UNDERSTANDING CONSUMER PERCEPTION OF BEEF THROUGH THE DEVELOPMENT OF TENDERNESS AND JUICINESS THRESHOLDS, STATISTICAL MODELING, TRADITIONAL LIKING QUESTIONNAIRES, EYE TRACKING, AND FACIAL EXPRESSION SOFTWARE

A Dissertation

by

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ABSTRACT

Understanding factors that drive and motivate consumers requires a multi-disciplinary approach. As technology advances and statistical tools develop, new methods may be developed to better understand consumer opinion of beef products. Methods were used to quantify consumer data that included sensory studies, consumer emotional reactions to scientific information relevant to the agricultural industry, and consumer eye tracking responses to images of beef steak that varied in quality attributes.

Warner-Bratzler shear force (WBS) threshold values based on trained descriptive sensory evaluations were updated. Recommended thresholds were "Very Tender," WBS < 1.5 kg, "Tender," 1.5 kg < WBS < 2.3 kg, "Intermediate," 2.3 kg < WBS < 3.1 kg, and "Tough," WBS > 3.1 kg. These values created a more stringent classification standard for beef tenderness based on current data.

Analysis groups that varied in USDA quality grades, subprimal cuts, cook methods, and end temperature cook points were created. Using trained, descriptive flavor attributes, chemical data, and volatile, aromatic flavor compounds, variables were identified as important contributors to understanding consumer overall liking within each analysis. Bloody/serumy and metallic were important across most analyses. Top loin steaks were associated with liver-like and volatile compounds associated with lipid oxidation and off-flavors. Maillard reaction compounds contributed to each analysis group, even where minimal amounts were expected.

Eye tracking and facial expression analysis were used to assess consumer reaction to infographics discussing six topics related to agricultural production including antibiotic usage, sustainability, genetically modified organisms, animal welfare, vaccines, and hormone usage. The joy emotion was most associated with the animal welfare infographic. Using eye tracking data, a deeper understanding of what information was viewed from consumers allowed for insight into how to modify the current infographic layouts to increase consumer comprehension.

Eye tracking was also used to understand the impact of product placement and quality level of beef retail cuts through measuring consumer response to beef steak images. The placement of the steak image proved to be most influential in consumer overall liking. This may be due to the first image viewed by consumers serving as a benchmark to which all future comparisons are made to.

DEDICATION

I dedicate this work to all those who have committed and will commit themselves to working towards a degree of any level. Especially to those who have doubted their ability along the way in achieving their goals.

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Contributors

This work was supervised by a dissertation committee consisting of Professor Miller [advisor] and Professors Kerth and Tedeschi of the Department of Animal Science [Home Department] and Professor Palma of the Department of Agricultural Economics [Outside Department].

All work for the dissertation was completed by the Hillary Martinez, in collaboration with Professors Miller, Kerth, and Tedeschi of the Department of Animal Science and Professor Palma of the Department of Agricultural Economics.

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CHAPTER I

INTRODUCTION AND

REVIEW OF LITERATURE

The topics discussed pertaining to the meat science portion of this literature review were limited to subjects leading to and relating ultimately to the consumer perception of beef products. This includes factors that influence the appearance and intrinsic attributes of beef product, current methods of measuring consumer perception, and research findings summarizing key insights currently known of consumers.

Postmortem Factors

The conversion of muscle to meat is defined by four stages of postmortem metabolism including delay, onset, completion, and resolution. Throughout these stages, expected changes in pH, ATP depletion, extensibility, creatine phosphate, and etc. are well known. Deviations may result in quality issues in the final product that is perceived by the consumer. The normal pH of meat of a beef animal immediately post-slaughter is 7.2. Within 8 hours postmortem the pH will gradually decline from 7.2 to 5.8 and ultimately settle at approximately an ultimate pH of 5.6 at 24 h (Matarneh et al., 2017). The rate of decline impacts meat color, texture, water-holding capacity, and shelf-life. The pale, soft, and exudative (PSE) term describe a quality defect in which meat is characterized by an abnormally light color, soft texture, and exudative appearance to the lean surface. This defect causes the muscle to have a decreased ability to retain and hold water. The ultimate pH of PSE meat is reached within the first hour postmortem. This is due to the rapid metabolism of the muscle while the temperature of the carcass is still elevated. The combination of these factors leads to the denaturation of protein within the muscles. This condition is closely related to genetic factors and/or short-term preslaughter stress which may include handling, lairage, or mixing of animals. Poultry and swine are the species most commonly affected by PSE. Beef is most predominantly impacted my dark, firm, and dry (DFD) meat quality defect. This condition causes dark colored lean that has a firm texture and dry appearing lean surface. Abnormal glycogen depletion leads to the early termination of postmortem metabolism, causing a higher than normal ultimate pH level at approximately 6.0. This leads to the DFD quality defect. Long-term stress is often a precursor to this condition.

Water-Holding Capacity

Seventy-five percent of muscle is comprised of water. Within this percentage, 85% is held within the thin and thick filaments while the remaining water is distributed between the myofibrils (Offer and Trinick, 1983). The degree to which this water is bound to the electrically charged group within the muscle determines whether the water is classified as bound, immobilized, or free. Bound water is attached tightly and is not easily removed. Immobilized is attached to the bound water to an intermediate degree by steric effects (Huff-Lonergan and Lonergan, 2005). This classification of water is most impacted by internal and external forces. Free water elicits the weakest attraction as it is held by capillary forces and most often seen as purge.

Understanding the concepts of water-holding capacity in meat products is imperative as it directly reflects the juiciness of the end product that is ultimately judged by the consumer. Juiciness is a unique attribute to measure as there is not a common, standardized protocol developed. For example, the tenderness attribute is commonly objectively measured through instrumental measures such as the Warner-Bratzler shear force or slice shear force. Contrarily, juiciness assessment is commonly measure through subjective perceptions of consumers where it is calculated to contribute to 10% of the variation in consumer overall acceptability of meat (Watson et al., 2008).

Meat Color

The appearance of meat products serves as an indicator or freshness and quality to consumers and influence their purchasing decisions. The color of meat is controlled by its chemical and physical characteristics. Myoglobin is the predominant protein responsible for meat color. Its function in the live animal system is to store and deliver the oxygen necessary for aerobic metabolism.

