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The Influences of Texture and Mastication Pattern on Flavor Perception Across the Lifespan

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The Influences of Texture and Mastication Pattern on Flavor Perception Across the Lifespan

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of the requirements for the degree of
Doctor of Philosophy in Food Science

By

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Abstract

Texture is an often-overlooked food attribute and is known to influence other food characteristics. More specifically, texture has been repeatedly to influence how we perceive flavor. Several studies have linked this change in flavor perception to the altered mastication patterns that accompany texture changes. This dissertation is composed of four studies that were designed to address how American food consumers view texture and other food attributes as well as characterize how texture and mastication can influence temporal flavor dynamics. The first study was a survey that outlined consumer attitudes towards a variety of different foods. This study solidified that texture is indeed one of, if not the most important food attribute. Also, it was found that texture importance changes as consumers age. The second study started the exploration of how texture can influence flavor perception. Potato chips of different textures were given to participants and they were asked to rate their flavor perception over time. During the consumption of these chips the mastication of the participants was also recorded using electromyography. It was found that the temporal flavor dynamics were indeed different based upon the texture. Older adults don’t show the same influence of texture as displayed by younger adults. The number of chews was instrumental in helping to understand how texture influences flavor. Moving forward, the third and fourth experiments were fashioned to confirm that mastication was indeed a factor in flavor perception. The chewing rate and chewing duration was found to directly influence temporal flavor perception, as measured by Time-intensity methodology. Additionally, it was found that the effect of mastication on Temporal Dominance of Sensations was minimal, when compared to Time-intensity. This study characterizes how texture is viewed by the American food consumer and gives valuable information on the

mechanisms behind texture’s influence of flavor perception. Additionally, specific mastication parameters were identified as being integral in changes in temporal flavor dynamics.

Acknowledgements

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Dedication

I would like to dedicate this work to my family: my wife, Megan, my daughter, Harper, and my parents, Bob and Sherri.

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Luckett, C. R., Meullenet, J. F., & Seo, H. S. (2016). Crispness level of potato chips affects temporal dynamics of flavor perception and mastication patterns in adults of different age groups. *Food Quality and Preference*, 51, 8-19.

Chapter 1.

Introduction

Texture has long been in the shadows of other food attributes, mainly flavor. However in the 1960s and 1970s, texture began to gain some prominence when Alina Szczesniak began popularizing the importance, and later the quantification of textural characteristics. However, after the initial exploration into the food consumers' attitudes towards texture, a significant lull in research regarding how texture and other food attributes are viewed. Within this timeframe the food industry began to understand the importance of texture in the acceptance of new products (Szczesniak, 1990). Texture has been shown to be more important than flavor in the rejection of foods (Szczesniak, 1972), but mainly through high consumer awareness and high correlations between overall liking and flavor hedonicity (Szczesniak, 1972; Moskowitz and Krieger, 1995). The first study of this dissertation addresses the 50-year information gap with regard to consumer awareness of food attributes, especially texture.

The second study of this dissertation looks at the effect of texture changes on flavor perception. In liquid samples, viscosity has been shown to suppress intensities of tastes and flavors (Mackey and Valassi, 1956; Pangborn and Szczesniack, 1974; Christensen, 1977; Hollowood et al., 2002). In solid food samples, the effect of textural characteristics on flavor appeared to be food and flavor specific. For example, a texture-flavor interaction was observed for cheese-flavored waffles, but not a sweet waffle (Kremer et al., 2007). One obstacle in generalizing the relationship between texture and flavor is the individual variation (Mestres et al., 2006; Repoux et al., 2012). Among potential factors, age has been expected as a key source of variation in the influence of texture on flavor perception (Kremer et al., 2005). Oral processing has been found to change as we age (Mioche and Martin, 1998; Kohyama et al., 2002; Mioche et al., 2004). Jaw muscles have been shown to fatigue and bite forces decline, leading to compensatory strategies such as more mastication cycles and longer mastication sequences (Kohyama et al., 2002, 2003; Mioche et al., 2004). Also, the interaction between texture and flavor has been shown to be different among adults of different age groups (Kälviäinen et al., 2002; Forde and Delahunty, 2002; Kremer et al., 2005). These finding suggest that age factor plays a key role in better understanding the individuality of how texture influences flavor.

During the course of the second study, evidence of the number of chews playing an important role in temporal flavor perception was observed. To further discern the effect of mastication patterns on flavor perception, two follow-up studies (Studies 3 & 4) were designed. Only a few studies have directly addressed how changes in mastication parameters can influence temporal flavor dynamics and general flavor perception. Tarrega et al. (2008) found that maximum flavor intensity (I_{max}) was positively correlated with the number of chews, chew work, chew strength, and negatively correlated with chew duration. In contrast, other studies have reported an increase in flavor volatile release in slow chewing rates (Blissett et al., 2006). However, it has been reported that flavor volatile release is not always highly correlated to flavor perception (Weel et al., 2002; Leclercq and Blancher, 2012). Further research is needed to fully understand what specific mastication behaviors are related to subsequent changes in flavor release and perception. Study 3 looks for causal evidence of the number of chews affecting temporal flavor perception.

Since flavor has dimensions other than just intensity, the fourth study is designed to investigate an effect of mastication rate on the temporal dominance (TDS) of flavors. However, there is a lack of information on the effects of mastication on the perception of flavor dominance. As mentioned, earlier studies that have addressed the effect of mastication on flavor perception have tended to limit themselves to the Time-Intensity (TI) analysis (Weel et al., 2002; Blissett et al., 2006; Tarrega et al., 2008; Leclerq and Blancher, 2012; Luckett et al., 2016). The TI analysis has a major limitation in that it can only track one or two flavors, while the TDS can give temporal information about several flavors (up to ten flavors). There is also research showing that individual flavors respond differently to mastication pattern (Repoux et al., 2012). The fourth study of this dissertation centers on the effects of mastication pattern on the temporal dominance of flavors in a multiple flavor sample.

The objectives of this study are to:

1) Investigate the importance of textural characteristics in solid and semi-solid foods throughout the lifespan.
2) Examine the effect of texture manipulation on mastication pattern and flavor perception across different age groups.
3) Expand the findings of the objective 2 and look for causal evidence of mastication’s effect on temporal flavor perceptions.
4) Further understand how different measurements of temporal flavor perception can be uniquely influenced by mastication pattern.

References

Blissett, A., Hort, J., & Taylor, A. J. (2006). Influence of chewing and swallowing behavior on volatile release in two confectionery systems. *Journal of Texture Studies*, 37, 476-496.

Christensen, C.M.; Texture-taste interactions. *Cereal Foods World* 1977, 22, 243-256.

Forde, C.G., & Delahunty, C.M. (2002). Examination of Chemical Irritation and Textural Influences on Food Preferences in Two Age Cohorts using Complex Food Systems. *Food Quality and Preference*, 13, 571-582.

Hollowood, T.A., Linforth, R.S.T., & Taylor, A.J. (2002). The Effect of Viscosity on the Perception of Flavor. *Chemical Senses*, 27, 583-591.

Kalviainen, N., Roininen, K., Tuorila, H. (2003). The Relative Importance of Texture, Taste, and Aroma on Yogurt-type Snack Food Preference in the Young and the Elderly. *Food Quality and Preference*, 14, 623-635.

Kohyama, K., Mioche, L., & Martin, J. -F. (2002). Chewing patterns of various texture foods studied by electromyography in young and elderly populations. *Journal of Texture Studies*, 33, 269-283.

Kohyama, K., Mioche, L., & Bourdiol, P. (2003). Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. *Gerodontology*, 20, 15-23.

Kremer, S., Mojet, J., & Kroetze J.H.A. (2005). Perception of Texture and Flavor in Soups by Elderly and Young Subjects. *Journal of Texture Studies*, 36, 255-272.

Leclerq, S. & Blancher, G. (2012). Multimodal Sensory Integration during Sequential Eating—Linking Chewing Activity, Aroma Release, and Aroma Perception over Time. *Chemical Senses*, 37, 689-700.

Luckett, C. R., Meullenet, J. F., & Seo, H. S. (2016). Crispness level of potato chips affects temporal dynamics of flavor perception and mastication patterns in adults of different age groups. *Food Quality and Preference*, 51, 8-19.

Mackey, A. and Valassi, K. (1956). The discernment of primary tastes in the presence of different food textures. *Food Technology*, 10, 238-240.

Mestres, M., Kieffer, R., & Buettner, A. (2006). Release and perception of ethyl butanoate during and after consumption of whey protein gels: relation between textural and physiological parameters. *Journal of Agricultural and Food Chemistry*, 54, 1814-1821.

Mioche, L., & Martin, J. -F. (1998). Training and sensory judgment effects on mastication as studied by electromyography. *Journal of Food Science*, 63, 1-5.

Mioche, L., Boundial, P., & Peyron, M.A. (2004). Influence of Age on Mastication: Effects on Eating Behavior. *Nutrition Research Reviews*, 17, 43-54.

Moskowitz, H.R. and Krieger, B. 1995. The contribution of sensory liking to overall liking: An analysis of six food categories. *Food Quality and Preference*, 6, 83–90.

Pangborn, R.M. and Szczesniak, A.K. (1974). Effect of hydrocolloids and viscosity on flavor and odor intensities of aromatic flavor compounds. *Journal of Texture Studies,* 4, 467-482.

Repoux, M., Laboure, H., Courcoux, P., Andriot, I., Semon, E., Yven, C., Feron, G., & Guichard, E. (2012). Combined Effect of Cheese Characteristics and Food Oral Processing on *In Vivo* Aroma Release. *Flavour and Fragrance Journal*, 27, 414-423.

Szczesniak, A.S. 1972. Consumer awareness of and attitudes to food texture II. Children and teenagers. *Journal of Texture Studies*, 3, 206–217.

Szczesniak, A.S. 1990. Texture: Is it an overlooked food attribute? *Food Technology*, 44, 86–95.

Tarrega, A., Yven, C., Semon, E., & Salles, C. (2008). Aroma release and chewing activity during eating different model cheeses. *International Dairy Journal*, 18, 849-857.

Weel, K.G.C, Boelrijk, A.E.M., Alting, AC, Van Mil, P.J.J.M, Burger, J.J., Gruppen, H., Voragen, A.G.J, & Smit, G. (2002). Flavor release and perception of flavored whey protein gels: perception is determined by texture rather than by release. *Journal of Agricultural and Food Chemistry*, 50, 5149–5155.

Chapter 2.

Review of Literature

2.1. Texture

Texture is the response of tactile senses to physical stimuli that results from contact between the body and a food (Bourne, 2002). Texture is not limited to the somatosensory domain of touch because kinesthesis can also give valuable texture information during the eating process. Further, texture is not limited to touch as audition has been shown to play a large role in crispness, crunchy and crackly textures, and vision can provide information on things like rate of flow and degree of slump (Bourne, 2002).

Food texture is thought to have an importance beyond simple hedonic pleasure associated with eating food. Obviously the perception of sensory texture attributes in the oral cavity is a major determinate of how much someone likes a certain food product, and therefore can be very important in determining food choice and intake which would directly influence an individual’s nutritional status (Mioche et al., 2004).

Much of the texture changes in this experiment will center on crispness, due to the lack of research on crispness and flavor perception, as well as the general importance of crispness in acceptance and enjoyment of a food. Crisp is the most used texture term in the United States (Szczeniack and Kleyn, 1963). Crispness also has a higher importance than other texture descriptors due to its relationship with freshness. Many snack foods, vegetables, and fruits are perceived to be at their best when they are crisp and firm (Szczeniack and Kahn, 1971). In addition, earlier studies have shown the importance of crispness to the pleasure of eating which is thought to stem from the position that crispness holds in the fundamental psychology behind satiation and appetite (Szczeniack and Kahn, 1971).

Crispness is often measured instrumentally by combining physical measurements with auditory output from the food during deformation. Over time the auditory aspect of measuring crispness has become more and more prominent (Vickers, 1987). The perception of crispness is heavily dependent on the number of emitted sounds and their loudness during the chewing process (Vickers and Bourne, 1976). In addition, it was discovered that the frequency of the sound emitted is often important in the discrimination between crunchiness and crispness, which leads to the use of sound emission as a tool in determining the crispness of a food instrumentally (Vickers, 1985). Currently, a variety of methods are used to measure crispness, using a variety of force and auditory information to determine a crispness value and a consensus of the *best* method to measure crispness instrumentally is still far away.

2.1.1. Oral Processing of Foods

The oral cavity plays as a very important place in determining the acceptance or rejection of foods. In addition, the oral cavity provides information about the nutritional content of food (Hill and Lucas, 1996). The perception of texture involves a multitude of oral factors such as interaction with the mucosa, teeth, and saliva. The perception of texture constantly changes as chewing disrupts and saliva incorporates itself into the food matrix (Heath and Prinz, 1999). The chewed food-saliva mixture is known as the bolus.

Oral processing is often broken down into four phases: the ingestion and first bite, the main mastication sequence, clearance and swallowing, and debris (Heath and Prinz, 1999). The ingestion and first bit phase is thought to be the most important as the phase provides information about the food that will be used to determine subsequent oral processing. Information about a foods texture, shape, and size is collected by the proprioceptive system during mastication and through tongue movements (Cardello, 1996). One of the difficult things regarding texture measurement of food is that the texture properties of food are codependent with mastication changes. In other words, the texture of a food influences how we process the food in our oral cavity and the oral processing affects how we perceive the texture of that food. While these relationships create difficulties in quantifying the factors involved, they present an opportunity to manipulate aroma compound release from the food matrix by changing the food texture.

2.2. Flavor

Amerine et al. (1965) defined flavor as the sum of perceptions resulting from stimulation of the sense ends that are grouped together at the entrance of the alimentary and respiratory tracts. In sensory science, flavor is often characterized as the impressions perceived via the chemical senses from a product in the mouth (Caul, 1957). The three main components of flavor (smell, taste and chemesthesis) will be described in detail below.

2.2.1. Smell

Smell (or olfaction) is the sense that allows us to identify orthonasal and retronasal odors. The process of olfaction begins when an odorant comes in contact with the olfactory mucosa. Odorants are compounds that illicit an olfactory response, and are often small (< 400 Da) organic molecules that can vary in charge, size, shape, and functional groups (Amoore, 1970). The olfactory mucosa contains odorant-binding proteins (OBPs), which help, the usually hydrophobic odorants, travel through the aqueous mucus barrier (Pelosi et al., 1982; Pevsner et al., 1986). After traveling through the aqueous membrane the odorants interact with receptors on olfactory receptor neurons located on the olfactory epithelium (Buck, 1996; Dwyer et al., 1998; Malnic et al., 1999). Receptors are coupled to G-proteins, which activates adenyl cyclase (Pace and Lancet, 1986; Ronnett et al., 1993). Adenyl cyclase converts ATP to cyclic ADP (cAMP). cAMP opens sodium and calcium channels, resulting in a graded potential. There are secondary messenger systems that are thought to regulate secondary olfaction events, such as odor desensitization. However, these secondary messenger systems will not be covered by this review due to their number and complexity. The olfactory receptor neurons project through a part of the skull, known as the cribriform plate, to a part of the brain known as the olfactory bulb. From the olfactory bulb olfactory information travels to the olfactory cortex, where many higher-level cognitive functions associated with olfaction take place.

Olfactory receptor specificity is not well understood. There have been conflicting studies on the level of specificity of these odor receptors. It is clear that olfactory receptors do not bind to one specific odorant molecule but to a variety of different odorants. In addition, it is likely that a single odorant binds to multiple types of olfactory receptors. However, what the olfactory receptors' specificity is based on is not known. Recent studies on the olfactory receptors of flies have demonstrated that olfactory receptors can differentiate between two odor molecules, which only differ in hydrogen isotope (Franco et al., 2011).

Currently, it is estimated that humans have about 400 genes that code for ~1,000 different olfactory receptors. It is thought that each olfactory neuron only expresses one type of receptor protein (Nef et al., 1992; Strotmann et al., 1992; Ressler et al., 1993). Since each olfactory receptor can interact with multiple odorants and there is a large degree of convergence at the olfactory bulb level, the ability of humans to differentiate a seemingly infinite amount of odors. Olfaction must have a high-level cognitive component for our olfactory system to operate at the level it does. Studies suggest that the brain may have some type of chemotropic organization, due to the observation that odorants similar in chemical structure activate neurons in similar parts of the brain (Wilson, 2001; Leon and Johnson, 2003).

The olfactory system is dynamic and responsive to the environment. When specific olfactory signals are recognized as linked to particular odor sources they gain behavioral significance (Sicard, 2002). Repeated presentations of odors have been shown to increase the animals' sensitivity to that odor. In mice and rats the actual electrophysiological signal from the olfactory receptor neurons increased, leading to the hypothesis that the chemical environment of an organism affects olfactory receptor gene expression (Wysocki et al., 1989; Wang et al., 1993; Semke et al., 1995).

When humans chew or place food in the oral cavity, volatiles interact with the nasal epithelium (Mozell et al., 1969). This phenomenon is commonly known as retronasal olfaction. When eating, odor perception is contingent on the concentration of odor compounds reaching the nasal cavity via the retronasal route. The amount of aroma compounds reaching the nasal cavity is highly dependent on their release from the food matrix, which allows these flavor compounds to enter the gas phase. Once in the gas phase the odors are free to flow to the nasal cavity where they can elicit an olfactory response. The ability to perceive odors retronasally is integral for the concept of flavor.

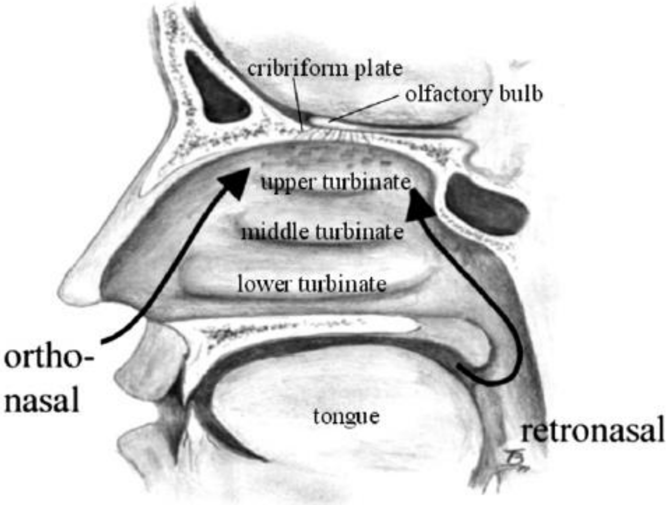

Figure 1. Anatomy of human nasal and oral cavity (source: Negoias et al., 2007)

The speed and strength of the neural response to an olfactory stimulus can be measured using electroencephalography (EEG), more specifically the olfactory event related potential (ERP). The ERPs are the measured brain response to a stimuli using EEG, which measures changes in electrical current on the scalp. The brain is constantly processing information, which makes any single EEG recording minimal in value to researchers. For this reason EEG recordings are often averaged over numerous responses to a stimulus, which increases the signal-to-noise ratio and allows the creation of a relevant ERP (Coles and Rugg, 1996). When analyzing an olfactory ERP they can be broken down into two classifications by the time at which they appear. In the initial period (for the first 100 ms) the components are often known as sensory or exogenous because of their dependence on characteristics of the stimulus itself (Sur and Sinha, 2009). Cognitive or endogenous ERPs are often found later in the ERP and are associated with higher-level processing of the stimuli (Sur and Sinha, 2009).

ERPs are often broken down further into common components based upon their orientation and latency. This review will offer a brief outline of the common olfactory ERP components and their associated interpretations. Olfactory ERPs often begin with a N1 component within the first 400 ms. There is not consensus on whether or not the N1 peak amplitude corresponds to odor concentration because of how almost all odorants also elicit a trigeminal sensation (Hummel, 2000). N1 latency has been shown to relate to odor quality, for example people responded earlier to rose odor than that of rancid butter (Pause et al., 1999). Following N1, a P2 event is often observed around 600 ms after odor presentation, which is thought to relate to the processing and encoding of the odor (Pause et al., 1996; Tateyama et al., 1998). The next event within an OERP is P2, which can be broken down further in to P2a and P2b. Krauel et al. (1999) showed that deviant odors elicit a strong P2a response, indicating the presence of a “mismatch detector” in the olfactory short-term memory system. P2b is also thought to correspond to attentional shifts due to odor presentation (Naatanen, 1990). The P3 element of OERP is associated with higher cognitive processes due to its latency of approximately 700 – 1000 ms. P3 amplitude has been shown to increase with infrequent stimuli and when odor is presented upon exhalation (Donchin and Coles, 1988; Lorig et al., 1996). These results have led to the belief that P3 is associated with unexpected odors and a subsequent switching of attentional resources (Naatanen, 1990).

2.2.2. Taste

Gustation, which is synonymous with taste, allows us to better characterize the food we eat. In general, five different tastes are recognized, *saltiness*, *sweetness*, *bitterness*, *sourness*, and *umami*. For a substance to elicit a gustatory response it must stimulate taste receptors on the tongue. When the tastant molecule binds with a taste receptor on the tongue a signal is sent through 3 cranial nerves (X, IX and VII) to the nucleus of the solitary tract in the medulla. The information travels from the solitary tract in the medulla to the thalamus. Interestingly, Beckstead et al. (1980) showed that the same thalamic nucleus that receives taste information also receives somatosensory input from the trigeminal nerve. From the thalamus, taste information proceeds to what is known as the primary gustatory cortex (Pritchard et al., 1986) and further to the secondary gustatory cortex (Rolls et al., 1990). The primary gustatory cortex does not just receive taste receptor input, but also receives thermal, mechanical, visceral, and pain stimuli (Carleton et al., 2010). Norgren (1976) showed that some gustatory information reaches other parts of the brains, such as the hypothalamus. The evidence of taste information being projected to the hypothalamus is thought by many researchers to be linked to sweet, salty, and umami tastes and their corresponding biological need. For example Rolls et al. (1986)

observed that certain neurons in the hypothalamus only responded to sweet tastes when the subject was hungry.

2.2.3. Chemesthesis

Chemesthesis is an important factor in the perception of flavor, but it is often overshadowed by taste and smell. Largely unknown until the early part of the 20th century when the discovery that certain compounds could stimulate free nerve endings in the mucosa led to reports of a common chemical sense (Parker, 1912). However, a chemesthetic response often necessitates much higher concentrations of a substance than is needed to elicit an olfactory or gustatory response (Meilgaard et al., 2007). The importance of chemesthetic sensations goes beyond flavor as they have shown to contribute to the overall acceptance of many foods (Carstens et al., 2002). To understand how chemesthesis plays a role in our food perception it is best to look at the neurophysiology behind chemesthetic sensation.

Chemesthesis starts when chemical compounds activate thermal, pain and touch receptors found in the skin. Typically mucus membranes are more sensitive to chemesthetic stimulation because they lack a cornfied skin layer. Chemesthetic information is carried to the brain by three cranial nerves: the vagus, the glossopharyngeal, and the trigeminal nerves. The trigeminal nerve is responsible for all nasal and most oral chemesthetic sensations. As mentioned earlier, almost all odor compounds activate the chemesthetic system so it is accepted that interaction between olfaction and chemesthesis is the norm rather than the exception. While the physical aspect has been well-documented work by Cain and Murphy (1980) has provided evidence of a neural basis for odor-chemesthesis interaction as well. In their experiment Cain and Murphy used n-amyl butryrate (as an odorant) in conjunction with carbon dioxide (as an irritant) in an attempt to ascertain the relationship between olfaction and chemesthesis (Cain and Murphy, 1980). They found that CO_2 suppresses the perceived olfactory magnitude of n-amyl butryrate even when the stimuli are given in different nostrils.

It is often thought that much of the role chemesthesis plays in flavor is due to convergence of taste and trigeminal information in the ventroposteromedial nucleus of the thalamus, which is often called the thalamic taste area (Pritchard et al., 1986). However, the impact of chemesthesis on flavor is more complicated due the fact that almost all odor compounds can produce trigeminal sensation (Silver and Moulton, 1982). Evidence of the trigeminal sensation of odor compounds comes from work on anosmics, people without the sense of smell. Doty et al. (1978) performed odor detection testing on 15 anosmics and found that 45 out of 47 common odors were detected by at least one of the anosmics.

2.3. Multisensory Integration

In everyday life humans receive constant sensory stimulation, much of which is not processed independently. When stimuli are temporally comparable and carry congruent information, perceptual improvements are often observed (Stein et al., 1993). This enhanced perception is due to central processing of these multisensory inputs in the nervous system. The evolutionary basis of multisensory integration is easily understood; the integration of environmental stimuli leads to quicker response times, and in general, being more perceptive of the environment.

While the examples of multisensory integration phenomena in our daily life are numerous, but this review will exclusively focus on multisensory integration related to eating and drinking. Multimodal food and drink perception can have a neurocognitive basis or be based in more psychological means, such as mood changes. This review will concentrate on the physiological basis, since there is not proposed link between food texture and mood/emotion. Since not all of the senses associated with eating and drinking behavior decline at the same rate, it would be anticipated that the interaction of the senses would be differ between older adults and younger adults (Kremer et al., 2007). When eating or drinking, people experience many different stimulation of many different senses, which are seamlessly integrated into one product concept (Kremer et al., 2007). The best example of multisensory integration in the food consumption process is the concept of flavor, which is the combined input of taste, smell, and chemesthesis. Many times it is impossible to detach either of the three senses from the overall concept of flavor.

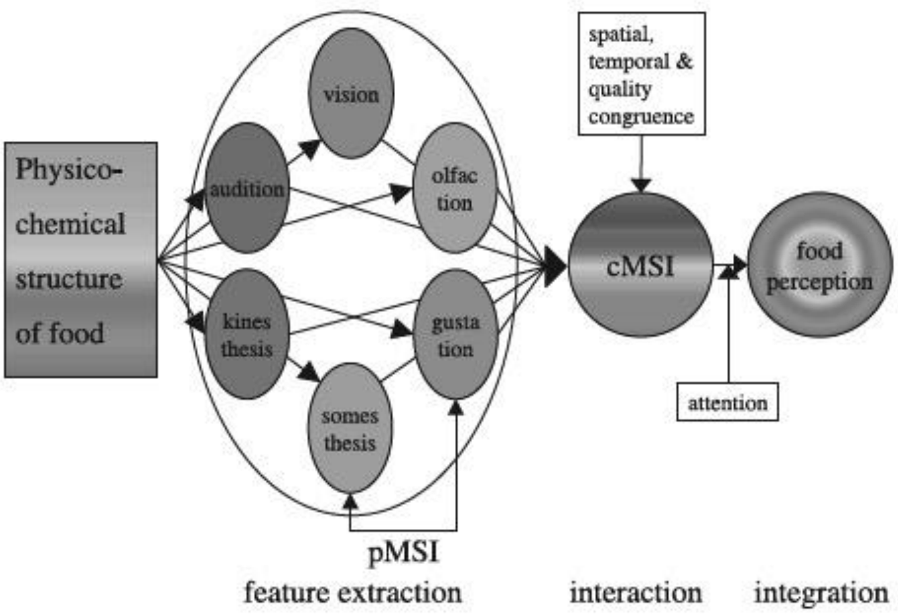

Figure 2. The integration of food perception by the nervous system (source: Verhagen and Engelen, 2006)

2.4. Texture – Flavor Interaction

There are two proposed mechanisms in which texture can influence other aspects of food perception, mainly flavor. The first is through changes in aroma release kinetics and the second is through multisensory integration. Several studies have examined the relationship between food texture and flavor. In model systems the release of aroma decreases as the food viscosity increases (Cayot et al., 2004; Terta et al., 2006). In human studies, flavor depression with an increase in viscosity has been consistently reported in liquids and semi-solid foods (Kremer et al., 2005). Repoux et al. (2012) observed such a trend in a solid food; an increase in cheese firmness increased the rate and amount of aroma released. However, changes in the cheese texture altered salivary output and chewing duration, pointing towards an indirect relationship between texture and flavor perception (Repoux et al., 2012).

2.4.1. Volatile Release

Cook et al. (2005) were able to use real time mass spectroscopy (MS-Nose) to show a high correlation between rosemary flavor perception and breath-by-breath aroma release. Data such as this, which measure of the volatiles released from a food matrix, are useful for estimating the flavor perception, but the drivers of flavor release need to be addressed when linking texture to flavor perception. Detailed understanding of *in vivo* flavor release is a key to understanding the role of food composition and structure on the perceived flavor.

The relationship of texture on other aspects of food perception is easily understood when the act of consuming these foods is examined. As mentioned earlier, the chewing process is dependent on the food texture and the perception of food texture is dependent on the chewing process. In addition, the manner in which the food matrix is changed in the oral cavity directly influences how volatile flavor compounds are released, as well as how taste molecules can interact with taste receptors on the tongue. Several studies have attempted to characterize how changes in food texture affect taste and smell perception. From these studies there are three main factors governing how human flavor perception could be influenced by food texture. The first is that changes in texture can lead to changes in mastication and mastication changes govern how aroma compounds are released from the food matrix (Brown et al., 1998; Harrison, 2000). Second, swallowing and nasal airflow determine the concentration of odor compounds that come in contact with olfactory receptors in the nasal cavity (Buettner and Schieberle, 2000; Harrsion, 2000; Buettner et al., 2001). Third, different flavor compounds have different kinetics of release. Specifically, more hydrophobic compounds usually peak after swallowing, while hydrophilic compounds are released in the highest amounts earlier in the masticatory process (Repoux et al., 2012).

With the link to texture-flavor interactions so tightly tied to masticatory changes, the role of oral mechanisms and processes needs to be incorporated to fully understand the relationship (Buettner et al., 2001; Trelea et al., 2008). Experiments designed to examine how texture affects other food related senses are almost exclusively designed using a liquid or semisolid food. This is done mainly due to the fact that texture is much easier to manipulate in liquid and semisolid foods, but these practices limit the conclusions that can be drawn.

2.4.2. Neural Convergence

Even though there is substantial evidence relating food texture to changes in aroma release kinetics there are also studies that have shown alternative sources, mainly integration of the information in the brain. The exact mechanism neural convergence has not been uncovered, but there are several psychophysical phenomena that point toward texture-flavor neural integration. Leclercq and Blancher (2012) observed cross-modal interaction of texture with aroma perception in chewable candy by cases of an increase in aroma compounds in the nasal cavity coupled with a decrease in the participants’ flavor perception. They concluded that the in-nose concentration of aroma compounds is only one part of the total perception of flavor and cannot be the sole factor in models attempting to predict the texture-flavor relationship of a food (Leclerq and Blancher, 2012). In addition, the occurrence of adaptation and contrast effects, when samples were given sequentially, points towards cognitive influence on texture-flavor perception (Leclerq and Blancher, 2012). Burseg et al. (2011) did not observe a decrease in perceived sweetness intensity as the viscosity of apple juice was increased, which contradicts the tastant-kinetics hypothesis that states that the observed taste suppression is a function of reduced tastant diffusion rates. However, there are other theories as to the observed viscosity induced taste suppression. It is common to vary viscosity by adding hydrocolloids, which may bind to certain tastants (Baines et al., 1987; Cook et al., 2005; Ferry et al., 2006). Another theory revolves around the flavors themselves. There are several possible explanations on why studies have produced, what may seem like conflicting results. First, it is thought that texture-flavor interactions may be food-specific, meaning that they may occur in one food and be absent in another (Pangborn et al., 1978). This product-specific interaction may be due to the differences in oral processing; for example, a soup is consumed much differently than snack samples (Kremer et al., 2007). Second, the effect of texture on taste perception may be more different than that of aroma. Evidence for this is the study completed by Kremer et al. (2007) in which a texture-taste interaction was observed for sweet waffles, but not cheese flavored waffles. Sweet is solely a taste, while cheese flavoring has a strong retronasal odor aspect that is integral for the concept of cheese flavor.

2.5. Sensory Perception Changes Associated with Age

As humans age, they suffer from a deterioration of unisensory processing. As mentioned earlier, multisensory integration is stronger when the individual components are weaker. Thus, older adults have shown enhanced multisensory integration, benefiting from receiving multiple sensory inputs than younger people. However, these changes do not occur in each sense at the same rate, making multisensory integration changes in older adults seem unpredictable at times. An understanding of the complex sensory changes that could affect eating and drinking is integral to understanding the multifaceted, and sometimes contradictory, food-related changes that are observed as humans age.

2.5.1. Taste

Overall taste loss has not been found repeatedly in older adults, but there are studies that have observed specific taste losses in older adults. Even so, if a true diminishing of taste does exist the decreases are much less than olfaction. Taste losses in older adults can be disproportionately significant because coupled with the common loss of olfactory sensitivity they can lead to weight loss, malnutrition, anorexia, impaired immunity, and worsening of medical illnesses (Mattes and Cowart, 1994; Schiffman and Wedral, 1996; Doty and Laing, 2003). Regional decreases in taste sensitivity have been observed (Matsuda and Doty, 1995). Regional taste loss can be described as the loss of taste in certain parts of the mouth, but as mentioned in the study, the taste system is redundant so there is not overall loss in taste perception. Higher detection thresholds were reported for older adults using the compounds quinine (bitter), citric acid (sour), NaCl (salty), and sucrose (sweet) (Bartoshuk et al., 1986). In addition, Cowart (1999) reported *normal* seniors to rate tastes stimuli less strong than young people. In the same study conducted by Cowart the conclusion was reached that detection thresholds were not significantly affected by age, contradicting Bartoshuk et al. (1986)’s research which found several differences between older and younger adults’ taste sensitivity. However, it should be mentioned Cowart (1989) did observe a trend on increasing taste thresholds (i.e., decreased sensitivity) to sodium chloride and quinine sulfate, but the observation was not statistically significant. Figure 3 illustrates the findings of Cowart in 87 adults taste sensitivity to sodium chloride (NaCl).

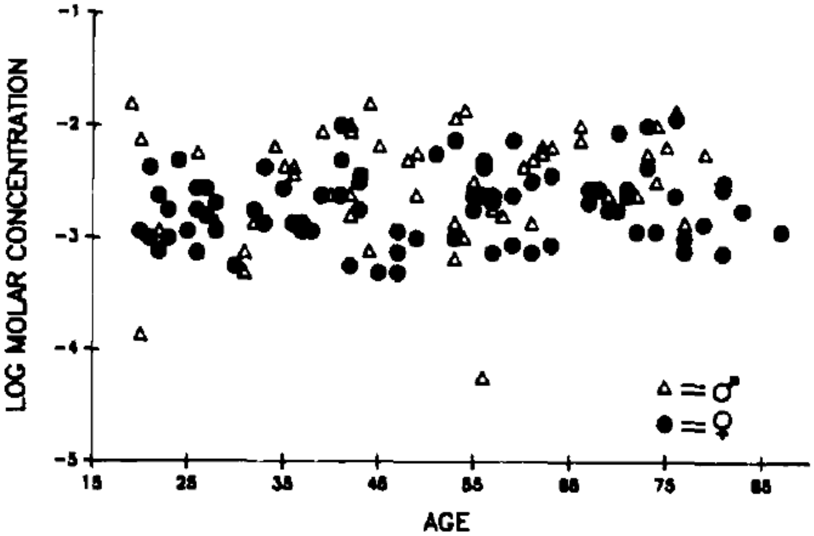

Figure 3. Taste thresholds for sodium chloride in adult humans (source: Cowart, 1989)

2.5.2. Smell

Smell is affected by age much more than taste, with 75% of adults over 80 years of age experiencing a noticeable level of olfactory dysfunction (Doty et al., 1984; Stevens et al., 1984). Many of the observed decreases in olfactory function start to be observed beyond the age of 60, but often men show olfactory declines earlier than women (Doty and Laing, 2002). Olfactory decline in older adults has been observed in many ways including: discrimination, adaptation, suprathreshold intensity perception, identification and detection threshold (Schiffman and Pasternak, 1979; Corso, 1981; Murphy, 1983; Shipp and Weiffenbach, 1993). This review will outline olfactory changes in two physiological areas (central nervous system and olfactory epithelium), as well as illustrate some of the findings from psychophysical and neurological studies on human olfaction across different age groups.

