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INVESTIGATING DIFFERENCES IN ORAL SOMATOSENSATION AND VISCOSITY PERCEPTION

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ABSTRACT

Viscosity, the extent to which a fluid resists flow, affects the perception and liking of many foods and beverages. However, the mechanism of human perception of viscosity in the mouth is poorly understood. This study involved measuring oral touch perception and oral viscosity perception to determine if there is any relationship between the two. Detection and discrimination threshold estimates of oral point pressure were measured on the midline superior surface of the tongue just posterior to tongue tip for each participant. Discrimination threshold estimates were determined with commercially available Von Frey Hair monofilaments, while commercially available Cochet-Bonnet Aesthesiometers, which deliver less force, were used to determine detection threshold estimates. Model solutions of maltodextrin were used to assess differences in viscosity perception. Using known Weber fractions, pairs of solutions were formulated, such that viscosity differed by 10% above the Just Noticeable Difference (JND). Participants were presented with the pairs of solutions in a 2-AFC format and asked to identify the thicker of the two solutions.

Despite the lower amount of force provided by Cochet-Bonnet Aesthesiometers, I observed a floor effect for detection threshold estimates: there was very little variance in the data as nearly all participants could detect the lowest available test stimuli. Therefore, the discrimination threshold estimates were used for remaining analyses. Point pressure discrimination threshold estimates showed sufficient variance to allow separation of participants into high and low discrimination groups, similar to prior work. However, when the viscosity discrimination results of these two groups were analyzed with Fisher’s exact tests, there was no evidence to suggest that oral point pressure discrimination ability was associated with viscosity perception. For the low series viscosity samples, of the group with better oral acuity, 16 of 26 (61.5%) correctly identified the more viscous sample, while the group with less oral acuity had 24 of 34 (70.5%) correct identifications. This difference was not significant at a p-value of 0.05. Similar results were observed for the high series viscosity samples, with 14 of 26 (53.9%) correct identifications by those with better oral acuity and 17 of 34 (50.0%) correct identifications by the less acute individuals. These data suggest mechanisms of viscosity perception are not related to phenotypic differences in oral somatosensation when using point-pressure assessments. Future work is needed to develop a more sensitive and verified instrument that may yield more conclusive results in regard to detection thresholds. Also, it may be beneficial to explore roughness discrimination, as it may provide a better indication of an individual's ability to distinguish viscosity.

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Chapter 1

Introduction

Viscosity affects the perception and liking of many foods and beverages. However, the mechanisms involved with oral perception of viscosity are poorly understood. The present work was performed in an effort to better understand the relationship between human somatosensory function on the tongue and the detection of viscosity. While viscosity is a complex property, it is often thought of as a physical property of a liquid that is fundamentally related to texture perception. In a previous study conducted by Breen, texture perception of food, specifically grittiness, was correlated with oral point pressure discrimination thresholds (Breen 2018). The rationale behind the present experiment is to examine participants' point pressure sensitivity on the tongue tip and to investigate how differences in tactile sensitivity in this area might affect the detection of viscosity in solutions. Inspired by the prior work by Breen, we hypothesized that participants with more acute lingual somatosensory function would be better at identifying maltodextrin solutions that differed in viscosity.

Viscosity

Viscosity is defined as, "the internal friction of a fluid or its tendency to resist flow". However, it is often referred to as 'thickness' by the average consumer. Common consumer terms used for viscosity usually range from thin to viscous. Viscosity is closely related to texture, though a simple distinction is that texture applies to solids, while viscosity applies to fluids (See Food Texture and Viscosity, 1982 for a review). Although this seems simple, there are a fair number of foods that don’t fit the solid/liquid binary, such as liquid foods that may exhibit intermediate properties between solids and liquids. One example is ketchup, which generally resists flow unless a certain amount of sheer is applied. For the purpose of this study, viscosity was solely considered to be a property of liquids and near-liquids. However, due to the fact that most research available regarding consumer preferences and perception is on food texture rather than liquid viscosity, much of the background reviewed here considers both food texture and liquid viscosity.

Choices based on viscosity perception occur in many facets of our lives: personal care products, as well as foods and beverage. Viscosity can be the reasoning behind choosing a particular lotion, yogurt, or even chocolate milk. The reason viscosity is so important to food and beverage is that it often influences preference and liking, and therefore selection or choice. According to Cardello, “while flavor is commonly found to be the most important sensory factor responsible for the liking of many foods, texture is often cited by consumers as the reason for not liking certain foods. This is especially true for foods the texture of which may be observed as creating a lack of control in the mouth, e.g., foods with sticky, soggy or slimy textures” (Cardello 1996). Slight differences in viscosity may be the difference between acceptance and rejection by consumers. When developing new beverages and food products, it is vital to understand consumer perception of viscosity. Despite being so important in the acceptability of a food or beverage, very little is known about the oral perception of viscosity. In fact, to the best of our knowledge, no work has been done to measure the relationship between human somatosensory function on the tongue and the detection of thickness in solution.

Physical properties of texture can be measured instrumentally, such as resistance to flow and yield stress. However, measures of physical properties don’t tell us much about the consumer perception of these properties. Understanding the relationship between instrumental and sensory evaluation of texture and viscosity is a very important step in fully comprehending the perception of those properties. Further understanding can lead to the development of quality control instruments, improve the ability to predict consumer liking and acceptability of new products, and could even optimize instrumental measures to mimic or complement sensory evaluation (Szczesniak 1987).

Oral perception of foods is difficult to understand, especially when it comes to viscosity. This is because liquid and near-liquid foods are squeezed between the tongue and palate when eaten. Therefore, the perception of the texture and thickness is closely related to the food's rheological behavior as a thin film flowing between the tongue and the roof of the mouth. One study determined that instrumental texture measures, if adjusted to roughly match conditions those found in the oral cavity, can predict human texture perception based on the shear rate, which was obtained from the apparent viscosity (Kurotobi et al. 2018). However, this study was limited in scope, testing only pectin thickened strawberry jam. According to Conti-Silva, studies have been conducted with intent to predict texture and mouthfeel perception of food by using rheological properties (Conti-Silva et al. 2018). Unfortunately, the results have been inconclusive and contradictory. Substantial work remains to be done on the topic of viscosity perception, especially with regard to psychophysics and oral somatosensation.