The myoglobin structure is comprised of two major components, a globular protein portion and a nonprotein portion called heme. The oxidation state of the iron portion within the heme ring determines the color of meat. The heme iron contains six coordination sites. Four of the six sites are bound to nitrogen atoms and secure iron within the planar structure of heme. The fifth coordination site anchors the heme molecule while the sixth is available to bind a ligand (Faustman and Suman, 2017). Ligands in meat may include oxygen, water, nitric oxide, or carbon monoxide. The chemical state of the iron in the heme ring determines what ligand may be bound to the sixth coordination site. The valence state of the iron may be either reduced (ferrous state) or oxidized (ferric state). The transition of myoglobin to and from ferric and ferrous states is referred to as metmyoglobin reduction activity. The binding of different ligands is characterized by different colors in fresh meat. Interconversions that occur in reduced states include deoxygenation (purple in color), oxygenation (red in color), and the less common carboxymyoglobin (red in color). In the ferric state iron is not able to bind with other molecules. In fresh meat the oxidation process is unavoidable, as over time and in varying conditions the browning of fresh meat is expected and occurs in the metmyoglobin state.

The variation found in the color of meat is explained by factors including, but not limited to, the species, age, sex, muscle function, and physical activity level of the animal. Each species has an ideal lean color. For example, pork lean characterized as grayish pink, beef as bright cherry red, and lamb as a light red color. The age of an animal influences the color of is lean as oxygen loses its ability to bind with oxygen as an animal increases in age. This is exemplified by veal having pale colored lean compared to the dark lean found in mature beef. Sex influences lean color as intact males' muscles have a greater level of myoglobin and are therefore darker in appearance compared to its castrated or female counterparts. Each muscle within an animal serves a specific purpose, and therefore contains unique characteristics. The functionality of muscles is most simply classified as either red or white muscle fiber types. Muscles composed of predominately red muscle fibers appear darker in color. Red muscle fibers are referred to as slow-twitch myofibers as their energy is obtained through aerobic means. As mentioned previously, myoglobin's function is to store and deliver the oxygen required for aerobic metabolism. Therefore, slow-twitch muscle fibers are composed of a greater concentration of myoglobin. Muscles with a high proportion of red muscle fibers, approximately 30 – 40%, appear dark red in color (Aberle et al., 2001). White muscle fibers are considered fast-twitch myofibers and rely on the process of glycolysis to generate ATP. This leads to this muscle type appearing “white” due to less myoglobin concentration.

Intramuscular Fat

Four theories exist regarding the effect of intramuscular fat on muscle tenderness. Smith and Carpenter (1974) summarized each in a comprehensive review of the role of fat in palatability in multiple species as follows:

Bite Theory: As a portion of cooked meat increases in its percent marbling, the mass per unit of volume decreases, thus lowering the bulk density of the product as the protein is replaced with lipid. The increase in the lipid content leads to an increase in perceived tenderness.

Strain Theory: Marbling is deposited in the perimysium or endomysium, specifically in the perivascular cells. This causes the walls of the connective tissue that are pierced by the intramuscular fat deposits to become thinned, ultimately decreasing their overall strength.

Lubrication Theory: As an association of juiciness and tenderness exists, the intramuscular fat present in and surrounding muscle fibers may serve as lubrication to meat. As cooked meat releases its juices and fat during mastication, the degree of marbling may affect the duration of the perception of moistness due to the juiciness.

During long periods of mastication, this may cause meat to seem more tender in correlation with the amount of marbling present.

Insurance Theory: A higher degree of marbling allows an increase in cooking temperature, especially in the use of dry-heat cookery methods, to occur by minimizing the risk of negatively affecting product palatability. Therefore, more advanced degrees of doneness may be obtained that still allow for the procurement of acceptable products.

Research by Savell and Cross (1988) primarily intended to justify the balance of necessary fat needed in beef, pork, and lamb products to ensure consumer acceptability, and also meet changing health recommendations for lowering fat in the diet due to health-related issues. Previous research from Savell et al. (1986) reported the percentage of chemical fat present in uncooked *longissimus dorsi* steaks from an array of marbling scores. The resulting mean chemical fat percentage ranged from 1.77 to 10.42 for strips representing marbling levels of Practically Devoid and Moderately Abundant, respectively. Savell and Cross (1988) used these data to determine a range to represent the minimum percentage of fat necessary for consumer palatability and the maximum percentage to ensure nutritional worth. Termed as the "window of acceptability", it was concluded beef should contain a minimum of 3% and a maximum of 7.3% fat (uncooked basis) to satisfy both, palatability and health desires and ultimately includes meat cuts graded from low Select to the middle of high Choice (Savell and Cross, 1988).

Trained Descriptive Sensory Panel

Trained, descriptive attribute sensory panels are used in both, academic and industry settings to objectively assess the sensory properties of a wide range of products.

Sensory evaluation is designed to use a scientific method to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing (Stone et al., 2012). Trained panelists differ from normal consumers because they are trained to assess aroma, flavor, and texture attributes of products. Their viewpoints are essentially altered from a subjective (normal consumer) viewpoint to a calibrated, more detailed analysis of the specific attributes within a product. Panelists preform flavor evaluation to evaluate specific attributes through either vocabulary development or existing lexicons. Depending on the type of method used, the amount of training necessary may vary. Commonly used descriptive test methods using trained panelists include the Flavor Profile Method, Texture Profile Method, Quantitative Descriptive Analysis Method, and the Spectrum Descriptive Analysis Method. Meilgaard et al. (2016) describes in detail the process of panelist selection and training with regard to the method of choice.

The meat industry's effort to standardize the measurement of descriptive attribute sensory evaluations of meat products began with the publishment of the AMSA research guidelines in 1978 (AMSA, 1978). These guidelines were modified in 1995 to include overall flavor intensity in addition to the defined attributes of juiciness, connective tissue amount, muscle fiber tenderness, and overall tenderness (AMSA, 1995). The updated 2015 research guidelines included collecting and preparing samples for sensory evaluation of fresh beef, pork, and lamb steaks/chops, roasts, and ground patties with some application to certain enhanced, cured, or comminuted products (AMSA, 2016).

Consumer Sensory Evaluation

Dr. David R. Peryam, referred to as the “Father of Sensory Science,” published his first articles in December of 1950. His work described the purpose for the developmental use of the hedonic scale. The hedonic scale was intended for food research for the Armed Forces. A method was sought to evaluate the liking of the food served to the armed services that gave a predictive value for the product’s acceptance on a large scale. The process in which these products were evaluated needed to be applicable and comparable to a broad range of foods. As Peryam (1950) described, “ a method is required that will, for example, do more than tell how one brand of pork and beans stands up to another-that is, also give some idea of how the value of pork and beans in relation to canned biscuits, chocolate candy, or food bar “No. X-21.” The terms “like extremely” and “dislike extremely” were preferred to such terms such as “pleasant” and “unpleasant” because they were more likely to mean the same thing to all persons.