Many neuronal changes have been documented in the human brain as we age. These changes include increased neurotransmitter leakage in the synapse and difficulty regulating intracellular calcium concentrations (Smith, 1988). Since olfactory receptors are neurons, it would be logical to expect them to undergo similar changes with age, decreasing their performance. Specific to olfaction, atrophy of the olfactory bulb has been observed in older adults (Smith, 1941). Further research has shown that olfactory bulb atrophy appears to be a normal part of aging and is due to a decrease in the number of glomeruli and mitral cells (Meisami et al., 1998). There is also evidence to suggest that narrowing of the holes in the cribriform plate may contribute to some of the observed olfactory deficits (Krmpotic-Nemancic, 1969).

The olfactory receptor neurons (ORNs) of older adults have been shown to maintain their ability to respond to odorants and in some cases the ORNs of older adults have been shown to respond to a wider variety of substances than ORNs of younger adults (Rawson et al., 1998). It has been hypothesized that this ORN “tuning” is a compensatory strategy developed by older adults who experience a decrease in the amount of functioning olfactory receptor neurons (Rawson et al., 1998).

Most of the observed olfactory deficiencies associated with aging are attributed to changes in the olfactory epithelium (OE). The olfactory epithelium is integral to the support of olfactory receptors in the nasal cavity. As we age the number of supporting microvilli and cilia in the OE diminishes (Hirai et al., 1996). A patchy appearance of the olfactory epithelium has been observed in older adults, which has been attributed to the constant cell death of the epithelial cells in the nasal cavity, beginning at birth (Morrison and Costanzo, 1990; Carr and Farbman, 1993).

Beyond physiological observations, psychophysical data has also been able to shed light on the olfactory losses associated with getting older. Odor detection thresholds have been shown repeatedly to increase (decreased sensitivity) with age (Cowart, 1989). The loss of olfactory threshold has often been imputed to the deterioration of the OE (Nakashima et al., 1984; Rosli et al., 1999). Thresholds are often considered a measure the peripheral olfactory function because they do not require higher levels of cognition, while odor identification tasks are associated with higher level olfactory processing (Hummel et al., 2002). Neurological studies have also been used to characterize olfactory changes in older adults. Many of the main findings center on olfactory event related potentials (ERPs). One of the most important features of chemosensory ERPs are their ability to distinguish between excitation of the trigeminal nerve and the olfactory nerve, and as mentioned earlier these two signals are often tightly intertwined, making research findings hard to decipher (Hummel and Kobal, 1992). Studies examining the olfactory ERPs of humans have also shown decreases in olfactory sensitivity that were observed in the psychophysical studies outlined in this review. Studies have observed both a change in the speed and strength of olfactory ERPs starting from a relatively early age (Hummel et al., 2002). Using vanillin, CO_2, and hydrogen sulfide (H_2S), Hummel et al. (1998) found decreases in N1P2 amplitudes in both the trigeminal and olfactory ERPs. One of the most interesting findings in this study was the substantial decrease in amplitude between the younger people (15-35) and those in middle age (35-53). Other age-related changes in olfactory ERPs that have been reported include prolongation of N1 and P2 latency and a decrease in P2 and N1P2 amplitude (Evans et al., 1995; Hummel et al., 2002). However, Stevens et al. (1989) showed that the decreased ERP amplitudes might be due to an increased adaptation in older adults when it comes to repetitive olfactory stimulation. The P3 component of the ERP, which has been associated with determining the usefulness and novelty of a stimulus, also appears to decrease in amplitude with increasing age.

A study by Cain et al. (1995) showed that decreases in odor identification are observed after decreases in olfactory thresholds. Table 1 summarizes some of the many studies completed showing an increase in olfactory thresholds over the years and the odor compounds they used.

Table 1. Summary of studies showing an increase in olfactory thresholds.

Compounds Used	Author(s)	Year
musk odor	Schiffman and Pasternak	1979
Phenol	Fordyce	1961
d-limonene, isoamyl butyrate and benzaldehyde	Stevens and Cain	1987
n-butanol	Kimbrell and Furchtgott	1963
1-butanol, isoamyl butyrate, pyridine, ethylcarbinol and phenyl ethylmethyl ethylcarbinol	Cain and Gent	1991
coffee and citral	Megighian	1958
various commercial food odors	Schiffman, Moss, and Erickson	1976

Smell-taste interactions do not seem to be age dependent (Hornung and Enns, 1984; Enns and Hornung, 1988). However, as mentioned earlier, it is very difficult for people to separate smell and taste inputs. This makes research using the two senses very difficult, and results are often contingent on the participants’ ability to separate the two. In addition, the response to volatile chemicals in the nasal and oral cavity has been observed to be influenced by age and as discussed earlier chemesthesis and olfaction are tightly linked meaning that changes in chemesthetic sensitivity may be hard to separate form olfactory changes (Stevens and Cain, 1986).

2.5.3. Texture

There is not a consensus that as people age, their texture sensitivity changes. The comprehensive research by Calhoun et al. (1992) has examined many physiological factors that would affect texture perception. In their study Calhoun et al. examined adults ranging from 23 to 96 years old, with at least 10 people in 5 age groups (20-34, 35-49, 50-64, 65-80, 80+), for various parameters related to oral sensitivity. The findings are broad, but highlight the complexity how possible changes in texture perception can manifest in older adults. They found oral proprioception, as well as thermal and somesthetic sensitivities did not change with age (Calhoun et al., 1992). The ability to differentiate tactile from vibratory sensations on the lips was observed to decline after 80 years of age, but this phenomena was not observed in other parts of the oral cavity such as the soft palate (Calhoun et al., 1992). Two-point discrimination on the upper lip and cheek declined with age, yet stayed constant on the tongue and palate (Calhoun et al., 1992). One of the most interesting findings of the study was in regard to stereognosis, which is defined as the ability to perceive and recognize the form of an object without using vision (Yekuteil et al., 1994). The stereognostic ability was observed to remain relatively constant until beyond 80 years of age, where it markedly declined (Calhoun et al., 1992).

In addition to the findings of Calhoun et al. (1992), there are many changes in oral physiology with age that make it extremely likely that changes in texture perception accompany aging (Kremer et al., 2005). Known changes in oral physiology as we age include a decreased bite force, changes in dental status, changes in saliva composition, and increased muscle fatigue (Shipp, 1999). Older adults have been observed implementing compensatory strategies such as increasing the chewing time or the number of chews (Mioche, 2004). With these compensations it is unclear whether the overall product concept differs between young and old food consumers (Kremer et al., 2007).

There are multiple examples of texture alteration affecting the food perception of the elderly different than young adults. Manipulation of the texture in Muesli impacted the pleasantness ratings in the elderly than the young (Kalviainen et al., 2002). Using a soup, texture-flavor interaction differences were observed between young and old (Kremer et al., 2005). Pleasantness was affected by changes in texture attributes more in the elderly than young people (Forde and Delahunty, 2002). A better understanding of how texture affects the oral processes of older people during the eating process and the subsequent changes in flavor perception could be integrated in to the design of bespoke food products.

2.5.4. Sensory Preferences

Many people passively observe changes in their food preferences throughout their lifespan. Research has been done on many of these changes that are thought to exist in food sensory preferences throughout the lifespan, but the individuality of food attribute preferences has complicated the findings. It has been shown that infants find salt to aversive or neutral, while adults find it pleasurable and young children tend to prefer their food more sweet than adults (Desor et al., 1975; Grinker et al., 1976).

2.5.5. Multisensory Integration

Multisensory integration has been shown to exhibit inverse effectiveness, which has been central to the theory that multisensory integration effectiveness will increase with age (Hairston et al., 2003; Laurenti et al., 2006). The thought process behind this theory is as follows: as we age we undergo natural decreases in sensory processing which makes weakens unisensory input.

Following the theory of inverse effectiveness this decrease in unisensory signal strength caused by the aging process will lead to a greater benefit from multisensory stimuli.

The studies that have looked at multisensory integration as a function have aging have shown conflicting results, however many of the studies have been criticized for measuring significant cognitive processes, not only sensory processes (Laurenti et al., 2006). Peiffer et al. (2007) showed that in a higher-order cognition task (audiovisual detection), older adults showed faster multisensory responses than younger participants. Enhanced multisensory integration was also shown in a study done by Laurenti et al. (2006) which showed a decrease in reaction time for both young and older adults, but with older adults showing a significantly greater gain from the multisensory condition. More specifically, the multisensory condition brought the reaction time of the older adults to that of one equal to the younger adult group. Currently there is not a known mechanism behind the observed enhances in MSI effectiveness in older adults (Laurenti et al., 2006). Laurenti et al. (2006) offered up the theory that older adults may simply be better able to utilize redundant sensory cues, possibly stemming from a change in attention. This may explain some of their own results, but many other studies in the field were completed only comparing a multisensory condition to a single unisensory condition while Laurenti et al. compared a multisensory condition to a combination of unisensory stimuli.

2.6. **References**

Amarantos, E., Martinez, A., Dwyer, J. (2001). Nutrition and quality of life in older adults. *Journals of Gerontology*, 56, 54-64.

Amerine, M.A., Pangborn, R.M., & Roessler, E.B. (1965). Principles of Sensory Evaluation of Food. Academic Press: New York.

Amoore, J. (1970). Molecular Basis of Odor, I.N. Kugelmass, ed. (New York: Charles C. Thomas).

Baines, Z., Morris, E. (1987). Flavour/taste perception in thickened systems: the effect of guar gum above and below **c***. *Food Hydrocolloids*, 3, 197–295.

Bartoshuk, L.M., Rifkin, L.E., Marks, E., & Bars, P. (1986). Taste and Aging. *The Journal of Gerontology*, 41, 51-57.

Beckstead, R.M., Morse, J.R., Norgren, R. (1980). The Nucleus of the Solitary Tract in the Monkey: Projections to the Thalamus and Brain Stem Nuclei. *The Journal of Comparative Neurology*, 190, 259-282.

Boland, A.B., Delahunty, C.M., & van Ruth, S.M. (2006). Influence of Texture of Gelatin Gels and Pectin Gels on Strawberry Flavor Release and Perception. *Food Chemistry*, 96, 542-460.

Bourne, M.C. (2002). Food Texture and Viscosity: Concept and Measurement 2^{nd} Ed. Academic Press: London, UK.

Buck, L.B. (1996). Information Coding in the Vertebrate Olfactory System. *Annual Reviews in Neuroscience*, 19, 517-544.

Bult, J. H. F.; de Wijk, R.; Hummel, T. (2007). Investigations on multimodal sensory integration: texture, taste, and ortho- and retronasal olfactory stimuli in concert. *Neuroscience Letters*, *411*, 6–10.

Burseg, K.; Camacho, S.; Bult, J.H. (2011). Effects of pulsation rate and viscosity on pulsation-induced taste enhancement: new insights into texture-taste interactions. *Journal of Agricultural and Food Chemistry*, 59, 5548-5553.

Cain, W.S., & Gent, J.F. (1991). Olfactory Sensitivity: Reliability, Generality, and Association with Aging. *Journal of Experimental Psychology*, 17: 382-391.

Cain, W.S., & Murphy, C.L. (1980). Interaction Between Chemoreceptive Modalities of Odour and Irritation. *Nature*, 284, 255-257.

Cain, W.S., Stevens, J.C., Nickou, C.M., Giles, A., Johnston, I., & Garcia-Medina, M.R. (1995). Life-Span Development of Odor Identification, Learning, and Olfactory Sensitivity. *Perception*, 24, 1457-1472.

Calhoun, K.H., Gibson, B. Hartley, L. Minton, J., & Hokason, A. (1992) Age-related Changes in Oral Perception. *The Laryngoscope*, 102, 109-116.

Cardello, A.V. (1996). The Role of the Human Senses in Food Behavior. II. Texture. *Cereal Foods World*, 41, 469-470).

Carleton, A., Accolla, R., & Simon, S.A. (2010). Coding in the Mammalian Gustatory System. *Trends in Neurosciences*, 33, 326-334.

Carr, V.M., & Farbman, A.I. (1993). The Dynamics of Cell Death in the Olfactory Epithelium. *Experimental Neurology*, 124, 308-314.

Carstens, E, Carstens, M.I., D, J-M., O'Mahony, M., Simons, C.T., Makoto, S., & Sudo, S. (2002). It Hurts So Good: Oral Irritation by Spices and Carbonated Drinks and the Underlying Neural Mechanisms. *Food Quality and Preference*, 13, 431-443.

Caul, J.F. (1957). The Profile Method of Flavor Analysis. *Advances in Food Research*, 7, 1-40.

Cayot, N., Pretot, F.., Doublier, J-L, Meunier, J-M, & Cuchard, E. (2004). Release of Isoamyl Acetate from Starch Pastes of Various Structures: Theromdynamic and Kinetic Parameters. *Journal of Agricultural and Food Chemistry*, 52, 5436-5442.

Christensen, C.M.; Texture-taste interactions. *Cereal Foods World* 1977, *22*, 243-256.

Coles, M.G.H., & Rugg, M.D. (1996). "Event-related brain potentials: an introduction". *Electrophysiology of Mind*. Oxford Scholarship Online Monographs. pp. 1–27.

Cook, D. J.; Hollowood, T. A.; Linforth, R. S. T.; Taylor, A. J. (2005). Correlating instrumental measurements of texture and flavour release with human perception. International Journal of Food Science and Technology., 40, 631–641.

Corso, J.F. (1981). Aging Sensory Systems and Perception. pp 282 New York: Praeger

Cowart, B.J. (1989). Relationship between Taste and Smell Across the Adult Life Span. *Annals New York Academy of Sciences*, 561, 39-55.

Desor, J.A., Greene, L.S., & Maller, O. (1975). Preferences for Sweet and Salty in 9-15-year-old and Adult Children. *Science*, 190, 686-687.

Donchin E Coles MGH (1988). Is the P300 Component a Manifestation of Context Updating? *Behavioural and Brain Sciences*, 11, 357-374.

Doty, R.L., Brugger, W.E., Jurs, P.C., Orndorff, M.A., Snyder, P.J. & Lowry, L.D. (1978). Intranasal Trigeminal Stimulation from Odorous Volatiles: Psychometric Responses from Anosmic and Normal Humans. *Physiology & Behavior*, 20, 175-185.

Doty, R.L., & Laing, D.G., (2003). Psychophysical measurement of human olfactory function, including odorant mixture assessment. In: Doty, R.L. (Ed.), *Handbook of Olfaction and Gustation*. Marcel Dekker, New York.

Doty, R.L., Shaman, P., Applebaum, S.L., Giberson, R., Sikorski, L., & Rosenberg, L. (1984). Smell Identification Ability: Changes with Age. *Science*, 226, 1441-1443.

Dwyer, N.D., Troemel, E.R., Sengupta, P., & Bargmann, C.I. (1998). Odorant Receptor Localization to Olfactory Cilia is Mediated by ODR-4, a novel Membrane-associated Protein. *Cell*, 93, 455-466.

Enns, M.P., & Hornung, D.E. (1988). Comparison of the Estimates of Smell, Taste and Overall Intensity in Young and Elderly. *Chemical Senses*, 13, 131-139.

Evans, W.J., Cui, L., & Starr, A. (1995). Olfactory Event-related Potentials in Normal Human Subjects: Effects of Age and Gender. *Electroencephalography and Clinical Neurophysiology*, 95, 293-301.

Ferry, A. L.; Hort, J.; Mitchell, J. R.; Cook, D. J.; Lagarrigue, S.; Pamies, B. V. Viscosity and flavour perception: why is starch different from hydrocolloids? *Food Hydrocolloids* 2006, 20, 855–862.

Forde, C.G., & Delahunty, C.M. (2002). Examination of Chemical Irritation and Textural Influences on Food Preferences in Two Age Cohorts using Complex Food Systems. *Food Quality and Preference*, 13, 571-582.

Fordyce, I.D. (1961). Olfaction Tests. *British Journal of Industrial Medicine*, 18, 213-215.

Fillion, L., Kilcast, D. (2001). Towards a measurement of oral tactile sensitivity and masticatory performance: development of texture tests. *Leatherhead Food RA Research Report*, No. 781.

Franco, M.I., Turin, L., Mershin, A., & Skoulakis, E.M.C. (2011) Molecular Vibration-sensing Component in Drosophila melanogaster Olfaction. *Proceedings of the National Academy of Sciences of the United States of America*, 108: 3797-3802.

Grinker, J.A., Price, J.M., Greenwood, M.R.C. (1976). Studies of Tasted in Childhood Obesity. *Hunger: Basic Mechanisms and Clinical Implications (Novin, D., Wyrwicka, W., & Bray, G. eds)*, Raven Press: NY, NY.

Hairston W.D., Laurienti P.J., Mishra G., Burdette J.H., & Wallace M.T. (2003). Multisensory enhancement of localization under conditions of induced myopia. *Experimental Brain Research*, 152, 404-408.

Harrison, M. (2000). Mathematical Models of Release and Transport of Flavors from Foods in the Mouth to the Olfactory Epithelium. In: Flavor Release (Ch. 15) (pp. 179–191). American Chemical Society.

Heath, M.R. (1982). The Effect of Maximum Biting Force and Bone Loss on Masticatory Function and Dietary Selection in the Elderly. *International Dental Journal*, 32, 345-356.

Heath, M. R., & Prinz, J. F. (1999). Oral processing of foods and the sensory evaluation of texture. In A. J. Rosenthal (Ed.), Food texture, measurement and perception (Ch. 2) (pp. 18–29). Gathersburg: Aspen Publishers Inc.

Hill, D.A., & Lucas, P.W. (1999). Toughness and fiber content of major leaf foods of Japanese macaques (*Macaca fuscata yakui*) in Yakushima. *American Journal of Primatology*, 38, 221-231.

Hirai, T., Kojima, S., Shimada, A., Umemura, T., Sakai, M., Itakurat, C. (1996). Age-related Changes in the Olfactory System of Dogs. *Neuropathology and Applied Neurobiology*, 22, 531-539.

Hollowood, T.A., Linforth, R.S.T., & Taylor, A.J. (2002). The Effect of Viscosity on the Perception of Flavor. *Chemical Senses*, 27, 583-591.

Hornung, D.E., & Enns, M.P. (1984). The Independence and Integration of Olfaction and Taste. *Chemical Senses*, 9, 97-106.

Hummel, T., & Kobal, G. (1992). Differences in Human Evoked Potentials Related to Olfactory or Trigeminal Chemosensory Activation. *Electroencephalography and Clinical Neurophysiology*, 84, 84-89.

Hummel, T., Barz, S., Pauli, E., & Kobal, G. (1998). Chemosensory Event-related Potentials Change as a Function of Age. *Electroencephalography and Clinical Neurophysiology*, 108, 208-217.

Hummel, T. (2000). Assesment of Intranasal Trigeminal Function. *International Journal of Psychophysiology,* 36, 147-155.

Hummel T., Konnerth O.G., Rosenheim K., & Kobal G. (2001). Screening of Olfactory Function with a Four-Minute Odor Identification Test: Reliability, Normative Data, and Investigations in Patients with Olfactory Loss. *Annals Otololgy Rhinology Laryngology*, 110, 976-981.

Kalviainen, N., Roininen, K., Tuorila, H. (2003). The Relative Importance of Texture, Taste, and Aroma on Yogurt-type Snack Food Preference in the Young and the Elderly. *Food Quality and Preference*, 14, 623-635.

Katz, E.E., & Labuza, T.P. (1981). Effect of Water Activity on the Sensory Crispness and Mechanical Deformation of Snack Food Products. *Journal of Food Science*, 46, 403-409.

Kimbrell, G.M., & Furchtgott, E. (1963). The Effect of Aging on Olfactory Threshold. *Journal of Gerontology*, 18,, 364-365.

Krauel, K., Schott, P., Sojka, B., Pause, B.M., Ferstly R. (1999). Is There a Mismatch Negatvitiy Analogue in the Olfactroy Event-related Potential? *Journal of Neurophsysiology*, 13, 39-55.

Kremer, S., Bult, J., Moet, J., & Kroeze, J.H.A. (2007). Food Perception with Age and its Relationship with Pleasantness. *Chemical Senses*, 32, 591-602.

Kremer, S., Mojet, J., & Kroetze J.H.A. (2005). Perception of Texture and Flavor in Soups by Elderly and Young Subjects. *Journal of Texture Studies*, 36, 255-272.

Krmpotic-Nemanic, J. (1969). Prebycusis, Prebystasis and Prebyosmia as Consequences of the Analogous Biological Process. *Acta Oto-laryngologica (Stockholm)*, 67, 217-223.

Larson-Powers, N., & Pangborn, R.M. (1978) Paired Comparison and Time-Intensity Measurements of the Sensory Properties Of Beverages and Gelatins Containing Sucrose or Synthetic Sweeteners. *Journal of Food Science*, 43, 41-46.

Laurenti, P., Burdette, J.H., Maldjian, J.A., & Wallace, M.T. (2006). Enhanced Multisensory Integration in Older Adults. *Neurobiology of Aging*, 27, 1155-1163.

Lawless, H.T., & Heymann, H. (1998). *Sensory Evaluation of Food*. New York, New York, Champan & Hall.

Leclerq, S. & Blancher, G. (2012). Multimodal Sensory Integration during Sequential Eating—Linking Chewing Activity, Aroma Release, and Aroma Perception over Time. *Chemical Senses*, 37, 689-700.

Leon, M., & Johnson, B.A. (2003). Olfactory Coding in the Mammalian Olfactory Bulb. *Brain Research Reviews*, 42, 23-32.

Lorig, T.S., Matia, D.C., Peszka, J.J., & Bryant, D.N. (1996). The Effects of Active and Passive Stimulation on Chemosensory Event-related Potentials. *International Journal of Psychophysiology*, 23, 1999-205.

Lundahl, D.S. (1992). Comparing Time-Intensity to Category Scales in Sensory Evaluation. *Food Technology*, 46, 98-105.

Mackey, A. and Valassi, K. (1956). The discernment of primary tastes in the presence of different food textures. *Food Technology*, 10, 238-240.

Malnic, B., Hirono, J., Sata, T., & Buck, L.B. (1999). Combinatorial Receptor Codes for Odors. *Cell*, 96, 713-723.

Matsuda, T., & Doty, R.L. (1994). Region Taste Sensitivity to NaCl: Relationship to Subject Age, Tongue Locus and Area of Stimulation. *Chemical Senses*, 20, 283-290.

Mattes R.D. & Cowart B.J. (1994). Dietary Assessment of Patients with Chemosensotyr Disorders. *Journal of the American Dietetics Association*, 94, 50-56.

Megighian, D. (1958) Variazioni della soglia olfattiva nell;eta senile. *Minerva Otolaringologica*, 9, 331-337.

Meilgaard, M.C., Carr, B.T., & Civille, G.V. (2007). Sensory Evaluation Techniques, 4th Ed. CRC Press: New York, New York.

Meisami, E., Mikhail, L., Baim, D., & Bhatnagar, K.P. (1998). Human Olfactory Bulb: Aging of Glomeruli and Mitral Cells and a Search for the Accessory Olfactory Bulb. *Annals of the New York Academy of Sciences*, 855, 708-714.

Mioche, L., Boundial, P., & Peyron, M.A. (2004). Influence of Age on Mastication: Effects on Eating Behavior. *Nutrition Research Reviews*, 17, 43-54.

Morrison, E.E., & Costanzo, R.M. (1990). Morphology of the Human Olfactory Epithelium. *Journal of Comparative Neurobiology*, 297, 1-13.

Mozell, M.M., Smith, B.P., Smith, P.E., Sullivan, R.L., & Swender, P. (1969) Nasal Chemoreception in Flavor Identification. *Archives of Otolaryngology – Head & Neck Surgery*, 90, 367-373.

Murphy, C. (1983). Age-related Effects on the Threshold, Psychophysical Function and Pleasantness of Menthol. *Journal of Gerontology*, 38, 217-222.

Naatanen, R. (1990). The Role of Attention in Auditory Information Processing as Revealed by Event-related Potentials and Other Bran Measures of Cognitive Function. *Behavioral and Brain Scineces*, 13, 201-288.

Nakashima, T., & Kimmelman, C.P., & Snow, J.B. (1984). Structure of Human Fetal and Adult Olfactory Neural Epithelium. *Archives of Otolarynogology*, 110, 641-646.

Nef, P., Hermans-Borgmeyer, I., Artieres-Pin, H., Beasley, L., Dionne, V.E., & Heinemann, S.F. (1992). Spatial Pattern of Receptor Expression in the Olfactory Epithelium. *Proceedings of the National Academy of Sciences of the United States of America*, 89, 8948-8952.

Negoias, S., Visschers, R., Boelrijk, A., & Hummel, T. (2008). New Ways to Understand Aroma Perception. *Food Chemistry*, 108, 1247-1254.

Norgren, R. (1976). Taste Pathways to Hypothalamus and Amygdala. *Journal of Comparative Neurology*, 166, 17-30.

Pace, U., & Lancet, D. (1986). Olfactory GTP-binding Protein: Signal-transducing Polypeptide of Vertebrate Chemosensory Neurons. *Proceedings of the National Academy of Sciences*, 83, 4947-4951.

Pangborn, R.M. and Szczesniak, A.K. (1974). Effect of hydrocolloids and viscosity on flavor and odor intensities of aromatic flavor compounds. *Journal of Texture Studies*, 4, 467-482.

Parker, G.H. (1912). The Relation of Smell, Taste, and the Common Chemical Sense in Vertebrates. University of Chicago Press: Chicago.

Pause, B.M., Miranda, A., Raack, N., Sojka B., Goder, R., Aldenhoff, J.B., & Ferstl R. (1999). Olfactoin and Affective States: is odor evaluation and perception Altered in patiernts with Major Depression? *Chemical Senses*, 24, 100.

Peiffer, A.M., Mozolic, J.L., Hugenschmidt, C.E., & Laurenti, P.J. (2007). Age-Related Multisensory Enhancement in a Simple Audiovisual Detection Task. *Sensory and Motor Systems*, 18, 1077-1081.

Pelosi, P., Baldaccini, N.E., & Pisanelli, A.M. (1982). Identification of a specific olfactory receptor for 2-isobutyl-3-methoxypyrazine.*Biochemistry Journal*, 201, 245-248.

Pevsner, J., Sklar, P.B., & Snyder, S.H. (1986). Odorant-binding Protein: Localization to Nasal Glands and Secretions. *Proceedings of the National Academy of Sciences*, 83, 4942-4946.

Pineau, N., Cordelle, S., & Schlich, P. (2003). Temporal Dominance of Sensations: A New Technique to Record Several Sensory Attributes Simultaneously Over Time. *5th Pangborn symposium*, (p. 121). July 20–24.

Pritchard, T.C., Hamilton, R.B., Morse, J.R., & Norgren, R. (1986). Projections of Thalamic Gustatory and Lingual Areas in the Monkey, *Macaca fascilaris*. *The Journal of Comparative Neurology*, 244, 213-228.

Rawson, N.E., Gomez, G., Cowart, B., & Restrepo, D. (1998). The Use of Olfactory Receptor Neurons (ORNs) from Biopsies to Study Changes in Aging and Neurodegenerative Diseases. *Annals of the New York Acadmemy of Sciences*, 855, 701-707.

Repoux, M., Laboure, H., Courcoux, P., Andriot, I., Semon, E., Yven, C., Feron, G., & Guichard, E. (2012). Combined Effect of Cheese Characteristics and Food Oral Processing on *In Vivo* Aroma Release. *Flavour and Fragrance Journal*, 27, 414-423.

Ressler, K.J., Sullivan, S.L., & Buck, L.B. (1993). A Zonal Organization of Odorant Recpetor Gene Expression in the Olfactory Epithelium. *Cell*, 73, 597-609.

Rolls, E.T., Murzi, E., Yaxley, S.J., Thorpe, Simpson S.J. (1986). Sensory-specific Satiety: Food-specific Reduction in Responsiveness of Ventral Forebrain Neurons after Feeding in the Monkey. *Brain Research*, 368, 79-86.

Rolls, E.T., Yaxley, S., & Sienkiewicz, Z.J. (1990). Gustatory Repsonses of Single Neurons in the Caudolateral Orbitalfrontal Cortex of the Macaque Monkey. *Journal of Neurophysiology*, 64, 1055-1066.

Ronnett, G.V., Cho, H., Hester, L.D., Wood, S.F., & Snyder, S.H. (1993). Odorants Differentially Enhance Phosphoinositide Turnover and Adenylyl Cyclase in Olfactory Receptor Neuronal Cultures. *The Journal of Neuroscience*, 13, 1751-1758.

Rosli, Y., Breckenridge, L.J., & Smith, R.A. (1999) An Ultrastructural Study of Age-related Changes in Mouse Olfactory Epithelium. *Journal of Electron Mircroscopy*, 48: 77-84.

Roudnitzky, N., Bult, H.F., de Wijk, R.A., Reden J., Schuster, B., & Hummel, T. (2011). Investigation of Interactions Between Texture and Ortho- and Retronasal Olfactory Stimuli Using Psychophysical and Electrophysiological Approaches. *Behavioural brain research*, 216, 109-115.

Schiffman, S. (1979). Changes in Taste and Smell with Age: Physchophyiscal Aspects. In: *Sensory Systems and Communication in the Elderly*, ed. JM Ordy & K Brizzee pp 227-246. New York: Raven Press.

Schiffman, S. & Pasternak, M. (1979). Decreased Discrimination of Food Odors in the Elderly. *Journal of Gerontology,* 34, 73-79.

Schiffman, S., Moss, J. & Erickson, R.P. (1976). Thresholds of Food Odors in the Elderly. *Experimental Aging Research,* 2, 389-398

Schiffman, S.S., & Wedral, E. (1996). Contribution of Taste and Smell Losses to the Wasting Syndrome. *Age and Nutrition*, 7, 106-120.

Semke, E., Distel, H., & Hudson, R. (1995). Specific Enhancement of Olfactory Receptor Sensitivity Associated with Foetal Learning of Food Odors in the Rabbit. *Naturwissenschaften*, 82, 148-149.

Sicard, G. (2002) Odor coding at the periphery of the olfactory system. In Rouby, C., Schaal, B., Dubois, D., Gervais, R. and Holley, A. (eds), Olfaction, Taste, and Cognition. Cambridge University Press, Cambridge, United Kingdom, pp. 293–308.

Shipp, J.A. (1999). Influence of Aging on Oral Health and Consequences for Taste and Smell. *Physiology and Behavior*, 66, 209-15.

Shipp, J.A., & Weiffenbach, J.M. (1993). Age, Gender, Medical Treatment, and Medication Effects of Smell Identification. *Journal of Gerontology*, 48, M26-32.

Silver, W.L., & Moulton, D.G. (1982). Chemosensitivity of Rat Nasal Trigeminal Receptors. *Physiology & Behavior*, 28, 927-931.

Smith, C.G. (1941). Incidence of Atrophy of the Olfactory Nerves in Man. *Archives of Otolaryngology*, 34, 73-79.

Smith, D.O. (1988). Cellular and Molecular Correlates of Aging in the Nervous System. *Experimental Gerontology*, 23, 399-412.

Stein, B.E., Meredith, M.A. (1993). Merging of the Senses. MIT Press, Cambridge, MA.

Stevens, J.C., & Cain, W.S. (1987). Old-Age Deficity in the Sense of Smell as Gauged by Thresholds, Magnitude Matching, and Odor Identification. *Psychology of Aging*. 2, 36-42.

Stevens, J.C., & Cain, W.S. (1986). Aging and the Perception of Nasal Irritation. *Physiology and Behavior*, 37, 323-328.

Stevens, J.C., Bartoshuk, L.M., & Cain, L.M. (1984). Chemical Senses and Aging: Taste versus Smell. *Chemical Senses*, 9, 167-179.

Stevens, J.C., Cain, W.S., Schiet, F.T., & Oatley, M.W. (1989). Olfactory Adaptation and Recovery in Old Age. *Perception*, 18, 265-276.

Strotmann, J., Wanner, I., Krieger, J., Raming, K., & Breer, H., (1992). Expression of Odorant Receptors in Spatially Restricted Subsets of Chemosensory Neurones. *Neuroreport*, 3: 1053-1056.

Sur, S., & Sinha, V.K. (2009). Event-related Potential: An Overview. *Industrial Psychiatry Journal*, 18, 70-73.

Szczesniack, A.S. & Kleyn, D.H. (1963). Consumer Awareness of Texture and Other Food Attributes. *Food Technology*, 17, 74-77.

Szczesniack, A.S. & Kahn, E.L. (1971). Consumer Awareness of and Attitudes to Food Texture. *Journal of Texture Studies*, 2, 280-295.

Tateyama, T., Hummel, T., Roscher, S., Post, H., &Kobal, G. (1998). Relation of Olfactory Event-related Potentials to Changes in Stimulus Concentration. *Electroencephalography and Clinical Neurophysiology*, 28, 85-112.

Terta, M., Blekas, G., Paraskevopoulou, A. (2006). Retention of Selected Aroma Compounds by Polysaccharide Solutions: A Thermodynamic and Kinetic Approach. *Food Hydrocolloids*, 20, 863-871.

Thomas-Danguin, T., Rouby, C., Sicard, G., Vigoroux, M., Farget, V., Johansson, A., Bengtzon, A., Hall, G., Ormel, W., de Graaf, C., Rousseau, F., & Dumont, J.-P. (2003). Development of the ETOC: a European test of olfactory capabilities. *Rhinology,* 41, 142–151.

Trelea, I.C., Atlan, S., Deleris, I., Saint-Eve, A., Marin, M., & Souchon, I. (2008). Mechanistic Mathematical Model for In Vivo Aroma Release during Eating of Semiliquid Foods. *Chemical Senses,* 33, 181-192.

Van Gemert, L. J. (1985). De 4-basissmakentest. *Instituut CIVO-analyse TNO,* Rapport nr. A 89.586.

Verhagen, J.V., & Engelen, L. (2006). The Neurocognitive Bases of Human Multimodal Food Perception: Sensory Integration. *Neuroscience and Biobehavioral Reviews*, 30, 613-650.

Vickers, Z.M. (1987). Sensory, Acoustical, and Force-Deformation Measurements of Potato Chip Crispness. *Journal of Food Science*, 52, 138-140.

Vickers, Z.M., (1985). Crispness and Crunchiness – A Difference in Pitch? *Journal of Texture Studies*, 15, 157-163.

Vickers, Z.M. & Bourne, M.C. (1976). A Psychoacoustical Theory of Crispness. *Journal of Food Science,* 41, 1158-1164.