Psychophysics

Psychophysics is the study of the relationship between energy in the environment and the sensory response to that energy (Lawless 2013). The human body is constantly bombarded with stimuli from the outside world which is detected by mechanoreceptors on the body. This information is sent to the brain and interpreted as information, where cognitive perception occurs. This experiment, in particular, involved measuring touch sensations on the tongue in order to determine psychophysical thresholds. Psychophysical thresholds are a way of measuring and defining sensory functions. Thresholds are boundary values that separate stimuli eliciting one response from stimuli eliciting a different or no response (Woodworth et al. 1971). Thresholds can be measured experimentally in a number of ways depending on the application of the stimulus and the sensory acuity of the participant. Common threshold tests, based on the signal detection theory (SDT), involve the subject detecting whether a target stimulus is present or not in comparison to a blank stimulus. The stimuli and the blank trials should be presented normally distributed with equal variance (Orellana-Escobedo et al. 2012). When the participant correctly detects the stimuli, it is considered a hit, while incorrectly identifying the stimuli when the blank is present is a false alarm. Another important consideration with the SDT, is noise. Noise can be background stimuli or random activity that makes it hard to discern the test stimuli. Analysis is done based on false alarms, hits, possible noise, and even severity of decision criteria to understand and define the thresholds. For this particular study, we were focused specifically on detection and difference threshold estimates.

The absolute detection threshold is the lowest level of the stimulus that is detectable by that person (Gescheider 1997). The discrimination threshold is considered to be the smallest difference between two stimuli that the participant is able to detect. Detection and discrimination threshold estimates can both be determined using the ascending forced choice method of limits. For detection thresholds, the subject must choose the target stimulus from other presented blank stimuli. Discrimination threshold estimates involve require participants to distinguish between stimuli pairs of increasing intensity (Gescheider 1997). Detection and discrimination thresholds can be used in industry for a number of purposes. For example, these thresholds can determine the level of an ingredient can be detected by consumers, whether it is a positive flavor compound or a defective off-flavor. Thresholds have been used to study the pungency of chili peppers (Orellana-Escobedo et al. 2012). This is also valuable when considering possible cost savings and other formula changes.

Discrimination thresholds are considered to be a type of difference threshold. Difference threshold testing is used in all industries to access perceivable differences across a variety of human senses. In literature, the difference threshold is often used interchangeably with the Just Noticeable Difference (JND) (Lawless 2013). The JND is defined as the smallest change that can be detected between two stimuli. For example, two beverages may be perceived as having the same viscosity though they aren’t identical. This could be due to the fact that the difference in viscosity between the two samples is too small to be perceived. If the JND values are known for a particular stimulus, they can be used to calculate the corresponding Weber Fraction. The Weber Fraction (K) is an index of the sensitivity of the sensory system to detect changes of a certain stimulus (Camacho et al. 2015). Weber’s law states that the larger the stimulus, the larger the change required to be noticeably different. The value generated by Weber’s law is often called the Weber Fraction (K) and demonstrates the ability of the sensory system to detect changes (Lawless and Heymann 2010). Knowledge of a stimuli’s Weber Fraction provides vital information which allows for comparison of sensory discrimination across different stimuli and modalities (Breen 2018).

Oral Somatosensation

Orofacial somatosensory inputs in humans are necessary for speech and swallowing and therefore, may play a role in viscosity detection mechanisms. Perceived viscosity depends on nerve signals and sensitivity as well as the physical structure of the food or beverage. Despite the importance of oral touch and perception for liking and preference, it remains poorly understood, especially when compared to the understanding of taste and smell, or touch with hands.

Minimal work has been performed to measure human somatosensory input in the lingual region, especially in relation to the detection of viscosity. One exception is recent work by Breen, who completed a study on the relationship between human somatosensory function on the tongue and the detection of particle size in a real food, chocolate (Breen 2018). Although Breen's study was focused on texture in solid foods, rather than viscosity, it did establish a connection between point pressure threshold estimates and perceived particle size (Breen 2018).

Breen's study was completed using Von Frey Hair (VFH) monofilaments to estimate discrimination threshold estimates for oral point pressure sensitivity. The use of VFH monofilaments allowed Breen to measure applied point pressure from 8mg to 10g (Breen 2018). Here, a Cochet-Bonnet Aesthesiometer was used in addition to VFH monofilaments. Cochet-Bonnet Aesthesiometers are similar to the Von Frey Hair Monofilaments conceptually, but they are theoretically much more sensitive, as they delivery less force. While Cochet-Bonner Aesthesiometers are designed to clinically evaluate the cornea for neurotrophic keratopathy, ultimately, they still measure applied point pressure (Legault and Bernfeld 2015). In Breen's 2018 study, the majority of healthy young adult participants were able to detect the Von Frey Hair monofilaments at or below the second lowest stimulus level (0.02 grams of pressure) yielding no meaningful data from his detection threshold measurements (Breen 2018). Here, I used Cochet-Bonnet Aesthesiometers to expand the range force tested to more accurately measure point pressure detection thresholds on the tongue.

Aims and Objectives

The main objective of this experiment was to measure oral touch perception and its relationship to oral viscosity perception. To complete our primary objective, a pilot study on viscosity perception was conducted to determine the appropriate viscosity levels of the stimuli for use in the main study. Second, for the main study on oral pressure point sensitivity and viscosity test, participants' detection and discrimination threshold estimates were measured, as well as their ability to distinguish the chosen viscous solutions. Analysis was conducted to determine the relationship between these measurements. I hypothesized that by grouping individuals into high and low oral touch acuity groups, as Breen did for grittiness, there would be a difference in ability to discriminate beverages viscosities.