Consumers tests are used to assess consumer preference or acceptance of products. The type and design of the test is determined by the sensory objective. Each test has strengths and weakness concerning the extent of information that may be derived. Qualitative evaluations include focus groups, one-on-one interviews, and observational research. Quantitative evaluations are conducted through either central location tests or home use tests.

Gas Chromatography with Mass Spectrometry

The molecular composition of a meat product affects the perceived flavor. Its flavor is determined by the major precursors, proteins, and lipids which contribute to the volatile compounds formed during processing and leads to the aroma development (Mottram, 1998). Major reactions that contribute to the aroma of cooked meat include lipid degradation, Maillard reactions, Strecker degradation, thiamine degradation, and carbohydrate degradation reactions (Flores, 2017).

The Gas chromatography and mass spectrometry systems (GC/MS) are often used in combination as the techniques of choice to isolate and identify volatile compounds. The gas chromatography system separates the volatile flavors and aromas into compounds while the mass spectrometry system identifies the produced compounds. These systems may also include an olfactory port where a trained panelist may smell and identify compounds that are generated through the GC. These additional data allow researchers to match reported smells with identified compounds. Meat scientists have researched and continue to research the impact of intrinsic and extrinsic factors in the chemical production of volatile aromas. The alteration of cooking method and degree of doneness are prevalent ways to change the volatile production and flavor profile of meat products (Lorenzen et al., 1999; Lorenzen et al., 2003; Kerth and Miller, 2015). Previous literature has been designed to collect aroma volatile chemical data, trained, descriptive sensory analysis data, and consumer sensory data to find relationships to understand how the chemical analysis of meat products relate to eating experience (Miller and Kerth, 2012; Glascock, 2014; Miller et al., 2014; Kerth and Miller, 2015).

Contributions to Understanding Beef Flavor

Researchers have been extensively involved in first defining what flavors are present in beef whole muscle cuts by developing the beef whole muscle flavor lexicon

Adhikari et al. (2011). Researchers then used the beef lexicon to examine the effect of cooking method, degree of doneness, and cut on beef flavor attributes and consumer liking. They have determined perceptions of millennials, non-millennials, heavy beef-eaters, and light beef-eaters through consumer studies including Central Location Tests and In-Home Use Tests to assess consumer liking. The studies that contributed to these findings are described below.

Consumer Perception of Beef Flavor Attributes

Glascock (2014) sought to understand the relationship between trained descriptive flavor attributes, consumer liking ratings, and volatile aromatic compounds. Through the experimental design, levels of positive and negative beef flavor attributes (determined by (Miller et al., 2014) were created through using several beef cuts that varied in USDA quality grade, pH, and connective tissue amount. These beef cuts were cooked to 58 °C or 80 °C utilizing George Foreman (GF), food-service grill, or crock-pot. Flavor was evaluated through the use of trained descriptive sensory attribute panel, consumer panel, and GC-O. Additionally, fatty acid composition, non-heme iron and myoglobin content, pH, and fat and moisture analysis were determined.

Glascock (2014) reported that beef identity increased as degree of doneness increased. High pH top loin strip steaks had less beef identity than USDA Choice top loin strip steaks then cooked on a GF grill to either internal temperature endpoint. This also held true for the grilled cooking method treatment cooked to an internal temperature endpoint of 58 °C. The bottom round roast of the USDA Choice quality grade had higher beef identity compared to those of the USDA Select quality grade when cooked to 58

°C. For all beef cut treatments, the brown/roasted flavor was lower and bloody/serumy was higher when cooked to 58 °C. Neither non-heme iron or myoglobin content were correlated to beef flavor while variation for beef flavor was significant for fatty acid composition. Of the 149 volatile aromatic compounds identified in the study, 15 accounted for 55 percent of consumer overall liking. Through PCA, it was determined that lower temperatures individually, or in combination with shorter cooking durations generated lipid-degradation products. Higher temperatures individually, or in combination with longer cooking durations produced Maillard reaction product. Grill and beef flavor liking accounted for 90% of the variation in overall liking.

Light Beef Eater Consumer Perception of Beef Flavor Attributes

Luckemeyer (2015) built from the work by Glascock (2014) by contributing to the next phase of understanding the consumer perception of beef flavor from light beef eaters, specifically. This subset of consumers was defined as those who eat beef one to two times per week. The experimental design was similar to Glascock (2014), with the exception of the addition of the tenderloin beef cut and WBSF was conducted. Consumers rated Choice tenderloin and Select top sirloin steaks cooked on the grill, to either internal temperature endpoint of 58 °C or 80 °C, highest for overall, overall flavor, beef flavor, and grill flavor liking. Consumer liking increased as the intensity levels of brown/roasted and fat-like increased. From the 248 identified volatile aromatic compounds identified, fifteen accounted for 57% of the variation in consumer liking. Luckemeyer (2015) also reported a partial least squares regression ($r^2 = 0.87$) that showed the relationship between trained-descriptive flavor and texture attributes, consumer liking, and volatile aromatic compounds.

Consumer Perception of Steaks Differing in Thickness, Quality Grade and Cooking Surface Temperatures

Berto (2015) progressed this work by seeking to understand the effect of cooking surface temperature and beef steak thickness on the development of flavor and the volatile aromatic compounds related to positive flavor. Thickness and surface temperature combinations were created from beef top loin steaks of either USDA Select or USDA Top Choice quality grades with thicknesses of either 1.3 cm or 3.8 cm cooked on a flat-top grill with cooking surface temperatures of either 177 °C or 232 °C. Treatments were analyzed through trained descriptive sensory panel, consumer panel, and GC/MS with an olfactory port.

Berto (2015) reported that as thickness and surface temperature increased, beef identity and brown/roasted flavor increased. Steaks cooked at a surface temperature level of 232 °C and thickness of 3.8 cm had the highest levels of burnt flavor and bitter taste. Steaks with a thickness of 3.8 cm and cooked on a surface temperature of 177 °C resulted in higher intensity levels of umami and higher levels of positive beef flavor attributes. Thickness by USDA quality grade interactions were significant for liver-like and brown/roasted flavor attributes. Consumer ratings were lowest in overall, beef flavor, and grill flavor liking for the 3.8 cm thick steaks cooked on a grill surface temperature of 232 °C, whereas the 177 °C, 3.8 cm steaks were highest in beef flavor liking. The volatile aromatic compounds were used for regression analysis to predict several trained, descriptive sensory panel attributes. Eighteen volatiles accounts for 22% of the variability of consumer overall liking.