Wang, H.W., Wysocki, C.J., & Gold, G.H. (1993). Induction of Olfactory Receptor Sensitivity in Mice. *Science,* 260, 998-1000.

Wilson, D.A. (2001). Receptive Fields in the Rat Piriform Cortex. *Chemical Senses*, 26, 577-584.

Wysocki, C.J., Dorries, K.M., & Beauchamp, G.K. Ability to Perceive Androstenone can be Acquired by Ostensibly Anosmic People. *Proceedings of the National Academy of Sciences of the United States of America,* 86, 7976-7978.

Yekuteil, M., Jariwala, Stretch, P. (1994). Sensory Deficit in the Hands of Children with Cerebral Palsy: A New Look at Assessment and Prevalence. *Developmental Medicine and Child Neurology,* 36, 619-624.

Chapter 3.

Consumer Attitudes towards Texture and other Food Attributes

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Abstract

This study aimed to revisit the often-cited work done in the 1960's and 1970's regarding consumer attitudes towards food. The participants were asked to give the first three words that come to mind when a food image was presented. The responses were grouped into categories and the frequencies of answers from participants in various demographic segments were compared. *Food attribute* was the most common response category. *Texture* was the most common *food attribute*, followed by *flavor*. *Texture* responses became less common as age increased. Similar to *texture*, there was a difference between the proportion of *form and temperature* responses of the people under 40 years old (6.2%) and people over 40 years old (8.8%). The most common texture response was *crunchy*, followed by *crispy*. This study highlights the changes in food consumers of the last several decades, as well as the changes in food attitudes as we age.

Keywords: Consumer attitudes, Texture, Flavor, Age

3.1. Introduction

In the 1960s and 1970s, texture was brought into mainstream of food science by several studies showing texture to be a prominent food characteristic determining food acceptability (Szczesniak and Kleyn, 1963; Szczesniak, 1971; Szczesniak and Kahn, 1971). Texture continued to secure its place as an important food attribute and there were calls to revisit the original studies on consumer awareness and attitudes toward food texture (Szczesniak, 1990). However, it appears that the majority of continuing research in this area has centered on cross-cultural and language validation (Yoshikawa et al., 1970; Rohm, 1990; Lawless et al., 1997; Nishinari et al., 2008; Antmann et al., 2011).

Over 50 years have passed since the original study by Szczesniak and Kleyn (1963). In that time, many food-related changes have occurred. There are numerous popular media reports regarding changes in the North American consumers' eating behavior and attitude toward foods. For example, there are often reports of an increased health consciousness of certain consumers. These are often manifested in a perceived negative consumer reaction to a food product, processing method or ingredient. Recent food-related issues include the use of artificial sweeteners, high-fructose corn syrup, genetically modified crops, gluten-free foods and sodium reduction in foods. Beyond health-related changes, there are often talks of a breakdown in traditional meal structures. Conversely, there has been numerous reporting on the growth of the slow-food movement, which aims to promote local foods and centuries-old traditions of gastronomy and food production (Meneley, 2004). Overall, there is consensus that visible changes are occurring among the food consumers in the United States, but quantification of these changes has been lacking.

One major food-related change in the United States is the increase in the popularity of ethnic foods (Lee et al., 2014). The ethnic food market in the United States has consistently grown 5–6% over the last several years (Mintel Group, 2012). Ethnic foods often expose consumers to different textures; a common example is the unique texture of crisp-cooked vegetables found in many Asian cuisines. In traditional cooking in the United States, cooked vegetables are often expected to be soft and mushy (Szczesniak, 2002). Additionally, the population of the United States is changing to an older more multicultural populace. For example, in 1970, the estimated percentage of Hispanic people in the United States was 4.7%, while today that number is estimated to be above 16% (Ennis et al., 2011). The ethnicities and backgrounds that make up the American landscape have changed drastically in the last several decades. We are in the process of seeing drastically increasing numbers of older Americans. By 2030, it is estimated that nearly one in five US residents will be aged 65 or older (Vincent and Velkoff, 2010). In 2050, the number of Americans older than 65 is projected to be 88.5 million, more than double its projected population of 40.2 million in 2010 (Vincent and Velkoff, 2010). In 1972, Szczesniak reported that teenagers differed slightly from adults in their texture awareness. While there might be differences between how teenagers and older adults view texture, it is also possible that the results from teenagers in 1972 was evidence of a generational change in how texture is regarded.

Texture has also seen a rise in attention from the food industry, which has begun to realize the importance of positive texture in the launch of a viable product (Szczesniak, 1990). Texture has been shown to be more important than flavor in the rejection of foods (Szczesniak, 1972). However, flavor has remained the dominant food attribute for a multitude of reasons. Mainly, flavor is highly correlated with overall liking of a food product and flavor benefits from high consumer awareness (Szczesniak, 1972; Moskowitz and Krieger, 1995).

Building on previous works of Szczesniak and Kleyn (1963), Szczesniak (1971) and Szczesniak and Kahn (1971), this study aimed to examine the current attitudes of North American consumers (mainly, Northwest Arkansas residents) toward food attributes, focusing on the effect of gender and age. In addition, in an effort to explore the changes in consumer attitudes toward food attributes for past 50 years, this study revisited the often-cited works carried out in the 1960s and 1970s regarding consumer attitudes toward foods. However, as this study was not designed to directly compare the results with the previous findings drawn by Szczesniak et al., there were methodological modifications as shown in the succeeding text.

3.2. Materials and Methods

Participants

Using an online survey program (http://www.surveymonkey.com), the questionnaire was sent out to potential participants registered through the consumer profile database of the University of Arkansas Sensory Service Center (Fayetteville, AR). The access to the survey was discontinued when the authors reached an adequate amount of responses; survey data were collected over three days (November 24–26, 2013). The consumer database contains over 5,000 area residents (34% males and 66% females), with the majority of the consumers between 18 and 55 years old. A total number of 337 volunteers (93 males and 244 females) with an age range from 19 to 81 years old filled out the survey. There were no specific criteria of selecting the participants. A detailed breakdown of the demographics of the participants is presented in Table 1.

Samples and presentation

Thirty-two foods were chosen mainly from the foods used by Szczesniak (1971). Modifications were made in an attempt to make the foods more relevant to modern consumers and to choose foods that were recognizable using images. For example, liver was not used in this study because of its lack of popularity and nondescript appearance after being prepared for consumption. As shown in Table 2, 22 food items of the total 32 foods came from the original study of Szczesniak (1971) and new 10 food items were added in this study.

In a preliminary study, when a name of the food without its image was presented, a substantial amount of volunteers had difficulty in reporting words relevant to the name of the presented food. In addition, the authors thought that viewing the image while answering might help the participants to remain focused. In particular, young adults appear to be more comfortable with image than text itself in a modern society. Conversely, a preliminary study showed that an image without the name of the food resulted in a high proportion of responses simply naming the food. Thus, in conjunction with an image (640 pixels × 480 pixels) of each food, the name of the food was presented. The name of the food was also presented below the photo. Preliminary studies showed that pictures without a text title resulted in a high proportion of responses simply naming the food.

Procedure

This test was completed using a free word association to a variety of different foods (Table 2). That is, the participants were asked to give the first three words that come to mind immediately when the image and name of each food was presented. The order of presentation of the food names with their images was randomized across participants. The participants were free to control the pace of the test; i.e., there was no time limit.

Data analysis

The data analysis was performed using XLSTAT (version 2013.5.05, Addinsoft, New York, NY). The responses were classified into seven main categories and subcategories by their content (Szczesniak and Kahn, 1971; Table 3). In an effort to ensure consistency, only one person assigned each answer to a main category and subcategory. In the instances where words could fit into multiple categories, the response was assigned to the main category that was thought to be most fitting. The proportion of responses in each of the main categories was compared across demographic groups, using the chi-squared test. To analyze the subcategories, the proportions were compared using the chi-square test of only the frequencies within each category. A statistically significant difference was defined as $P < 0.05$. Correspondence analysis was performed to get a bidimensional representation of age groups and the relationship between age groups and the response categories.

3.3. Results

Age group effect

All of the categories showed significant differences in the frequency of answers between age groups, except the "other" category (Table 4). The 70+ group listed "food attribute" responses (29.8%) less frequently than any other age groups (37.5–46.5%). The highest proportion of "food attribute" responses was found in the 50–59 age group (46.5%).

All of the age groups showed differences in the frequency of answers that were classified in to each food category, except the *other* category. The 70+ group listed food attribute responses less frequently than any other age groups (Table 3). The 70+ age group listed words classified as food attributes 29.8% of answers, while the other age groups listed food attributes for approximately 40% of their answers. The highest proportion of *food attribute* responses was found in the 50-59 age group (46.5%).

Within the “food attribute” responses, texture was by far the most popular subcategory in all age groups. Texture responses comprised of 41.6% of the total “food attribute” responses. Texture results were more common in the two youngest age groups (18–29 and 30–39; 43.3%) when compared with the oldest age group (70+; 35.2%). The frequency of texture responses appeared to be trending downward as age increased. When the participants under 40 (43.3%) were compared with those over 40 (40.3%), a significant difference in the percentage of texture responses was observed ($P < 0.001$). Conversely, the proportion of form or temperature responses was lower for people under 40 years old (6.2%) than people aged over 40 years old (8.8%; $P < 0.001$).

Overall, flavor was the second most popular “food attribute”, accounting for 25.6% of the total “food attribute” responses. The proportion of aroma responses was not significantly different across age groups, and in general aroma responses made up less than 1.5% of the total “food attribute” responses. Color responses comprised 6.6% of the “food attribute” responses. Color responses were more popular in the youngest (18–29 age group) compared with people ranging from 30 to 69 years old. However, the popularity of appearance was much closer among age groups as compared with the response of color. The 40–49 age group showed lower proportion of appearance responses than the 18–29, 60–69 and 70+ age groups.

“Menu uses” were more common in the 70+ (29.4%) and 30–39 (30.1%) age groups compared with the 40–49 (25.4%), 50–59 (18.7%) and 60–69 (22.3%) age groups. Under “menu uses”, other foods subcategory (i.e., foods other than the presented foods) was the most popular, accounting for approximately 40% of the “menu uses” responses. There were no differences between age groups in the proportion of answers relating to occasion or other foods. The method of cooking or eating subcategory was more popular for the 50–59 age group than for the 18–29 age group.

The main category of “type” (responses related to brand, food category and food type) was more popular with the 18–29-year-old age group than with the 30–69 age groups. Overall, the food category was the most popular subcategory within the “type” category. The 70+ age group had higher proportion food category responses (63.0%) than the 18–29 (48.5%), 30–39 (45.2%) and 50–59 (49.1%) age groups. However, within the “type” category, there were no significant differences in the proportion of responses classified under the type subcategory. The percentage of answers in the brand subcategory showed a significant difference among age groups. For example, the 18–29 age group (9.2%) listed brand responses more frequently than the 60–69 (4.9%) and 70+ age (3.0%) groups.

In general, the frequency of “personal preference” category increased with age. The 18–29 age group gave the smallest proportion “personal preference” responses (5.9%), while the 50–59, 60–69 and 70+ groups gave the highest proportions of “personal preference” responses. For all groups, the “personal preference” responses were predominately the like subcategory. Overall, older age group (60–69 and 70+), in comparison with younger age group (18–29), listed more responses of the like subcategory. The proportion of the dislike subcategory response showed opposite trend.

Generally, the “health and nutrition”-based responses increased with age (Table 4). The highest proportion of “health and nutrition” responses was the 70+ groups (11.6%). The proportion of “health and nutrition” answers was lower in the younger groups (18–49) than in the older group (60–69 and 70+).

Finally, “regional origin” words were more common in the 18–29 age group, listing the highest proportion of regional origin words (2.1%), than in the 40–69 age groups (1.0–1.2%).

As shown in Figure 1, a biplot drawn by the correspondence analysis shows overall relationship between main categories and age groups. As mentioned earlier, “personal preference” and “health and nutrition” responses increased with age. In addition, “type” and “regional origin” responses were more common in younger adult group, while “food attribute” were more frequent in the middle-aged group.

Gender effect

When the participants were broken down by gender, significant differences were observed as shown in Figure 2. Female participants (42.2%) gave more “food attribute” responses than male participants (36.7%). Interestingly, flavor responses were more common in males, while texture responses were more common in females. Males (8.5%) also gave a higher amount of color responses than females (5.9%). There were no differences between the proportion of answers by gender in the other “food attribute” subcategories, which included appearance and aroma.

Males (26.2%) also showed to have a higher proportion of responses referring to “menu uses” compared with females (24.5%). However, there were no significant differences observed by gender in the subcategories within “menu uses” (Figure 2).

Figure 2 shows that “type” was a more prevalent response among males (11.6%) than females (9.4%). Within the “type” main category, the type subcategory was not found to be different by gender. However, food category and brand were both found to have gender differences. Food category was more common among males than among females. Furthermore, “personal preference” responses were more common among females (9.1%) when compared with males (8.2%). However, no significant differences with respect to gender were found within the subcategories of the “personal preference” category. The responses related to “regional origin” were more common among males (1.9%) than females (1.4%). Finally, there was no difference between males and females in the proportion of responses referring to “health and nutrition”.

Most Common Word Responses Elicited by the Name and Image of Food Items

Age group effect

Figure 3 shows the relative prominence of word responses elicited by the name and image of food items in relation to age group. Specific words were commonly used in describing the food items presented in this survey: e.g., “sweet,” “salty,” “crunch/crunchy,” “crisp/crispy,” “tasteful/tasty” and “healthy/not-healthy.”

Figure 3 also demonstrates variations in the percentage of responses across age groups. The percentages of flavor (strictly taste)-related word responses, “sweet” and “salty,” began decreasing at 50–59 and 60–69 age groups. Similarly, the percentages of texture-related word responses, “crunch/crunchy” and “crisp/crispy,” began decreasing at 60–69 and 70+ age groups. By contrast, “tasteful/tasty” and “healthy/not-healthy” words were increased with age. Particularly, the “health and nutrition”-related words were the most frequently used in the +70 age group.

Gender effect

Figure 4 demonstrates a gender difference in the relative prominence of word responses elicited by the name and image of food items. Overall, both male and female participants used specific words more commonly: e.g., “sweet,” “salty,” “crunch/crunchy,” “crisp/crispy,” “tasteful/tasty” and “healthy/not-healthy.” Females used “crunch/crunchy” ($P < 0.001$) and “crisp/crispy” ($P < 0.001$) words more frequently compared with males. Especially, the gender differences in crunch/crunchy and crisp/crispy were more pronounced in the 50–59 and 60–69 age groups ($P < 0.001$), respectively.

Most common texture-related words

The words that were used by the survey participants to convey textural awareness were summarized. The 10 most common words were “crunch/crunchy” (19.1%), “crisp” (14.6%), “creamy” (13.3%), “juicy” (6.3%), “smooth” (6.2%), “soft” (5.1%), “moist” (3.5%), “dry” (3.0%), “greasy” (3.0%) and “sticky” (2.5%).

3.4. Discussion

The study demonstrates variations in consumer attitudes toward food items in relation to age and gender. While the previous study (Szczesniak, 1971) did not go into detail about age-related comparisons in responses, this study paid more attention to the age-induced variation in consumer awareness and attitudes toward food items. Due to the scope of the journal, much of the discussion will be focused on texture. It is known that oral physiology changes with age, which may result in age-induced texture perception (Kremer et al., 2005). Furthermore, the age-induced changes in texture perception may alter consumers' attitudes toward texture characteristics of food items in later adulthood, which was supported by this study.

The “food attribute” responses became less common in the oldest adults (70+). In particular, the age-induced decrease in texture response was pronounced as shown in Table 4. The decline in texture responses is interesting from the standpoint that texture manipulation has shown a larger impact on overall liking of the foods in older adults (Forde and Delahunty, 2002; Kälviäinen et al., 2003; Kremer et al., 2005). Unlike texture, form or temperature-related responses did not display sharp declines in older adults. Oral proprioception and somesthetic sensitivity have been shown to remain constant into late adulthood (Calhoun et al., 1992; Fukunaga et al., 2005). In addition, previous research has shown that thermal sensitivity did not decline with age (Calhoun et al., 1992). From these findings, there is evidence of changing attitudes toward “food attributes”, especially texture, as humans age (70+). However, the sources of these changing attitudes toward “food attributes” are not readily apparent and do not always coincide with the age-related physical changes. For example, although olfactory and gustatory performances decline with age (Doty et al., 1984; Mojet et al., 2001), the frequencies of flavor and aroma responses were not different with age. In other words, consistent attention and appreciation are paid to flavor and aroma attributes across life span. This finding is in line with previous research demonstrating that people are consistently interested and attentive to the sense of smell as well as everyday odors across life span (Croy et al., 2010; Seo et al., 2013).

In this study, males were found to be most likely to list flavor-related words, while females listed texture-related words at a higher proportion. This result is in agreement with the previous finding where females were found to be more texture-oriented, while males were more flavor-oriented (Szczesniak, 1971). Additionally, Szczesniak (1971) demonstrated that females listed texture-related words in their first and the second responses at a higher rate than flavor-related words, but this difference was not present in males. Based on these findings, it would be notable that food industries and marketers may highlight or often use texture-related words when they develop or promote a new product targeting female consumers, thereby increasing female consumers' awareness and interests on the product.

In comparison with the work performed by Szczesniak (1971), the top 10 texture-related terms are reasonably similar. Overall, the top eight texture-related terms in the Szczesniak study were found in the top 10 of the current study. As noted earlier, “crunch(y)” was found to be the most common texture term in the current study, while “crispy” was the most frequent texture term in the previous study (Szczesniak, 1971). It should be noted that the words used to describe texture can be most likely affected by the food items chosen for the survey and in this study two crunchy snacks Cheez-It crackers (Kellogg, Battle Creek, MI) and graham crackers were added. The addition of these foods to this study might make an even stronger case that “crunch(y)” has become more common in the consumer texture lexicon. While the distinct reversal in these two words (crispy versus crunch) may be interesting to some readers, the authors have noticed how interchangeably the average food consumer uses these two words.

The biplot drawn by the correspondence analysis (Figure 1) shows overall relationships between consumer attitudes toward foods and age groups. On the biplot, the seven main categories tended to be separated in to three separate groups: group 1 (“other,” “type” and “menu uses”), group 2 (“food attribute”) and group 3 (“health and nutrition” and “personal preference”). The younger participants (18–39 years old) were plotted near group 1 (i.e., “other,” “type” and “menu uses”), whereas middle-aged groups (40–69 years old) were allocated near group 2 (“food attribute”), which makes sense when looking at the trend with age and the proportion of answers in those categories (Table 4). The older age groups (60+ years old) gave more responses related to group 3 (“health and nutrition” and “personal preference”). Younger participants responded with less “health and nutrition” responses than older participants. It has been reported that as adults age, the energy density and energy of their diet decreases (Marti-Henneberg et al., 1999). It has also been reported that the intake of key micronutrients is lower in older adults than their younger counterparts. (Koplan et al., 1986). It appears that “health and nutrition”, similarly to “regional origin”, shows a disconnection between observed behavior and awareness. That is, older adults have been shown to eat diets with fewer energy and nutrients than younger people, but still have more “health and nutrition” responses than younger adults (see Figure 1). As shown earlier, this study found no significant difference in the response rate of “health and nutrition” between males and females. This finding differs from the previous study by Szczesniak (1971) where females showed significantly higher amount of “health and nutrition” responses than males. There are numerous possibilities regarding the reasons why there would be gender differences regarding attitudes toward healthy eating. Several psychological postulations have attempted to explain a perceived emphasis on healthy eating attitudes by females. Fürst (1994) developed a theory that the food attitudes of males are based on what they eat, conversely the food attitudes of females are centered on what they do not eat. Furthermore, in many cultures meat and other energy-dense foods are classified as manly, while many lower calorie foods (e.g., fruit, fish and vegetables) are often considered to be associated with females (Barthes, 1979; Fagerli and Wandel, 1999). The current study shows no differences between males and females in the proportion of “health and nutrition” responses, which could be evidence of declining role of gender in food attitudes. Further research is needed to confirm this hypothesis, but from the current study, it is observed that females are not more likely than males to have “health and nutrition” attitudes toward food. The current findings are, to some extent, in line with those of Fagerli and Wandel (1999).

This study shows a noticeable increase in “food attribute” responses compared with previous work (Szczesniak, 1971). Accompanying the increase in “food attribute” responses was a substantial decrease in “menu uses,” which is comprised of occasions for serving the food, accompanying food, methods for preparing the food or ingredients in the foods (Szczesniak, 1971). These decreases might be due to the decrease in the in-home food preparation (Guthrie et al. 2002). Furthermore, the method of cooking or eating subcategory under “menu uses” category was less popular in young adults (18–29) than old adults (50–59). This finding is in line with research showing that cooking is important in older generations for multiple reasons including health, household economics and socialization (Chen et al., 2012). Additionally, studies have shown a drastic decrease in the amount of time the average American spends cooking, meaning that younger Americans are more likely spending less time on cooking than the generations that preceded them (Smith et al., 2013). Building on the premise that older Americans are more inclined to prepare food at home, it is understandable that the subcategory brand was less popular in older adults and more popular in older adults. The brand of a food is more tightly linked to prepared foods. Foods used for preparation at home often are not branded or done so inconspicuously. For example, pizza made at home would not have a strong brand association, while pizza ordered from a pizza chain would be strongly linked to a brand. In a similar vein, it can be understandable that the brand subcategory was more popular in males than females who are more likely to prepare food at home (Figure 2).

By contrast, both subcategories of the “health and nutrition” and “regional origin” were more popular in the current study, when compared with the work of Szczesniak (1971), shedding light on an increased awareness on the health-related impact of different foods and the origin of foods. The increased awareness of “health and nutrition” and “regional origin” is in line with recent food trends reported. For example, in the United States, farmers markets have increased almost fivefold in the last 20 years (United States Department of Agriculture 2014). Similarly, the organic food market is the fastest-growing food sector in the United States, which is being driven by consumer concern over health and perceived health benefits of organic foods (Hughner et al., 2007). Furthermore, it should be noted that ethnic food consumption is consistently increasing in the United States (MSI, 2009). In a similar vein, the current result that younger people, relative to older adults, were more likely to give a response under the main category "regional origin" is understandable. Younger adults appear to be more interested in cultural and ethnic foods than older adults.

The sizeable differences between the current and previous studies (Szczesniak, 1971) provide a possibility that consumers' attitudes toward food have changed in the past 50 years. Even though the authors do not believe that the observed differences could be solely attributed to modifications in the foods used or the use of images, it should be noted that there were procedural differences between the current study and that of Szczesniak (1971). The difference in the proportion "food attribute" responses could be attributed to the food images used in this study. Previous research has shown images to affect the perception of food-related stimuli such as odors and tastes (Sakai et al., 2005; Demattè et al., 2009). Additionally, the presented images could lead participants to expect sensory attributes such as flavor and texture. Therefore, the possibility of food images influencing consumer attitudes toward foods is plausible. More research would need to be performed, but it is entirely possible that food images lead to a higher awareness of certain food attributes. The implications of this phenomenon may be that the specific food image selected may have a significant effect on the food attributes listed by the participant. Images featuring a specific style of a food or a particular method of preparing that food may result in allowing for certain attitudes toward that food to surface, but when in other circumstances, those attitudes may be changed. For example, the image of thin-crust pizza may evoke more "crispy" responses than that of a deep dish pizza. As another example, using the image of sashimi to portray fish might produce different responses than an image of grilled fish. However, the authors contend that the use of food images in a study such as this allows older adults to participate and makes the survey more suited for administration online.

3.5. Conclusion

This study delivers new information about the variations in consumer attitudes toward foods as a function of age and gender. Older adults were less likely to give food attribute, texture and regional origin-related responses, while they showed an increase in the amount of responses regarding health/nutrition and personal preference. In addition, male participants were more likely to give color, flavor and food brand-related responses than female participants. By contrast, female participants were more likely to list texture, form/temperature and personal preference-related words compared with male counterparts. Furthermore, even though there were procedural differences from the original study (Szczesniak, 1971), this study shows the changes in consumer attitudes toward foods since the 1970s. Our findings may allow the food researchers and processors to better understand the continually changing food consumers. However, as this survey was administered in a local area (Northwest Arkansas) of the United States, further studies should be conducted with people who have a variety of regional, cultural and demographical backgrounds.

3.6. References

Antmann, G., Ares, G., Varelam, P., Salvador, A., Coste, B. and Fiszman, S.M. (2011). Consumers' texture vocabulary: Results from a free listing study in three Spanish-speaking countries. *Food Quality and Preference,* 22, 165–172.

Barthes, R. (1979). Towards a psychosociology of contemporary food consumption. In Food and drink in history. Selection from the annales, Economies, Societes, Civilisations, Vol. 5 (R. Forster and O. Ranum, eds.) pp. 28–35, The Johns Hopkins University Press, Baltimore, MD.

Calhoun, K.H., Gibson, B., Hartley, L., Minton, J. and Hokanson, J.A. (1992). Age-related changes in oral sensation. *Laryngoscope,* 102, 109–116.

Chen, R.C.Y., Lee, M.S., Chang, Y.H. and Wahlqvist, M.L. (2012). Cooking frequency may enhance survival in Taiwanese elderly. *Public Health Nutrition*, 15, 1142–1149.

Croy, I., Buschhüter, D., Seo, H.S., Negoias, S. and Hummel, T. (2010). Individual significance of olfaction: Development of a questionnaire. *European Archives of Otorhinolaryngology,* 267, 67–71.

Demattè, M.L., Sanabria, D. and Spence, C. (2009). Olfactory discrimination: When vision matters? *Chemical Senses*, 34, 103–109.

Doty, R.L., Shaman, P., Applebaum, S.L., Giberson, R., Siksorski, L. and Rosenberg, L. (1984). Smell identification ability: Changes with age. *Science*, 4681, 1441–1443.

Ennis, S.R., Ríos-Vargas, M. and Albert, N.G. (2011). The Hispanic population: (2010). US Department of Commerce, Economics and Statistics Administration, US Census Bureau.

Fagerli, R.A. and Wandel, M. (1999). Gender differences in opinions and practices with regard to a “Healthy Diet”. *Appetite,* 32, 171–190.

Forde, C.G. and Delahunty, C.M. (2002). Examination of chemical irritation and textural influences on food preferences in two age cohorts using complex food systems. *Food Quality and Preference*, 13, 571–582.

Fukunaga, A., Uematsu, H., & Sugimoto, K. (2005). Influences of aging on taste perception and oral somatic sensation. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 60, 109-113.

Fürst, E.L. (1994). Kvinnelig og mannlig mat. Mat-et annet språk. En studie av rasjonalitet, kropp og kvinnelighet belyst med litterœrer tekster. Iso rapport nr. 7. Oslo, Norway: Department of Sociology, University of Oslo.

Guthrie, J.F., Lin, B.H. and Frazao, E. (2002). Role of food prepared away from home in the American diet, 1977-78 versus 1994-96: Changes and consequences. *Journal of Nutrition. Education and Behavior*, 34, 140–150.

Hughner, R.S., McDonagh, P., Prothero, A., Shultz, C.J. and Stanton, J. (2007). Who are organic food consumers? A compilation and review of why people purchase organic food. *Journal of Consumer Behavior,* 6, 94–110.

Kälviäinen, N., Roininen, K. and Tuorila, H. (2003). The relative importance of texture, taste, and aroma on yogurt-type snack food preference in the young and the elderly. *Food Quality and Preference*, 14, 623–635.

Koplan, J.P., Annest, J.L., Layde, P.M. and Rubin, G.L. (1986). Nutrient intake and supplementation in the United States (NHANES II). *American Journal of Public Health,* 76, 287–289.

Kremer, S., Mojet, J. and Kroeze, J.A.H. (2005). Perception of texture and flavor in soups by elderly and young subjects. *Journal of Texture Studies*, 36, 255–272.

Lawless, H., Vanne, M. and Tuorila, H. (1997). Categorization of English and Finnish texture terms among consumers and food professionals. *Journal of Texture Studies*, 28, 687–708.

Lee, J.H., Hwang, J. and Mustapha, A. (2014). Popular ethnic foods in the united states: A historical and safety perspective. *Comprehensive. Reviews Food Science and Food Safety,* 13, 2–17.

Marti-Henneberg, C., Capdevila, F., Arija, V., Perez, S., Cuco, G., Vizmanos, B. and Fernandez-Ballart, J. (1999). Energy density of the diet, food volume and energy intake by age and sex in a healthy population. *European Journal of Clinical Nutrition,* 53, 421–428.

Meneley, A. (2004). Extra virgin olive oil and slow food. *Anthropologica*, 46, 165–176.

Mintel Group. (2012). Ethnic restaurants – US – March 2012, p. 2, Mintel Group: London.

Mojet, J., Christ-Hazelhof, E. and Heidema, J. (2001). Taste perception with age: Generic or specific losses in threshold sensitivity to the five basic tastes? *Chemical Senses,* 26, 845–860.

Moskowitz, H.R. and Krieger, B. (1995). The contribution of sensory liking to overall liking: An analysis of six food categories. Food Quality and Preference. 6, 83–90.

MSI. (2009). Gallup 2009 study of dinner. Multi-Sponsor Surveys, Princeton, N.J.

Nishinari, K., Hayakawa, F., Xia, C.F., Huang, L., Meullenet, J.F. and Sieffermann, J.M. (2008). Comparative study of texture terms: English, French, Japanese and Chinese. *Journal of Texture Studies,* 39, 530–568.

Rohm, H. (1990). Consumer awareness of food texture in Austria. *Journal of Texture Studies,* 21, 363–374.

Sakai, N., Imada, S., Saito, S., Kobayakawa, T. and Deguchi, Y. (2005). The effect of visual images on perception of odors. *Chemical Senses,* 30, i244–i245.

Seo, H.S., Lee, S. and Cho, S. (2013). Relationships between personality traits and attitudes toward the sense of smell. *Frontiers in Psychology*, 4, 901.

Smith, L.P., Ng, S.W. and Popkin, B.M. (2013). Trends in US home food preparation and consumption: Analysis of national nutrition surveys and time use studies from 1965–1966 to 2007–2008. *Nutrition Journal,* 12, 45.

Szczesniak, A.S. (1971). Consumer awareness of texture and of other food attributes II. *J. Texture Studies,* 2, 196–206.

Szczesniak, A.S. (1972). Consumer awareness of and attitudes to food texture II. Children and teenagers. *Journal of Texture Studies,* 3, 206–217.

Szczesniak, A.S. (1990). Texture: Is it an overlooked food attribute? *Food Technology,* 44, 86–95.

Szczesniak, A.S. (2002). Texture is a sensory property. *Food Quality and Preference*, 13, 215–225.

Szczesniak, A.S. and Kahn, E.E. (1971). Consumer awareness of and attitudes to food texture I. . *Journal of Texture Studies,* 3, 280-295.

Szczesniak, A.S. and Kleyn, D.H. (1963). Consumer awareness of texture and other food attributes. *Food Technology,* 17, 74–77.

United States Department of Agriculture. (2014). Farmers markets and local food marketing. http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateS&leftNav=WholesaleandFarmersMarkets&page=WFMFarmersMarketGrowth&description=Farmers+Market+Growth (accessed August 16, 2014).

Vincent, G.K. and Velkoff, V.A. (2010.) The Next Four Decades: The older population in the United States: 2010 to 2050 (No. 1138). US Department of Commerce. Economics and Statistics Administration, US Census Bureau.

Yoshikawa, S., Nishimaru, S., Tashiro, T. and Yoshida, M. (1970). Collection and classification of words for description of food texture. *Journal of Texture Studies*, 1, 443–451.