Chapter 2

Solution Viscosity Perception Pilot Study

A pilot study was conducted on the model solutions in order to determine if the viscosity levels of the stimuli were distinguishable enough to continue with testing. The criteria for making this decision is explained in the discussion below. We were aiming for solutions that could be distinguishable by the group as a whole, however, still close enough to one another that they could be mistaken by some panelists. This hopefully would lead to a test that could distinguish those with high oral acuity from those with low oral acuity.

Materials and Methods

Participants of the viscosity pilot study were recruited from the Penn State Sensory Evaluation Center (SEC) participant databases. They had all previously opted to be contacted about studies on taste and flavor research and were all residents of State College, PA and the surrounding area. Inclusion criteria included:

1. Not pregnant or nursing
2. Nonsmoker (including Vaping and E-Cigarettes)
3. 18-45 years of age
4. Fluent in the English Language
5. No known food or spice allergies
6. No known defect of smell and taste

7. No history of choking or difficulty swallowing
8. No speech disorders, craniofacial anomalies, and/or neurological disorders
9. No tongue, cheek, or lip piercings
10. No history of chronic pain
11. Not currently taking prescription pain medication
12. Not currently using medications known to alter taste or smell function
13. No symptoms of Tardive Dyskinesia
14. Not currently ill with a chest cold, flu, or other respiratory condition that could affect sense of taste or smell
15. No history of viral illnesses such as Bell's Palsy or Shingles
16. No injuries to the lower face region in the past 3 months
17. No visits to the dentist that involved general or local anesthesia in the past month

Seventy-two participants met the study recruitment criteria and were scheduled for a single visit to the in the Sensory Evaluation Center in the Erickson Food Science Building at The Pennsylvania State University. Participants were asked not to eat or drink for at least 1 hour prior to their scheduled session. Of the 72 recruited (33 males and 39 females), only 50 participants actually attended the session, which included 25 males and 25 females.

After arrival, participants were seated in individual sensory booths. The test took about 15 minutes and was completed on October 12th, 2018. Participants provided informed consent and received financial compensation for their participation. Research was approved by the Penn State Institutional Review Board [protocol #00010516].

Participants of the viscosity pilot study were provided with six samples of model solutions at four different viscosity levels. The model solution chosen for this study used maltodextrin as a thickener. This was used because it is food-grade, easy to make at the lab bench, and is easy to control the viscosity. This solution consisted of various amounts of Roquette 6DE Maltodextrin, (with a reported dextrose equivalence of 5.0) and distilled water; 200 ppm vanillin was also added to further mask slight differences in sweetness, and to make the solutions more palatable for the panelists (Camacho et al. 2015). To minimize any effects of alpha-amylase levels on the breakdown of maltodextrin, all participants followed the same protocol during the evaluation stage. They were all asked to hold each solution in their mouth for 5 seconds before spitting, to allow time to evaluate the viscosity (Camacho et al. 2015). Camacho and colleagues reported various formulations of maltodextrin solutions, their measured viscosities, and their Weber Fractions (Camacho et al. 2015); these published values served as the basis for stimuli in the present study. Calculations and sample formulations can be found in Appendix A.

Participants in the pilot study received three sets of the model solutions. The first pair was made up of samples that differed greatly in terms of viscosity. This was our "warm-up" pair to ensure that participants were familiar with both the procedure and the stimuli before proceeding. These two samples were at viscosity levels of 25 mPa*s and 95.62 mPa*s – i.e., the least viscous and the most viscous samples that were prepared. It was expected that all of participants would be able to accurately identify the thicker sample in the pair without difficulty. Data from this series was excluded from analysis, as it was intended as a warmup. The next two pairs contained our test stimuli. One was a low series and one was a high series, in terms of viscosity, in case there was range specific effects for viscosity perception. For these two pairs, a maltodextrin solution of a known viscosity was selected and then paired with a maltodextrin solution that was more viscous by 10% more than the JND. This level above the JND was chosen as it was expected that the pairs would be discernible by slightly more than half of the participants. This resulted in a low series of 25 mPa*s and 35.2 mPa*s, and a high series of 75 mPa*s and 95.62 mPa*s. The JND calculations were conducted with previously published Weber Fractions from (Camacho et al. 2015), and can be found in Appendix A.

Solutions were prepared by following published methods (Camacho et al. 2015). Briefly, maltodextrin and vanillin were gradually added to room temperature distilled water on a stir plate until the solution reached a uniform consistency. The solutions were prepared in single batches and then poured, 10 mL at a time, into 1-inch diameter, lidded medicine cups that were labeled with 3-digit blinding codes. These samples were stored in a refrigerator overnight and removed at least 1 hour prior to testing to allow the solutions to return to room temperature.

After consenting to the study, participants received the three pairs of maltodextrin solutions in order of warm-up pair, low series pair, and then high series pair. Participants were first presented with a definition of the term thickness: “Thickness is the degree to which the fluid resists flow under an applied force in the mouth. Consider for example, 3 fluids: water, a smoothie, and honey. Water has the lowest thickness, a smoothie is thicker than water and honey is the thickest fluid of all 3” (Camacho et al. 2015). Here, the term ‘thickness’ was used instead of ‘more viscous’, as it is a more consumer friendly term. The participants were then provided with detailed directions and asked to identify the thicker sample of each pair in 3 separate paired comparisons (2-AFC test). The order of the pairs was fixed, but within a pair the order of the samples was counterbalanced. Participants were instructed to assess the samples by taking the first one of the pair completely into their mouth and swishing it around for 5 seconds. They then spit into the provided spit cup, rinsed with water, spit again into the spit cup, and repeated with the next sample. After this, the participants indicate which the sample they believed was thicker, and then had a forced 30-second break before assessing the next pair (Camacho et al. 2015). The session ended when participants finished all three comparisons.