Millennials' Perception of Beef Flavor

Given the current level of knowledge of consumers' perception of beef flavor from the aforementioned studies, Laird (2015) sought to understand how four combinations of consumer groups (identified as either millennial or non-millennial and light- or heavy-beef eaters) were similar or different in their perception of positive and negative beef flavor attributes. Trained, descriptive sensory attribute panel, CLT, HUT, and GC-MS-O were used to determine flavor of top choice strip loin steaks and USDA Select outside round flat roasts. Additionally, raw meat fatty acid composition, non-heme iron and myoglobin content, pH, and fat and moistures were determined. Millennials (ages 18 – 34), non-millennials (ages greater than 34), light-beef eaters (eat beef 2 to 4 times per month), and heavy-beef eaters (eat beef 3 or more times per week) were identified.

Laird (2015) concluded that millennials and non-millennials did not differ in response to their liking of beef flavor, indicating that other factors may drive their beef consumption other than palatability. Light-beef eaters rated overall flavor lower than heavy-beef eaters. Overall flavor, tenderness, meat flavor, grill flavor and juiciness liking accounted for 84% of the variation in consumer overall liking.

Consumer Acceptance of Ground Beef Patties

Beavers (2017) further extended beef flavor work by researching how to optimize flavor and consumer acceptance of ground beef through optimizing grind (6.4

mm and bowl-chopped), lean source (chuck, regular, sirloin, and round), and fat level (10% and 20%) of ground beef patties. Beavers (2017) reported that bowl-chopped patties were higher in hardness and springiness scores while 6.4 mm ground patties were higher in umami and particle size. Meat source affected bitter, cardboard, fat-like, liver-like, sour, sour milk/dairy, hardness, and springiness flavor and texture attributes. Consumers rated the 6.4 mm ground treatment higher in liking compared to bowl-chopped patties. Flavor and texture liking were dependent on meat source while texture liking was influenced by fat level. Interactions were present for grind and fat for consumer overall cooked appearance liking, overall liking, and flavor liking. A meat source by fat interaction existed for flavor liking among consumers. Volatile, aromatic compounds were impacted most by grind treatment.

Empirical Assessment of Consumer Satisfaction

Researchers in the marketing sciences field have careers dedicated to shifting consumer satisfaction from a theological to an empirical viewpoint. Szymanski and Henard (2001) assessed research on consumer satisfaction and concluded that the following factors are most often focused on in modeling expected buyers' level of satisfaction: expectations, disconfirmation of expectations, performance, affect, and equity.

Expectations: The role of expectations in consumer satisfaction is often modeled as anticipation, meaning that consumer expectation has a direct influence in their level of satisfaction. This perspective relies on the theory that consumers are not influenced by comparisons to other stimuli or the actual outcomes of the use of the stimulus. This leads the adaptation to the situation from the consumer. Oliver (1997) explains that by definition, expectations are simply the probability or likelihood of an event occurring without the influence of the event being positive or negative, for example, drawing a jack from a deck of cards. It is not known whether a jack would have a positive or negative impact in the card player's hand and even if this were known, the likelihood of drawing this particular card would not change. The author further explains that consumers do hold a desired expectation from their decision, such as when they purchase a steak with certain characteristics they expect a positive eating experience. They may not completely understand their expectation knowledge, but it would be rare for the consumer to not have any basis of expectation. Therefore, the consumer's anticipation of a product will influence their post purchase response. If they held a high expectation, they expect a desirable event will occur verses if they hold a low expectation, they expect a desirable event to not occur.

Disconfirmation of Expectations: Expectation disconfirmation assesses post-purchase or post-adoption satisfaction as a function of expectations. Furthermore, consumers are said to be satisfied when actual outcomes exceed expectations, dissatisfied when outcomes do not exceed expectations, or satisfied when expectations are equivalent to the outcome (Oliver, 1981; Oliver and DeSarbo, 1988). These outcomes are divided into three disconfirmation categories of positive, zero, and negative. Positive disconfirmation occurs when low-probability desirable events occur, or high-probability undesirable events do not occur. Negative disconfirmation occurs when high-probability desirable events do not occur, or low-probability undesirable events occur. Zero disconfirmation occurs when low- and high-probability events do or do not occur as expected. Oliver (1981) compared these scenarios to a common grocery retail setting scenario for clearer understanding. A positive disconfirmation example is when the checkout lines during the busiest part of the day are short, leaving a consumer pleasantly surprised. A negative-disconfirmation situation would be the disappointment of a consumer when a common main-ingredient item is out of stock. A zero-disconfirmation event may occur when the grocery store experiences high traffic during holiday seasons, as consumers expect this to occur.

Performance: Customers are more likely to be satisfied with a product that offers a solution to a need or desire that the consumer has. The consumer's judgement of the product's performance is based on the result of their rational processing based on their preemptive thought of the specific attributes or benefits a brand or product must provide in order to meet there wants and needs (Woodruff et al., 1983). Furthermore, prior attitudes and experiences of a product or brand may shift during post-use evaluation from the consumer's original expectation and may affect the adjusted expectations of the consumer's evaluation in the event of repurchase of the product or brand.

Affect: This is often referred to as affective-processing mechanisms. Westbrook and Oliver (1991) proposed that memories are created as emotion is elicited during the consumption of a product. Consumers are then able to access and incorporate these traces into their satisfaction assessment. In addition, dependent on whether or not a consumer classifies their perception of the product as a success or failure, affect can also be viewed as a component of post-purchase expression (Oliver and DeSarbo, 1988). This assessment seems critical especially to the food industry as it has unique characteristics that must be considered in the measurement of consumer satisfaction as compared to other industry. For example, the approach to measure the satisfaction of consumers in regards to purchasing home decorative goods, vehicles, or clothing will differ greatly compared to a food commodity due to the difference the product's purpose and use. Food is used to not only for means of survival, but as product that is the center of social events, hobbies, and leisure activities. This provides numerous opportunities that may create memories in consumer's minds that may affect their perception of satisfaction and future purchasing decisions.

Equity: The assessment of equity has often been included in consumer satisfaction modeling. Equity is defined as fairness, rightness, or deservingness judgement that consumers make in reference to what others receive (Oliver, 1997). This theory is based on the idea of distributive justice. As an example, a consumer will base their satisfaction of a dining experience on the environment of the restaurant, the delivery of their food, and how they are treated. Their satisfaction in this dining situation will shift based on their input such as whether they are paying for a fast-food meal or dining in a 5-star restaurant. If their equity ratio is greater than the level of their expectation, then they are said to be satisfied.

Perception of Sensory Attributes

As described by Meilgaard et al. (2016), food items are perceived by consumers in a specific order: appearance, odor, consistency and texture, and lastly, flavor, which includes aromatics, chemical feelings, and basic tastes. In the process of perception, individuals who are not trained to separate and individually identify these components receive a near-simultaneous sensory observations (Meilgaard et al., 2016). This adds to the complexity of understanding and predicting consumer impressions of food products, as each individual has a unique process of sensing.