Table 1. Foods used for word association interview

Chocolate Bar
Orange Juice
Ice Cream
Butter
Pretzels
Apple
Corn
Noodles
Jell-O®
Lettuce Salad
Black Beans
Scrambled Eggs
Potato Chips*
Bacon
Cucumber
Mashed Potatoes
Cheese
Watermelon
Pizza
Turkey
Cheez-It®*
Chicken Nuggets
Pudding
Graham Crackers*
Cake
Carrots
Beef Steak
Fish
Peanut Butter
Rice
Milk
Bread

* Foods different from original Szczesniak study (1971)

Table 2. Categories and subcategories for analyzing responses

Menu uses	Food attribute	Type	Personal Preference	Health & nutrition	Regional origin	Others
Other foods Component Occasion Method of cooking or eating	Flavor Texture Color Appearance Aroma Form or temperature Others	Type Food category	Like Dislike 50 – 50			

Table 3. Response category by age group

	Age Group					
Response Category	18-29	30-39	40-49	50-59	60-69	70+
Food Attribute	40.0% bc	37.5% b	42.7% c	46.5% d	42.2% c	29.8% a
Flavor	23.9 a	26.1 a	26.2 a	26.9 a	25.9 a	26.3 a
Texture	43.4 b	43.4 b	40.3 ab	40.5 ab	41.6 ab	35.1 a
Form or temperature	6.2 a	6.1 a	9.9 b	9.4 b	7.3 ab	8.6 ab
Color	9.2 c	5.9 b	5.5 ab	3.5 a	6.2 b	8.9 bc
Appearance	3.5 b	2.3 ab	1.6 a	2.7 ab	3.5 b	4.4 b
Aroma	0.6 a	1.0 a	0.8 a	1.2 a	0.8 a	1.3 a
Others	13.4 a	15.3 a	15.7 a	15.8 a	14.8 a	15.3 a
Menu Uses	26.5% cd	30.1% e	25.4% c	18.7% a	22.3% b	29.4% de
Other foods	36.7 a	37.7 a	39.1 a	35.3 a	41.0 a	42.2 a
Component	18.8 c	13.2 b	9.4 ab	13.1 b	11.3 ab	8.2 a
Occasion	21.6 a	25.8 a	26.9 a	22.8 a	21.2 a	22.9 a
Method of cooking or eating	22.8 a	23.4 ab	24.6 ab	28.8 b	26.6 ab	26.7 ab
Type	12.2% c	9.9% ab	8.8% ab	8.1% a	8.7% ab	10.5% bc
Type	42.3 a	46.3 a	37.0 a	43.0 a	38.8 a	34.0 a
Food Category	48.5 ab	45.2 a	55.0 abc	49.1 ab	56.3 bc	63.0 c
Brand	9.2 b	8.5 ab	8.0 ab	7.9 ab	4.9 a	3.1 a
Personal Preference	5.9% a	7.7% b	8.0% b	12.1% c	10.3% c	12.6% c
Like	85.7 a	88.8 abc	92.9 bc	88.7 ab	94.7 c	93.0 bc
Dislike	13.6 c	10.6 bc	6.8 ab	9.6 bc	4.6 a	7.0 abc
50-50	0.7 ab	0.6 ab	0.3 ab	1.7 b	0.7 ab	0.0 a
Health & Nutrition	7.5% ab	6.3% a	7.8% ab	8.6% bc	10.3% cd	11.6% d
Regional Origin	2.1% c	1.9% bc	1.2% ab	1.0% a	1.2% ab	1.2% abc
Other	5.8% a	6.6% a	6.1% a	5.0% a	5.0% a	4.9% a
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4. Response category by gender

	Gender	
Response Category	Female	Male
Food Attribute	42.2% b	36.7% b
Flavor	24.9 a	27.6 b
Texture	43.0 b	37.3 a
Form or temperature	8.0 b	6.5 b
Color	5.9 a	8.5 b
Appearance	2.8 a	3.5 a
Aroma	0.7 a	0.9 a
Others	14.4 a	15.9 b
Menu Uses	24.5% a	26.2% b
Other foods	37.6 a	39.6 a
Component	13.2 a	14.9 a
Occasion	23.8 a	21.8 a
Method of cooking or eating	25.4 a	23.7 a
Type	9.4% a	11.6% b
Type	40.4 a	41.9 a
Food Category	52.8 b	47.9 a
Brand	6.7 a	10.1 b
Personal Preference	9.1% b	8.2% a
Like	90.1 a	90.8 a
Dislike	9.1 a	8.1 a
50-50	0.8 a	1.1 a
Health & Nutrition	8.3% a	8.6% a
Regional Origin	1.4% a	1.9% b
Other	5.1% a	6.9% b
	100.00%	100.00%

Table 5. Most commonly used texture words

Word	% of total texture responses
Crunchy	19.1%
Crisp(y)	14.4%
Creamy	13.3%
Juicy	6.2%
Smooth	6.2%
Soft	5.1%
Moist	3.5%
Dry	3.0%
Greasy	3.0%
Sticky	1.6%
Tender	1.6%

Table 6. Flavor and texture responses by order

	Flavor			Texture		
Age Group	1st	2nd	3rd	1st	2nd	3rd
18-29	22.6% a	25.4% a	23.5% a	48.2% b	42.1% a	38.9% a
30-29	24.5% a	27.1 % a	26.9% a	48.6% b	44.1 % b	36.5% a
40-39	24.7% a	27.2 % a	26.7% a	41.9% ab	42.5% b	35.0% a
50-59	22.6% a	30.6% b	27.8% ab	43.7% b	40.5% ab	35.9% a
60-69	21.8% a	28.3% b	28.1% b	45.7% b	40.9% ab	37.3% a
70+	18.1% a	27.8% b	35.0% b	39.6% b	37.7% b	25.7% a
Total	22.7% a	27.6% b	26.7% b	45.6% c	41.7% b	36.4% a

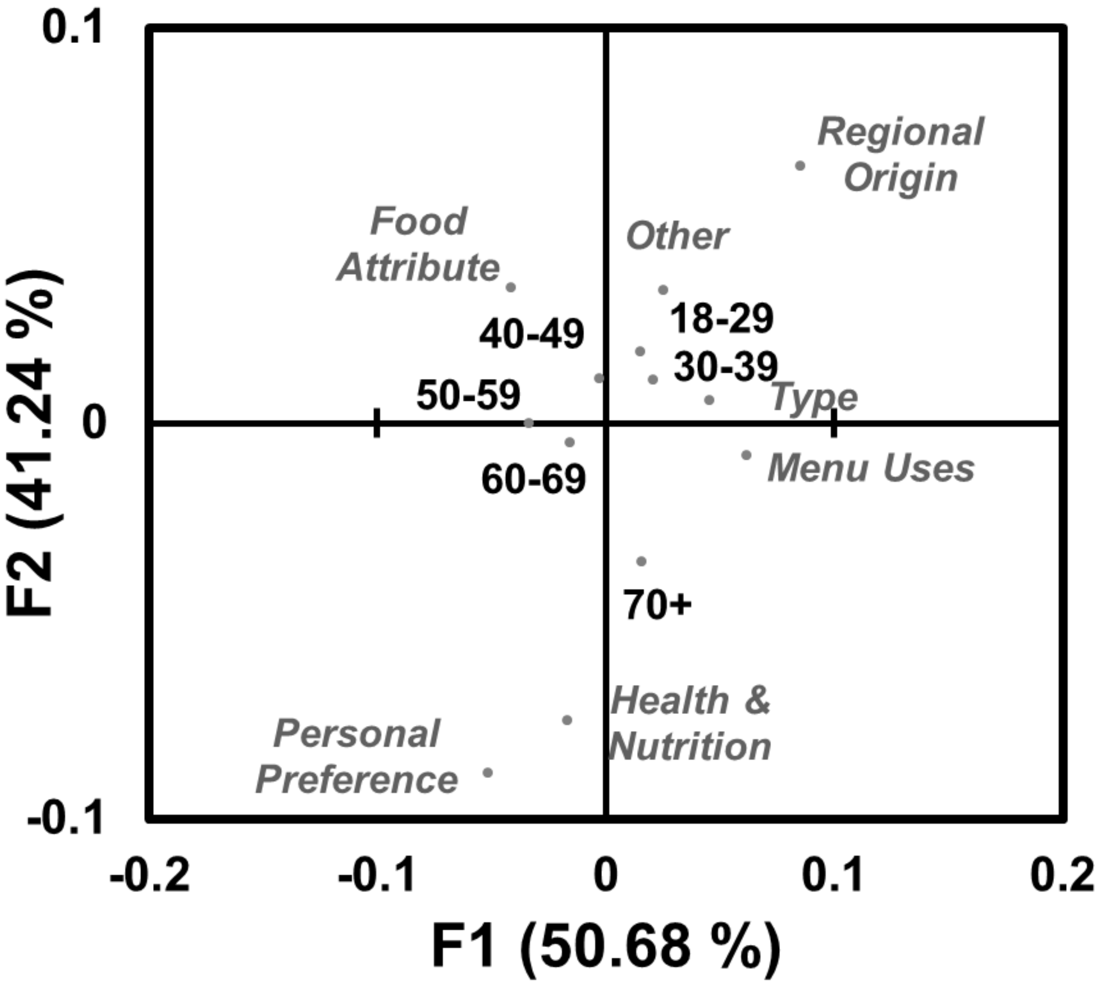

Figure 1. A biplot drawn by the correspondence analysis in the association between the age groups and main categories of attitudes towards foods.

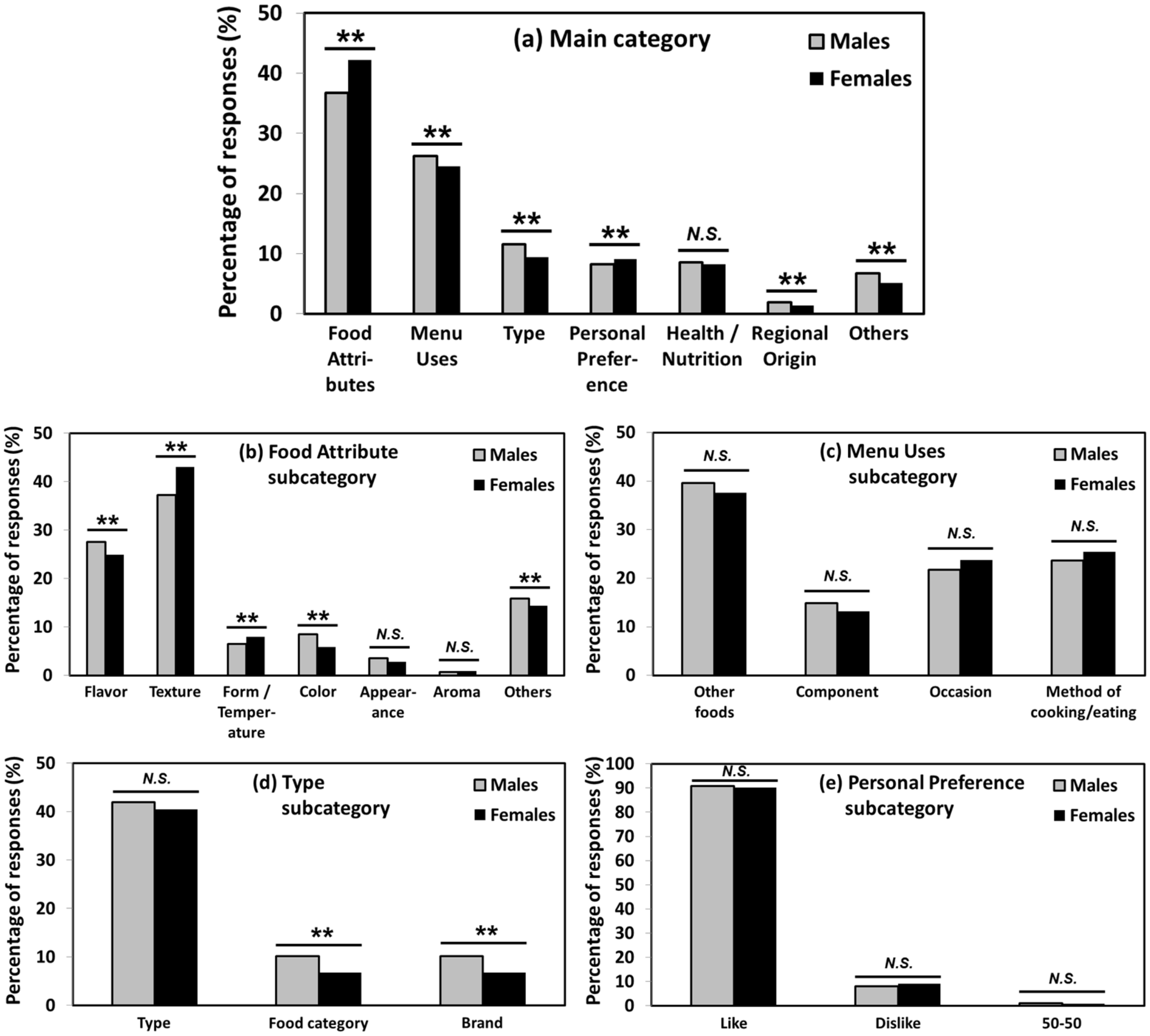

Figure 2. Gender-induced differences in the frequencies of the main and subcategories of the responses elicited by the name and image of food items. n.s. indicates no significant difference at $p < 0.05$. ** indicates a significant difference at $p < 0.01$.

(a) 18-29

(b) 30-39

(c) 40-49

(d) 50-59

(e) 60-69

(f) 70+

Figure 3. Age group-induced variations in the relative prominence of word responses (left side) and in the percentage of the most six common words (right side) elicited by the name and image of food items. The size of a word in the left visualization is proportional to the number of responses reported in this survey; the color and layout of each word have no specific meaning. in the right visualization, the most six common words were “sweet” (SWE), “salty” (SAL), “crunch/crunchy” (CRU), “crisp/crispy” (CRI), “tasteful/tasty” (TAS) AND “healthy/not-healthy” (HEA).

(a) Males

(b) Females

Figure 4. Gender-induced differences in the relative prominence of word responses elicited by the name and image of food items. The size of a word in the visualization is proportional to the number of word responses reported in this survey. The color and layout of each word have no specific meaning.

Chapter 4.

Crispness Level of Potato Chips affects Temporal Dynamics of Flavor Perception and Mastication Patterns in Adults of Different Age Groups

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Abstract

Little attention has been paid to the texture-flavor association in solid foods, especially crisp foods. This study aimed to determine whether crispness level affects temporal dynamics of perceived intensity of three types, i.e., plain, cheese, and spicy, of flavored potato chips with respect to three age groups: younger (20-25 years), middle-aged (40-45 years), and older (65+ years) adults. While eating potato chips, participants' mastication pattern was also assessed by electromyography (EMG). Time-Intensity analysis showed that flavors were rated more intense and maximum flavor perception occurred quicker as crispness of potato chips increased. Overall, the effect of crispness level on flavor perception was more pronounced in the older participants. The average chew strength was greater in the crisper samples and regardless of flavor type the younger participants displayed shorter chew durations than older adults. A partial least squares regression demonstrated that mastication patterns, such as the number of chews, could well predict several key temporal flavor parameters such as the maximum intensity and the area under the curve in the middle age and older age groups. In conclusion, this study extends previous research showing that textural characteristics can influence flavor perception in liquid and soft foods to crisp/brittle foods. In addition, the effect of crispness level on flavor perception varies by flavor type, age group, and mastication pattern.

Keywords: Crispness; Flavor; Texture; Time-Intensity Analysis; Age; Mastication

4.1. Introduction

Textural characteristics have been found to affect flavor perception in a wide variety of foods and beverages (Brown et al., 1998; Buettner and Schieberle, 2000; Harrison, 2000; Buettner et al., 2001; Repoux et al., 2012). The influence of textural characteristics on flavor perception has been shown to be dependent on the oral processing exhibited when consuming the food (Buettner et al., 2001, Mestres et al., 2006; Repoux et al., 2012). Changes in textural characteristics lead to variations in mastication that may change the physical properties of the food bolus altering how aromatic compounds are released from the food matrix (Brown et al., 1998; Harrison, 2000; Salles et al., 2011). The majority of work on texture-flavor interactions has been performed with a focus on rheological properties such as flow and deformation in liquid and soft foods; however, crisp or brittle foods have received little attention.

One main factor complicating the study of texture influence on flavor perception is individual variations in food volatile release patterns between food consumers (Mestres et al., 2012). Age can be one of the main sources explaining such individual variation (Kremer et al., 2005). Kremer et al. (2005) showed that younger participants, but not older participants, perceived higher amounts of mushroom flavor in more thickened soups (Kremer et al., 2005). Age has been also found to influence oral processing (Mioche and Martin, 1998; Kohyama et al., 2002; Mioche et al., 2004). More specifically, as individuals age, while their bite force decreases (Kohyama et al., 2003), their jaw muscle fatigue increases (Shipp, 1999). These physiological changes have led to observations of older adults implementing compensatory strategies, such as increasing the chewing time or the number of chews (Kohyama et al., 2003; Mioche et al., 2004). Furthermore, age has been found to affect texture-related food preference. For example, when compared to younger adults, older adults preferred Muesli in which the texture manipulated to minimize the mastication required before swallowing (Kälviäinen, et al., 2002). Overall pleasantness appears to be affected by changes in texture attributes more in the elderly than young people (Forde and Delahunty, 2002).

Even though there is substantial evidence relating food texture to changes in aroma release kinetics, there are also studies that show flavor perception to change independently of the concentration of actual flavor volatiles (Weel et al., 2002; Leclercq and Blancher, 2012). This has led to the thought that psychological mechanisms could also be a cause of the texture-flavor interaction. The leading hypothesis centers on selective attention, more specifically, that firmer gels require more attention to process in the mouth. Accordingly, while more attention is paid to the texture of the product, less attention is given to the flavor aspects of the food, leading to a decrease in flavor perception (Gierczynski et al., 2008).

As mentioned earlier, while almost all research on texture-flavor interactions has examined this phenomenon in soft foods, very little research has been done to address interactions in crisp foods. Crisp foods seem to be popular in the U.S. As a result, crisp or crunch(y) characteristics of foods appear to be commonly known for U.S. adults. A survey for 337 U.S. adults aged from 19 to 81 years old demonstrated that “crunch/crunchy” (19.1%) and “crisp” (14.6%) are the two most common texture-related words with respect to 32 food/beverage items (Luckett and Seo, 2015). While crispness in foods is broadly known, its effect on flavor perception has received little attention. As a result, this study was designed to determine whether crispness level affects flavor perception in potato chips with a focus on individuals’ mastication pattern and age which are known influential factors in the texture-flavor interaction. When eating potato chips (i.e., from a first biting to swallowing), flavor and texture perceptions can vary with time, which may affect individuals’ mastication patterns. Thus, to measure temporal dynamics of flavor perception during eating of potato chips, the Time-intensity (TI) analysis (Larson-Powers and Pangborn, 1978) was used. In addition, to examine how mastication patterns, such as chewing and swallowing, can be associated with the effect of crispness on temporal dynamics of flavor perception in potato chips, surface electromyography (EMG) signals were measured.

4.2. Materials and Methods

Ethical statement

This study was conducted according to the Declaration of Helsinki for studies on human subjects. The protocol was approved by the Institutional Review Board of the University of Arkansas (Fayetteville, AR). The experimental procedure was thoroughly explained to all participants and a written informed consent was obtained prior to participation.

Participants

Ninety volunteers (45 males and 45 females) that fell into three age groups, i.e., younger (20-25 years old), middle age (40-45 years old), and older (+65 years old) groups, were recruited from a local population (Fayetteville, AR, USA). All volunteers reported that they had neither full denture nor food allergy; six volunteers (1 for middle age group and 5 for older age group) reported to have partial dentures. Volunteers were screened with respect to olfactory impairment and gustatory impairment using the “Sniffin’ Sticks” screening test (Burghart Instruments, Wedel, Germany; Hummel, Konnerth et al., 2001) and the taste spray test (Burghart Instruments, Wedel, Germany; Vennemann et al., 2008), respectively. In addition, volunteers’ oral stereognostic ability was tested using the oral stereognosis test (Kremer et al., 2007a) with a modification. More specifically, the volunteers were asked to identify five confectionary alphabet letters (Haribo, Bonn, Germany) using their in-mouth tactile sense. During the test they were not allowed to visually observe the letters or handle them using their fingers. Unlike the method used by Kremer et al. (2007a) the volunteers were not provided with a list of possible answers or graded on the difficulty of each letter. In the present study, the score was calculated as the number of correct answers out of five.

A total of 68 volunteers (31 males and 37 females) completed the entire study. Three age groups, i.e., younger (11 males and 12 females), middle age (11 males and 13 females), and older (9 males and 12 females) group, did not significantly differ with respect to gender ratio (P = 0.95), taste identification score (P = 0.38), and oral stereognosis score (P = 0.40); however, older age group (mean ± standard deviation = 10.0 ± 2.2) showed significantly lower score in the odor identification test than did younger age group (11.2 ± 1.2) (P = 0.02).

Food sample and preparation

Three different flavors, i.e., plain, cheddar cheese, and jalapeno, of potato chips (Pringles®, Kellogg Co., Battle Creek, MI, USA) were used in this study. The crispness level was manipulated to three different levels, i.e., low, medium, and high crispness, by a combination of steaming and storing in a humidity chamber (Corning Inc., Corning, NY, USA). Two potato chips (approximately 3.5 g) contained in a perforated Styrofoam cup (237 mL) were placed under steaming conditions using a food steamer (Hamilton Beach, Glen Allen, VA, USA), followed by being placed in a humidity chamber. More specifically, for a high crispness level, the potato chips were not placed in the steaming condition, but placed in a humidity chamber at 11% relative humidity (RH). For a medium crispness level, the potato chips were placed in the steaming condition for 50 s, followed by being placed in a humidity chamber at 33% RH. Finally, for a low crispness level, the potato chips were subjected to the steaming condition for 100 s and then placed in a humidity chamber at 75% RH. The RH in the humidity chamber was modulated by saturated salt solutions: lithium chloride (11% RH), magnesium chloride (33% RH), and sodium chloride (75% RH).

Time-Intensity analysis

To measure temporal dynamics of flavor intensity during eating of potato chips, the Time-Intensity (TI) analysis (Larson-Powers and Pangborn, 1978) was used using the sensory analysis software, Compusense® five (Release 4.6-SP3, Compusense Inc., Guelph, ON, Canada). Overall flavor intensity of the potato chip was rated on a 10-cm vertical line scale, with a slider that represented overall flavor intensity. The scale was anchored by “Maximum” on the top and “0” on the bottom via the TI scaling software; the sampling rate was 0.5 s. The participants used the mouse to portray their perceived flavor intensity, moving the mouse up (when they felt the flavor increasing) and down (when they felt the flavor decreasing). The TI parameters used, as well as their definitions, are presented in Table 1.

Electromyography

Because the nature of texture perception is dependent on how the food is processed orally, it is important to account for the chewing and swallowing processes. To measure the jaw muscles in the timeframe of the tasting, surface electromyography (EMG) signals were measured by placing four electrodes (Biopac Systems Inc., Goleta, CA, USA) on the masseter muscle (left and right) and anterior-temporalis muscle (left and right) areas (Lee et al., 2009). A reference electrode was placed on the left wrist. Participants were asked to refrain from wearing lotions, makeup, and ferrous metal during the measurement. Before attaching the electrodes, the contact points were cleaned with 70% isopropyl alcohol (Vi-Jon, Smyrna, TN, USA). The activities of the jaw muscles during natural eating were measured as the average of the electrical currents of the masseter and the anterior temporalis muscles. The EMG signals were filtered using a band-pass filter and integrated manually using AcqKnowledge 4.1 (Biopac Systems Inc., Goleta, CA). The mastication parameters obtained by EMG are presented in Table 1.

Experimental procedure

Each participant was seated in front of a 17 in. computer monitor that displayed the TI scales. As mentioned above, electrodes were placed on both the masseter muscle and the anterior-temporalis muscle areas for EMG measurement. Prior to an actual experiment, two practice sessions were given to let participants be familiar with the TI scaling and EMG measurement during tasting the potato chips. Another type of plain flavored potato chips (Lay’s, Frito-Lay, Plano, TX) was used for the practice sessions. Furthermore, only one participant performed the experiment per session, which allowed the experimenters to ensure the participants were performing the study correctly and that noise from other participants chewing did not influence his/her performance.

In an actual experiment, a total of 9 different potato chip samples (i.e., 3 flavor types by 3 crispness levels) were presented to each participant in a sequential monadic manner. The sample presentation was randomized across the participants using a Williams Latin square design (Williams, 1949). While naturally consuming a potato chip for 60 s, participants were asked to rate overall flavor intensity of the potato chip via the TI scaling software; the duration of the TI analysis was determined by a preliminary test. At the same time, the participants' mastication pattern was measured by EMG with a sampling rate of 0.001 s. Both the TI and EMG recordings were initiated simultaneously with the potato chip making contact with any part of the oral cavity and continued for 60 s. Between the sample presentations, a brief break was given for 60 s with unsalted crackers (Nabisco Premium, Mondelēz Intl., East Hanover, NJ) and spring water (Clear Mountain Spring Water, Taylor Distributing, Heber Springs, AR) for palate cleansing.

Following the TI analysis and EMG measurement with the 9 potato chip samples, another 300 s break was imposed on subjects. Then, the 9 potato chip samples were again presented in a sequential monadic fashion to ask the participants to rate crispness level on a 15-cm line scale ranging from 0 (not at all crisp) to 15 (extremely crisp).

Data analysis

The data obtained from the TI analysis and the EMG measurement were analyzed using SPSS 22.0 for Windows^{TM} (IBM SPSS Inc., Chicago, IL, USA). A total of 10 TI parameters were extracted from each individual TI curve. To determine whether crispness level affected flavor perception in different age groups, a three-way repeated measures ANOVA (RM-ANOVAs) was ran treating the crispness level (low, medium, and high), flavor type (plain, cheese, and spicy), and age group (younger, middle age, and older groups) as main factors. If the Mauchly sphericity test indicated that the sphericity assumption was violated, the degrees of freedom were adjusted by using "Huynh–Feldt" correction. If a significant difference in means was determined by RM-ANOVAs, post hoc comparisons between independent variables were conducted using Bonferroni *t*-tests. A statistically significant difference was defined as $P < 0.05$.

To better understand the relationship between mastication parameters and flavor perception, partial least squares regression (PLSR) was performed. To explain the differences in flavor perception using mastication parameters, weighted regression coefficients were obtained in the PLSR using the Unscrambler software was used (Version 10.1, CAMO, Oslo, Norway). Each TI parameter was predicted separately. The standardized mean values of each combination of the three factors (crispness, flavor, and age group; 27 values in total) were used in the PLSR. Significant models with regression coefficient (R^2) > 0.81 were considered excellent in determining predictability of EMG signals on each parameter of the TI analysis (Kramer, 1951).

4.3. Results

As mentioned above, the participants were asked to rate the crispness of the 9 samples after completing the entire TI analysis session. A two-way ANOVA revealed that the crispness ratings significantly differed among the three levels of crispness: low (mean ± standard deviation = 4.5 ± 3.1), medium (6.5 ± 3.0), and high (11.7 ± 2.7) levels ($P < 0.001$). However, the crispness ratings did not significantly differ among the three types of flavor ($P = 0.07$) and did not show a significant interaction with the flavor type ($P = 0.68$) among the potato chip samples used in this study. These results validate that the potato chip samples were well controlled with respect to crispness level across the three types of flavor.

Time-Intensity ratings of flavor perception

Figure 1 shows the temporal dynamics in flavor perception with respect to crispness level (low, medium, and high), flavor type (plain, cheese, and spicy), and age group (younger, middle age, and older groups). The temporal dynamics of flavor perception were analyzed by the TI parameters. The three major TI parameters, i.e., time at the maximum intensity (T_{max}), maximum intensity (I_{max}), and area under the curve (AUC), are shown in Figures 2 to 4, while the 7 minor parameters are presented in Table 2.

There were no significant three-way interactions among the three main factors (i.e., crispness level, flavor type, and age group) with respect to the TI parameters (for all, $P > 0.05$), except "decreasing area" ($P = 0.04$).

Time at the maximum intensity (T_{max})

There were no significant two-way interactions among the three main factors (crispness level, flavor type, and age group) with respect to the T_{max} (for all, $P > 0.05$). Crispness level was found to affect the T_{max} of flavor perception [$F(2, 130) = 7.62$, $P = 0.001$]. As shown in Figure 2(A), it took less time for participants to perceive the maximum intensity of flavor when the crispness level of potato chips was high compared to when their crispness level was medium ($P = 0.001$) or low ($P = 0.01$). Figure 2(B) shows that flavor type was not found to influence the T_{max} of flavor perception [$F(2, 130) = 0.86$, $P = 0.43$]. Finally, Figure 2(C) shows that age group significantly affected the T_{max} of flavor perception [$F(2, 65) = 10.21$, $P < 0.001$]. The older age group took significantly longer to perceive the maximum intensity of flavor than did the younger age ($P < 0.001$) or the middle age ($P = 0.04$) group.

Maximum Intensity (I_{max})

No significant two-way interactions among the three main factors were found with respect to the I_{max} of flavor perception (for all, $P > 0.05$). Crispness level was found to significantly affect the I_{max} of flavor perception [$F(2, 130) = 44.22$, $P < 0.001$]. The I_{max} was significantly greater when the crispness level of potato chips was high when compared to when the crispness level was medium ($P < 0.001$) or low ($P < 0.001$); the I_{max} did not significantly differ between the low and medium crispness levels ($P = 0.20$) as shown in Figure 3(A). Flavor type was also found to significantly influence the I_{max} [$F(2, 130) = 150.70$, $P < 0.001$]. As expected, the I_{max} was significantly greater for the flavored chips (i.e., spicy or cheese flavor) when compared to the plain flavored chips. Additionally, the I_{max} of spicy flavored chips was significantly greater than that of cheese flavored chips [Figure 3(B)]. Finally, as shown in Figure 3(C), age group was not found to influence the I_{max} [$F(2, 65)$ =0 0.61, $P = 0.55$].

Area Under the Curve (AUC)

Figure 4(A) presents a significant interaction between crispness level and flavor type with respect to the AUC [Huynh–Feldt correction: $F(3.30, 214.66) = 2.77$, $P = 0.04$]. More specifically, for plain and spicy flavored chips, high crispness level showed significantly greater AUC than medium and low crispness levels, with no significant difference between the low and medium crispness levels. However, for cheese flavored chips, high crispness level showed significantly greater AUC than low crispness level ($P = 0.001$), but not than medium crispness level ($P = 0.34$).

As shown in Figure 4(B), the AUC also showed a significant interaction between crispness level and age group [F (4, 130) = 3.32, $P = 0.01$]. For both middle-aged and older adults, the AUC was the greatest when the crispness level of potato chips was high compared to when it was medium or low. However, for younger adults, the AUC was greater when the crispness level of potato chips was high compared to when the crispness level was low ($P = 0.04$), but not medium ($P = 0.11$). Moreover, there was a mild interaction between flavor type and age group with respect to the AUC of flavor perception, but it was not statistically significant [$F(4, 130) = 2.20$, $P = 0.07$].

Duration

No significant two-way interactions among the three main factors were found with respect to the duration of flavor perception (for all, $P > 0.05$). Crispness level of potato chips appeared to influence the duration of flavor perception, yet the effect was not statistically proven [$F(2, 130) = 3.03$, $P = 0.052$] (Table 2). Flavor type was found to significantly affect the duration of flavor perception [$F(2, 130) = 17.11$, $P < 0.001$]. As expected, the duration of flavor perception was significantly shorter in plain flavored chips when compared to cheese ($P = 0.002$) or spicy ($P < 0.001$) flavored chips (Table 3). In addition, the duration of flavor perception did not significantly differ among the three age groups [$F(2, 65) = 1.42$, $P = 0.25$] (Table 2).

Increasing angle

There were no significant two-way interactions between crispness level and age group [$F(4, 130) = 0.47$, $P = 0.76$] and between crispness level and flavor [$F(4, 260) = 1.31$, $P = 0.27$] with respect to the increasing angle of flavor perception (Table 2). A significant two-way interaction was found between flavor type and age group with respect to the increasing angle [$F(4, 130) = 2.83$, $P = 0.03$]. More specifically, in the younger and the older age groups, the increasing angle of flavor perception was greatest for the spicy flavored chips, followed by the cheese flavored chips, and it was the smallest for the plain flavored chips. In the middle age group, the increasing angle of flavor perception was significantly smaller in plain flavored chips than in the two flavored chips, but it was not significantly different between the two flavored chips. In addition, the increasing angle was found to differ as a function of crispness level [$F(2, 130) = 48.60$, $P < 0.001$]. The increasing angle of flavor perception was significantly greater in the high crispness level than in the medium or low crispness level (for all, $P < 0.001$) (Table 2). In other words, flavor perception increased the most steeply in the crispiest chips.

Increasing area

The increasing area showed no significant two-way interactions between crispness level and age group [$F(4, 130) = 0.47$, $P = 0.76$] and between crispness level and flavor type [$F(4, 260) = 1.31$, $P = 0.27$] (Table 2). However, there was a significant two-way interaction between flavor type and age group [$F(4, 130) = 2.83$, $P = 0.03$]. Like the pattern of increasing angle, for the younger and the older age groups, the increasing area of flavor perception was the greatest for the spicy flavored chips, followed by the cheese flavored chips, and it was the smallest for the plain flavored chips. For the middle age group, the plain flavored chips showed the smallest increasing area, but there was no significant difference between the cheese and spicy flavored chips ($P = 1.00$). Finally, the increasing area was found to differ as a function of crispness level [$F(2, 130) = 48.60$, $P < 0.001$]. Like the pattern of increasing angle, the increasing area was significantly greater in the high crispness level than in the medium or low crispness level (for all, $P < 0.001$) (Table 2).

Decreasing angle

No significant two-way interactions among the three factors were found with respect to the decreasing angle of flavor perception (for all, $P > 0.05$) (Table 2). In addition, the decreasing angle of flavor perception was not found to be affected by crispness level [Huynh–Feldt correction: *F*(1.79, 116.20) = 0.39, *P* = 0.65], flavor type [*F*(2, 130) = 1.93, *P* = 0.15], and age group [*F*(2, 65) = 0.68, *P* = 0.51] (Table 2).

Decreasing area

The decreasing area showed no significant two-way interactions between crispness level and age group [*F*(4, 130) = 1.45, *P* = 0.22] and between flavor type and age group [*F*(4, 130) = 1.06, *P* = 0.38] (Table 2). There was a significant interaction between crispness level and flavor type with respect to the decreasing area [*F*(4, 260) = 3.01, *P* = 0.02]. More specifically, for plain and spicy flavored chips, the decreasing area was significantly greater when its crispness level was high compared to when the crispness level was medium or low. A similar trend was found in the cheese flavored chips, but there was no significant difference between the high and medium crispness levels with respect to the decreasing area (*P* = 0.15). Moreover, the decreasing area did not significantly differ among the three age groups [*F*(2, 65) = 1.99, *P* = 0.15] (Table 2).

Initial delay

There were no significant two-way interactions among the three main factors with respect to the initial delay of flavor perception (for all, *P* > 0.05) (Table 2). In addition, the initial delay of flavor perception did not significantly differ as a function of crispness level [*F*(2, 130) = 1.65, *P* = 0.20], flavor type [*F*(2, 130) = 2.20, *P* = 0.12], and age group [*F*(2, 65) = 0.91, *P* = 0.41] (Table 2).

Initial intensity

The initial intensity did not show any significant two-way interactions among the three main factors with respect to the initial intensity of flavor perception (for all, $P > 0.05$) (Table 2). Moreover, the initial intensity of flavor perception was not found to be affected by crispness level [$F(2, 130) = 0.74$, $P = 0.48$] and flavor type [$F(2, 130) = 1.06$, $P = 0.35$] (Table 2). However, the initial intensity of flavor perception significantly differed among the three age groups [$F(2, 65) = 4.23$, $P = 0.02$]. The initial intensity of flavor perception was significantly lower in the older age group compared to in the younger age group ($P = 0.02$) (Table 2).

Mastication patterns

The effects of the three main factors, i.e., crispness level, flavor type, and age group, on mastication patterns were assessed using EMG and analyzed based on the 7 parameters as follows (Table 3). There were no significant three-way interactions among the three main factors with respect to the 7 parameters of mastication (for all, $P > 0.05$), except “average duration between chews” ($P = 0.047$).

Chew work

The chew work, i.e., the area of all individual chews of the mastication sequence, showed no significant two-way interactions among the three main factors (for all, $P > 0.05$). Moreover, the chew work did not significantly differ as a function of crispness level [$F(2, 130) = 2.21$, $P = 0.11$], flavor type [$F(2, 130) = 1.35$, $P = 0.26$], and age group [$F(2, 65) = 0.45$, $P = 0.64$] (Table 3).

Average chew work

The average chew work, i.e., the average area of each chew of the mastication sequence, was found to show no significant two-way interactions among the three main factors (for all, $P > 0.05$). Moreover, the average chew work was not found to be influenced by flavor type [$F(2, 130) = 0.25$, $P = 0.78$] and age group [$F(2, 65) = 0.36$, $P = 0.70$] (Table 3). However, the average chew work significantly differed with respect to crispness level of potato chips [$F(2, 130) = 4.10$, $P = 0.02$]. The average chew work was significantly smaller when the crispness level was high compared to when it was low ($P = 0.03$) (Table 3).

Average chew max

The average chew max, i.e., the average maximum chew strength of the chews in a mastication sequence, showed no significant two-way interactions among the three main factors (for all, $P > 0.05$). The average chew max did not significantly differ with respect to flavor type [$F(2, 130) = 0.60$, $P = 0.55$] and age group [$F(2, 65) = 0.26$, $P = 0.77$] (Table 3). However, the average chew max was found to significantly differ with respect to the crispness level of potato chips [$F(2, 130) = 4.29$, $P = 0.02$]. As shown in Table 3, the average chew max was significantly lower when the crispness level was low compared to when it was medium ($P = 0.02$) or high ($P = 0.04$).

Number of chews

The number of chews showed no significant two-way interactions between crispness level and age group [$F(4, 130) = 0.36$, $P = 0.84$] and between crispness level and flavor type [Huynh–Feldt correction: $F(3.41, 221.79) = 0.38$, $P = 0.79$]. Figure 5(A) shows a significant interaction between flavor type and age group was found with respect to the number of chews

[*F*(4, 130) = 4.76, *P* = 0.001]. Participants in the middle age group chewed the plain flavored chips significantly less than the cheese (*P* = 0.009) or spicy (*P* = 0.005) flavored chips. However, this trend was not observed in the younger (*P* = 0.23) and older (*P* = 0.25) age groups. In addition, the number of chews did not significantly differ as a function of crispness level [*F*(2, 130) = 1.70, *P* = 0.19] (Table 3).