Results

This pilot study tested the ability of the participants to distinguish viscous solutions that differed by 10% more than the JND. Forty-nine out of the 50 participants accurately selected the more viscous sample in the warm-up series, which compared 25 mPa*s and 95.62 mPa*s. It was expected that all of our participants would be able to distinguish these two and this series was mainly just to familiarize them with the process. Therefore, the warm-up data was not used in subsequent analysis. For the low series, 25 mPa*s versus 35.2 mPa*s, 41 of 50 participants identified the correct sample, a p-value of 0.000012. For the high series, 75 mPa*s and 95.62 mPa*s, 40 of 50 participants identified the correct sample, a p-value of 0.000041. The panelists for this study were young nominally healthy adults without oral pathology. However, nothing else was known about these individuals or their oral point pressure sensitivities.

Discussion

The purpose of this pilot study was to validate sets of maltodextrin solution pairs that should work well for our main oral point pressure study. We were looking for stimuli that were distinguishable by the group as a whole, but not by all participants. The results of this pilot study were collected from a sample of young, nominally healthy adults. Due to the fact that ~80% of participants got both the high and low series correct, I considered these stimuli to be appropriately difficult to proceed with the main study. The goal for the solution pairs, with a viscosity difference of 10% above the JND, was for a little more than 50% of average healthy individuals to be able to accurately distinguish them. I did not collect any data on these participants' oral point pressure thresholds (as this was a pilot study) so there was no way to know the breakdown of this selected group in terms of high or low oral acuity.

Chapter 3

Quantification of Oral Point Pressure Sensitivity and Relation to Solution Viscosity Perception

Sixty healthy adults completed the oral point pressure assessments and solution viscosity portion of the main study. This was done in an effort to observe a relationship between lingual tactile sensation and solution viscosity perception. Here, Von Frey Hair (VFH) monofilaments were used to measure lingual point pressure discrimination thresholds and Cochet-Bonner Aesthesiometers were used to determine the detection thresholds. The goal was to correlate the lingual tactile threshold estimates to the participant's ability to distinguish the viscosity of solutions that differed in viscosity by amount slightly above the JND. All data were collected one-on-one at the Erickson Food Science Building in a windowless examination room. Data were collected using Compusense Cloud software (Guelph, ONT, Canada) and analyzed by dividing participants into high and low oral acuity groups based on oral point pressure discrimination. Fisher's exact tests were used to compare the ability of those two groups to distinguish the viscosity of the model solutions. It was predicted that the high oral acuity group would be able to distinguish the model solutions significantly better than the low oral acuity group. Those results would demonstrate a relationship between oral point pressure sensitivity and viscosity perception.

Materials and Methods

For the main study on oral pressure point sensitivity and viscosity perception, the same screening criteria and procedure as in Chapter 2 were used. A total of 60 participants (24 men and 36 women), met the study inclusion criteria and were scheduled for a one-on-one appointment with the experimenter. Participants were asked not to eat or drink for at least 1 hour prior to their scheduled session. All testing was conducted in a windowless examination room in the Erickson Food Science Building at The Pennsylvania State University. Testing took ~ 30 minutes and was completed over the course of three weeks in November and December 2018. Participants provided informed consent and received financial compensation for their participation. Research was approved by the Penn State Institutional Review Board and conducted under protocol #00010516.

The viscous stimuli used in this study were identical to those prepared in Chapter 2, as the pilot study suggested these viscosity levels would work well for the study objectives. The samples were prepared each Monday for that week's testing sessions, which occurred Tuesday through Friday. The samples were stored in lidded medicine cups in the refrigerator and removed at least 1 hour prior to testing to allow them to come up to room temperature (~20C).

During testing, participants were seated in a comfortable and relaxed position in a private exam room in the Erickson Food Science Building. At the beginning of each session, the participant answered standard demographic questions including age, date of birth, handedness, and gender. This portion also included questions about history of diabetes, use of insulin, past speech problems, tobacco usage, musical instruments played, and whether they have had a lower face injury or any neurologic injury such as a stroke or concussion. They were also asked to comment on their general health by providing a rating on a five-point scale, with 1 being poor and 5 being excellent. Participants identified their current level of speech on a five-point scale with the higher numbers corresponding to increased average speech use (Baylor et al. 2008).

At this point, lingual tactile detection threshold estimates were collected using a Cochet-Bonnet Corneal Aesthesiometer; according to documentation from the manufacturer, these provided a range of pressure from 0.4g to 15.9g/mm^2 (Luneau Cochet-Bonnet Aesthesiometer, Western Ophthalmics Corporation, Lynnwood WA). Cochet-Bonnet Corneal Aesthesiometers were used to determine detection of the lingual region, as they are similar to Von Frey Hair monofilaments, but can presumably provide a lighter force range. Previous research has shown that the majority of healthy young adult participants are able to detect the Von Frey Hair monofilaments at or below the second lowest stimulus level (0.02 grams of pressure), as reported by Breen (2018) and Etter et al. (2017). Therefore, Cochet-Bonnet Aesthesiometers were used with the hopes that participants would have detection thresholds at or above the lowest force level, resulting in meaningful and variable detection threshold estimates.

Detection threshold estimates were determined using a two-alternative forced choice (2-AFC) task where participants were instructed to choose which of the two sequentially presented observation intervals contained the stimulus. The researcher would say, “trial one” and “trial two” in which the stimulus was randomly presented in only one of those trials. The participants were then instructed to hold up one or two fingers depending on the trial they felt the stimulus. All participants started at the same level of pressure on the Cochet-Bonnet Aesthesiometer, 15.9 g/mm^2 (a fiber length of 0.5 cm). If participant gave three positive consecutive detections, the researcher decreased the Cochet-Bonnet Corneal Aesthesiometer to the next level (10.3 g/mm^2, a fiber length of 1 cm). One negative detection, or missed response, and the researcher increased the grams/pressure to the next level. The stopping point for this assessment was considered 5 crossings or reversals of a given level, or six in a row correct at the lowest level (i.e., 0.5^6 = p of 0.0156). The threshold detection values were calculated as the grand mean of those five reversals or the six correct at the lowest level. No feedback was given during assessment. Participants were allowed to rinse with water at any point during the testing period.