The appearance of the product or the package that holds the product receives the first judgement of the consumer and can determine whether or not they consider it further for purchase. At any moment, our five senses are taking in more than 11,000,000 pieces of information. Our eyes alone receive and send over 90% of these signals to our brain each second (Norretranders, 1998; Wilson, 2002). The human brain has the ability to reconstruct our visual world. Neuroscience researchers and cognitive scientists have developed theories into how the eyes and the brain communicate to produce vision. Visual attention is the ability for the our eyes to select and focus on one or several sources of information while simultaneously filtering the information of less significance (Burmester, 2015). It is thought that visual attention is necessary to aid in binding together elementary features of color, shapes, and orientation in order for the brain to develop a complete perception of the environment.

The sense of touch can be divided into two categories of either somesthesis, which includes tactile sense and skin feel, or kinesthesis which includes deep pressure sense or proprioception (Meilgaard et al., 2016). Although this definition of touch requires either a physical or perceptual sense, touch can also be described as a way to produce feelings. As such, touch is directly linked to emotional language. For example, people may say phrases such as “this feels wrong”, or “it was a touching piece” (Palmer, 2018). Further, the visual texture perception of a product has been shown to influence the feelings of consumers, possibly by eliciting memories related to the product (Lee and Sato, 2001). Companies also understand the important role touch plays in their sales as touching a product has been found to increase not only the attitude of consumers, but also their purchasing intent towards products (Peck and Childers, 2003).

Odorants that are airborne are sensed by the olfactory epithelium that is located in the roof of the nasal cavity and communicates with the brain directly (Meilgaard et al., 2016). Sight, sound, and touch do not have this direct connection and therefore are not as closely linked to memories or emotions (Lewis, 2015). Researchers have developed the theory of the "Proustian memory effect" where childhood memories that are linked to scent stay with people throughout their later life and can impact their behavior (Bergland, 2015; Sugiyama et al., 2015). Retailers and companies are utilizing the concept of the emotional effects of aromas in order to increase profits (White, 2011; Orvis, 2016; Abassi, 2018). The perception of sensations such as burn, heat, cold, or pungency are due to the stimulation of the trigeminal nerve ends (Meilgaard et al., 2016). Consumers often are not able to separate trigeminal sensations from olfactory and gustatory sensations.

The chemical sensation of gustation, or taste, involves the identification of stimuli dissolved in water, oil, or saliva via the taste buds located on the surface of the tongue and the mucosa on the palate and areas in the throat (Meilgaard et al., 2016). Taste buds, physiologically, are able to detect five basic tastes: sweet, sour, bitter, salty, and umami. A strong link between taste and emotion exists due to evolution as taste aids us in evaluating food as we consume it. A sour or bitter taste was indicative of poisonous plants or spoiled food while the sweet and salty attributes were associated with food rich in nutrients (IQWiG, 2011). Physiology and neuroscience literature argue taste is derived from multiple intrinsic sensory components (Elder and Aradhna, 2010). Smell affects taste perception both, before (orthonasal) and after (retronasal) food enters the mouth (Rozin, 1982). Further, literature supports the notion that the design of food advertisements and verbal stimulus impact consumer perception of a product's taste (De Araujo et al., 2005; Elder and Aradhna, 2010).

Sound is transmitted as air, which causes vibrations of the eardrum. The vibrations are then transmitted through the small bones that lie within the middle ear. This creates hydraulic motion in the fluid of the cochlea. The cochlea is a canal covered in hair cells that become agitated from incoming sound and send neural impulses to the brain (Meilgaard et al., 2016). Hearing impacts consumers' overall perception of a product as the expected characteristic sound of the consumption of a product is important. For example, a consumer may expect the crisp, snapping sound as they bite a pickle or a crunching sound as they consumer their favorite potato chip. An additional perspective of the impact of hearing on the consumer experience is part of foundation of the understanding atmospherics. Researchers argue that the atmosphere of a place is sometimes more influential than the product itself in the purchase decision process (Kotler, 1973). Music has shown to have an influence in consumer perception of the atmosphere of retail settings, and consequently influences purchasing decisions. This is justified as research has shown the influence of French and German music on wine purchases (North et al., 1999), music's effects on emotional responses to consumers' reactions to waiting for services (Hul et al., 1997), and how consumers' liking of music in a retail setting can positively affect the length of shopping time (Vida et al., 2007).

Consumer Perception of Beef

Perceived quality is multidimensional and is influenced by factors including organoleptic attributes, health concerns, convenience, lifestyle, and processing characteristics. Additionally, consumers are influenced by external factors on a conscious and non-conscious level that influence them on a cognitive and emotional level. The effects of these external factors may not reach the consumers' conscious realm of thoughts, and therefore are difficult to observe and analyze in most experimental conditions. A common approach to collect information regarding what type of information consumers seek in order to make purchasing decisions regarding meat products is through survey methods. A large amount of published literature is available with varying conclusions

USDA Quality Grades

The degree of intramuscular fat is used as a visual indicator for estimated beef palatability in the quality grading systems established by USDA (2016). The usage of segregating carcasses by their USDA Maturity Group (Smith et al., 1982), USDA Quality Grade (Smith et al., 1987), and their USDA marbling groups (Smith et al., 1985) are said to increase consumer acceptance of beef steaks. The beef grading and marketing system in the United States uses USDA Quality Grades as a way to market beef products to consumers. Researchers have investigated the consumer knowledge of the USDA quality grades (DeVuyst et al., 2014). A survey of over 1,000 consumers revealed a response of 14.4% that were able to correctly rank Prime, Choice, and Select grades in terms of leanness. Furthermore, 57.1% incorrectly identified Prime as the quality grade that represented the leanest product. Consumers were also asked to match steak pictures of Prime, Choice, and Select quality grades to expected prices. Fifty four percent incorrectly match the Prime quality grade to the lowest price threshold. DeVuyst et al. (2014) concluded that consumers were confused over the nomenclature at the retail level and a need for more consumer education, or more clear terminology are needed.