Average chew duration

The average chew duration, i.e., the average time of the chews in the mastication sequence, was found to show no significant two-way interactions among the three main factors (for all, $P > 0.05$). In addition, the average chew duration was not found to be affected by crispness level [Huynh–Feldt correction: *F*(1.08, 69.91) = 1.13, *P* = 0.30] and flavor type [Huynh–Feldt correction: *F*(1.08, 70.18) = 1.78, *P* = 0.19] (Table 3). However, the average chew duration was found to significantly differ among the three age groups [*F*(2, 65) = 4.70, *P* = 0.01]. The average chew duration increased steadily with age. More specifically, participants in the older age group took significantly longer to chew potato chips than did those in younger age group (*P* = 0.01) (Table 3).

Average duration between chews

The average duration between chews showed no significant two-way interactions among the three main factors (for all, $P > 0.05$). In addition, the average duration between chews was not found to be influenced by crispness level [*F*(2, 130) = 0.75, *P* = 0.48] and flavor type [*F*(2, 130) = 0.85, *P* = 0.43] (Table 3). The average duration between chews appeared to increase with age, but this trend was not significantly proven [*F*(2, 65) = 3.09, *P* = 0.052] (Table 3).

Time to swallow

The time from ingestion to the first swallow of the mastication sequence (i.e., Time to swallow) showed no significant two-way interactions between crispness level and flavor type [$F(4, 260) = 0.83$, $P = 0.51$] and between flavor type and age group [$F(4, 130) = 1.08$, $P = 0.37$]. Figure 5(B) shows a significant interaction between crispness level and age group with respect to the time to swallow [Huynh–Feldt correction: $F(3.82, 124.\ 25) = 2.78$, $P = 0.03$]. Participants in the older age group appeared to take longer time to swallow with an increase of crispness level in chips, yet this trend was not significantly proven ($P = 0.07$). This trend was not found in the younger ($P = 0.12$) and middle ($P = 0.64$) age groups. In addition, the flavor type was not found to influence the time to swallow [$F(2,130) = 0.96$, $P = 0.39$] (Table 3).

Relationships between the flavor Time-Intensity and mastication pattern with respect to age group

Since age group was found to influence the relationship of texture and flavor, separate PLSR models were made for each of the three age groups (Table 4).

Younger age group (20 to 25 years old)

The flavor perception of the younger age group was the least well predicted of all the age groups. Only the time at the maximum intensity (T_{max}; $R^2 = 0.984$) and the increasing angle ($R^2 = 0.999$) were predicted at reasonably high rate. The time at the maximum intensity of the TI analysis was predicted by three EMG parameters, i.e., average chew max (β-coefficient = 20.88), time to swallow (2.16), and chew work (-3.75). In addition, the increasing angle of the TI analysis was predicted by the EMG parameter, the average chew duration (β-coefficient = 387.06). However, the rest of the TI parameters were not predicted well by the EMG parameters.

Middle age group (40 to 45 years old)

Efforts to predict the flavor TI parameters from the EMG parameters appear to be much more successful in the middle age group compared to in the younger age group (Table 4). More specifically, "the number of chews" among the EMG parameters was found to well predict six individual parameters of the TI analysis: maximum intensity (β-coefficient = 8.48), area under the curve (AUC; 309.52), increasing angle (3.44), increasing area (82.92), decreasing angle (1.98), and decreasing area (226.66). However, time-related TI parameters, i.e., time at the maximum intensity (T_{max}), duration, and initial delay, were not well predicted by the EMG parameters.

Older age group (65+ years old)

Similarly to the middle age group, the flavor TI parameters of the older age group were well predicted by the EMG parameters (Table 4). More specifically, the maximum intensity of the TI analysis was well predicted by the number of chews (β-coefficient = 23.14) of the EMG parameter. The area under the curve (AUC) was also well explained by the four EMG parameters, i.e., the number of chews (β-coefficient = 949.57), chew work (-653.24), average chew work (677.78), and average duration between chews (-3,430.73). Additionally, the increasing area of the TI parameter was well predicted by the three EMG parameters, i.e., the number of chews (β-coefficient = 345.03), chew work (-220.35), and average duration between chews (-1,112.17). Finally, the decreasing area of the TI parameter was well predicted by the four EMG parameters, i.e., the number of chews (β-coefficient = 627.10), chew work (-452.26), average chew work (449.94), and duration between chews (-2,171.78).

4.4. Discussion

This study extended the notion that textural characteristics affect the flavor perception on soft foods to a crisp/brittle food (potato chips). In addition, flavor type and age group were found to work as modulators in the crispness influence on flavor perception of potato chips.

Crispness level was found to affect temporal dynamics of flavor intensity in potato chips

One of the most notable findings of this study was that, regardless of age, the crispest samples were perceived to have the highest flavor intensity as shown in Figures 3(A) and 4(A). One possible explanation of increased flavor perception with increasing crispness is bolus changes leading to an increase in flavor volatile release. As a food is crisper, it fractures more easily and rapidly so that the crisper chips possibly have more surface area due to their smaller particles created upon fracturing. This increase in surface area is thought to be influential in allowing volatile flavor compounds more rapidly diffuse into the gas phase and be drawn into the nasal cavity (Repoux et al., 2012), which may increase a perceived intensity of the flavor. Similar pattern was also observed in other foods varying in firmness; an increase in firmness was found to increase aromatic volatile releases in cheese (Repoux et al., 2012) and gel models (Boland et al., 2006). However, the positive relationship between firmness/hardness and flavor perception has not been consistently obtained; for example, in milk gels flavors have been shown to decrease with increasing gel hardness (Gierczynksi et al., 2008).

Another explanation for the observation that the flavor intensity increases with an increase of crispness level is the halo-dumping effect (Clark and Lawless, 1994) since intensities of flavor and crispness were not simultaneously rated in this study. Clark and Lawless (1994) demonstrated that participants rated the sweetness of a beverage higher when only given the option to rate sweetness when compared to a condition in which both vanilla flavor and sweetness responses were given. In the context of the present study, the participants could have been consciously allowing the crispness ratings to be expressed in their ratings of overall flavor intensity. In addition, the halo-dumping effect could be mediated by the loudness of eating sound; the louder sound of eating the crisper potato chips might result in greater flavor perception. On the other hand, participants could have rated overall flavor intensity of the crisper potato chips producing louder eating-sound as more intense based on their experience that as potato chips elicit louder eating-sound, they are fresher (Zampini and Spence, 2004) and fresh potato chips are likely to have greater flavor intensity than stale potato chips showing smaller levels of crispness and loudness of eating-sound. In this way, the crispness-enhanced flavor intensity might result from the halo-dumping effect and/or the cognitive association process.

The effect of crispness level on temporal dynamics of flavor intensity was found to vary by type of flavor in potato chips

The effect of crispness level on the temporal flavor perception was relatively similar across the flavors used in this study. Even though the three types of flavors did not significantly differ with respect to the time at the maximum intensity [Figure 2(B)], they showed significant differences in terms of the maximum flavor intensity [Figure 3(B)] and the area under the curve [Figure 4(A)]. More specifically, the flavor of spicy potato chips was rated the most intense among the three types of flavors, which might be due to that spicy flavor elicits more trigeminal sensation than does plain or cheese flavor. A mixture of olfactory and trigeminal cues has been found to lead to higher olfactory intensity and cortical activation than the sum of the individual cues in the psychophysical and neuroanatomical assessments (Boyle et al., 2007; Bensafi et al., 2012). In addition, as shown in Figure 1 and Table 2, since spicy flavor potato chips, in comparison to the plain and cheese flavor potato chips, were placed in the oral cavity longer, participants could have perceived spicy flavor more intensely. However, these explanations for the greatest ratings of perceived spicy flavor among the three flavors (i.e., plain, cheese, and spicy flavors) should be further clarified because the concentrations of the three flavors were not controlled (i.e., commercial products were used in this study).

The effect of crispness level on flavor intensity, especially the AUC, appears to be more pronounced in the spicy flavor potato chips than in the plain or cheese flavor potato chips [Figure 4 (A)]. A plausible explanation for this trend is that spicy flavor potato chips showed greater decreasing-area of the TI curve with an increase of crispness level as shown in Figure 1. However, plain flavor and cheese flavor potato chips did not show noticeable variation with respect to the decreasing area of the TI curve. In other words, when crispness level of spicy flavor potato chips increases, their spicy flavor tend to last in the mouth, increasing perceived flavor intensity.

On the other hand, the effect of crispness level on flavor perception in cheese flavor potato chips was less pronounced than in spicy flavor potato chips. While research in flavor specificity of texture-flavor interactions is rather limited, there is evidence that different flavor compounds behave differently to texture manipulation and the subsequent changes in oral processing. More specifically, the hydrophobicity of cheese flavor volatiles have been shown to be a factor in how individual flavor compounds are affected by mastication and release from the food matrix (Trelea et al., 2008; Repoux et al., 2012). For example, Kremer et al. (2007b) found texture-flavor interactions in sweet waffles, but not cheese-flavored waffles. While more research is needed, the findings of this study add to the evidence of flavor-type being a factor that modulates texture-flavor interactions. The results of this study suggest that a flavor rooted in a trigeminal sensation is influenced more by texture changes than a more traditional flavor such as cheese flavor.

The effect of crispness level on temporal dynamics of flavor intensity was found to vary by age group

The changes in crispness did not affect the flavor perception in all age groups equally. For example, the effect of crispness level on the area under the curve (AUC) was more drastic in the older adults, when compared to the younger adults [Figure 1 and Figure 4(B)]. One possible reason that the older adults showed an increased effect of texture on flavor perception may be due to an increased efficiency with respect to multisensory integration. The texture manipulations in this study were primarily related to crispness, which has a significant auditory component (Vickers, 1982). Older adults have been shown to lose some hearing ability stemming from the destruction of hair cells in the inner ear, thickening of the eardrum, and damage to the auditory nerve cells (Zampini and Spence, 2004). Additionally, odor perception has been reported to decrease in older adults (Cowart, 1989). Thus, to compensate for the decreased sensory performances with respect to sensitivity and identification, the multisensory integration is likely to occur more efficiently in older adults. It has been found that as unisensory input decreases the importance of a second sensory input increases (Wallace et al., 1996;

Hairston et al., 2003). The integration of multiple sensory inputs has been shown to be more powerful in older adults who have a decrease in unisensory sensitivity (Laurienti et al., 2006; Peiffer et al., 2007). In this way, the older adults in this study appear to rely on the texture-flavor association more compared to the younger adults.

The present study also found instances where the crispness manipulation changed oral processing parameters in the older adults, but not the younger ones. More specifically, when crispness increased the older adults showed longer time to swallow the potato chips, but such difference was not observed in the young and middle-aged participants. The changes in oral processing with age have been reported to remain relatively constant (Calhoun, et al., 1992). However, a recent study demonstrated a decrease in lingual tactile sensitivity with age (Steele et al., 2014). Additionally, it has been reported that tongue strength decreases with age and may play a role in the decrease in lingual sensitivity (Steele et al., 2014). Older adults have been found to exhibit compensatory strategies such as performing more chewing cycles and chewing for a longer duration (Kohyama et al., 2002) which is in line with the results of our study; older adults are likely to need more time for chewing and between chews, and swallowing (Table 3). Although it did not significantly differ among the three levels of crispness (Table 3), the number of chews was integral to predicting temporal dynamics of flavor perception in the middle-aged and older adults (Table 4). Especially, as shown in Table 4, the number of chews was found to play more important role in the middle-aged adults than in the younger and older adults. This result may be related to the observation that participants in the middle age group, but not those in the younger and older age groups, chewed the cheese or spicy flavored chips significantly more than the plan flavored chips [Figure 5(A)]. In other words, to perceive flavors longer and stronger, the middle-aged adults might chew flavored potato chips significantly more than plain flavored chips. Based on the fact that middle-aged adults show no remarkable decreases in terms of retronasal olfactory ability (Croy et al., 2014), middle-aged participants appear to be more interested and attentive to flavor dynamics compared to younger and older participants.

Temporal dynamics of flavor intensity were found to be predicted by mastication pattern

Mastication parameters explained much of the variance observed in temporal flavor perception, underscoring the importance of oral processing in texture-flavor interactions. Tarrega et al. (2008) found that differences in mastication parameters were able to explain the majority of the variation with respect to volatile concentrations of cheese flavor. However, in the present study the flavor perception of the younger age group was not well predicted by the mastication parameters. When searching for reasons for the poor prediction of flavor perception for the younger age group, the range in the number of chews for that age group stood out. More specifically, the range for the younger age group was 81 chews, while the range of the older age group was only 60 chews. Upon further investigation, the number of chews for the younger age group is bimodal, while the older age groups are more homogenous in structure. In summary, it appears much of the failure of the mastication parameters to predict flavor perception is tightly linked to the larger variation in number of chews within the younger age group. In the two oldest age groups (40-45 and 65+) the number of chews tended to increase with increasing sample crispness, but in the younger age group the number of chews was independent of the sample crispness.

The number of chews was found in several instances to be a good predictor of flavor perception. Tarrega et al. (2008) found that maximum intensity (I_{max}) was positively correlated with the number of chews, chew work, chew strength, and negatively correlated with chew duration. Conversely, Blissett et al. (2006) found, when looking at the effect of mastication on flavor release of candy. They concluded that participants who exhibited a low bite force and slow chewing rates released more flavor volatiles than those who chewed strongly and more quickly. This study found several instances where the number of chews showed a positive relationship with I_{max}, AUC and other temporal flavor parameters. In this sense, this study agrees with the findings of Tarrega et al. (2008) that as the number of chews increases so does the overall flavor impact.

Limitations and further studies

Our results should be interpreted with caution because of several limitations of this study. First, it was plausible that the additional requirement of temporal flavor rating (i.e., the TI analysis) may have altered their oral processing parameters even though the participants in this study were asked to “eat naturally”. While more research would need to be done, it cannot be ruled out that in this study the individual participants used a mastication sequence to maximize their flavor perception since mastication patterns were found to be specifically modulated to optimize the recognition of the specified sensory attribute (Dan et al., 2007). In a similar vein, the EMG electrodes placed on the face might affect the participants’ natural chewing pattern, thereby resulting in biased results for flavor perception. Second, while this study provides useful information regarding the interaction of flavor and crisp texture in a food matrix, further research would be able to assign causality to the numerous psychophysical phenomena observed in the present work. Future research should look to measure the real time flavor compound concentration released from the food matrix with different levels of crispness and examine dynamics in mastication patterns that are manipulated by changes in crispness. Third, since detailed information about oral health factors (e.g., general oral health, salivary output) that can account for differences between the age group was not obtained in this study, potential effects of oral health factors on age-related texture-flavor perception should not be ignored. To completely understand how people of different age groups process texture-flavor perception in their mouth, more advanced measurements of oral processing factors and oral health, such as salivary output, and detailed information of oral tactile sensitivity should be taken into account (Guinard et al., 1997; Duffy et al., 1999; Engelen et al., 2003). Finally, since this study was limited to one type of crisp food, potato chips, the present results cannot be generalized to other crisp foods as well as solid foods. Thus, further studies with a variety of crisp or solid food are needed to derive more conclusive evidence. In addition, because crispness level of foods can probably be changed by other technological processes such as different cooking parameters, it would be interesting to conduct further studies with different levels of crispness obtained by other preparation conditions.

4.5. Conclusions

This study provides for the first time evidence that crispness level affects dynamic flavor perception. Crispness manipulations were shown to cause changes in flavor perception. Furthermore, the effect of crispness level on the flavor perception of potato chips did not manifest itself the same among food consumers of different age groups or in potato chips of different flavors. Attempts to explain the changes in flavor perception as a function of mastication parameters were rather successful, producing compelling evidence that flavor perception is largely influenced by mastication patterns. Moreover, our findings demonstrate that the effect of crispness level on dynamic flavor perception is more pronounced in older adults.

4.6. References

Bensafi, M., Iannilli, E., Poncelet, J., Seo, H. S., Gerber, J., Rouby, C., & Hummel, T. (2012). Dissociated representations of pleasant and unpleasant olfacto-trigeminal mixtures: an FMRI study. *PLoS One*, 7(6), e38358. doi: 10.1371/journal.pone.0038358.

Blissett, A., Hort, J., & Taylor, A. J. (2006). Influence of chewing and swallowing behavior on volatile release in two confectionery systems. *Journal of Texture Studies*, 37, 476-496.

Boland, A. B., Delahunty, C. M., & van Ruth, S. M. (2006). Influence of the texture of gelatin gels and pectin gels on strawberry flavour release and perception. *Food Chemistry*, 96, 452-460.

Boyle, J. A., Frasnelli, J., Gerber, J., Heinke, M., & Hummel, T. (2007). Cross-modal integration of intranasal stimuli: A functional magnetic resonance imaging study. *Neuroscience*, 149, 223-231.

Brown, W. E., Eves, D., Ellison, M., & Braxton, D. (1998). Use of combined electromyography and kinesthesiology during mastication to chart the oral breakdown of foodstuffs: Relevance to measurement of food texture. *Journal of Texture Studies*, 29, 145-167.

Buettner, A., & Schieberle, P. (2000). Influence of mastication on the concentrations of aroma volatiles - Some aspects of flavour release and flavour perception. *Food Chemistry*, 71, 347-354.

Buettner, A., Beer, A., Hannig, C., & Settles, M. (2001). Observation of the swallowing process by application of videofluoroscopy and real-time magnetic resonance imaging - consequences for retronasal aroma stimulation. *Chemical Senses*, 26, 1211-1219.

Calhoun, K. H., Gibson, B., Hartley, L., Minton J., & Hokanson J. A. (1992). Age-related changes in oral sensation. *Laryngoscope*, 102, 109-116.

Clark, C. C., & Lawless, H. T. (1994). Limiting response alternatives in time-intensity scaling: an examination of the halo-dumping effect. *Chemical Senses*, 19, 583-594.

Cowart, B. J. (1989). Relationships between taste and smell across the adult life span. *Annals of the New York Academy of Sciences*, 561, 39-55.

Croy, I., Hoffmann, H., Philpott, C., Rombaux, P., Welge-Luessen, A., Vodicka, J., Konstantinidis, I., Morera, E., & Hummel, T. (2014). Retronasal testing of olfactory function: an investigation and comparison in seven countries. *European Archives of Otorhinolaryngology*, 271, 1087-1095.

Dan, H., Okamoto, M., Wada, Y., Dan, I., & Kohyama, K. (2007). First bite for hardness judgment as haptic exploratory procedure. *Physiology & Behavior*, 92, 601-610.

Duffy, V. B., Cain, W. S., & Ferris, A. M. (1999). Measurement of sensitivity to olfactory flavor: Application in a study of aging and dentures. *Chemical Senses*, 24, 671-677.

Engelen, L, de Wijk, R. A., Prinz, J. F., van der Bilt, A., & Bosman, F. (2003). The relation between saliva flow after different stimulations and the perception of flavor and texture attributes in custard desserts. *Physiology & Behavior*, 78, 165-169.

Forde C. G., & Delahunty C. M. (2002). Examination of chemical irritation and textural influence on food preferences in two age cohorts using complex food systems. *Food Quality and Preference*, 13, 571-581.

Gierczynski, I., Laboure, H., & Guichard, E. (2008). In vivo aroma release of milk gels of different hardnesses: Inter-individual differences and their consequences on aroma perception. *Journal of Agriculture and Food Chemistry*, 56, 1697-1703.

Guinard, J.-X., Zoumas-Morse, C., & Walchak, C. (1997). Relation between parotid saliva flow and composition and the perception of gustatory and trigeminal stimuli in foods. *Physiology & Behavior*, 63, 109-118.

Hairston, W. D., Laurienti, P. J., Mishra, G., Burdette, J. H., & Wallace, M. T. (2003). Multisensory enhancement of localization under conditions of induced myopia. *Experimental Brain Research*, 152, 404-408.

Harrison, M. (2000). Chapter 15. Mathematical models of release and transport of flavors from foods in the mouth to the olfactory epithelium. In D. D. Roberts & A. J. Taylor (Eds.), *ACS Symposium Series, Flavor Release* (pp. 179-191). Washington, DC: American Chemical Society.

Hummel, T., Konnerth, C. G., Rosenheim, K., & Kobal, G. (2001). Screening of olfactory function with a four-minute odor identification test: reliability, normative data, and investigations in patients with olfactory loss. *Annals of Otology, Rhinology & Laryngology*, 110, 976-981.

Kälviäinen, N., Salovaara, H., & Tuorila H. (2002). Sensory attributes and preference mapping of muesli oat flakes. *Journal of Food Science*, 67, 455-460.

Kramer, A. (1951). Objective testing of vegetable quality. *Food Technology*, 5, 265-269.

Kremer, S., Mojet, J. O. S., & Kroeze, J. H. (2005). Perception of texture and flavor in soups by elderly and young subjects. *Journal of Texture Studies*, 36, 255-272.

Kremer S., Bult J. H., Mojet J, & Kroeze J. H. (2007a). Food perception with age and its relationship to pleasantness. *Chemical Senses*, 32, 591-602.

Kremer S., Mojet, J., & Kroeze, J. H. A. (2007b). Differences in perception of sweet and savoury waffles between elderly and young subjects. *Food Quality and Preference*, 18, 106-116.

Kohyama, K., Mioche, L., & Martin, J. -F. (2002). Chewing patterns of various texture foods studied by electromyography in young and elderly populations. *Journal of Texture Studies*, 33, 269-283.

Kohyama, K., Mioche, L., & Bourdiol, P. (2003). Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. *Gerodontology,* 20, 15-23.

Larson-Powers, N., & Pangborn, R. M. (1978). Descriptive analysis of sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. *Journal of Food Science*, 43, 47-51.

Laurienti, P. J., Burdette, J. H., Maldjian, J. A., & Wallace, M. T. (2006). Enhanced multisensory integration in older adults. *Neurobiology of Aging*, 27, 1155-1163.

Lawless, H. T., & Heymann, H. (2010). Chapter 8. Time–intensity methods. In H. T. Lawless & H. Heymann (2nd eds.), *Sensory Evaluation of Food-Principles and Practices* (pp. 179-201). New York: Springer.

Leclercq, S., & Blancher, G. (2012). Multimodal sensory integration during sequential eating - Linking chewing activity, aroma release, and aroma perception over time. *Chemical Senses*, 37, 689-700.

Lee, Y. S., Owens, C. M., & Meullenet, J. -F. (2009). Tenderness perception of poultry *major pectoralis* muscle during mastication. *Journal of Food Science*, 74, S413-S422.

Luckett, C. R., & Seo, H. S. (2015). Consumer Attitudes Toward Texture and Other Food Attributes. *Journal of Texture Studies*, 46, 46-57.

Mestres, M., Kieffer, R., & Buettner, A. (2006). Release and perception of ethyl butanoate during and after consumption of whey protein gels: relation between textural and physiological parameters. *Journal of Agricultural and Food Chemistry*, 54, 1814-1821.

Mioche, L., & Martin, J. -F. (1998). Training and sensory judgment effects on mastication as studied by electromyography. *Journal of Food Science*, 63, 1-5.

Mioche, L., Bourdiol, P., & Peyron, M. A. (2004). Influence of age on mastication: effects on eating behavior. *Nutrition Research Reviews*, 17, 43-54.

Peiffer, A. M, Mozolic, J. L., Hugenschmidt, C. E., & Laurienti, P. J. (2007). Age-related multisensory enhancement in a simple audiovisual detection task. *Neuroreport*, 18, 1077-1081.

Repoux, M., Labouré, H., Courcoux, P., Andriot, I., Sémon, É., Yven, C., Feron, G., & Guichard, E. (2012). Combined effect of cheese characteristics and food oral processing on *in vivo* aroma release. *Flavour and Fragrance Journal*, 27, 414-423.

Salles, C., Chagnon, M. C., Feron, G., Guichard, E., Laboure, H., Morzel, M., Semon, E., Tarrega, A., & Yven, C. (2011). In-mouth mechanisms leading to flavor release and perception. *Critical Reviews Food Science and Nutrition*, 51, 67-90.

Shipp, J. A. (1999). The influence of aging on oral health and consequences for taste and smell. *Physiology & Behavior*, 66, 209-215.

Steele, C. M., Hill, L., Stokely, S., & Peladeau-Pigeon, M. (2014). Age and strength influences on lingual tactile acuity. *Journal of Texture Studies*, 45, 317-323.

Tarrega, A., Yven, C., Semon, E., & Salles, C. (2008). Aroma release and chewing activity during eating different model cheeses. *International Dairy Journal*, 18, 849-857.

Weel, K. G. C, Boelrijk, A. E. M., Alting, A. C., Van Mil, P. J. J. M., Burger, J. J., Gruppen, H., Voragen, A. G. J, & Smit, G. (2002). Flavor release and perception of flavored whey protein gels: perception is determined by texture rather than by release. *Journal of Agricultural and Food Chemistry*, 50, 5149–5155.

Williams, E. J. (1949). Experimental designs balanced for the estimation of residual effects of treatments. *Australian Journal of Chemistry, A2*, 149-168.

Vennemann, M. M., Hummel, T., & Berger, K. (2008). The association between smoking and smell and taste impairment in the general population. *Journal of Neurology*, 255, 1121-1126.

Vickers, Z. M. (1982). Relationships of chewing sounds to judgments of crispness, crunchiness and hardness. *Journal of Food Science*, 47, 121-124.

Wallace M. T., Wilkinson, L. K., & Stein, B. E. (1996). Representation and integration of multiple sensory inputs in primate superior colliculus. *Journal Neurophysiology*, 76, 1246-1266.

Zampini, M., & Spence, C. (2004). The role of auditory cues in modulating the perceived crispness and staleness of potato chips. *Journal of Sensory Studies*, 19, 347-363.

Table 1. Parameters of the Time-Intensity (TI) analysis and the electromyography (EMG) used in this study.

Parameter	Unit	Definition
Time-Intensity Analysis		
Time at the maximum intensity (T_{max})	s	Time to reach peak intensity
Maximum intensity (I_{max})	N/A	Height of highest point on TI record
Area under the curve (AUC)	N/A	Total area under the curve
Duration	S	Time from onset to return to baseline
Increasing angle	º	Rate of increase (linear fit) from onset to peak intensity
Increasing area	N/A	Area under the curve from onset to peak intensity
Decreasing angle	º	Rate of decrease (linear fit) from initial declining point to baseline.
Decreasing area	N/A	Area under the curve from declining point to baseline
Initial delay	S	Time from ingestion until onset of the sensation
Initial intensity	N/A	Intensity at the onset of sensation
Electromyography		
Chew work	mV × s	The area of all individual chews of the mastication sequence
Average chew work	mV × s	The average area of each chew of the mastication sequence
Average chew max	mV	The average maximum chew strength of the chews in a mastication sequence
Number of chews	N/A	The number of chews in the mastication sequence
Average chew duration	S	The average time of the chews in the mastication sequence
Average duration between chews	S	The average time between chews in the mastication sequence
Time to swallow	S	The time from ingestion to the first swallow of the mastication sequence

N/A: Not applicable.

Definitions of the TI analysis parameters were determined based on a previous study by Lawless and Heymann (2010).

Definitions of the EMG parameters were determined based on a previous study by Lee et al. (2009).

Table 2. Means (± standard error of the mean) of each Time-Intensity parameter with respect to crispness level, flavor type, and age group.

(*N* = 68)

Main factor	Duration (s)	Increasing angle (º)	Increasing area	Decreasing angle (º)	Decreasing area	Initial delay (s)	Initial intensity
Crispness level							
Low	48.0 (± 1.5)	53.5 (± 1.7)	455.3 (± 31.6)	40.8 (± 1.9)	883.9 (± 82.4)	1.6 (± 0.1)	3.6 (± 0.3)
Medium	48.5 (± 1.5)	54.8 (± 1.5)	496.8 (± 36.2)	40.9 (± 1.9)	968.7 (± 79.2)	1.6 (± 0.1)	3.3 (± 0.3)
High	50.0 (± 1.5)	63.1 (± 1.6)	550.0 (± 39.5)	42.0 (± 1.9)	1227.1 (± 93.7)	1.4 (± 0.1)	3.8 (± 0.5)
Flavor type							
Plain	45.6 (± 1.7)	50.0 (± 1.8)	350.5 (± 30.6)	39.7 (± 1.9)	652.2 (± 68.0)	1.7 (± 0.1)	3.3 (± 0.3)
Cheese	49.1 (± 1.5)	58.3 (± 1.5)	475.1 (± 33.2)	41.7 (± 1.8)	984.3 (± 85.1)	1.5 (± 0.1)	3.6 (± 0.4)
Spicy	51.7 (± 1.4)	63.2 (± 1.6)	676.4 (± 46.6)	42.3 (± 1.9)	1443.1 (± 109.8)	1.5 (± 0.1)	3.9 (± 0.4)
Age group							
Younger age	45.7 (± 2.4)	62.7 (± 2.6)	370.4 (± 56.3)	39.0 (± 2.9)	1085.1 (± 140.0)	1.4 (± 0.2)	4.7 (± 0.5)
Middle age	49.3 (± 2.3)	57.9 (± 2.5)	522.6 (± 55.1)	40.8 (± 2.9)	1192.4 (± 137.1)	1.5 (± 0.2)	3.3 (± 0.5)
Older age	51.5 (± 2.5)	50.9 (± 2.7)	609.0 (± 58.9)	43.9 (± 3.1)	802.2 (± 146.5)	1.7 (± 0.2)	2.8 (± 0.5)

Table 3. Means (± standard error of the mean) of each electromyography (EMG) parameter with respect to crispness level, flavor type, and age group.

(*N* = 68)

Main factor	Chew work (mV·s)	Average chew work (mV·s)	Average chew max (mV)	Number of chews	Average chew duration (s)	Average duration b/t chews (s)	Time to swallow (s)
Crispness level							
Low	16.68 (± 1.43)	0.48 (± 0.03)	3.15 (± 0.17)	33.75 (± 1.43)	0.53 (± 0.01)	1.34 (± 0.06)	18.10 (± 0.61)
Medium	15.94 (± 1.37)	0.46 (± 0.03)	3.03 (± 0.17)	34.24 (± 1.51)	0.52 (± 0.01)	1.32 (± 0.06)	18.19 (± 0.63)
High	15.95 (± 1.34)	0.46 (± 0.03)	3.03 (± 0.17)	34.66 (± 1.49)	0.55 (± 0.02)	1.38 (± 0.06)	17.99 (± 0.61)
Flavor type							
Plain	15.86 (± 1.36)	0.47 (± 0.03)	3.06 (± 0.17)	33.51 (± 1.43)	0.55 (± 0.02)	1.35 (± 0.06)	17.91 (± 0.58)
Cheese	16.38 (± 1.41)	0.47 (± 0.03)	3.10 (± 0.16)	34.31 (± 1.51)	0.52 (± 0.01)	1.38 (± 0.07)	17.91 (± 0.65)
Spicy	16.33 (± 1.35)	0.46 (± 0.03)	3.05 (± 0.17)	34.83 (± 1.49)	0.53 (± 0.01)	1.32 (± 0.06)	18.46 (± 0.65)
Age group							
Younger age	14.97 (± 2.33)	0.45 (± 0.05)	3.09 (± 0.28)	33.78 (± 2.49)	0.49 (± 0.02)	1.18 (± 0.09)	17.62 (± 0.97)
Middle age	15.58 (± 2.28)	0.45 (± 0.05)	2.92 (± 0.28)	35.32 (± 2.44)	0.54 (± 0.02)	1.35 (± 0.09)	17.44 (± 0.95)
Older age	18.01 (± 2.44)	0.50 (± 0.05)	3.20 (± 0.30)	33.54 (± 2.61)	0.58 (± 0.02)	1.51 (± 0.10)	19.21 (± 1.02)

Table 4. Partial least squares regression (PLSR) models predicting each parameter of the Time-Intensity (TI) analysis of potato chips based on electromyography (EMG) parameters with respect to age group.

	Regression coefficient (R^2)	**Root mean square error (RMSE)**	**EMG parameters (β-coefficient)**
Younger age group (N = 23)			
T_{max}	0.984	0.172	Time to swallow (2.16) Chew work (-3.75) Average chew max (20.88)
I_{max}	0.064	11.688	-
AUC	0.046	403.688	-
Duration	0.041	3.358	-
Increasing angle	0.999	0.220	Average chew duration (387.06)
Increasing area	0.136	72.933	-
Decreasing angle	0.123	2.794	-
Decreasing area	0.058	332.077	-
Initial delay	0.112	0.200	-
Initial intensity	0.266	0.712	-
Middle age group (N = 24)			
T_{max}	0.028	1.25	-
I_{max}	0.901	4.52	Number of chews (8.48)
AUC	0.863	196.82	Number of chews (309.52)
Duration	0.429	2.05	-
Increasing angle	0.694	4.23	Number of chews (3.44)
Increasing area	0.873	51.07	Number of chews (82.92)
Decreasing angle	0.906	1.18	Number of chews (1.98)
Decreasing area	0.852	150.50	Number of chews (226.66)
Initial delay	0.167	0.23	-
Initial intensity	0.088	0.72	-
Older age group (N = 21)			
T_{max}	0.087	1.38	-
I_{max}	0.943	3.67	Number of chews (23.14)
AUC	0.982	79.15	Number of chews (949.57) Chew work (-653.24) Average chew work (677.78) Duration b/t chews (-3430.73)
Duration	0.411	2.37	Time to swallow (1.26)
Increasing angle	0.567	5.47	Number of chews (2.82) Time to swallow (3.98)

Table 4. Partial least squares regression (PLSR) models predicting each parameter of the Time-Intensity (TI) analysis of potato chips based on electromyography (EMG) parameters with respect to age group.

	Regression coefficient (R^2)	Root mean square error (RMSE)	EMG parameters (*β*-coefficient)
Increasing area	0.938	53.26	Number of chews (345.03) Chew work (-220.35) Duration b/t chews (-1112.17)
Decreasing angle	0.277	2.42	-
Decreasing area	0.990	39.11	Number of chews (627.10) Chew work (-452.26) Average chew work (449.94) Duration b/t chews (-2171.78)
Initial delay	0.157	0.23	-
Initial intensity	0.252	0.62	-

T_{max}: time at the maximum intensity; I_{max}: maximum intensity; AUC: area under the curve
Definition of each parameter of the TI analysis and EMG signals was mentioned in Table 1.