After detection thresholds were assessed, participants were given a three-minute break enforced by the experimenter before discrimination threshold testing began. Discrimination thresholds were obtained with Von Frey Hair monofilaments nominally ranging from 0.008 grams of pressure to 15 grams, according to documentation from the manufacturer (Aesthesio® Precision Tactile Sensory Evaluators, DanMic Global LLC, San Jose CA). Von Frey Hair monofilaments were used here as they are widely used to measure point pressure sensitivity and are proven to be highly reliable and sensitive when using a three-down one-up forced choice staircase procedure (e.g., (Tracey et al. 2012)). For the discrimination threshold estimates, the Von Frey Hair monofilaments were used, as work by Breen yielded significant data in the pressure range of the VFH (Breen 2018). A similar method to the detection threshold procedure was used for discrimination thresholds; it was modified in that participants were told that they would feel pressure in both trials. They were instructed to indicate, using one or two fingers, which trial had the "stronger" or "harder" pressure. Participants started discrimination trials at 0.07g (the 4th VFH in the set). The same determinations for correct, incorrect, and stopping points were used as above. Both detection and discrimination assessments were completed on the center (medial) edge of the tongue tip. All assessment equipment was cleaned immediately after completing testing with a participant and a second time prior to testing on a new participant. This was done using paper towels and a 70% solution of USP grade ethyl alcohol. All responses and threshold data were collected and recorded on paper ballots that were coded with a participant code for confidentiality. After testing, data were compiled and entered into Microsoft Excel for further analysis.

At this point, participants assessed three sets of the food-grade maltodextrin solutions. The preparation and procedure as this point was identical to that in Chapter 2; briefly, the participants were asked to indicate which sample is thicker within a pair of samples in a 2-AFC task. The only difference was that Compusense was accessed via a touch screen iPad, rather than a desktop computer with a mouse, as this testing occurred one-on-one in a private exam room.

Results

Oral point pressure detection threshold estimates were measured on the center of the tongue tip in 60 participants. Fifty-nine of the 60 participants were able to accurately detect stimuli at the lowest available test stimuli (0.4 g/mm^2) during the detection threshold measurements with a Cochet-Bonnet Corneal Aesthesiometer. Similar to prior work by Breen (2018), the majority of healthy young adult participants in this study were able to detect the lowest available test stimuli on the tongue tip. The very low detection threshold estimates observed in this study, here, may be due to a limitation in the assessment equipment. This is discussed further below in the limitations section. Still, given the lack of variance in the present detection threshold data, I could not meaningfully test our hypothesis.

Oral point pressure discrimination thresholds were also measured at midline on the tongue tip in the same 60 participants. As expected, they demonstrated substantial variance in lingual discrimination threshold estimates, so these discrimination thresholds estimates were used for subsequent analyses.

A histogram of discrimination threshold estimates, from Von Frey Hair monofilament data, was created to visualize the variance across participants: based on a clear bimodal distribution, I split the individuals into groups using the antimode of 0.04g. This classification puts 26 people in the higher sensitivity group, with discrimination thresholds of 0.02g, while the remaining 34 participants are in the lower sensitivity group with thresholds above 0.05g.

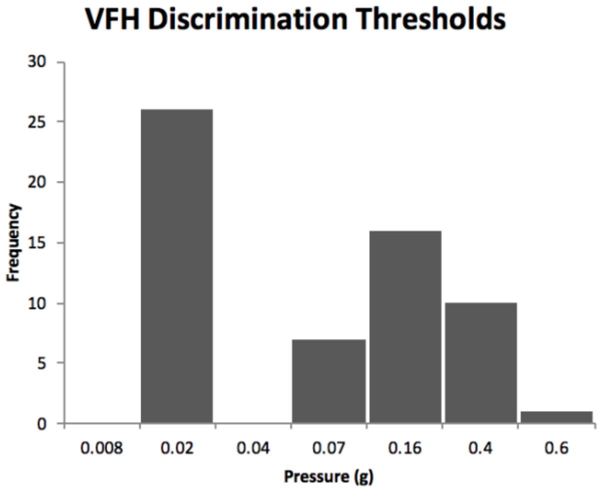


Figure 1: VFH Discrimination Threshold Estimates

Next, the maltodextrin discrimination data was analyzed with respect to the high and low sensitivity groups. For the low series, 25 kPa*s versus 35.2 kPa*s, the more discriminating, higher sensitivity group had 16 correct and 10 incorrect answers. The less discriminating, lower sensitivity group had 24 correct and 10 incorrect answers. These results were analyzed with a Fisher's exact test, which can be found in Appendix B. The resulting p-value was 0.58, meaning I observed no evidence to suggest that lingual discrimination thresholds estimates were associated with viscosity perception for our low series.

For the high series, 75 kPa*s versus 95.6 kPa*s, the more discriminating, higher sensitivity group had 14 correct and 12 incorrect answers. The less discriminating, lower sensitivity group had 17 correct and 17 incorrect answers. These results were analyzed with a

Fisher's exact test, which can be found in Appendix B. The resulting p-value was 0.80, again demonstrating that there is no evidence to suggest that lingual discrimination threshold estimates were associated with viscosity perception.

Discussion

This study was done in effort to understand potential relationships between oral point pressure sensitivity and viscosity perception. First, a Cochet-Bonnet Aesthesiometer was used to measure oral point pressure detection thresholds. The next step involved using Von Frey Hair monofilaments to measure oral point pressure discrimination thresholds. A series of comparisons were run to determine if the oral point pressure thresholds were related to the viscosity perception of maltodextrin solutions. The purpose of the present study was to improve knowledge of viscosity perception in humans.