The National Consumer Retail Beef Study concluded consumers may be segmented into two classes based on their evaluation of USDA Choice and USDA Select beef retail cuts (Savell et al., 1989). USDA Choice retail products were either evaluated positively for their high flavor ratings or were critiqued for their level of fat. Retail cuts representing the USDA Select quality grade were either rated high in liking for their leanness, or criticized for their flavor or texture. It was recommended that these two grades of beef are best merchandised based on their perceived benefits from the two classes of consumers. Further, an extensive amount of research supports a regional influence on consumer satisfaction of beef dependent on USDA quality grade and other factors (Savell et al., 1987; Neely et al., 1998; Lorenzen et al., 1999; Neely et al., 1999)

Beef Intrinsic Properties

An issue facing the beef industry in terms of meeting consumer satisfaction for beef quality is the concept that consumers misconstrue intrinsic and extrinsic cues that lead to unsuitable quality expectations (Grunert et al., 2004). Consumers rely on intrinsic cues of fresh meat products such as color, fat content, and freshness to assess the quality of beef products (Bello Acebrón and Calvo Dopico, 2000). This is not due to their ability to access product and infer the quality based on the cues, but because retail fresh meat is most commonly marketed as an unbranded product (Grunert, 2006). This may be misleading to the consumer to evaluate meat products based on the intrinsic properties because raw color is not an accurate indicator of its palatability (Jeremiah et al., 1972). When Jeremiah et al. (1972) built multiple regression equations, only 10% of the variation in flavor and juiciness, and 6% of the variation in tenderness were explained by using pH, visual color score, marbling score, and texture score as independent variables. The researchers concluded that creating limits for beef color in order to objectively identify and exclude unacceptable products from reaching consumers would be beneficial. The color groups the researchers identified as the lower and upper bounds were product appearing as pale pink (color group 2) and slightly dark red (color group 6), respectively.

Some intrinsic cues may further be classified as “search” and “experience” attributes (Nelson, 1970). Consumers use search attributes to assess the quality of a meat product before purchasing. Experience attributes are not evaluated until the consumer prepares, cooks, and finally consumes the meat product. Therefore, consumers are limited to search attributes in order to predict the expected quality of their experience attributes of meat products. It may be argued that some fresh meat products are at a disadvantage due to a limitation of extrinsic cues available to the consumer. Due to commonality of unbranded fresh meat, consumers must rely more heavily on the intrinsic search cues. This leads to the biochemical and biophysical characteristics of meat, especially for fresh retail merchandising, representing a critical importance for the meat industry in determining consumer purchasing behavior.

Consumers use the visual characteristics of raw meat to determine a product that will satisfy their desire for a tender, juicy, and flavorful finished product. Consumers cannot do this reliably, as they relate their finished product characteristics with a product with a fresh appearance, maximum lean content, absence of gristle, and a bright red color (Barton, 1970). Research exploring what factors consumers use in the formation of their expected quality of meat products indicated perceived fat and place of purchase as the most important factors (Grunert, 1997). These findings exemplified the uncertainty of the consumer in their product selection as they selected against marbling due to the belief that it did not contribute towards an end product of satisfactory desire, but that it detracted from it. Interestingly, consumers showed a reliance towards the knowledge of the available butcher, showing they entrusted their purchasing decision based on the advice of someone viewed as an expert in the field (Grunert, 1997). Although this finding supports the benefit of the role of a butcher present in a retail setting, this occupation is not common in current retail settings.

Interaction of Tenderness, Juiciness, and Flavor

Tenderness, juiciness, and flavor each play a critical role in the overall palatability of beef products. Research has discussed the degree to which each of these attributes influence a consumer's overall liking of beef steak. Kukowski et al. (2004) reported tenderness as the trait with the highest correlation with consumer overall liking and proposed that consumers may find tenderness as the most important palatability trait. However, tenderness, juiciness, and flavor were all highly correlated not only among the seven different muscles analyzed by Kukowski et al. (2004), but also with one another. Additional studies have reported that flavor may be as important (Neely et al., 1998), equally important (Reicks et al., 2011), or more important (Behrends et al., 2005b, a) than tenderness in correlation with consumer overall liking. Juiciness and flavor may play an even more important role when consumers view the tenderness of the product as not acceptable or when WBS values are consistent between samples (Miller et al., 2001). Nonetheless, all studies (Neely et al., 1998; Behrends et al., 2005b, a; Reicks et al., 2011) acknowledge tenderness, juiciness, and flavor liking were all positively, strongly correlated with overall liking. The collaboration of all three traits must be considered in determining consumer satisfaction of beef steaks as a consumer's opinion of its eating quality is determined by the consumer's singular or combined responses to tenderness, juiciness, and flavor attributes (Smith and Carpenter, 1974).

Beef Extrinsic Properties

It was hypothesized by Grunert (2006) and Bernués et al. (2003) that the use of extrinsic cues for inferring meat quality will increase. Henchion et al. (2017) sought to review research sources to identify the most relevant quality attributes in beef that consumers seek in terms of search, experience, and credence attributes. The authors theorized that consumer ranking of search and experience attributes are not expected to change in the future, but credence attributes may shift with time in regards to consumer attention level. This robust review began with 3,498 literature sources that were reduced to a final 15 articles through removal of duplicates, irrelevant titles, quality parameters, search terms, methodology, and quantity of attributes included in study.

In terms of credence attributes, origin, animal welfare, and production system/feeding were the three most important to consumers (Henchion et al., 2017). These findings contradict those by Grunert (1997) who reported country of origin and had no impact on quality expectations of the consumer. Henchion et al. (2017) found animal breed, traceability, and environmental issues were the lowest ranked credence attributes. Health and safety were ranked 5th and 6th, respectively of the 10 total credence attributes that consumers are concerned with. It was hypothesized by Grunert (2006) that interests in health and safety issues would increase the use of extrinsic cues in marketing beef products in the future.

Within the search attributes, price was most important followed by the certification, labels, brands, and information category (Henchion et al., 2017). The intrinsic factors of visible fat and meat color then followed. Henchion et al. (2017) termed the price attribute as the “ultimate attribute” due to its ranking within the search attribute category, its relative ranking of second most important, and its high regard found in a large number of research papers included in the review. Price also aids consumers in deciphering product quality as expected quality increases with increasing price (Bello Acebrón and Calvo Dopico, 2000). Although packaging was ranked 20th out of the 21 total quality attributes that were perceived as important to consumers in work by Henchion et al. (2017), Bello Acebrón and Calvo Dopico (2000) concluded that consumers held an unfavorable viewpoint of meat processed in pre-packaged trays compared to those cut fresh from the service case.