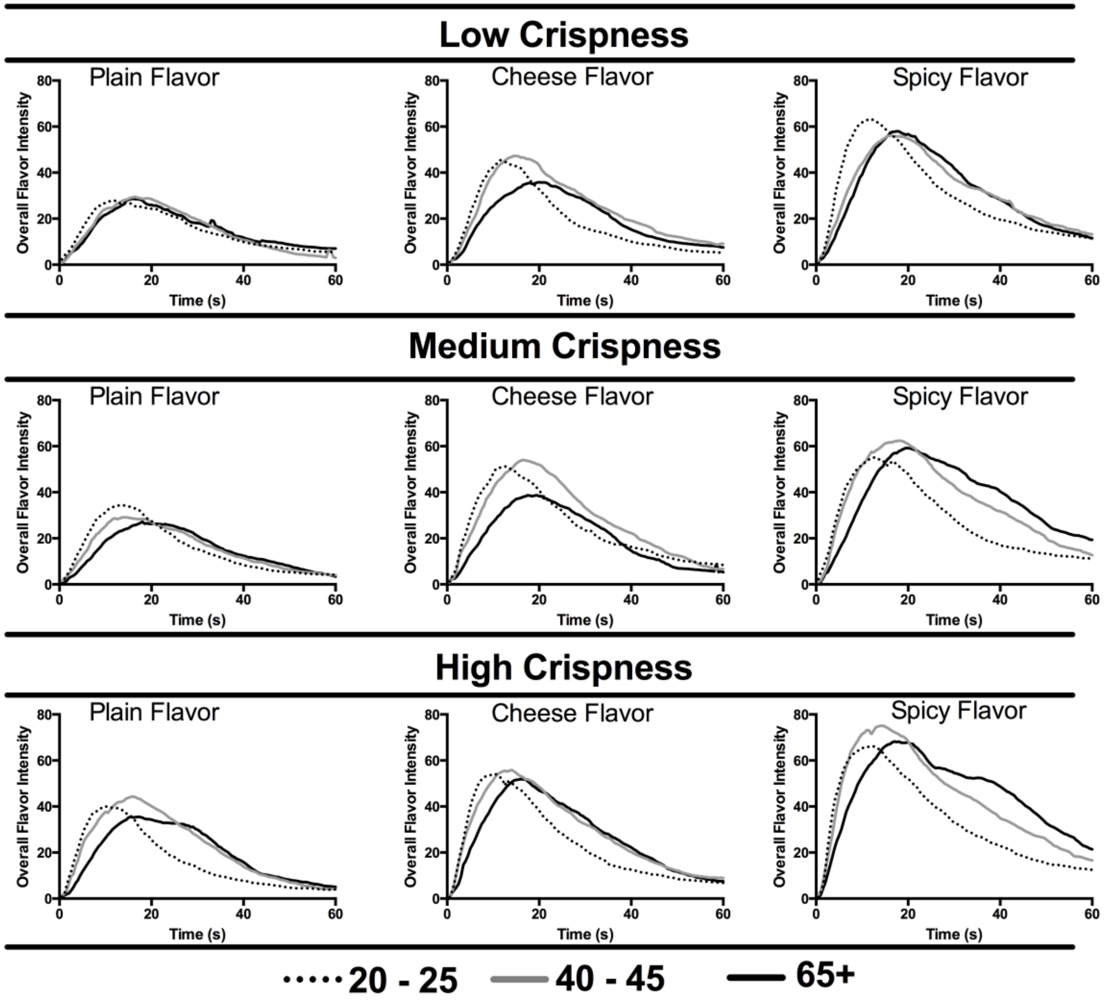

Figure 1. Mean Time-Intensity curves of potato chips as a function of crispness level (low, medium, and high), flavor type (plain, cheese, and spicy), and age group [younger (20-25 years old), middle age (40-45 years old), and older (65+ years old) groups].

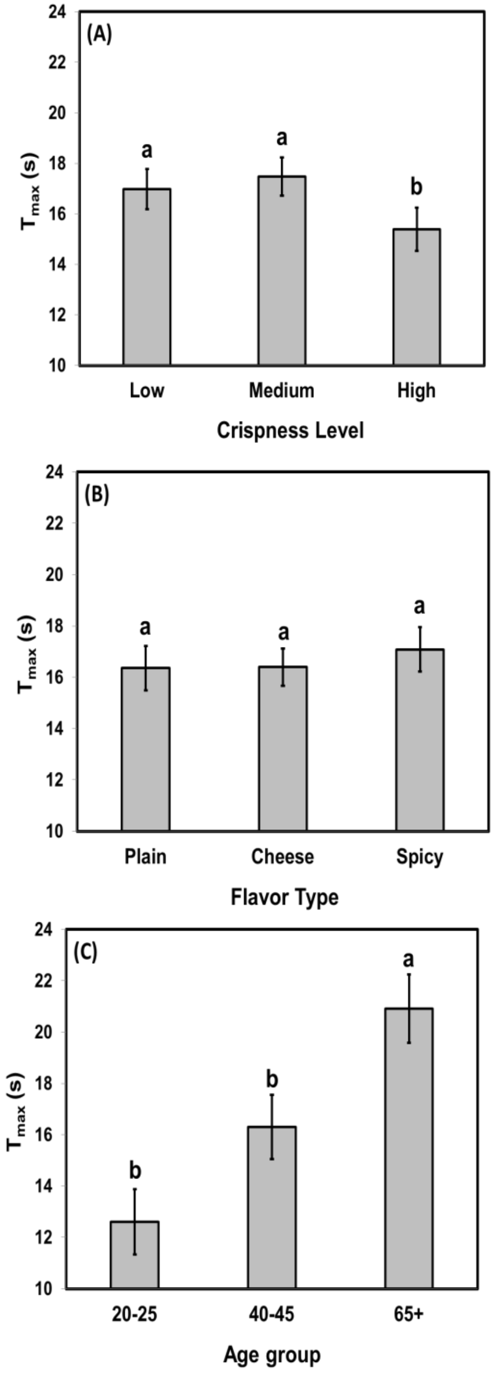

Figure 2. Mean comparisons with respect to the time at the maximum flavor intensity (T_{max}) of the Time-Intensity analysis for potato chips as a function of crispness level (A), flavor type (B), and age group (C). Mean ratings with different letters within a category indicate a significant difference at $P < 0.05$. Error bars represent standard errors of the means.

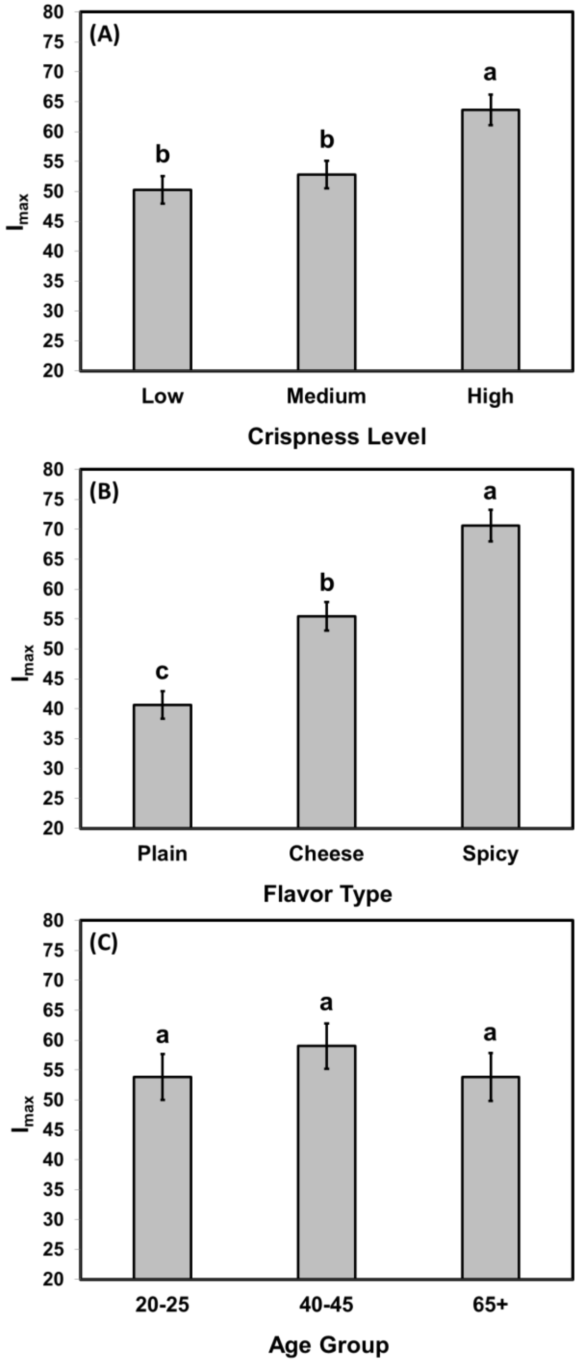

Figure 3. Mean comparisons with respect to the maximum flavor intensity (I_{max}) of the Time-Intensity analysis for potato chips as a function of crispness level (A), flavor type (B), and age group (C). Mean ratings with different letters within a category indicate a significant difference at $P < 0.05$. Error bars represent standard errors of the means.

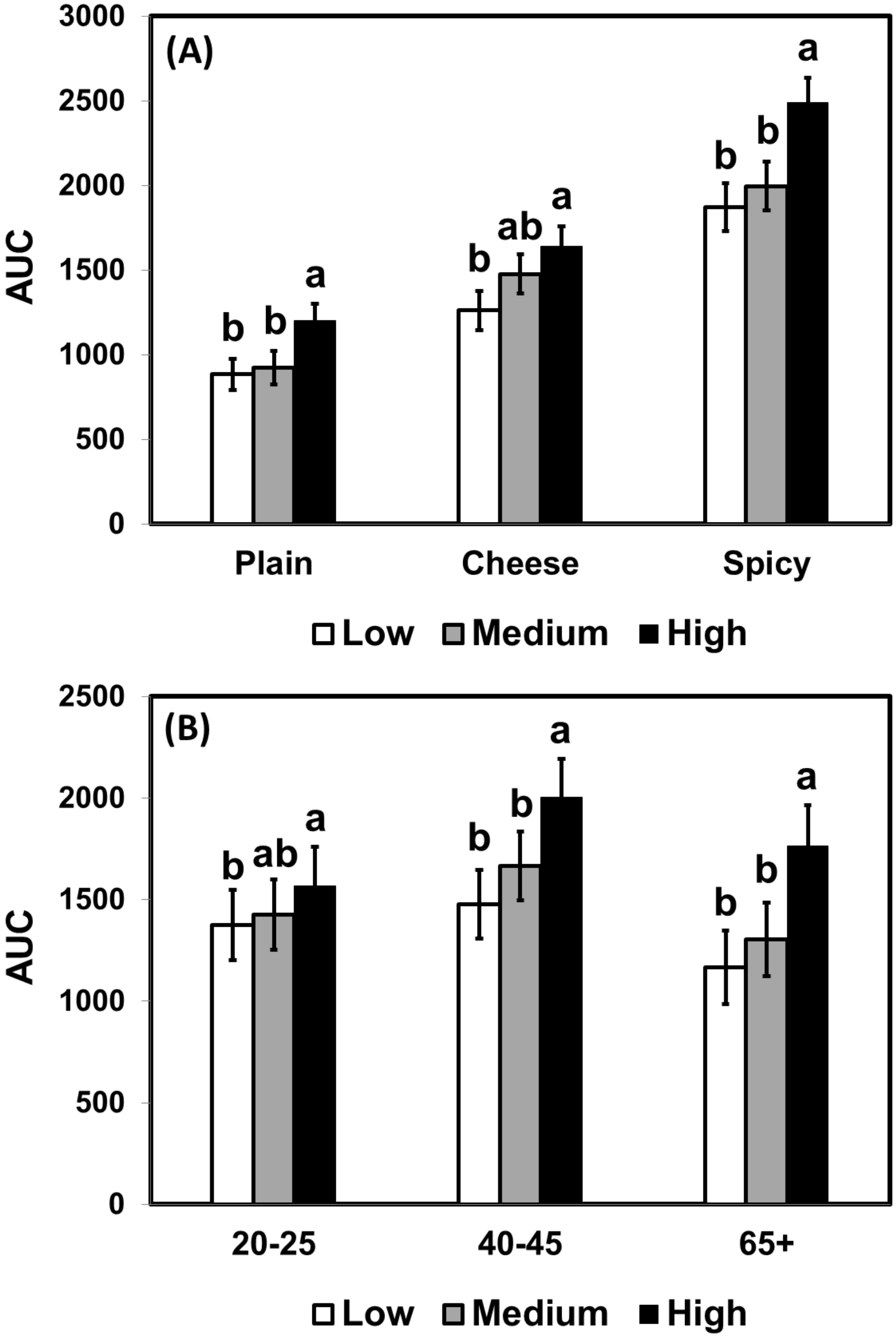

Figure 4. Interactions of crispness level (low, medium, and high) with flavor type (A) and age group (B) with respect to the area under the curve (AUC) of the Time-Intensity analysis for potato chips. Mean ratings with different letters within a category indicate a significant difference at $P < 0.05$. Error bars represent standard errors of the means.

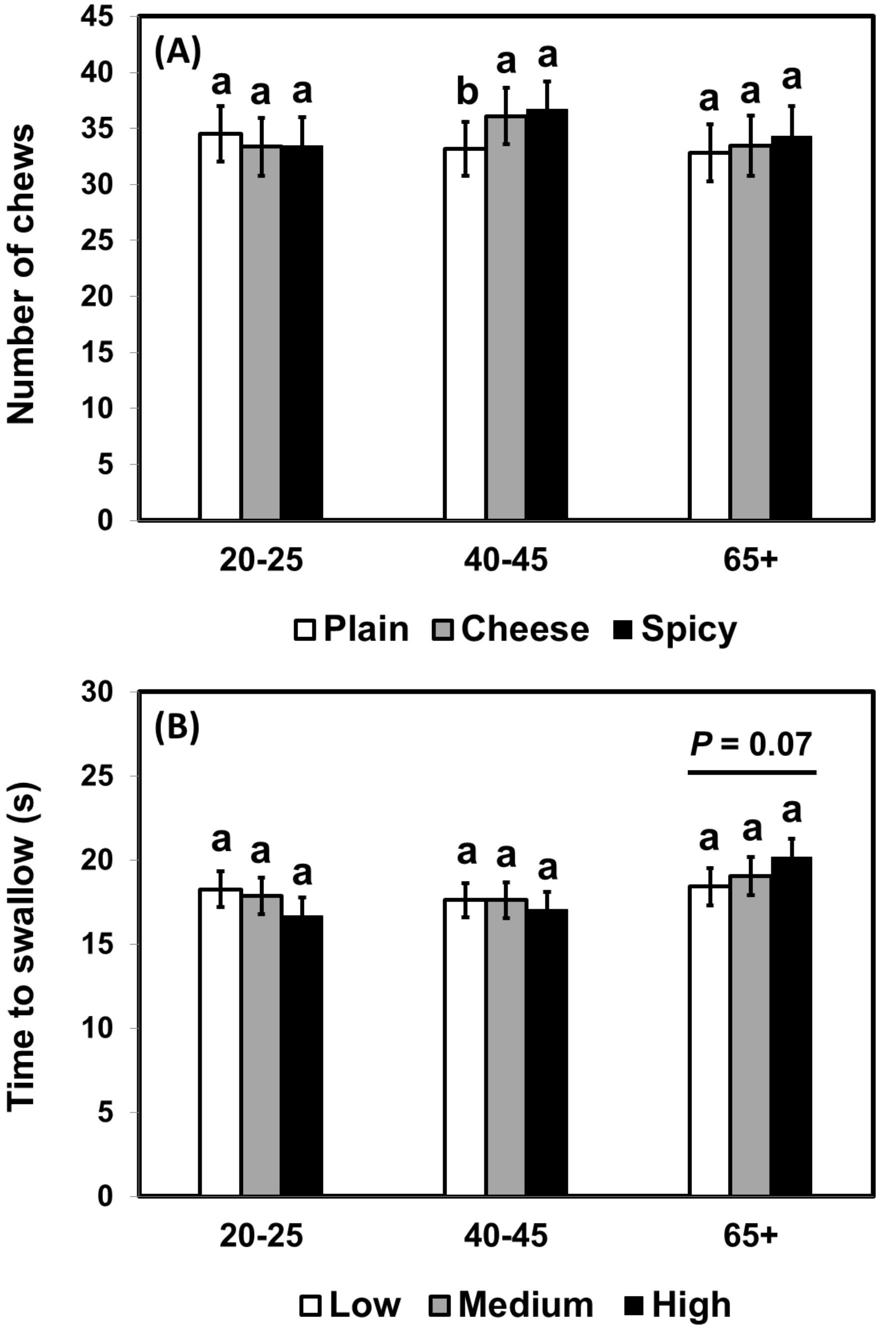

Figure 5. Interactions between flavor type and age group (A) and between crispness level and age group (B) with respect to the number of chews and the time to swallow, respectively, of the Time-Intensity analysis for potato chips. Mean ratings with different letters within a category indicate a significant difference at $P < 0.05$. Error bars represent standard errors of the means.

Chapter 5.

The Effect of Mastication Rate and Swallowing Time on Temporal Flavor Perception

Curtis R. Luckett and Han-Seok Seo[*]

Abstract

Previous research showed that the number of chews among mastication parameters has been shown to influence flavor perception in crispy potato chips. This study aimed to further determine how the number of chews modulates the temporal dynamics of flavor perception in potato chips. The number of chews was manipulated not only by changing chewing rate (40, 80, and 120 chews/min) in a fixed swallowing time (at 25 s after the onset of the first biting; Experiment 1), but also by changing the time to swallow (10, 20, and 30 s after the onset of the first biting) in a consistent chewing rate (80 chews/min; Experiment 2). In Experiment 1, the Time-Intensity (TI) analysis showed that the maximum flavor intensity (I_{max}) and the area under the curve (AUC) was significantly higher in the medium (80 chews/min) and fast (120 chews/min) chewing rates than in the slow (40 chews/min) chewing rate in both plain and spicy flavored chips. In Experiment 2, the temporal flavor perception varied by the interaction between the chewing duration before swallowing and flavor type of the potato chips. More specifically, in the natural chewing rate, while the I_{max} and AUC of spicy flavored chips were the greatest when the bolus was swallowed after the natural chewing-duration (for 20 s), the AUC of plain flavored chips was significantly greater in the longer chewing-duration (for 30 s) than the natural chewing-duration. In conclusion, this study supports and extends the notion that the number of chews and its corresponding parameters such as chewing rate and duration affect temporal flavor perception in the plain and spicy flavored potato chips. Further study should be conducted with a variety of foods to better understand whether and how the mastication parameters affect temporal dynamics of flavor perception. Further studies are needed to better understand how the mastication patterns affect temporal flavor perception in a variety of foods and age-groups.

Keywords: Oral processing; flavor; mastication; Time-Intensity analysis

5.1. Introduction

It is well known that textural characteristics of foods and beverages influence flavor perception (Buettner et al., 2001; Repoux et al., 2012; Luckett et al., 2016). Earlier research has uncovered that mastication pattern is an important factor in understanding how textural characteristics affect flavor perception in the mouth (Buettner and Schieberle, 2000; Mestre et al., 2006; Repoux et al., 2012; Luckett et al., 2016). More specifically, changes in textural characteristics resulted in variations in the mastication pattern that may modulate the physical properties of the food bolus altering aromatic release kinetics released from the food matrix (Brown et al., 1998; Buettner and Schieberle 2000; Harrison, 2000; Salles et al., 2011). There are also studies that suggest a more psychological mechanism behind the influence of textural characteristics on flavor perception. For example, it has been shown that flavor perception changes independently of the concentration of actual flavor volatiles (Weel et al., 2002; Leclercq and Blancher, 2012). Gierczynksi et al. (2008) have attempted to explain such observations through selective attention. They stipulated that firmer gels took more effort to breakdown and thus required more attention toward the textural characteristics of the gels during oral processing, in turn limiting the attention paid to other aspects, especially flavor, of the gels (Gierczynksi et al., 2008).

Even though previous studies demonstrated that food texture influences mastication behavior, relatively few studies have directly addressed how changes in mastication patterns can affect temporal flavor dynamics, as well as general flavor perception (Blissett et al., 2006; Tarrega et al., 2008). Tarrega et al. (2008) showed that the number of chews, chew work, and chew strength positively correlated with the maximum flavor intensity (I_{max}) of model cheese in the Time-Intensity (TI) analysis, while chew duration showed a negative correlation with the maximum flavor intensity. More recently, Luckett et al. (2016) demonstrated that the number of chews was an extremely good predictor of several parameters, such as maximum flavor intensity and area under the curve, of the TI analysis, which was in agreement with the findings of the study by Tarrega et al. (2008). On the other hand, other researchers observing the effect of mastication on flavor release in candy reported that the participants who exhibited a slow chewing rate and low bite force exhibited the release of more flavor volatiles than others who chewed more aggressively (Blissett et al., 2006). Thus, further research is needed to fully understand what specific mastication behaviors are related to subsequent changes in flavor release and perception.

While the number of chews has been found to be a good predictor of several temporal flavor perception parameters, it is difficult to modify the number of chews in an experimental setting. Changing the number of chews by modifying the chewing rate also changes other mastication parameters such as the time between chews. To change the number of chews, and also not modifying the time between chews, the time to swallow needs modified. Since time to swallow (or chewing duration) was found to be a significant factor in flavor perception (Luckett et al., 2006), two experiments needed to be completed to fully understand how the number of chews and/or its related mastication patterns affect the temporal flavor perception. This study was therefore composed of the two experimental settings. The first experiment (Experiment 1) was designed to determine the effect of chewing rate on temporal flavor perception by modifying the number of chews in a fixed time to swallow (at 25 s after the onset of the first biting). The second experiment (Experiment 2) aimed to determine the effect of chewing duration on temporal flavor perception by modifying the time to swallow at a fixed chewing rate (80 chews/min).

This study was conducted according to the Declaration of Helsinki for studies on human subjects. The protocol was approved by the Institutional Review Board of the University of Arkansas (Fayetteville, AR). The experimental procedure was thoroughly explained to all participants and a written informed consent was obtained prior to participation.

5.2. Experiment 1

Experiment 1 aimed to determine whether not only the number of chews (17, 33, and 50 chews), but also chewing rate (40, 80, and 120 chews/min) can affect temporal flavor perception of potato chips in the Time-Intensity analysis.

5.2.1. Materials and Methods

Participants

Forty-five volunteers (21 males and 24 females) ranging in age from 40 to 50 years participated in this study. All participants reported to have no artificial or missing teeth and were screened with respect to olfactory impairment using the "Sniffin' Sticks" screening test (Burghart Instruments, Wedel, Germany; Hummel et al., 2001).

Food sample and preparation

Two different flavors, i.e., plain and jalapeno, of potato chips (Pringles®, Kellogg Co., Battle Creek, MI) were used in this study. Each sample was placed in a 2-oz (59-mL) soufflé cup identified by a 3-digit code and was served in a sequential monadic fashion, in which the presentation order was based on the Williams Latin Square design (Williams, 1949).

Time-Intensity analysis

To measure temporal dynamics of flavor intensity during eating of potato chips, the Time-Intensity (TI) analysis (Larson-Powers and Pangborn, 1978) was used via sensory evaluation software, Compusense® five (Release 5.6, Compusense Inc., Guelph, ON, Canada). Overall flavor intensity of the potato chip was rated on a 10-cm vertical line scale that was anchored by "Maximum" on the top and "0" on the bottom by using a slider that represented overall flavor intensity. The sampling rate was 0.5 s. The participants were asked to use the mouse to portray their perceived flavor intensity on the TI scale, moving the mouse up when they felt the flavor increasing and down when they felt the flavor decreasing. The TI parameters used, as well as their definitions, are presented in Table 1.

Procedure

Each participant was seated in front of a 17 in. computer monitor that displayed the TI scale. Prior to the actual test, an introduction about the experimental protocol and TI methodology was given, verbally, to each participant. Additionally, two practice sessions were given to let participants become familiar with the TI scaling. Another type of plain flavored potato chips (Lay's, Frito-Lay, Plano, TX) was used for the practice sessions.

Each participant was asked to consume both plain and jalapeno flavor potato chips in a sequential monadic fashion under the mastication protocol. Each participant was asked to consume the entire sample in one single bite and then chew at three different chewing rates: 40 chews/min ("slow chewing rate"), 80 chews/min ("medium chewing rate"), and 120 chews/min ("fast chewing rate") for 60 s. At 25 s after the onset of the first biting, the participant was asked to swallow the potato chip sample, creating three different chewing numbers before swallowing: approximately 17 chews, 33 chews, and 50 chews. The chewing rates were governed by a metronome (Seiko SQ50V, Seiko Instruments, Hagiwara, Japan) in the background, and swallowing was prompted by the flashing of the word ‘‘swallow’’ on the computer screen; the participant was asked to refrain from swallowing before or after the specified swallowing time. The duration (60 s) of the TI analysis and the swallowing time (25 s) were set up based on a previous study (Luckett et al., 2016).

While consuming each potato chip for 60 s, the participant was asked to rate overall flavor intensity of the potato chip via the TI scaling software. The TI was initiated simultaneously with the potato chip making contact with any part of the oral cavity and lasted for 60 s. All 6 pairs of 2 flavor-types and 3 chewing-rates were randomly tested in duplicate based on a Williams Latin square design (Williams, 1949). Between the sample presentations, a break was given for 60 s with unsalted crackers (Nabisco Premium, Mondelēz Intl., East Hanover, NJ) and spring water (Clear Mountain Spring Water, Taylor Distributing, Heber Springs, AR) for palate cleansing.

Data analysis

The data obtained from the TI analysis was analyzed using SPSS 23.0 for Windows^{TM} (IBM SPSS Inc., Chicago, IL). The TI parameters were extracted from each individual TI curve. To determine whether chewing rate affects flavor perception a two-way repeated measures ANOVA (RM-ANOVA) was ran treating the chewing rate (slow, medium, and fast) and the flavor type (plain and spicy) as main effects. If the Mauchly sphericity test indicated that the sphericity assumption was violated, the degrees of freedom were adjusted by using “Huynh–Feldt” correction. If a significant difference in means was determined by RM-ANOVAs, post hoc comparisons between independent variables were conducted using Bonferroni *t*-tests. A statistically significant difference was defined as $P < 0.05$.

5.2.2. Results

No two-way interactions were observed between the flavor type and the chewing rate in all parameters of the TI analysis ($P > 0.05$, for all).

Time at the maximum intensity (T_{max})

There was no significant effect of chewing rate on the time at the maximum flavor intensity [Huynh-Feldt correction: $F(1.76, 77.50) = 2.76$, $P = 0.08$]. Flavor type significantly affected the time at the maximum intensity [$F(1, 44) = 3.43$, $P = 0.07$], showing that the spicy flavored potato chip took 5 s longer to reach the maximum intensity in comparison to the plain flavored chip (Table 2).

Maximum flavor intensity (I_{max})

As shown in Figure 1A, chewing rate significantly influenced the maximum flavor intensity of the potato chip samples [$F(2, 88) = 12.02$, $P < 0.001$]. The maximum flavor intensity of potato chips was significantly lower when the chips were chewed slowly (40 chews/min) than when chewed normally (80 chews/min; $P = 0.002$) and quickly (120 chews/min; $P = 0.002$). In addition, as expected, there was a significant effect of flavor type on the maximum flavor intensity [$F(1, 44) = 99.24$, $P < 0.001$]; the spicy flavored samples were shown to have a considerably higher maximum flavor intensity than the plain flavored samples.

Area Under the Curve (AUC)

The area under the curve appeared to be higher in the medium and fast chewing rates than in the slow chewing rate (Table 2), but such a trend was not statistically proven [Huynh-Feldt correction: $F(1.83, 80.66) = 2.56$, $P = 0.09$]. In addition, as shown in Table 2, the AUC was significantly greater in the spicy flavored chips than in the plain flavored ones [$F(1, 44) = 2.56$, $P < 0.001$].

Duration

The duration of flavor perception was not affected by the chewing rate [$F(2, 88) = 1.78$, $P = 0.18$]. Similar to other TI flavor parameters, the duration was significantly longer for the spicy flavored chips in comparison to the plain flavored ones (Table 2) [$F(1, 44) = 15.58$, $P < 0.001$].

Increasing angle and Increasing area

Increasing angle was found to be affected by the chewing rate [Huynh-Feldt correction: $F(1.71, 75.11) = 8.62$, $P = 0.001$]. More specifically, the increasing angle was significantly greater in the fast chewing rate than in the slow chewing rate ($P = 0.001$); however, the increasing angle at the medium chewing rate was not significantly different from those at the slow ($P = 0.07$) and fast ($P = 0.24$) chewing rates (Figure 1B). The flavor type was another significant factor influencing the increasing angle [$F(1, 44) = 33.97$, $P < 0.001$]; the spicy flavored chips showed a greater increasing-angle than did the plain flavored chips.

Unlike the increasing angle, the increasing area was not found to be affected by chewing rate (Table 2) [$F(2, 88) = 1.27$, $P = 0.29$]. However, similar to the increasing angle, the increasing area was significantly affected by flavor type [$F(1, 44) = 23.49$, $P < 0.001$]; the increasing area was significantly greater in the spicy flavored chips than the plain flavored chips.

Decreasing angle and Decreasing area

The decreasing angle was affected by neither chewing rate [Huynh-Feldt correction: $F(1.66, 72.90) = 0.23$, $P = 0.75$] nor flavor type [$F(1, 44) = 1.05$, $P = 0.31$] as shown in Table 2.

The decreasing area was not influenced by the chewing rate [Huynh-Feldt correction: $F(1.65, 72.41) = 0.65$, $P = 0.50$]. However, the decreasing area was significantly different by flavor type of chip samples [$F(1, 44) = 83.63$, $P < 0.001$], the decreasing area was significantly greater in the spicy flavored chips than the plain flavored chips (Table 2).

Initial delay and Initial intensity

As shown in Figure 1C, the initial delay of flavor perception was found to be significantly influenced by the chewing rate [$F(2, 88) = 6.48$, $P = 0.002$]. The slow chewing rate showed an initial delay that was significantly longer when compared to the medium ($P = 0.02$) and the fast ($P = 0.01$) chewing rate. The medium chewing rate was not significantly different from the slow and fast chewing rates with respect to the initial delay of flavor perception. In addition, the initial delay of flavor perception was significantly affected by flavor type [$F(1, 44) = 4.40$, $P = 0.04$] showing a shorter initial delay of spicy flavor perception.

Unlike the initial delay, the initial intensity of flavor perception was not affected by the chewing rate (Table 2) [$F(2, 88) = 1.19$, $P = 0.31$]. However, the initial intensity was significantly greater in the spicy flavored chips than in the plain flavored chips [$F(1, 44) = 7.34$, $P = 0.01$].

5.3. Experiment 2

Experiment 2 aimed to determine whether not only the number of chews (13, 27, and 40 chews), but also the chewing duration (10, 20, and 30 s) can affect temporal flavor perception of potato chips when the chewing rate is consistent (80 chews/min).

5.3.1. Materials and Methods

Participants

Thirty-nine volunteers (11 males, 28 females) ranging in age from 40 to 50 years participated in this study. All volunteers reported to have no artificial or missing teeth and their olfactory impairment was screened using the "Sniffin' Sticks" screening test (Burghart Instruments, Wedel, Germany; Hummel et al., 2001). Approximately half of the participants in Experiment 1 participated in Experiment 2; there was a two-month interval between the Experiments 1 and 2.

Food sample and participation

In Experiment 2, like in Experiment 1, the two different flavors, i.e., plain and jalapeno, of potato chips (Pringles®, Kellogg Co., Battle Creek, MI) were prepared in the same manner. The samples were presented in a sequential monadic manner according to a Williams Latin Square Design (Williams, 1949).

Procedure

Like in Experiment 1, each participant was asked to rate temporal flavor intensity of each potato chip sample using the TI analysis. The difference in procedure from Experiment 1 was that the participant was asked to chew each potato chip sample at the consistent chewing rate of

80 chews/min and then swallow the bolus at 3 different times: 10, 20, and 30 s after the onset of the first bite. A chewing rate of 80 chews/min was provided by a metronome in the background. The participant was asked to refrain from swallowing before or after the specified swallowing time. Swallowing was prompted by the flashing of the word ‘‘swallow’’ on the computer screen. The participant was asked to consume the entire sample in one single bite.

Data analysis

To determine whether chewing duration affects flavor perception a two-way repeated measures ANOVA (RM-ANOVA) was conducted treating the chewing duration (for 10, 20, and 30 s) and the flavor type (plain and spicy) as the main effects. If the Mauchly sphericity test indicated that the sphericity assumption was violated, the degrees of freedom were adjusted by using “Huynh–Feldt” correction. If a significant difference in means was determined by RM-ANOVAs, post hoc comparisons between independent variables were conducted using Bonferroni *t*-tests. A statistically significant difference was defined as $P < 0.05$.

5.3.2. Results

Time at the maximum intensity (T_{max})

There was no significant interaction between the chewing duration and flavor type with respect to the time at the maximum intensity [Huynh–Feldt correction: $F(1.70, 62.72) = 1.95$, $P = 0.16$]. The time at the maximum flavor intensity was found to be unaffected by the chewing duration (Table 3) [$F(2, 74) = 2.50$, $P = 0.09$]. However, the spicy flavored chips took approximately 4 s longer to reach the maximum flavor intensity than did the plain flavored samples [$F(1, 37) = 12.70$, $P = 0.001$].

Maximum flavor intensity (I_{max})

The maximum flavor intensity was found to have a significant interaction between the chewing duration and flavor type [Huynh–Feldt correction: $F(1.71, 63.13) = 5.35$, $P = 0.01$]. Upon further analysis, as shown in Figure 2, the plain flavored chips did not significantly differ among the three chewing durations before swallowing ($P = 0.12$). However, for the spicy flavored chips, the maximum flavor intensity was rated significantly higher in the medium chewing-duration (for 20 s) than in the short (for 10 s; $P = 0.04$) and long (for 30 s; $P = 0.04$) chewing duration.

Area Under the Curve (AUC)

As shown in Figure 3, the area under the curve showed a significant interaction between the chewing duration and flavor type [$F(2, 74) = 9.03$, $P < 0.001$]. For the plain flavored chips, the AUC was significantly higher in the long chewing-duration than in the medium chewing-duration ($P = 0.006$). In contrast, the spicy flavored chips showed an opposite trend; the AUC was higher in the middle chewing-duration than in the short ($P = 0.04$) and long ($P = 0.01$) chewing-durations.

Duration

Figure 4 shows a significant interaction between the chewing duration and flavor type with respect to the duration of flavor perception [$F(2, 74) = 5.91$, $P = 0.004$]. For the plain flavored chips, the duration of flavor perception was significantly higher in the long chewing-duration than in the short ($P = 0.01$) and medium ($P = 0.001$) chewing-durations. However, such a trend was not observed in the spicy flavored chips ($P = 0.48$).

Increasing angle and Increasing area

The increasing angle was found to have no significant interaction between the chewing duration and flavor type [Huynh–Feldt correction: $F(1.72, 63.56) = 0.06$, $P = 0.92$]. In addition, the increasing angle was not affected by the chewing duration [$F(2, 74) = 0.19$, $P = 0.82$]. However, spicy flavored chips showed a significantly greater angle than did plain flavored chips (Table 3) [$F(1, 37) = 26.73$, $P < 0.001$].

The increasing area showed a significant interaction between the chewing duration and flavor type (Table 3) [$F(2, 74) = 5.22$, $P = 0.008$]. For the spicy flavored chips, the increasing area was marginally greater in the medium chewing-duration than in the short ($P = 0.09$) and long ($P = 0.07$) chewing-durations. However, for the plain flavored chips, the increasing area in the medium chewing-duration was marginally smaller than the increasing area in the long chewing-duration ($P = 0.09$).

Decreasing angle and Decreasing area

The decreasing angle showed no significant interaction between the chewing duration and flavor type [$F(2, 74) = 0.69$, $P = 0.51$]. In addition, the decreasing angle was affected by neither chewing duration [$F(2, 74) = 1.65$, $P = 0.20$] nor flavor type [$F(1, 37) = 0.71$, $P = 0.41$] (Table 3).