There was minimal variation in the detection threshold measurements, most likely due to the fact that participants were young, healthy adults and the majority could detect the lowest available stimuli, similar to prior work by Breen (2018). Conversely, due to the bimodal nature of the discrimination thresholds, the participants could be divided into two groups based on oral acuity. These groups of participants showed a range of individual differences in ability to discriminate oral point pressure on the center tongue tip. The higher sensitivity group was defined as the 26 individuals with discrimination thresholds of 0.02g. The lower sensitivity group was defined as the 34 individuals with discrimination thresholds of 0.05g and above.

Model solutions of maltodextrin were formulated to specific viscosity levels to assess viscosity perception and discrimination ability. The samples were presented in pairs. The first pair was just to ensure understanding of the procedure, inspired by the warm-up series employed by Camacho et al. (2015). It was expected that nearly all of our participants would be able to distinguish these two solutions, so this series was mainly used to familiarize them with the process. Therefore, the warm-up data was excluded from detailed analysis. The second pair, a low series, was a comparison between a 25 mPa*s solution and a 35.2 mPa*s solution, while the third pair, a high series, was a comparison between a 75 mPa*s solution and a 95.6 mPa*s solution. The high and low series each contained two samples that were different in viscosity by 10% more than the JND according to work done by Camacho et al. (2015).

The viscosity perception data was compiled with the oral point pressure data for analysis. Fisher's exact tests, found in Appendix B, were run on the data to determine the presence of a relationship between viscosity perception and oral acuity. According to data from the present study, there is no evidence suggesting that oral point pressure discrimination is related to viscosity perception. Although there were no significant findings in this experiment, it lends itself to further studies, discussed in Chapter 4. The present study is one of the first studies that explored the relationship between oral somatosensation and viscosity perception, a concept that should be investigated further.

Chapter 4

Conclusions and Future Work

The current work represents some of the first work on potential relationship between viscosity perception and oral point pressure thresholds. The results indicated that there was no evidence of a relationship between oral somatosensation and the perception of viscosity. However, as with any initial study, there were several challenges that can be improved upon in future work. Given that viscosity is such an important property in the food and beverage industry, it is vital to continue to study and better understand the human perception of texture, including viscous solutions. Such knowledge should hopefully lead to better understanding of consumer liking and preference and improved product formulation, especially in the beverage industry.

Limitations

After testing was complete, I learned of a serious issue with the instrument used to test detection thresholds, the Cochet-Bonner Aesthesiometer. While this work was underway, Marco Santagiuliana, a PhD student at Wageningen University & Research, was conducting validation studies on the same brand of Cochet-Bonner Aesthesiometers. He built an automated rig to lower the devices' filament onto a balance to measure the force produced while taking hand movement out of the equation. In doing so, he discovered that the Cochet-Bonner Aesthesiometers deliver substantially more force than the manufacturer claims. This suggests that the measurements obtained here with the Cochet-Bonnet fibers do not accurately reflect the participants' true detection thresholds, as they were calculated here based on the force values provided by the manufacturer. Critically, based on unpublished data from Santagiuliana (personal communication, Feb 2019), the Cochet-Bonner Aesthesiometers used here were actually delivering amounts of force much closer to what the Von Frey Hair monofilaments deliver. This explains why our participants exhibited a floor effect, much like they did in Breen's study (Breen 2018). This issue was a major contributor to the lack of significant findings regarding the detection thresholds.

Another limitation could be due to the fact that the measurement of discrimination thresholds was a discrete process. Each stairstep during testing was considered to be the next higher or lower Von Frey Hair monofilament in the set. However, there was no way to measure the pressure levels and forces between those filaments in the set. This discrete process leads to estimations during the determination of thresholds, as not all force levels could be tested. This is a possible limitation that could have affected the accuracy of the threshold calculations. Finally, the oral point pressure measurements were only taken on the center tongue; this was done to reduce participant burden, as prior work by Breen found no significant relationship between texture perception and oral touch thresholds on the left and right lateral edge of the tongue (Breen 2018). However, by limiting the data collection in this manner, it is possible that a significant relationship could have missed. That is, I cannot exclude the possibility that there may be a relationship between texture perception and oral somatosensation in other portions of the oral cavity, such as the palate.

Future Work

As mentioned above, there were some complications that may have resulted in the lack of significant results from this study. If this study were to be repeated, it would be beneficial to find a new tool to measure lingual point pressure detection. As observed previously by Breen, using the Von Frey Hair monofilaments resulted in a floor effect with the amount of force they deliver (Breen 2018). The Cochet-Bonner Aesthesiometer purportedly delivers less force according to the manufacturer, so it should have helped address this issue. However, because it now appears that the instrument was delivering much more force than claimed, the discrimination data from this study is inconclusive. Conducting this study again, but with a validated instrument with less force may result in more conclusive findings related to detection thresholds.

Another possible change to the procedure would be to use textured tongue depressors or metal blanks to measure participants' roughness discrimination, according to the roughness assessment procedure used by Breen in his 2018 study and Linne and Simons in 2017 (Linne and Simons 2017). Linne and Simons explored the relationship between roughness discrimination and astringency perception. They discovered that the individuals with lower roughness discrimination thresholds were more sensitive to certain astringent stimuli and also reported greater pleasantness from astringent foods than individuals with higher roughness discrimination thresholds (Linne and Simons 2017). Breen, on the other hand, found no correlation between roughness discrimination and texture perception, though it's possible a relationship may exist between roughness sensitivity and viscosity perception. Due to the fact that viscosity involves a fluid flowing across the tongue, not directly pressing down on it, the roughness assessments may provide a better indication of an individual's ability to distinguish viscosity. The reason Breen may not have had any significant findings with the roughness assessment could be due to the fact that particle size perception is more similar to the oral point pressure threshold measurements, as it involves particles directly applying pressure on to the tongue.