Development of the Current Beef Tenderness Thresholds

Research by Shackelford et al. (1991) set the standard for tenderness threshold levels used in development of instrument grading for tenderness for segmenting beef into very tender, tender, slightly tough, and tough categories and also in the development of *Certified Tender* and *Certified Very Tender* claims by (ASTM, 2011). These tenderness thresholds were developed by investigating the relationship of WBS force values with trained sensory panels and consumer sensory panel ratings for beef tenderness. Carcass data used for regression analysis were from a subsample of carcass data collected for Smith et al. (1982). A total of 678 beef carcasses from A and B maturity were collected from 8 meat plants in 6 states. A total of 8 steaks measuring 2.8 cm each were cut from each boneless loin. Four of the most anterior steaks were assigned to Texas A&M University. Additional collaborators, Iowa State University, Colorado State University, and the Meat Science Research Laboratory of USDA, were randomly assigned the remaining seat of four remaining steaks. After randomization, each collaborator had been assigned 4 steaks from 226 boneless loins. Within each set of four steaks, 2 were used for trained panel analysis and the other 2 were assigned to WBS force analysis. Sensory panelist scored each steak on an 8-point scale for overall tenderness where 8= extremely tender and 1= extremely tough. Trained panel rating scores of 4, 5, 6, and 7 were categorized as “slightly tough,” “slightly tender,” “moderately tender,” and “very tender,” respectively. Confidence intervals of 50 (mean), 68 (mean minus standard deviation), and 95% [mean minus (2 x standard deviation)] were determined for WBS values associated with the categories developed by trained panel ratings. The mean and the standard deviation of the WBS values were 3.8 and 1.3 kg, respectively. In conclusion, steaks having a WBS value less than 4.6 kg should have a 50% chance of being rated "slightly tender" or higher for overall tenderness by a trained sensory panel. Additionally, 3.9 kg was determined as the threshold for the 68% confidence interval and 3.2 kg for 95% confidence interval. The percent of carcasses that had WBS values greater that the 50, 68, and 95% confidence intervals were calculated according to Z-statistic analysis and reported 26, 46, and 67% of the carcasses were in excess, respectively. Shackelford et al. (1991) confirmed the accuracy of these results by testing the confidence intervals against the population of Smith et al. (1982) to determine if the values could identify beef rated less than "slightly tender." The percentage of top loin steaks predicted correctly in their rating of "slightly tender" or less for 50, 68, and 95% confidence intervals were 86.7, 81.5, and 56.7%, respectively. The percentage of these steaks that would contribute to a loss of profit (predicted to be tough, but were actually tender) were 6.6, 16.9, and 43.0 for 50, 68, and 95% confidence intervals, respectively. The proposed thresholds were tested once more for trained sensory data from the National Retail Beef Study (Savell et al., 1987). Accuracy values of 81.2, 76.8, and 54.8% were determined for 50, 68, and 95% confidence levels, respectively, resulting in a decrease of accuracy compared the results using work from Smith et al. (1982). The final set of data the proposed thresholds were tested against for accuracy were consumer in-home overall tenderness evaluations from Savell et al.

(1987). This comparison was important as it compared how the thresholds would predict subjective data from consumers, as the end goal was to increase the accuracy of predicting consumer satisfaction of overall tenderness opinions of beef strip steaks. Fifty and 68% confidence levels were 88.6 and 74.3% accurate, respectively, in determining if a consumer would rate a steak “slightly tender” or less. In conclusion, Shackelford et al. (1991) recommended the 4.6 kg (50% confidence interval) threshold level for determining consumer response for overall tenderness.

Tenderness Claims

The current USDA grading standards use intramuscular fat as a standard for quality. Intramuscular fat is poorly correlated with product tenderness as marbling explained, at most, five percent of the variation in beef tenderness (Wheeler et al., 1994). Therefore, additional quality parameters are needed to segregate product based on tenderness measurements (Lusk et al., 2001). The standard specification standards for beef tenderness market claims requires beef cuts being considered for tenderness marketing claims to be certified through a third party auditing activities (ASTM Standards F2925 ASTM, 2011). In addition to threshold values determined by Shackelford et al. (1991), research from Miller et al. (1995) aided in setting the MMTV as this study’s objectives were to determine the acceptability levels for beef tenderness in restaurants and home settings by the same group of consumers. In addition, WBS force was conducted in order to determine any relationship between WBS force and consumer beef tenderness ratings on paired steaks in both, home and restaurant settings. Warner-Bratzler shear force findings revealed the transition level for beef tenderness acceptability in the home setting was between 4.6 and 5.0 kg. The average WBS force value for steaks considered acceptable for tenderness by consumers was 3.5 kg. Standards developed by the ASTM International Committee F10.60 on Livestock, Meat, and Poultry Marketing Claims (ASTM Standards F2925 ASTM, 2011) define the difference in requirements for *Certified Tender* and *Certified Very Tender*. Briefly, *Certified Tender* beef must not have been enhanced or processed to be tender by measures previously described in the specifications and must meet MTTV of 4.4 and 20.0 kg (43.1 and 196.1 N) for WBS or SSF, respectively. Cooking procedures are required to follow American Meat Science Association (AMSA) research guidelines (AMSA, 1995). *Certified Very Tender* beef have the aforementioned requirements with the exception of exceeding the MTTV by at least 0.5 kg (5.0 N) for WBS or 4.6 kg (46.0 N) for SSF. If the carcass longissimus dorsi is directly measured or predicted through an approved method, then eight additional listed muscles also qualify for the tenderness claim without any required measuring.

Determining Consumer Willingness-To-Pay

Several methodologies attempt to determine consumer's WTP. A portion use actual products and consumer's money to create an environment that is more realistic to consumers in order to elicit responses from consumers that may more accurately reveal their true WTP for a product compared to completing the study in a laboratory setting, or through answer questions via survey (Cummings et al., 1995; Fox et al., 1998; List and Shogren, 1998). Lusk et al. (2004) reviewed the most frequently used auction mechanisms in the current research literature at the time designed to prompt consumer WTP for agricultural commodities. Four methods are briefly described below in order to explain the noted benefits of using an experimental auction setting for determining consumer WTP.

Second Price: In a second price auction consumers submit sealed bids for the good. The experimenters determine the individual who offered the highest bid as the winner and he/she must pay the second highest bid value for the product

Random nth price: Participants submit sealed bids for the good. One bid, referred to as the *n*th bid, is drawn from the samples submitted by the panelists. Participants with bids greater than the *n*th bid win the auction good and pay the price equivalent to the *n*th bid value.

Becker-DeGroot-Marschak (BDM): Individuals submit sealed bids for the good. Experimenters predetermine a distribution of prices or values that they then randomly draw from. The individuals who offer a bid greater than the drawn value win the good and purchase it as the randomly drawn price.

English: Lusk et al. (2004) recognizes the English style of auction as the most widely recognized style. The experimenter serves as the auctioneer in this setting and starts the bidding for the item at a low price. Consumers signify their willingness to purchase the item at the currently stated price and the auctioneer will continue increasing the bid until one participant is willing to pay the bid. Therefore, the English style of auctioning determines one consumer as the winner.