The decreasing area was found to have a significant interaction between the chewing duration and flavor type [$F(2, 74) = 3.97$, $P = 0.02$]. While the plain flavored chips showed smaller decreasing area in the medium chewing-duration than in the short and long chewing-durations, the spicy flavored chips had greater decreasing area in the medium chewing-duration than in other durations; however, these trends were not statistically proven (Table 3).

Initial delay and Initial intensity

With respect to the initial delay of flavor perception, no significant interaction was found between the chewing duration and flavor type [Huynh–Feldt correction: $F(1.54, 57.13) = 2.24$, $P = 0.13$]. Moreover, the initial delay was affected by neither chewing duration [Huynh–Feldt correction: $F(1.66, 61.37) = 0.64$, $P = 0.50$] nor flavor type [$F(1, 37) = 0.16$, $P = 0.69$] (Table 3).

Like the initial delay, the initial intensity of flavor showed no significant interaction between the chewing duration and flavor type [$F(2, 74) = 0.44$, $P = 0.64$]. In addition, there were no significant effects of chewing duration [Huynh–Feldt correction: $F(1.56, 57.75) = 1.33$, $P = 0.27$] and flavor type [$F(1, 37) = 1.47$, $P = 0.23$] with respect to the initial flavor intensity (Table 3).

5.4. Discussion

This study is a direct follow-up to the previous research that found the number of chews to be a strong predictor of the flavor perception in potato chips (Luckett et al., 2016). Additionally, other studies have found the number of chews to be a strong positive predictor of the maximum flavor intensity (Tarrega et al., 2008).

Experiment 1 showed that both maximum flavor intensity and area under the curve that related to flavor intensity were significantly less in the slow chewing rate (40 chews/min) than in the medium (80 chews/min) and fast (120 chews/min) rates. From the results of this study it is difficult to give causality to the phenomena observed. However, there are several possible reasons for the decrease in flavor perception that accompanied decreases in the chewing rate. First, the decreased chewing rate (also the decreased number of chews) could lead to less and greater particles of potato chips at the time to swallow (at 25 s after the onset of the first biting), decreasing the surface area of the bolus when compared to the medium (or natural) chewing rate. This decrease in surface area is thought to be influential in allowing volatile flavor compounds to more slowly diffuse into the gas phase and be drawn into the nasal cavity (Repoux et al., 2012), which may lessen a perceived intensity of the flavor. Second, the increase in flavor intensity with increased chewing rate could be through cognitive association process. This increase in chewing frequency and the speed at which the sample was contacting the teeth leads to a increase in the sound emitted by the potato chip samples. In this sense, such an increase in chewing sounds could cause attentional shifts toward the potato chips being masticated. The sound of the potato chips has been shown to be linked to the perceived freshness of potato chips (Zampini and Spence, 2004). Since the potato chips being perceived fresh is likely to have greater flavor intensity than stale potato chips showing smaller levels of crispness and loudness of eating sound, participants might perceive the potato chips as being more flavorful in the presence of louder eating sound elicited by the faster chewing rate. Third, the increase in flavor intensity with increased chewing rates could be due to a possible excitatory effect of the increased chewing rate. The increased speed of the metronome and its subsequent faster chewing rate are expected to elicit a heighted sensory sensitivity, similar to general excitement, thereby resulting in an increase in flavor intensity. Further studies, however, would need to be performed to fully understand the excitatory effect of increases in sound tempo and how excitement levels can influence the temporal flavor perception.

Experiment 2 demonstrated that chewing duration to maximize flavor intensity is dependent on flavor type of potato chips. For example, while spicy flavored chips were rated as being the most intense in the medium chewing-duration, plain flavored chips did not show such a trend. Opposed to the spicy flavored chips, for plain flavored potato chips, the longer chewing-duration showed a greater area under the curve than the medium chewing-duration, while for spicy flavored potato chips, this trend was the other way around. In other words, based on these results, for maximizing flavor perception, people are encouraged to chew plain flavored chips longer (for 30 s) and then swallow the bolus, whereas they are asked to chew spicy flavored chips in the medium chewing duration (for 20 s) and then swallow the bolus. What makes such a difference in Experiment 2? It might be due to that plain flavored chips need more time to perceive flavorful in the mouth since they have flat flavor, which is in line with the result of duration of flavor perception; the duration of flavor perception was the highest in the long chewing-duration. However, for the spicy flavored chips, longer chewing-duration did not help in boosting the duration of flavor perception (Table 3). Since the spicy flavored chips had shorter time at the maximum intensity and stronger flavor intensity than the plain flavored chips (Table 3), they might need less time to perceive flavorful in the mouth when compared to the plain flavored chips.

When the number of chews was manipulated using changes in chewing rate, a significant effect was found on several temporal flavor parameters, regardless of flavor type of the potato chips. However, when the time to swallow was used to change the number of chews, the effect of the number of chews on flavor perception does not manifest itself as clearly, regardless of flavor type of the potato chips. Based on the results, the importance of the number of chews appears to be more pronounced with the chewing rate. The important role of chewing rate has also been found in studies using simulated mastication to relate aroma release to chewing behavior (Hansson et al., 2003; Mestres et al., 2006). Earlier studies also found that chewing rate is the single most important factor regarding aroma release from food matrix (Hansson et al., 2003; Mestres, 2006; Salles et al., 2011).

Interestingly, this study showed that the time to max flavor intensity was relatively stable regardless of the chewing rate (Experiment 1) and the time to swallow (Experiment 2). Earlier studies have shown that the peak flavor volatile concentrations in the nasal cavity are immediately after swallowing (Deleris et al., 2011). However, the majority of those studies that also measured the perceived flavor intensity in conjunction with the flavor volatile concentrations showed a noteworthy disconnect between the perceived flavor and the flavor volatile concentration (Leclerq and Blancher, 2012; Weel et al., 2002). The present study also seems to show a plausible separation between the peak flavor concentrations, around swallowing, and the peak perceived flavor. Leclerq and Blancher (2012) reported that the time difference between the time at the maximum intensity and the maximum in-nose concentration of flavor volatiles is relatively short (for 2-5 s). However, they concluded that the limiting factor seems to be the time required for flavor volatiles to reach the olfactory receptor in the nasal cavity. This time required for the flavor volatiles to diffuse to the nasal cavity may be a significant factor in the timing of the maximum flavor intensity reported by the participants at different swallowing times. Interestingly, when we have performed several studies using TI, we have noticed a tendency for the flavor perception to peak around 20 seconds. This is often coincides with the swallowing time in a natural eating protocol, but when the time to swallowing is changed significantly the disconnect increases. The results of this study do point towards a mechanism closely linked to expectation, cognitive processing, and possible a certain amount of time for flavor volatiles to reach the nasal cavity. Further research should be conducted to validate this plausible assumption.

5.5. Conclusions

This study provides empirical evidence that mastication parameters such as, the number of chews, chewing rate, and chewing duration before swallowing are significant sources of temporal flavor perception in potato chips. To increase perceived flavor intensity in the plain and spicy flavored potato chips, it is suggested to chew them in the natural (80 chews/min) or faster (120 chews/min) chewing rate. In addition, in the natural chewing rate, while spicy flavor of potato chips can increase when the bolus was swallowed after natural chewing (for 20 s), plain flavor of potato chips can enhance when swallowed after longer chewing (for 30 s). In conclusion, our findings show that the number of chews and its subsequent parameters such as chewing rate and duration can modulate temporal flavor perception of potato chips. Further study should be conducted with a variety of foods to better understand whether and how the mastication parameters affect temporal dynamics of flavor perception.

5.6. References

Blissett, A., Hort, J., & Taylor, A.J. (2006). Influence of chewing and swallowing behavior on volatile release in two confectionery systems. *Journal of Texture Studies*, 37, 476-496.

Brown, W.E., Eves, D., Ellison, M., & Braxton, D. (1998). Use of combined electromyography and kinesthesiology during mastication to chart the oral breakdown of foodstuffs: Relevance to measurement of food texture. *Journal of Texture Studies*, 29, 145-167.

Buettner, A., & Schieberle, P. (2000). Influence of mastication on the concentrations of aroma volatiles - Some aspects of flavour release and flavour perception. *Food Chemistry*, 71, 347-354.

Buettner, A., Beer, A., Hannig, C., & Settles, M. (2001). Observation of the swallowing process by application of videofluoroscopy and real-time magnetic resonance imaging – consequences for retronasal aroma stimulation. *Chemical Senses*, 26, 1211–1219.

Davidson, J.M., Linforth, R.S.T., Hollowood, T.A., & Taylor, A.J. (1999) The effect of sucrose on the perceived flavor intensity of chewing gum. *Journal of Agriculture and Food Chemistry*, 47, 4336-4340.

Deleris, I., Saint-Eve, A., Dakowski, F., Semon, E., Le Quere, JL., Gullemin, H., & Souchon, I. (2011). The dynamics of aroma release during consumption of candies of different structures, and relationship with temporal perception. *Food Chemistry*, 127, 1615-1624.

Gierczynski, I., Laboure, H., & Guichard, E. (2008). In vivo aroma release of milk gels of different hardnesses: Inter-individual differences and their consequences on aroma perception. *Journal of Agriculture and Food Chemistry*, 56, 1697-1703.

Hansson, A., Giannouli, P., & Van Ruth, S. (2003). The influence of gel strength on aroma release from pectin gels in a model mouth and in vivo monitored with proton-transfer-reaction mass spectrometry. *Journal of Agriculture and Food Chemistry*, 51, 4732-4740.

Harrison, M. (2000). Mathematical models of release and transport of flavors from foods in the mouth to the olfactory epithelium. In *ACS Symposium Series* (Vol. 763, pp. 179-191). Washington, DC; American Chemical Society; 1999.

Hummel, T., Konnerth, C.G., Rosenheim, K., Kobal, G. (2001). Screening of olfactory function with a four-minute odor identification test: reliability, normative data, and investigations in patients with olfactory loss. *Annals of Otology, Rhinology & Laryngology*, 110, 976-981.

Larson-Powers, N., & Pangborn, R.M. (1978). Descriptive analysis of sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. *Journal of Food Science*, 43, 47-51.

Leclercq, S., & Blancher, G. (2012). Multimodal sensory integration during sequential eating - Linking chewing activity, aroma release, and aroma perception over time. *Chemical Senses*, 37, 689-700.

Luckett, C. R., Meullenet, J. -F., & Seo, H. -S. (2016). Crispness level of potato chips affects temporal dynamics of flavor perception and mastication patterns in adults of different age groups. *Food Quality and Preference,* 51, 8-19.

Mestres, M., Kieffer, R., & Buettner, A. (2006). Release and perception of ethyl butanoate during and after consumption of whey protein gels: relation between textural and physiological parameters. *Journal of agricultural and food chemistry*, 54: 1814-1821.

Repoux, M., Labouré, H., Courcoux, P., Andriot, I., Sémon, É., Yven, C., Feron, G., & Guichard, E. (2012). Combined effect of cheese characteristics and food oral processing on *in vivo* aroma release. *Flavour and Fragrance Journal*, 27, 414-423.

Salles, C., Chagnon, M.C., Feron, G., Guichard, E., Laboure, H., Morzel, M., Semon, E., Tarrega, A., & Yven, C. (2011). In-mouth mechanisms leading to flavor release and perception. *Critical Reviews Food Science and Nutrition*, 51, 67-90.

Tarrega, A., Yven, C., Semon, E., & Salles, C. (2008). Aroma release and chewing activity during eating different model cheeses. *International dairy journal,* 18, 849-857.

Terta, M., Blekas, G., & Paraskevopoulou, A. (2006). Retention of selected aroma compounds by polysaccharide solutions: A thermodynamic and kinetic approach. *Food Hydrocolloids*, 20, 863-871.

Trelea, I. C., Atlan, S., Déléris, I., Saint-Eve, A., Marin, M., & Souchon, I. (2008). Mechanistic mathematical model for in vivo aroma release during eating of semiliquid foods. *Chemical senses*, 33, 181-192.

Weel, K.G.C, Boelrijk, A.E.M., Alting, AC, Van Mil, P.J.J.M, Burger, J.J., Gruppen, H., Voragen, A.G.J, & Smit, G. (2002). Flavor release and perception of flavored whey protein gels: perception is determined by texture rather than by release. *Journal of Agricultural and Food Chemistry*, 50, 5149–5155.

Williams, E.J. (1949). Experimental designs balanced for the estimation of residual effects of treatments. *Australian Journal of Chemistry, A2*, 149-168.

Wilson, C. E., & Brown, W. E. (1997). Influence of food matrix structure and oral breakdown during mastication on temporal perception of flavor. *Journal of Sensory Studies*, 12, 69-86.

Table 1. Parameters of the Time-Intensity analysis used in this study.

Parameter	Unit	Definition
Time-Intensity Analysis		
Time at the maximum intensity (T_{max})	s	Time to reach peak intensity
Maximum intensity (I_{max})	-	Height of highest point on TI record
Area under the curve (AUC)	-	-
Duration	s	Time from onset to return to baseline
Increasing angle	º	Rate of increase (linear fit) from onset to peak intensity
Increasing area	-	Area under the curve from onset to peak intensity
Decreasing angle	º	Rate of decrease (linear fit) from initial declining point to baseline.
Decreasing area	-	Area under the curve from declining point to baseline
Initial delay	s	Time from ingestion until onset of the sensation
Initial intensity	-	Intensity at the onset of sensation

Table 2. Selected the Time-Intensity parameters of potato chips chewed at different rates.

Mastication Rate (chews/min)	Tmax (s)	Duration (s)	AUC	Increasing area	Decreasing angle (º)	Decreasing area	Initial intensity
Spicy							
40	21.1 (± 1.6)	52.3 (± 1.5)	2294 (± 162)	752 (± 70)	42.3 (± 2.8)	1541 (± 140)	11.1 (± 2.3)
80	20.8 (± 1.8)	53.3 (± 1.5)	2343 (± 156)	817 (± 84)	40.6 (± 2.8)	1526 (± 123)	7.7 (± 1.3)
120	20.1 (± 1.9)	52.8 (± 1.7)	2471 (± 176)	847 (± 98)	41.2 (± 2.6)	1624 (± 168)	8.1 (± 1.4)
Plain							
40	20.3 (± 1.5)	48.2 (± 1.7)	1215 (± 120)	437 (± 52)	39.3 (± 2.9)	778 (± 94)	6.2 (± 1.1)
80	18.0 (± 1.3)	50.2 (± 1.8)	1459 (± 139)	529 (± 61)	38.6 (± 2.9)	931 (± 104)	7.1 (± 1.1)
120	16.8 (± 1.6)	47.6 (± 2.0)	1275 (± 115)	445 (± 65)	40.1 (± 3.2)	830 (± 94)	6.4 (± 1.0)

Mean ± Standard Error of the mean

Table 3. Selected the Time-Intensity parameters of potato chips swallowed at different times.

Swallowing Time (s)	Tmax (s)	Increasing angle (º)	Increasing area	Decreasing angle (º)	Decreasing area	Initial delay (s)	Initial intensity
Spicy							
10	48.0 (± 1.5)	53.5 (± 1.7)	455.3 (± 31.6)	40.8 (± 1.9)	883.9 (± 82.4)	1.6 (± 0.1)	3.6 (± 0.3)
20	48.5 (± 1.5)	54.8 (± 1.5)	496.8 (± 36.2)	40.9 (± 1.9)	968.7 (± 79.2)	1.6 (± 0.1)	3.3 (± 0.3)
30	51.5 (± 2.5)	50.9 (± 2.7)	609.0 (± 58.9)	43.9 (± 3.1)	802.2 (± 146.5)	1.7 (± 0.2)	2.8 (± 0.5)
Plain							
10	48.0 (± 1.5)	53.5 (± 1.7)	455.3 (± 31.6)	40.8 (± 1.9)	883.9 (± 82.4)	1.6 (± 0.1)	3.6 (± 0.3)
20	48.5 (± 1.5)	54.8 (± 1.5)	496.8 (± 36.2)	40.9 (± 1.9)	968.7 (± 79.2)	1.6 (± 0.1)	3.3 (± 0.3)
30	51.5 (± 2.5)	50.9 (± 2.7)	609.0 (± 58.9)	43.9 (± 3.1)	802.2 (± 146.5)	1.7 (± 0.2)	2.8 (± 0.5)

Mean ± Standard Error of the mean

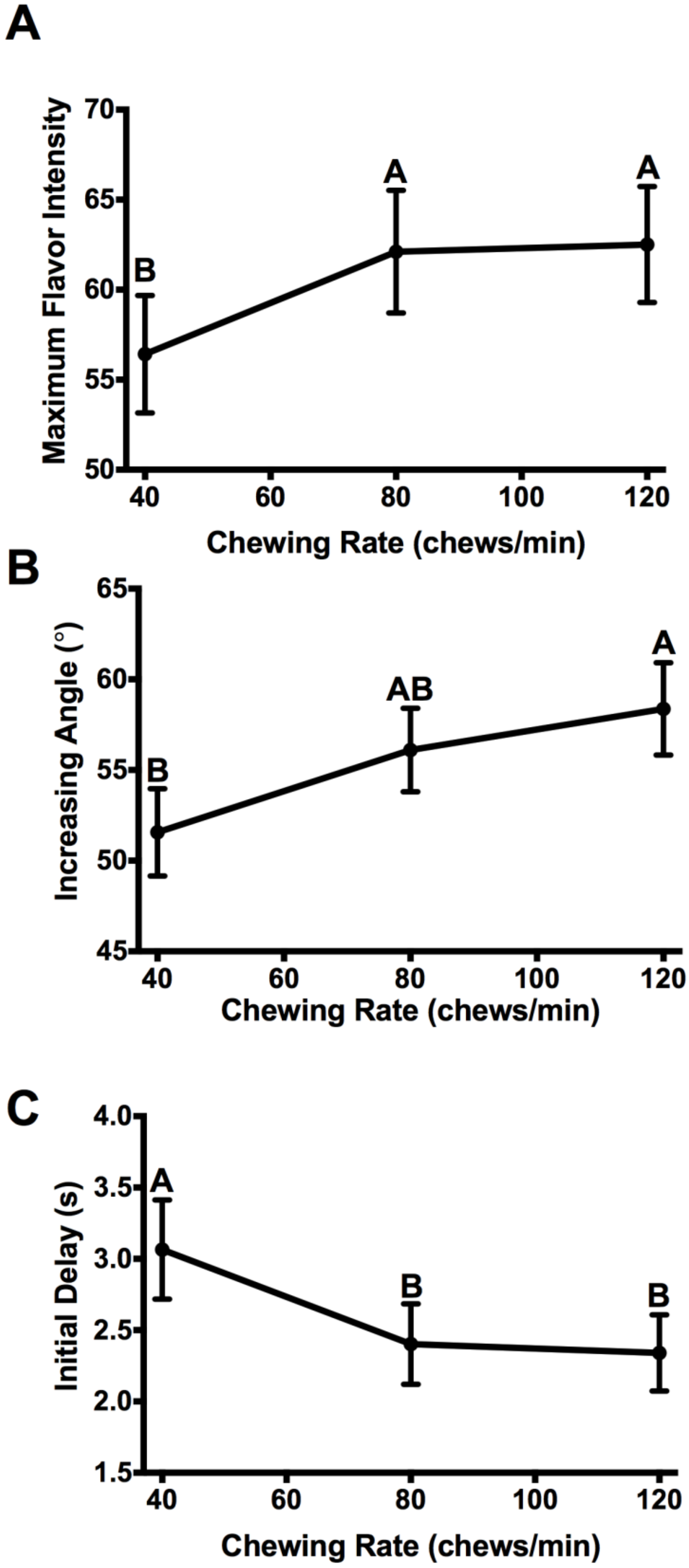

Figure 1. The maximum flavor intensity (A), increasing angle (B), and initial delay (C) as perceived by subjects chewing at different rates.

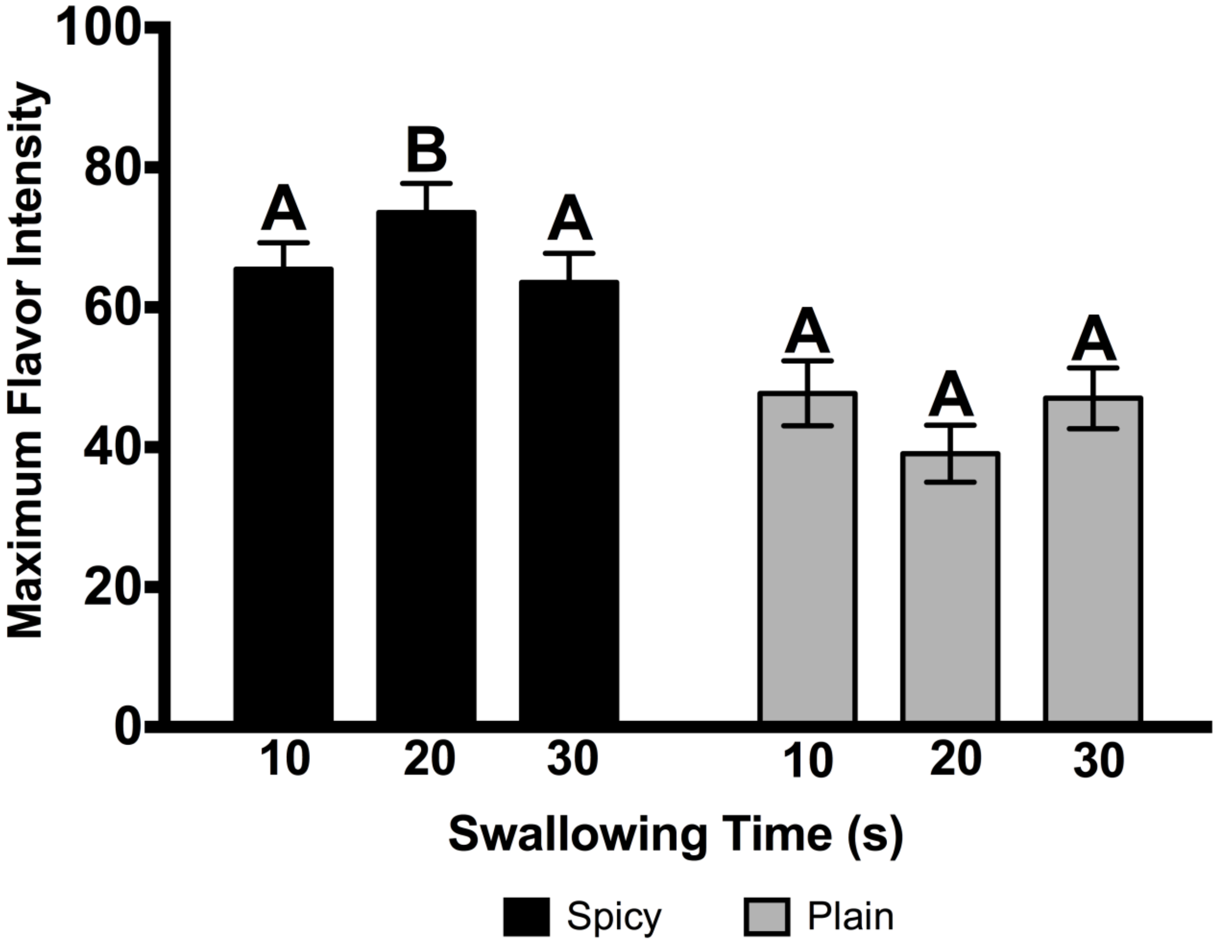

Figure 2. The maximum flavor intensity of spicy and plain potato chips as perceived by subjects chewing for different periods of time.

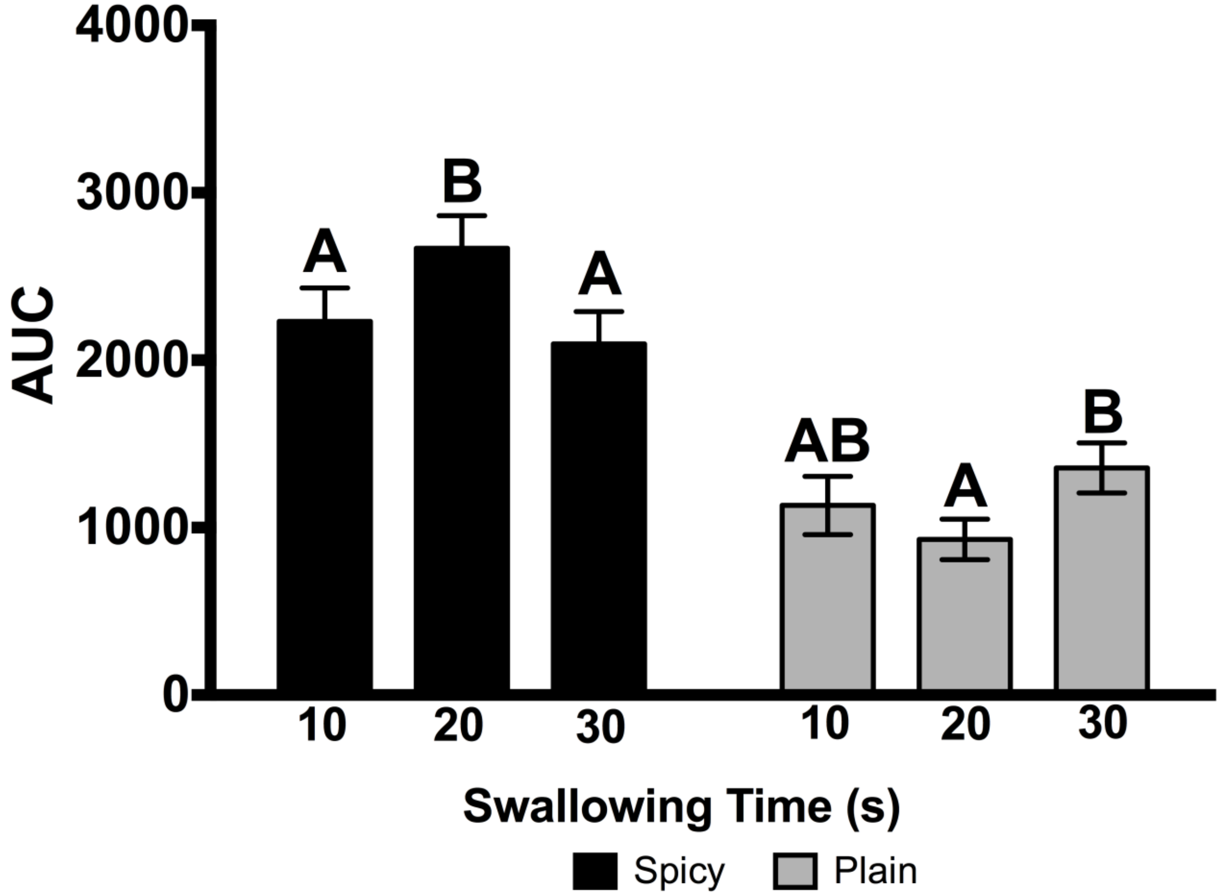

Figure 3. The area under the flavor-time curve of spicy and plain potato chips as perceived by subjects chewing for different periods of time.

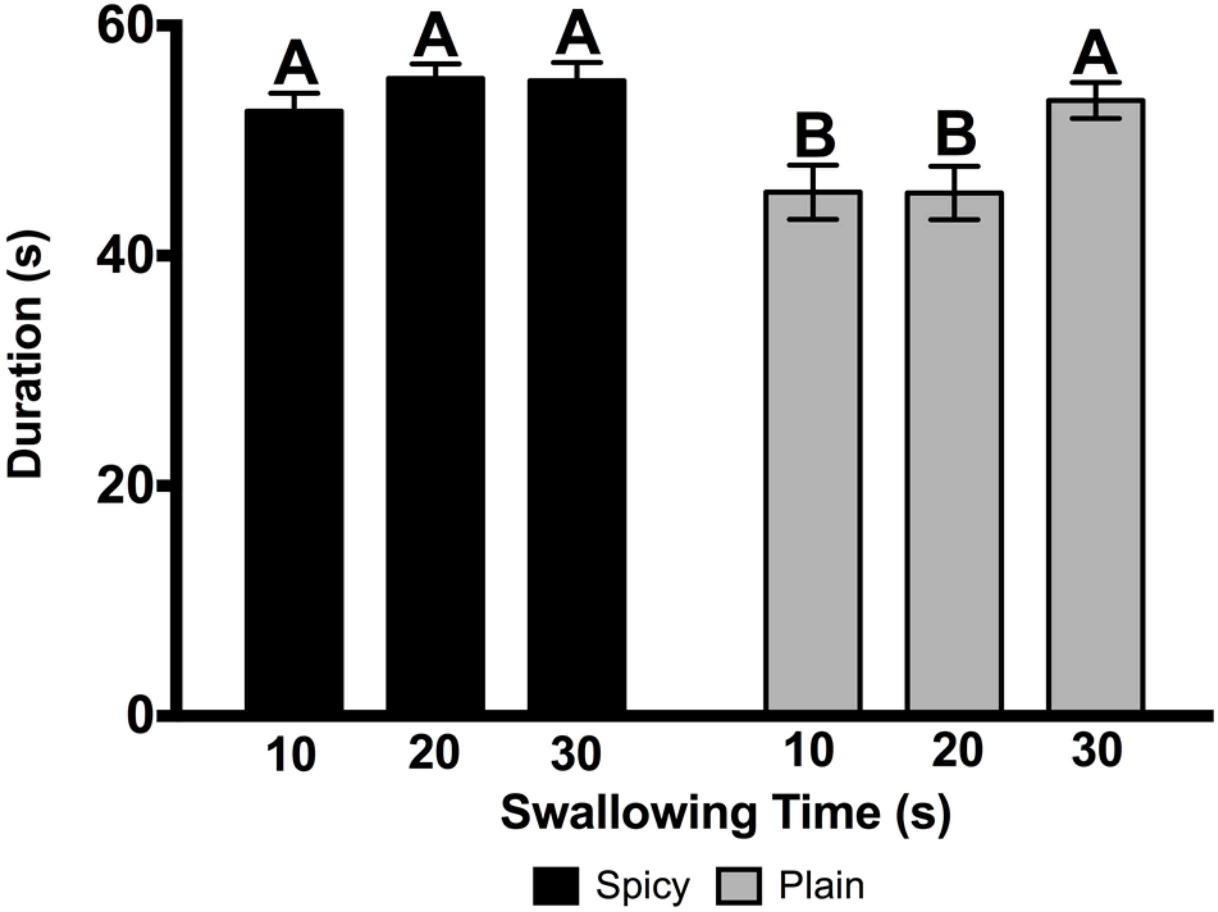

Figure 4. The duration of flavor of spicy and plain potato chips as perceived by subjects chewing for different periods of time.

Chapter 6.

Effects of Chewing Rate on the Temporal Dominance Sensation of Flavors

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Abstract

Chewing rate has been shown to influence temporal flavor perception. However, most of the studies uncovering this link have not taken into account that foods we commonly consume contain multiple flavors which are often not homogenously distributed. This study examined whether and how chewing rate influences the temporal dominance of specific flavors all contained in one sample. The sample used for this study was a gummy candy that contained three flavors in layers (lime, cherry, and grape). Participants were asked to chew at four specified rates (40 chews/min, 80 chews/min, 120 chews/min, and a natural chewing rate) while simultaneously rating the flavor dominance using the temporal dominance of sensations (TDS). Of all of the parameters measured from the TDS, only the time to the first attribute selection was affected by chewing rate. The participants took longer to select their first attribute in the slowest chewing rate (40 chews/min) and the natural chewing protocol, when compared to the faster chewing rates (80 chews/min and 120 chews/min). In addition, the total duration of flavor dominance was shorter in the slowest chewing rate than in the fastest chewing rate. However, the number of selections, first selected attribute, the time between attribute selections, and the average time per selection were not dependent on chewing rate. In conclusion, this study demonstrates that chewing rate affects the time to the first attribute selection, but not other parameters of temporal flavor perception. These results suggest that the TDS methodology is more useful for examining the temporal flavor perception of food samples for people with individual chewing variations when compared to the Time-Intensity methodology showing the significant variation of chewing rate on the temporal flavor perception.

Keywords: Mastication, Temporal Dominance of Sensations, Texture, Flavor

6.1. Introduction

Studies addressing the effects of mastication and other oral processing factors on temporal flavor perception have largely concentrated on the time-intensity flavor perception and/or the release of flavor compounds from the bolus (Blissett et al., 2006; Leclerq and Blancher, 2012; Luckett et al., 2016; Tarrega et al., 2008; Weel et al., 2002). From these studies there is consensus that mastication does indeed influence flavor perception, but there is not a consensus on how. Blissett et al. (2006) found that participants that had a slow chewing rate coupled with a low bite force showed a higher release of flavor volatiles when compared to those who masticated more aggressively. However, it has been reported that flavor volatile release is not always highly correlated to flavor perception (Weel et al., 2002; Leclercq and Blancher, 2012). The majority of studies have reported an opposite result regarding the relationship between flavor perception and mastication. Tarrega et al. (2008) found that maximum flavor intensity (I_{max}) was positively correlated with the number of chews, chew work, chew strength, and negatively correlated with chew duration. More recently, Luckett et al. (2016) found that the number of chews was a predictor of several time-intensity (TI) parameters of flavors. There were several instances where the number of chews showed a positive relationship with the maximum flavor intensity, area under the flavor-time curve, and other temporal flavor parameters, which is in agreement with the study by Tarrega et al. (2008).

While studies such as those mentioned above have drastically increased our understanding of how oral processing can influence flavor perception, the studies using the TI analysis did not consider that most of the foods we encounter in everyday life have numerous flavor types. One of the largest limitations to the Time-Intensity methodology is that only a few attributes can be recorded during one testing (Pineau et al., 2009). Such a limitation can be overcome using a method, Temporal Dominance of Sensation (TDS) of analyzing more number (up to 10 attributes) of sensory attributes over time during one test session (Pineau et al., 2004). The concept of TDS has surfaced as an intriguing alternative to the TI analysis, especially in cases of numerous attributes (Pineau et al., 2004). In the TI analysis, the actual intensity of the attribute(s) is rated, while in the TDS the most dominant attribute is selected. The TDS data is also notably different from the TI data, consisting of dominance rates, dominance durations, and so forth.

As mentioned earlier, the effects of mastication behavior on temporal flavor perception has been based on the TI methodology and our knowledge of the effects of oral processing on TDS is unknown. Building on the recent findings highlighted that chewing rate influences the temporal flavor perception (Luckett et al., 2016), this study was designed to further investigate the effect of chewing rate on the temporal dominance of flavors sensation.

6.2. Materials and Methods

This study was conducted according to the Declaration of Helsinki for studies on human subjects. The protocol was approved by the University Institutional Review Board of the University of Arkansas (Fayetteville, AR). The experimental procedure was thoroughly explained to all participants and they were asked to sign a consent form outlining the study.

Participants

Forty-seven (34 females, 13 males) participants completed this study. All panelists were between 40-49 years old (43.7 ± 2.9) and reported no more than 1 missing tooth, other oral health problems, smell, or taste problems. Panelists were asked not to eat or drink for 2 hours prior to the experiment.

