewing patterns being used. The finding that high sensitivity participants are more active chewers agrees with previous research (Engelen et al., 2004; K. Kohyama et al., 2003; K. Kohyama et al., 2002). It has been noted in older populations that there is a decrease in oral sensitivity, which can lead to compensatory strategies such as chewing for longer periods of time or chewing more in a specified amount of time (K. Kohyama et al., 2002; Mioche et al., 2004). These same strategies seem to play a role whenever oral sensitivity is not optimal, regardless of age.

It is also of interest that low oral sensitivity participants have a higher variance, when compared to the high sensitivity participants. Three of the variables showed unequal variance by the Brown-Forsythe test. Both the mean opening slope (in degrees) showed significantly higher variance in the low oral sensitivity group when compared to the high sensitivity group ($F_{1,648}$ = 7.41, p = 0.0067). It was also noted that chewing frequency variance was significantly different ($F_{1,657}$ = 46.8, p < 0.0001). In all of these comparisons the low sensitivity group showed a lack of control for these parameters, resulting in large variations in values from this group. As previously mentioned, this lack of control could be a result of a lack of feedback from the oral cavity due to a loss in sensitivity, which would result in a lack of confidence and potentially slower jaw movements.

Confidence is commonly studied with sport and motor movements, but the same theory can be applied here. There are two factors involved when developing confidence in movements, competency of the jaw muscles themselves and movement sense (or the expected sensory experience when that muscle is moved) (Griffin & Keogh, 1982). Jaw muscles and teeth have the potential to do harm; therefore, these movements need to be closely monitored in order to be confident when chewing. If a person's ability or senses are lacking, this would result in a lack of movement confidence in the jaw bite (Griffin & Keogh, 1982). Slower jaw closing velocities were noted in both groups, when potential damage could occur in the oral cavity (i.e. clashing of teeth, biting lips/tongue). The low sensitivity group was significantly slower when opening the jaw as well, which has significantly few hazards when compared to closing showing a potential lack of confidence. The same speed increase was also noted in cognitive experiments, in a study looking at decision speeds and reported confidence (Geller & Pitz, 1968). As participants became more confident in their decisions, their decision speed also increased.

It was also noted that masticatory behaviors were slight difference between genders. Females overall, regardless of sensitivity level, had a faster opening velocity ($F_{1,660} = 10.18$, $p = 0.0015$), while males had a faster closing velocity when compared to females ($F_{1,660} = 6.69$, $p = 0.0099$). There was also an interesting trend with the low sensitivity females using significantly lower proportion of no shape chewing cycles ($F_{1,660} = 24.43$, $p < 0.0001$) and also a higher proportion of crossed chewing cycles when compared to all other groups ($F_{1,660} = 50.64$, $p < 0.0001$). Although these results are not conclusive due to the small sample size that each group (low sensitivity: male n =10 and female n=10; high sensitivity: male n=12 and female n = 9), these results are supported by previous work (de Oliveira Scudine et al., 2016). A study by de Oliveira Scudine et al. showed that boys had a higher maximum bite force and depended more on their larger muscle capacity resulting in a higher masticatory performance; while for girls masticatory performance was based on chewing cycle patterns and overall chewing frequency (2016). Another study by Kohyama et al., was conducted solely with women in order to account for these potential gender differences in masticatory behavior (2016).

Limitations

Participants were instructed on how to perform the task prior to recording, some previously discouraged actions were still preformed and had to be corrected through-out testing. Due to the nature of video recording, in order to keep mastication as normal as possible the researchers did not intervene during a discrimination task. This would result in a loss of more data through talking or other unnatural movements. Therefore, any modification that needed to be made to a participant's behavior (i.e. moving hands from view, not swallowing between samples, etc.) were discussed between triangle testing. This resulted in some jaw tracking data not being able to be analyzed (e.g. chews were cut off or missed, the reference corners were not visible).

Conclusion

Our results show that there are notable differences between the masticatory behaviors of high and low oral sensitivity groups, but there is no such relationship between sensitivity to texture changes and oral sensitivity level. The lower sensitivity group tended to have higher levels of intragroup variance in mastication parameters than the high sensitivity group. High sensitivity participants were also more likely to use novel chewing patterns based on the feedback that is obtained during oral processing. Further research is required to quantify the relationship between oral sensitivity and texture discrimination utilizing a more difficult discrimination task.

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CONCLUSION

Overall, our results show that multiple factors contribute to oral sensitivity and texture perception, resulting in the need for a battery of tests measuring multiple aspects of oral sensitivity and a method to account for individual differences between consumers for mastication behaviors. When using a soft test food, there is a relatively small relationship between physiological factors and masticatory performance. This is believed to highlight the automaticity of the chewing process. Lingual acuity and stereognosis appear to be the most reliable measurements, while bite force sensitivity did not show any relationship with oral sensitivity or masticatory performance and did not differ with age.

When applying these principles to a dynamic food system our results show that there are notable differences between the masticatory behaviors of high and low oral sensitivity groups. There is no such relationship between sensitivity to texture changes and oral sensitivity level when using a dynamic food system, showing that even when sensory declines are present in a population, there is not always a decrease in sensory perception. Also, the lower sensitivity group tended to have higher levels of intragroup variance in mastication parameters than the high sensitivity group. Proving that the low sensitivity group does not exhibit the same movement confidence as the high sensitivity group, resulting in slower more cautious movements. High sensitivity participants were also more likely to use novel chewing patterns based on the feedback obtained during oral processing in order to maximize their chewing efficiency. Low sensitivity participants relied on crescent and crossed patterns while chewing.

Further research is required to quantify the relationship between oral sensitivity and texture discrimination utilizing a more difficult discrimination task, in order to remove the influences of mastication being an automatic cycle. Therefore, allowing for more variation between participants, making mastication easier to categorize. Furthermore, the tongue's contribution to mastication performance appears to be an important factor in mastication, showing that tongue movements or force may be a key physiological measure in future studies. While novel techniques such as bite force sensitivity and monofilaments may still lead to viable research. Overall this research has highlighted the impact that oral sensitivity can have on mastication and potential texture perception.

VITA

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