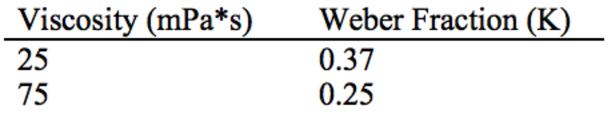
Conclusion

Despite the important role of viscosity on acceptability and liking of food and beverages, there is not much known about its perception. Prior to this experiment, there had been very little work done on the mechanisms of viscosity perception and its relationship with oral somatosensation. Using the point pressure thresholds estimates measured with the Von Frey Hair monofilaments, it appears that there is no evidence to suggest that lingual discrimination threshold estimates are associated with viscosity perception. Though there were no statistically significant findings, this experiment was still successful in expanding understanding the relationship between oral point pressure and viscosity. This study serves as a reminder of all the research that still needs to be done to understand viscosity perception and oral touch. The future work discussed above could be expanded on to hopefully lead to a better understanding of an aspect of oral touch that is very important to everyday life.

Appendix A

Chapter 2 Supplemental Data

Table A-1: Weber Fractions for corresponding viscosity levels (Camacho et al. 2015).



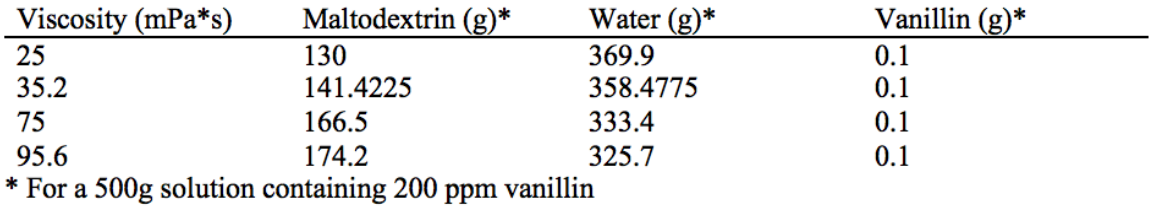
Viscosity (mPa*s)	Weber Fraction (K)
25	0.37
75	0.25

Calculation of viscosity pairing based on a goal of 10% above JND.

0.37 x 110% JND = 0.407
0.407 x 25 mPa*s = 10.175 mPa*s
25 mPa*s + 10.175 mPa*s = 35.175 mPa*s
Low Series: 25 mPa*s and 35.2 mPa*s

0.25 x 110% JND = 0.275
0.275 x 75 mPa*s = 20.625 mPa*s
75 mPa*s + 20.625 mPa*s = 95.625 mPa*s
High Series: 75 mPa*s and 95.6 mPa*s

Table A-2: Solution formulations as calculated with information from "Just Noticeable Differences and Weber Fraction of Oral Thickness Perception of Model Beverages" (Camacho et al. 2015).



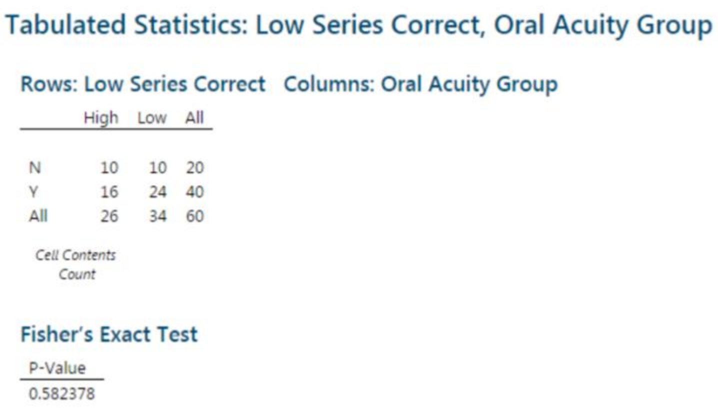
Viscosity (mPa*s)	Maltodextrin (g)*	Water (g)*	Vanillin (g)*
25	130	369.9	0.1
35.2	141.4225	358.4775	0.1
75	166.5	333.4	0.1
95.6	174.2	325.7	0.1

* For a 500g solution containing 200 ppm vanillin

Appendix B

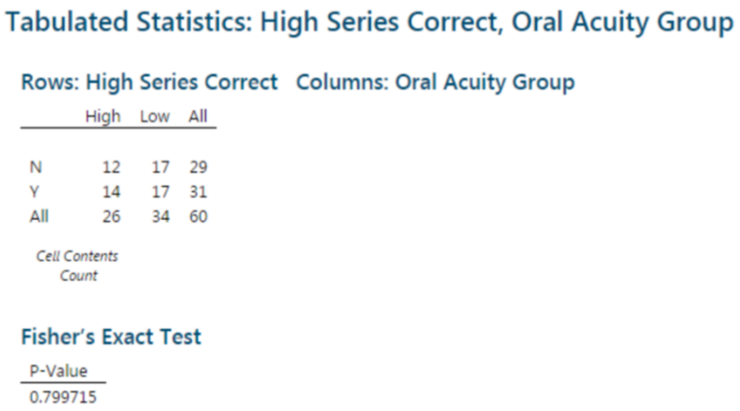
Chapter 3 Supplemental Data

Fisher’s Exact Test for Low Series Viscosity Discrimination based on Oral Acuity Group



```
Tabulated Statistics: Low Series Correct, Oral Acuity Group

Rows: Low Series Correct   Columns: Oral Acuity Group
         High   Low   All

N          10    10    20
Y          16    24    40
All        26    34    60

Cell Contents
    Count

Fisher's Exact Test
P-Value
0.582378
```

Fisher’s Exact Test for High Series Viscosity Discrimination based on Oral Acuity Group



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Tabulated Statistics: High Series Correct, Oral Acuity Group