Food Samples

Gummy candies were prepared for this experiment, using the ingredients and amounts in Table 1. The ingredients for the gummies were manually mixed together and heated to 80 °C using a boiling water bath. After being removed from the water bath the gummy solution was divided into three equally sized amounts and the flavor solution was added immediately before pouring the gummies into a silicone mold (Ozera Inc., Chengdu, China). The samples were formed into 3 cm x 1 cm x 2 cm (L × W × H) rectangles (Figure 1). The samples contained three equally-sized layers, in which each flavor was a specific flavor. The top layer was lime (865.156, FONA, Geneva, IL), the middle flavor was cherry (825.0137U, FONA, Geneva, IL), and the bottom flavor was grape (856.0287U, FONA, Geneva, IL). The flavors were matched in intensity through a preliminary experiment with ten volunteers. The test samples were labeled with 3-digit random codes.

Procedure

The participants were given a verbal introduction to TDS and instructions before starting the experiment. During the practice session, the participants were given written instructions on the testing procedure. During two practice sessions, the participants were then given a practice a sample to ensure they had the ability to perform the TDS correctly. They were familiarized with the test sample, as well as the TDS software (Timesens®, INRA, Dijon, France). The orientation of the sample when placed into the mouth by the participant was also standardized to ensure the flavor layers were oriented in the same direction for each sample. Prior to the experimental session, any additional directions and clarifications were given to the panelists.

In the experimental session, participants were asked to chew the test sample at the three different chewing conditions: 40, 80, and 120 chews/min. In addition, they were asked to naturally chew the test sample over time at their own chewing rate. In all cases the participants were instructed to swallow only once, at a time of their discretion. While chewing the test sample, the participants were asked to select the most dominant flavor among the three flavors: lime, cherry, and grape. The presentation order of chewing rate conditions was yet randomized, yet constant across the panelists. Participants were given a cracker and water to consumer in a one-minute break between the sample presentations.

Data analysis

The data obtained from the TDS was analyzed using SPSS 23.0 for Windows^{TM} (IBM SPSS Inc., Chicago, IL, U.S.A.) and JMP 12.0.1 (SAS Institute Inc., Cary, NC). To determine whether chewing rate affects flavor dominance a one-way repeated measures ANOVA (RM-ANOVA) was ran treating the chewing rate as the main effect. The TDS parameters used were the time to first attribute selection, the number of selections, the total duration of dominance, and the average time per selection. If the Mauchly sphericity test indicated that the sphericity assumption was violated, the degrees of freedom were adjusted by using “Huynh–Feldt” correction. If a significant difference in means was determined by RM-ANOVAs, post hoc comparisons between chewing rates were conducted using Bonferroni t-tests. To analyze the categorical TDS parameter (first attribute selected), a chi-squared test was performed. A statistically significant difference was defined as $P < 0.05$.

6.3. Results

Figures 2-5 show the standardized (from left and right) TDS dominance curves from the four chewing rate conditions used in this study. From these curves it is evident, while matched in intensity the flavor types do show differing temporal dynamics. The lime flavor is more delayed in its dominance and typically ends up as the final dominant flavor, while the grape and cherry flavors tend to assert dominance earlier in the chewing protocol. Interestingly, the grape flavor tended to be more dominant early in the eating process when the chewing rate was slow, but in the faster chewing rates and in the natural chewing protocol the grape flavor became more subtle and latent in its dominance. The cherry flavor was generally more dominant than the grape flavor, but failed to reach a statistical level of dominance ($P = 0.10$). It should be pointed out that this study only used the three main flavors of the gummies as attributes, making statistical significance of dominance rates difficult to reach. As evidenced by the statistical significance line, lime was the only flavor that reached statistical significance. However, the dominance was very late in the TDS measurement, i.e., most likely after swallowing across the four chewing conditions. Therefore, it is unlikely the chewing rate or mastication behavior contributed to the dominance of lime flavor.

Time to first attribute selection

The chewing rate was found to influence the time it takes for the participants to select the first dominant attribute [Huynh-Feldt Correction: $F(2.88, 262.31) = 3.44$, $P = 0.02$; Figure 6]. In comparison to the slowest (40 chews/min) chewing rate, participants chewing at 80 and 120 chews/min took longer to select their first attribute ($P = 0.05$). However, the time to first attribute selection was not found to be significantly different between the slowest chewing conditions and the natural eating protocol.

First attribute selected

The first attribute selected was not dependent on the chewing protocol ($\chi^2 = 5.68$, df = 6, $P = 0.46$). While there were three flavors in each gummy it is important to note that the location of each flavor placed in the gummy sample was fixed. In each sample the cherry flavor was always in the middle of the sample, with minimal exposure to the surrounding air. In other words, this data also can be used to state that the location of the flavor did not affect the likelihood of an attribute being selected first.

The number of selections

The number of selections was not found to be dependent on chewing rate [$F(3, 279) = 1.41$, $P = 0.24$]. For all chewing rate conditions, the number of selections was centered around 3.5, with the highest mean at 3.65 and the lowest at 3.32 (Table 2).

Time between selections

The time between selections was not dependent on the chewing rate [Huynh-Feldt Correction: $F(2.78, 258.29) = 1.61$, $P = 0.19$]. Across all chewing rate conditions, the time between selections was approximately 18 s, or one-third of the total analysis time.

Total duration of dominance

A two-way RM-ANOVAs treating chewing rate and flavor type as fixed effects showed no significant interaction between them with respect to the total duration of dominance [$F(6, 558) = 0.28$, $P = 0.95$]. The total duration of flavor dominance was found to be affected by chewing rate [Huynh-Feldt Correction: $F(2.85, 264.66) = 6.14$, $P < 0.001$]. The total duration of flavor dominance was significantly shorter at a slow chewing rate than at medium ($P = 0.02$) and fast ($P = 0.008$) chewing rates. There was a significant effect of flavor type on the total duration of flavor dominance [$F(2, 186) = 5.17$, $P = 0.007$]. As shown in the Figures 2-5, lime flavor showed a significantly higher total duration of flavor dominance than did grape flavor ($P = 0.01$).

6.4. Discussion

One of the most notable findings of this study was that in the faster chewing rates the participants were quicker to select their first attribute when compared to natural or slow chewing rate conditions. It has been consistently shown that the flavor intensity increased with the number of chews (Tarrega et al., 2008; Luckett and Seo, 2016). However, these studies also measured the time to the maximum flavor perception and did not find the same effect of chewing rate. While dominance is not always the most intense, the more flavor compounds reaching the nasal cavity could affect the perception of dominance. Researchers who have found that the strength of flavor perception increases with increasing number of chews or chewing rate often hypothesized that this intensification is due to an increase in surface area of the bolus (Brown et al., 1998; Harrison, 2000; Salles et al., 2011). More specifically, under more aggressive mastication behaviors the food is broken down into more particles and exhibits a higher surface area, allowing for more flavor volatiles to find their way into the air. In the context of this study it is possible that the shorter time for the panelists to select a dominant attribute in the faster chewing rate conditions is due to the increased surface area of the chewed sample allowing more flavor volatiles to reach the nasal cavity.

Another interesting finding is that the attribute that was selected first was not dependent on the chewing rate. Previous research has suggested that TDS is ideal for layered products, because of how different layers are exposed throughout the mastication process (Albert et al., 2012). It was hypothesized that the flavor in the middle of the gummy (cherry) would be less likely to be dominant early in the mastication process due to its location and the need for the mastication process to expose a significant portion of that flavor to the air in the oral cavity. However, the present evidence can be used to demonstrate that flavor location may not be affected by chewing rate when performing TDS on foods with a heterogeneous flavor distribution (i.e., no signification interaction between chewing rate and flavor type). However, since this study did not directly address the flavor location as a factor (i.e., a fixed location of each flavor), more research is needed to be done to confirm the observations in this study.

As mentioned earlier, several studies have examined the effects of oral processing on the temporal dynamics of flavor; however, flavor dominance has not been addressed. However, from the research that has been done, it does appear that TDS methodology is less sensitive to changes in mastication than TI scaling. In this study the chewing rate did not significantly affect many of the main TDS parameters, while it has been shown that several TI parameters have been shown to be affected by chewing rate (Luckett and Seo, 2016).

It has been suggested that the standardization of chewing behavior across panelists is a good way to decrease the variance between participants and can help with discrimination (Frank et al., 2011). However, in practice attempts at minimizing the natural variability in oral processing from one participant to another has not lead to significantly better results (Leclerq and

Blancher, 2012). More specifically, it was found that when the chewing patterns of participants were controlled they were not better at discriminating between different samples. However, they did find that the area under the curve (AUC) had less variation in both the perception and measurement of flavor compounds in the imposed protocol versus the free chewing protocol (Leclerq and Blancher 2012).

6.5. Conclusions

This study gives yet more evidence that chewing rates can influence temporal flavor dynamics. However, there is also evidence that TDS is less affected by chewing rate manipulation when compared to TI. The two TDS parameters that were changed by mastication patterns were the time to the first attribute selection and the total duration of dominance. On the other hand, since the TDS was less affected by chewing rate than the TI analysis, the TDS methodology can be useful to measure dynamic flavor perception for those with individual variations of chewing rates.

6.6. References

Albert, A., Salvador, A., Schlich, P., & Fiszman, S. (2012). Comparison between temporal dominance of sensations (TDS) and key-attribute sensory profiling for evaluating solid food with contrasting textural layers: Fish sticks. *Food Quality and Preference*, 24, 111-118.

Blissett, A., Hort, J., & Taylor, A.J. (2006). Influence of chewing and swallowing behavior on volatile release in two confectionery systems. *Journal of Texture Studies*, 37, 476-496.

Cheong, J. N., Foster, K. D., Morgenstern, M. P., Grigor, J., Bronlund, J. E., Hutchings, S. C., & Hedderley, D. I. (2014). The Application of Temporal Dominance of Sensations (TDS) for Oral Processing Studies: An Initial Investigation. *Journal of Texture Studies*, 45, 409-419.

Clark, C.C., & Lawless, H.T. (1994). Limiting response alternatives in time-intensity scaling: an examination of the halo-dumping effect. *Chemical Senses*, 19, 583-594.

Frank, D., Appelqvist, I., Piyasiri, U., Wooster, T. J., & Delahunty, C. (2011). Proton transfer reaction mass spectrometry and time intensity perceptual measurement of flavor release from lipid emulsions using trained human subjects. *Journal of Agricultural and Food Chemistry*, 59, 4891-4903.

Leclercq, S., & Blancher, G. (2012). Multimodal sensory integration during sequential eating - Linking chewing activity, aroma release, and aroma perception over time. *Chemical Senses*, 37, 689-700.

Luckett, C. R., Meullenet, J. F., & Seo, H. S. (2016). Crispness level of potato chips affects temporal dynamics of flavor perception and mastication patterns in adults of different age groups. *Food Quality and Preference*, 51, 8-19.

Pineau, N., Pessina, R., Cordelle, S., Imbert, A., Rogeaux, M., & Schlich, P. (2004, July). Temporal dominance of sensations: Comparison with conventional profiling and time intensity. *In 7th Sensometrics conference* (Vol. 40).

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., A., Rogeaux, M., Etiévant, P., & Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time–intensity. *Food Quality and Preference*, 20, 450-455.

Tarrega, A., Yven, C., Semon, E., & Salles, C. (2008). Aroma release and chewing activity during eating different model cheeses. *International Dairy Journal*, 18, 849-857.

Weel, K.G.C, Boelrijk, A.E.M., Alting, AC, Van Mil, P.J.J.M, Burger, J.J., Gruppen, H., Voragen, A.G.J, & Smit, G. (2002). Flavor release and perception of flavored whey protein gels: perception is determined by texture rather than by release. *Journal of Agricultural and Food Chemistry*, 50, 5149–5155.

Table 1. Gummy Candy Ingredients

Ingredient	Amount (g)
Gelatin (Perfectagel Platinum, Modernist Pantry, York, ME)	1.20
Water (Clear Mountain, Hot Springs, AR)	3.10
Glucose Syrup (Caullet, Erquinghem-Lys, France)	6.00
Sucrose (Domino Foods, Younkers, NY)	3.00
Sorbitol (4mular, Irvine, CA)	0.30
Citric Acid (SAFC, P, Switzerland)	0.03
Flavor Solution (FONA, Geneva, IL)*	0.67

Grape (8.0 % w/v), Cherry(10.6 % w/v), Lime(8.0 % w/v)

Table 2. Time between Selections and the Number of Selections using TDS Methodology on Gummy Candies.

Mastication Rate	Time Between Selections	Number of Selections
40 chews/min	18.3 (± 0.9) a	3.3 (± 0.3) a
80 chews/min	18.4 (± 0.9) a	3.4 (± 0.3) a
120 chews/min	17.3 (± 0.8) a	3.6 (± 0.3) a
Natural Eating Protocol	17.9 (± 0.9) a	3.5 (± 0.3) a

Mean ± Standard Error of the mean

Means that share the same letter are not significantly different ($P > 0.05$)

Figure 1. Photograph of gummy sample (L x W x H = 3 cm x 1 cm x 2 cm) used in this study.

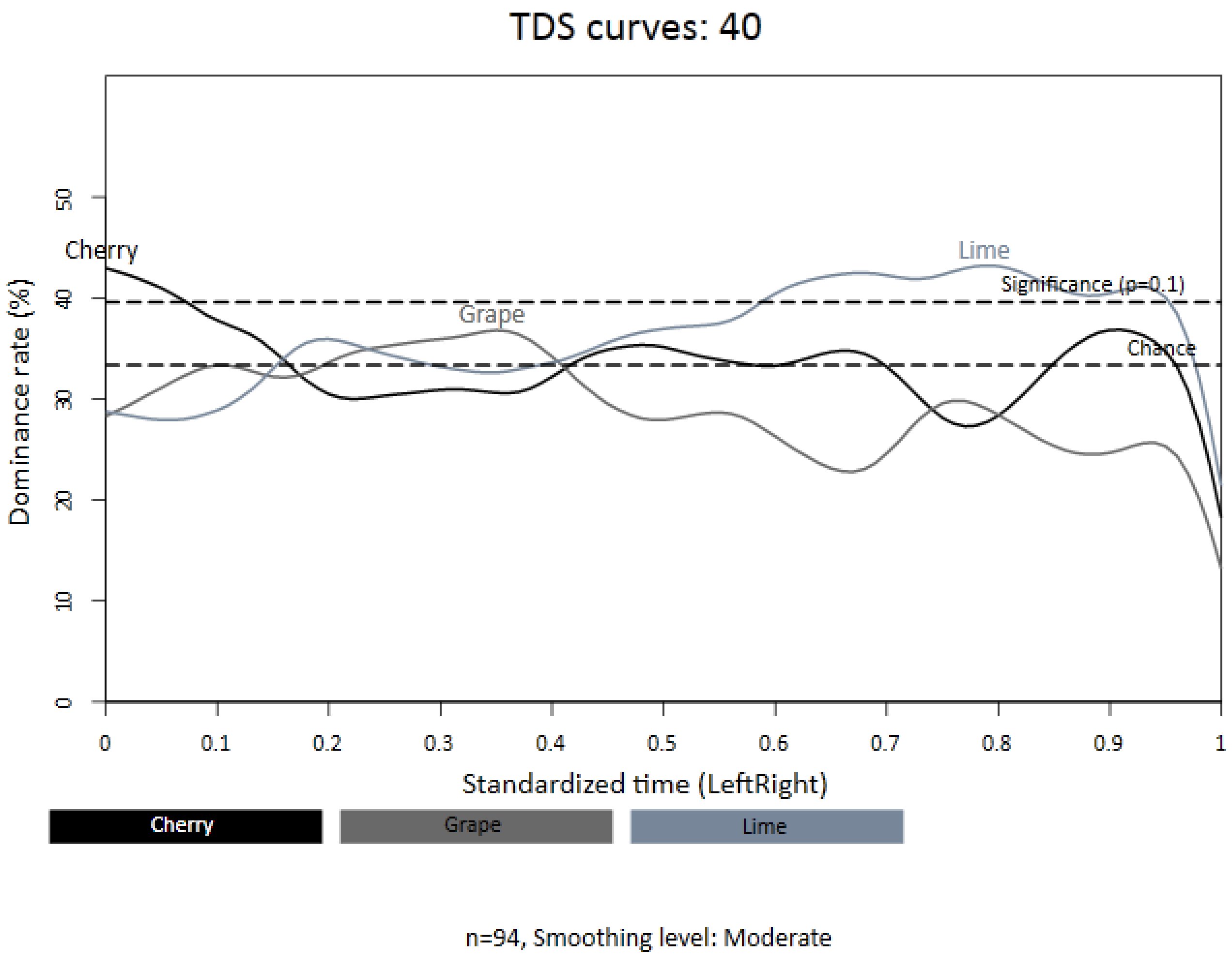

Figure 2. Temporal dominance of sensations (TDS) curves showing the dominance rates as perceived by panelists chewing at 40 chews/min.

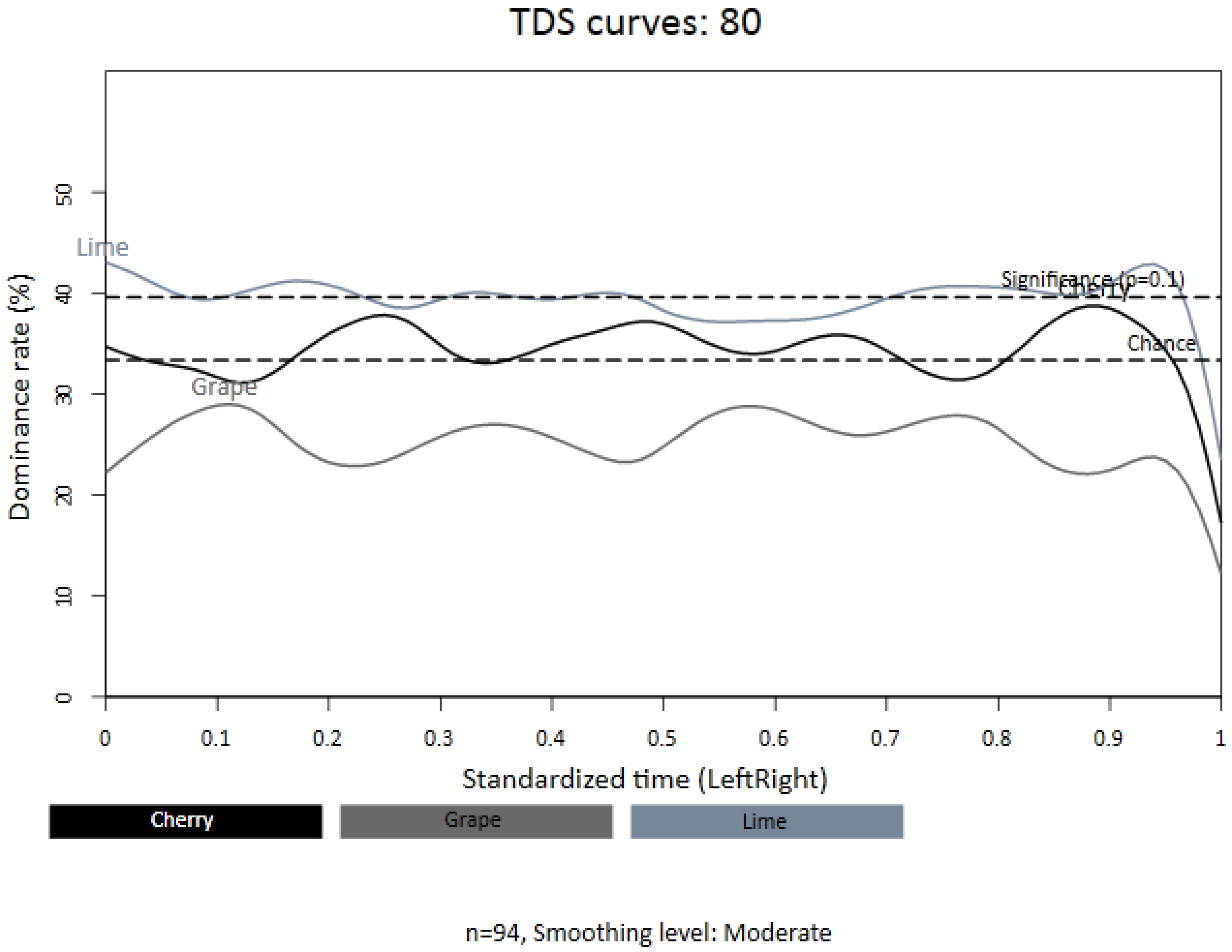

Figure 3. Temporal dominance of sensations (TDS) curves showing the dominance rates as perceived by panelists chewing at 80 chews/min.

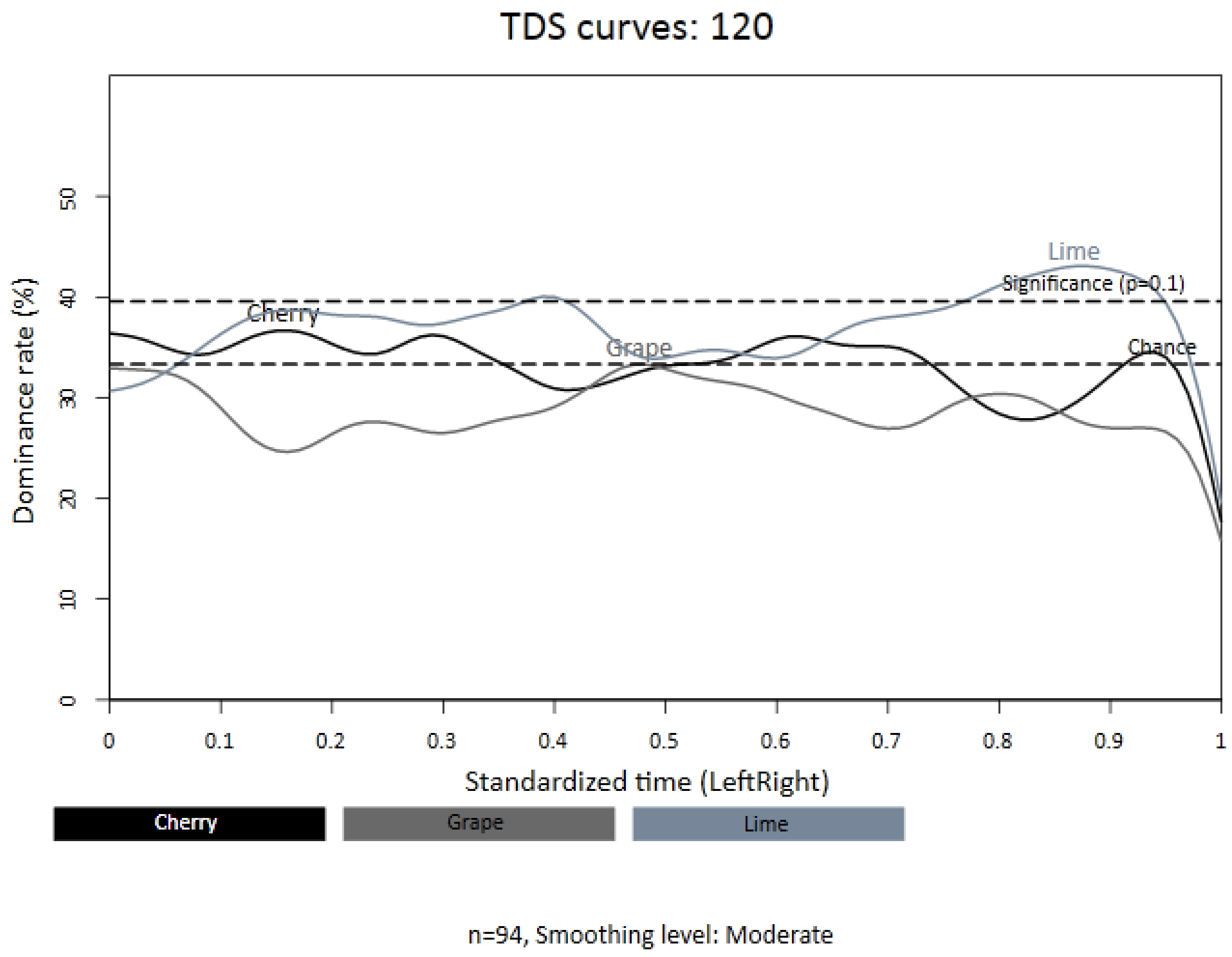

Figure 4. Temporal dominance of sensations (TDS) curves showing the dominance rates as perceived by panelists chewing at 120 chews/min.

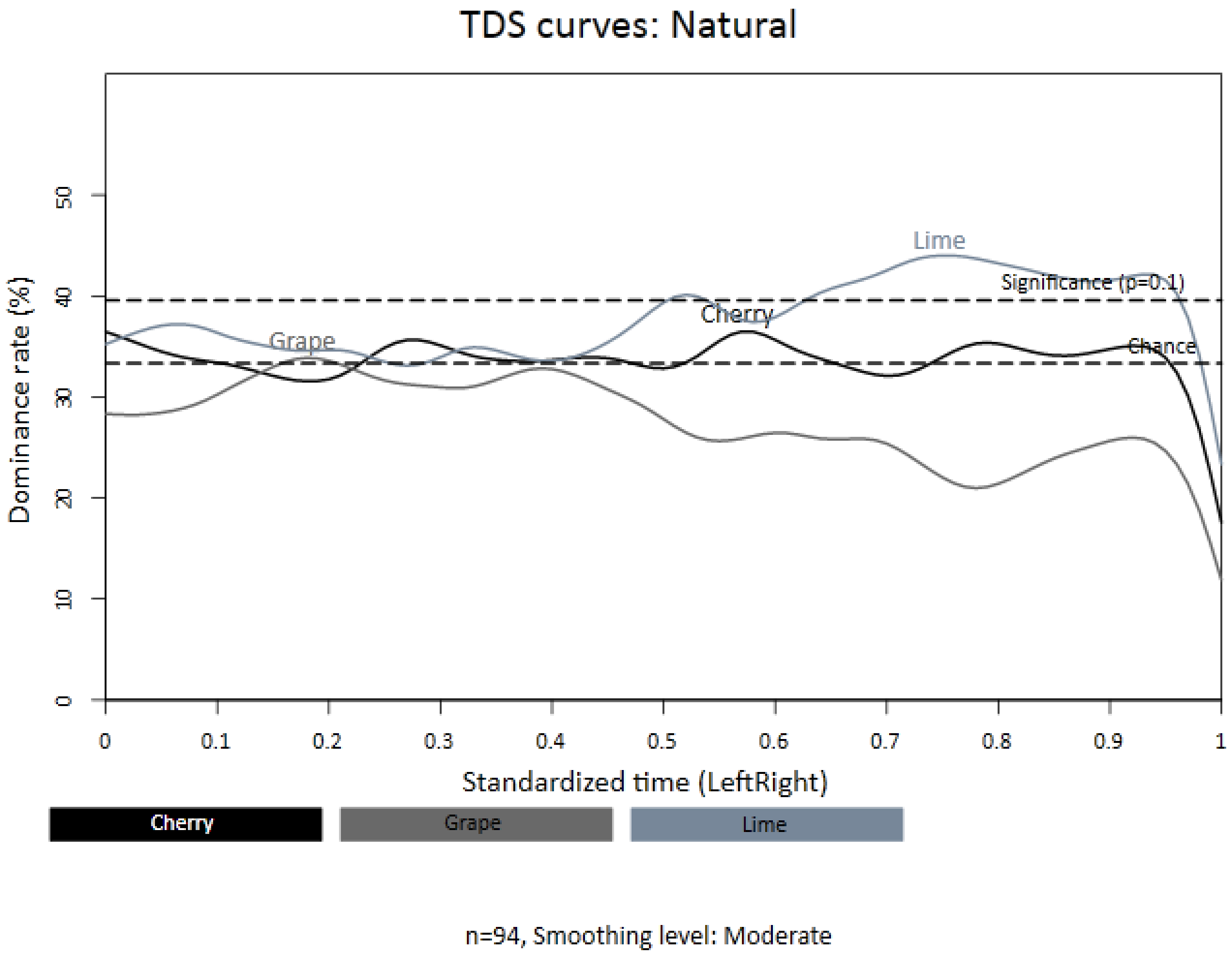

Figure 5. Temporal dominance of sensations (TDS) curves showing the dominance rates as perceived by panelists chewing naturally.

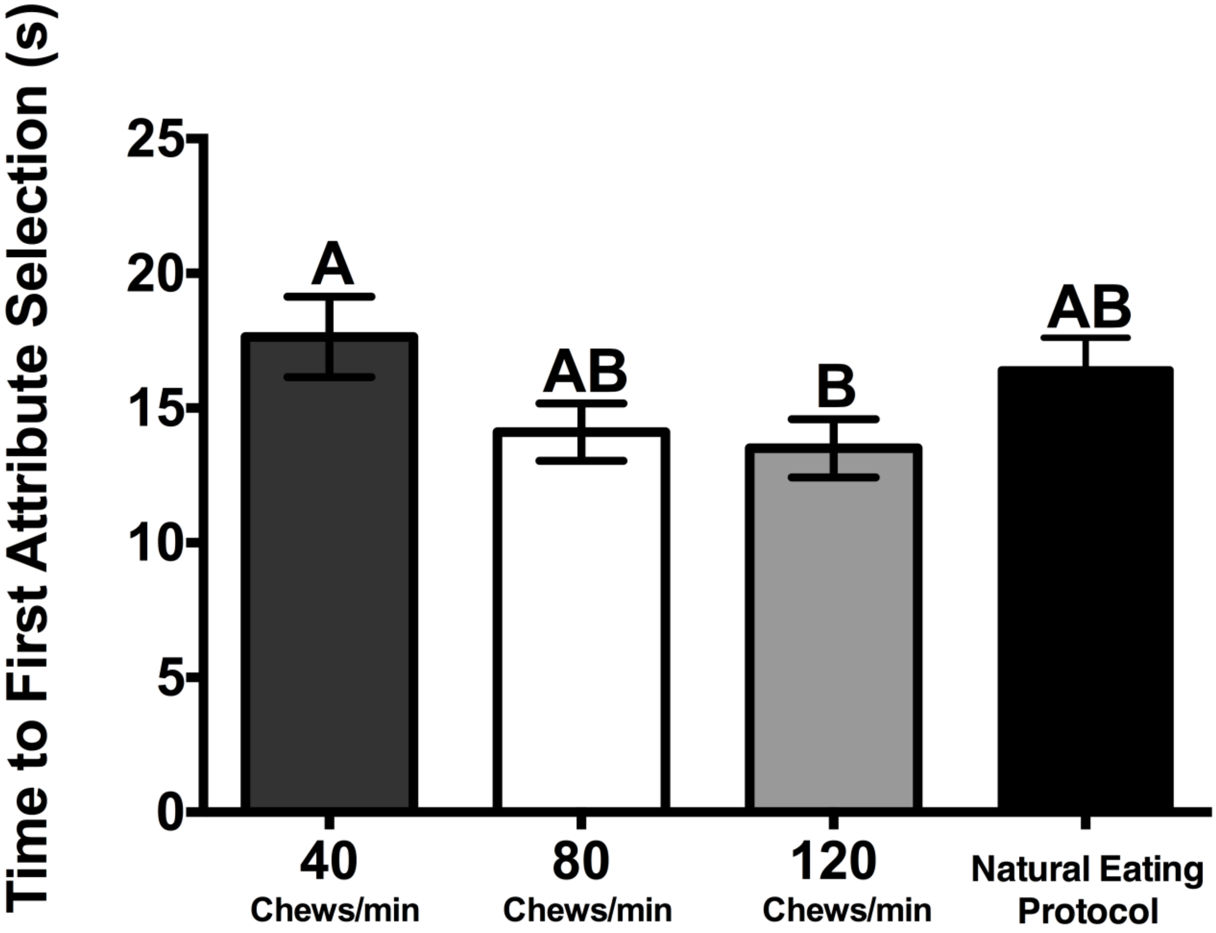

Figure 6. The time to first attribute selection under various chewing conditions.

Chapter 7.

Research Conclusions

This dissertation, which consisted of four unique experiments, first attempted to better understand how U.S. adults view texture across their lifespan. This initial study, in survey form, was able to uncover several interesting insights into how aware food consumers are of texture. As mentioned earlier, this study was designed to mimic a very influential study done in 1971 (Szczesniak, 1971). Additionally, this study was able to describe food attribute awareness differences amongst those of different ages and genders. We found that older adults are more likely to respond with a health/nutrition or personal preference and less likely to give a texture or food attribute response. Females were more likely to list personal preference texture and form/temperature terms, suggesting a higher awareness of oral tactile sensations associated with food and drink. Males tended to list more color and flavor responses, highlighting an awareness of visual and other food qualities, not in relation to texture. The survey was instrumental at showing notable changes in consumer attitudes towards foods in the past 50 years. Although there were some slight procedural differences between this study and the one performed by Szczesniak (1971), the landscape of what consumers' attitudes towards food has shifted drastically. These discoveries will allow those in the food industry to better understand the modern food consumer as well as delineate consumer language regarding food and drink.

Moving forward the manner in which texture influences flavor was addressed. The second study offered evidence that, like other texture manipulation, crispness level also affects dynamic flavor perception. It also demonstrated that the effect of texture changes on flavor perception did not establish themselves the same in food consumers of various ages. Additionally, evidence of flavor-specificity was observed as there were significant differences between how texture influenced flavor in the samples of different flavor-types. Regression models using mastication parameters to explain the changes observed in flavor perception with texture modifications provided valuable insight into the mechanisms behind textures-flavor interactions. Interestingly, the older adults displayed more pronounced changes in temporal flavor perception associated with changes in texture. In addition, the temporal flavor dynamics of the older adults were better predicted by the mastication parameters.

From the regression models of the second study it was clear that mastication parameters are strongly predictive of numerous temporal flavor dynamics. The third study of this dissertation took this finding and looked to expand upon it, looking for causal evidence that the number of chews influence temporal flavor dynamics. It was found that the number of chews, the chewing duration, and the chewing rate are significant sources of variance in temporal flavor perception. Flavor intensity is maximized when chewing was rapid (80 or 120 chews/min). These findings suggest that to increase flavor, food product developers can manipulate the texture of their products to elicit specific mastication patterns. Like previous studies, the effect of mastication changes on flavor perception also tended to be flavor specific. Unlike the salty samples, the spicy samples used in this experiment were perceived at peak flavor when swallowed at a more natural time (20 s). While from these results it is clear that the number of chews and other related mastication parameters can change the temporal flavor dynamics, but only in potato chips. To further extend the findings of this study, a wider variety of foods should be used in order to broaden the claims that can be made regarding the effect of mastication on flavor perception.

The final study was also designed to address the influence of mastication on temporal flavor perception, but using a different technique, the temporal dominance of sensation (TDS). It was found that two major TDS parameters were the total duration of dominance and the time to first attribute selection. However, when compared to the TI, the differences in TDS based upon changes in mastication were quite minor. More simply, TDS is less influenced by mastication, possibly making it more suitable for use analyzing the temporal flavor dynamics of food consumers; however, further research should be conducted to confirm this assumption.

These four studies combine to give clear direction on how today’s food consumer views texture and shed valuable insight onto how the texture of the food we eat, the way we chew that food, and the flavor perceived interact. This dissertation also provides unique insight into how age can influence mastication and flavor perception in foods of varying texture. Furthermore, by addressing crispness this dissertation was able to extend findings regarding texture-flavor interactions to a wider variety of foods, making our knowledge of texture’s influence on flavor perception more generalizable. After exposing the importance of mastication in regard to the influence of texture on flavor perception, follow-up studies were able to show that mastication alone can have a marked effect on temporal flavor perception.