Rows: High Series Correct   Columns: Oral Acuity Group
         High   Low   All

N          12    17    29
Y          14    17    31
All        26    34    60

Cell Contents
    Count

Fisher's Exact Test
P-Value
0.799715
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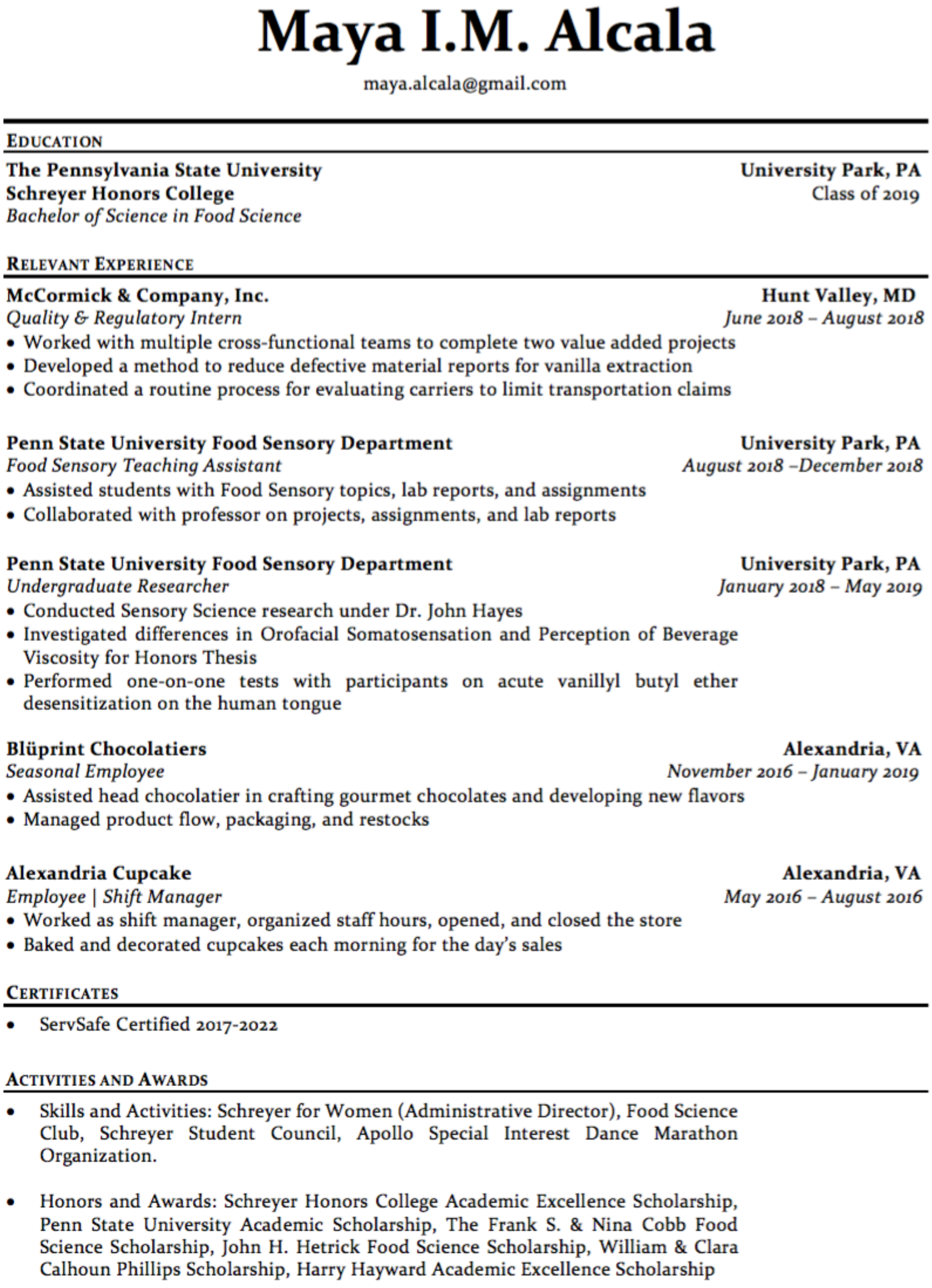
ACADEMIC VITA



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EDUCATION

The Pennsylvania State University **University Park, PA**
Schreyer Honors College Class of 2019
Bachelor of Science in Food Science

RELEVANT EXPERIENCE

McCormick & Company, Inc. **Hunt Valley, MD**
Quality & Regulatory Intern *June 2018 – August 2018*

- Worked with multiple cross-functional teams to complete two value added projects
- Developed a method to reduce defective material reports for vanilla extraction
- Coordinated a routine process for evaluating carriers to limit transportation claims

Penn State University Food Sensory Department **University Park, PA**
Food Sensory Teaching Assistant *August 2018 –December 2018*

- Assisted students with Food Sensory topics, lab reports, and assignments
- Collaborated with professor on projects, assignments, and lab reports

Penn State University Food Sensory Department **University Park, PA**
Undergraduate Researcher *January 2018 – May 2019*

- Conducted Sensory Science research under Dr. John Hayes
- Investigated differences in Orofacial Somatosensation and Perception of Beverage Viscosity for Honors Thesis
- Performed one-on-one tests with participants on acute vanillyl butyl ether desensitization on the human tongue

Blüprint Chocolatiers **Alexandria, VA**
Seasonal Employee *November 2016 – January 2019*

- Assisted head chocolatier in crafting gourmet chocolates and developing new flavors
- Managed product flow, packaging, and restocks

Alexandria Cupcake **Alexandria, VA**
Employee | Shift Manager *May 2016 – August 2016*

- Worked as shift manager, organized staff hours, opened, and closed the store
- Baked and decorated cupcakes each morning for the day's sales

CERTIFICATES

- ServSafe Certified 2017-2022

ACTIVITIES AND AWARDS

- Skills and Activities: Schreyer for Women (Administrative Director), Food Science Club, Schreyer Student Council, Apollo Special Interest Dance Marathon Organization.

- Honors and Awards: Schreyer Honors College Academic Excellence Scholarship, Penn State University Academic Scholarship, The Frank S. & Nina Cobb Food Science Scholarship, John H. Hetrick Food Science Scholarship, William & Clara Calhoun Phillips Scholarship, Harry Hayward Academic Excellence Scholarship