Within selecting an auction mechanism, additional details must be considered in the further designing of the procedures. Examples in research include whether or not to provide an endowment for the product, as each method may have potential impacts on

WTP estimates. In past studies, participants are endowed with a good and asked how much they would be willing to pay to exchanged their endowed good for a similar good with differing characteristics (Lusk et al., 2001). Others designed their experiment to require participants to bid full value for the good (Melton et al., 1996). One criticism of endowment is it may introduce bias into the study because of the theory of loss aversion; losses are valued more highly than gains. This idea is referenced as an expression of a good being reference dependent (Tversky and Kahneman, 1991). Lusk et al. (2004) further describes that if a reference-dependent preference exists, then it is dependent on the consumer's initial reference point: being whether or not they possess the good prior to determining their WTP for the good. The location and environment may also possibly influence the outcome of the data. Researchers have claimed that laboratory settings have been show to influence valuations from consumers compared to attracting participants in a field setting (Rutström, 1998). Due to the high costs of collecting data from consumer's regarding their thoughts and preferences among goods, many researchers design their experiments for multi-goods. This is due to the thought that more data may be collected for the same amount of fixed costs for collected data one a single good or treatment. Lusk et al. (2004) forewarns the disadvantages of multi-good valuation that must be considered before developing the experimental design. If poorly planned, consumer valuations may be affected by demand reduction or wealth effects. This occurs when the participants purchase a good in one treatment or round of auctioning, causing their demand to decrease for the next treatment or round. This decrease in WTP may not be due to the treatment itself, rather the movement along the demand curve for the consumer. Lusk et al. (2004) also states a simple solution to avoiding this bias is to create a binding round or treatment. This informs the participants before bidding takes place that they are able to approach each successive round the same because even if they were to “win” product in multiple rounds, ultimately one round is going to be randomly chosen as the binding round at the end of the experiment. This reduces winner(s) from multiple rounds to winner(s) of a single round, therefore, if there is movement along the consumer’s demand curve, it is more likely to be treatment related. Another disadvantage of multiple-good evaluations is consumers valuations differ significantly depending on whether goods were viewed independently or if consumers knew there were multiple alternatives, causing their WTP to be impacted (List, 2002).

Lusk et al. (2004) cautioned that often times methods are employed without formal consideration of how the procedures might affect the results. Utilizing the auction method in an experiment’s design requires special consideration for the not only the objectives of the experiment, but the details of the product being tested and the intended statistical analysis of the data to be collected. Lusk et al. (2004) considered three procedural issues in experimental valuation including auction mechanism, reference-dependent preferences, and the number of goods valued. The researchers designed three different procedures with combinations of participants either receiving an endowment or not, either two goods or five, and one of four auction mechanisms. The intention of varying the procedures for these mentioned issues was to determine if and to what degree the they influenced consumer WTP estimates.

Statistical Analysis Approaches for Consumer Data

The range of the scale was determined through experimental measures. Replication of tests reported that a 9-point scale were more consistent compared to 5,7, or 11-point scales and was able to sufficiently discriminate products tested. Interpretation of the results may be reduced to a single index by calculating the average score. In later work by Peryam and Pilgrim (1957) two approaches to interpreting like-dislike hedonic scale data are discussed. The first approach treats the scale data quantitatively by evaluating the means, standard deviations, standard error of the means, and the significant difference between means. Data may be evaluated through ANOVA procedures. The validity of using these statistical procedures have been questioned by some statisticians. The use of a normal procedures was justified in this era of research (1957) as a practical approach was needed until more appropriate techniques were developed. A second approach provided an index which yields a more respectable statistical approach since it dealt with calculating the percentage of responses that fell within categories (Peryam and Pilgrim, 1957). The authors note that a larger sample size may be required to eliminate the percentage response of categories of zero.

Researchers acknowledge the types of hedonic scales used for research as the scale may be categorized as “words” or “numbers” (Sukanya and Michael, 2015). The authors note that hedonic scales that use the “words only scale” approach reassign the numbers as verbal cues while the “numbers only scale” remain purely numerical. Often times, researchers label the scale at the ends and sometimes in the middle but this revised scale is still classified as a “numbers only scale.” These two approaches are independent as each are interpreted differently by the consumers who are recruited for testing. Sukanya and Michael (2015) acknowledge that appraisal for the purpose of using the scale must be asked when designing a ballot. They state that the original "words only scale" serves as a scale of liking that yields a more absolute result than comparative. The authors give a hypothetical example of its use as asking consumers how much they like the products they order and consume from a restaurant. The management can evaluate the foods that are well liked and disliked from consumers to determine which may remain on the menu or may be removed. The goal is to not compare the degree to which consumers like one plate compared to another but is to merely register whether a food is liked enough to remain on the menu. Contrarily, food science and research fields utilize the hedonic scale for comparative measures. If researchers use a "words only scale" then a measure of preference may be obtained. For example, if a Treatment 1 is "liked extremely" and Treatment 2 is "liked moderately" it can be concluded that Treatment 1 is liked more or is preferred to Treatment 2. Assigning a scale of values to the "words only scale" creates and ordinal measurement of preference. Sukanya and Michael (2015) report that research from Peryam and Pilgrim (1957) and Peryam and Girardot (1952) were among the first to use the hedonic scale in food science research literature. Their work evaluated scale data in comparative terms, as they used scales of liking from which preference was inferred. The authors considered the words on the scale as a continuum rather than categorical, discrete data. This early research considered the use of the "words only scale" in the manner in which Sukanya and Michael (2015) suggests in their menu example, for rare circumstances.

The case that Sukanya and Michael (2015) builds for simplifying the use of hedonic scale data interpretation in the research field is built on the objective of the project. If the project wants to measure the preference of an item from consumers, then the protocol should be simple. The authors give caution to researchers to remember the effects of rapid forgetting from consumers as they design their scaling protocols. They note that this may be overcome by allowing consumers the availability to re-taste samples as necessary to check their hedonic assessment so they may alter their scores accordingly. This is not as simple as it may seem as some products are time sensitive and do not allow consistent evaluation experiences as they decrease in holding temperature. Sukanya and Michael (2015) acknowledge the perspective that serving samples singularly may represent a more realistic setting that a consumer encounters in purchasing situations as they do not sample products before choosing which to purchase. The serial monadic protocol promotes absolute judgements that are not influenced by comparisons to other samples. Therefore, if this system is used as a means of comparison of preference for samples then biasness may be introduced as consumers are affected by forgetfulness. One way to account for and measure this biasness is to include the order of the presentation of the sample in the statistical analyses.

An additional criticism of the "numbers only scale" is the numbers are not equally spaced and are more similar to ranked data (Peryam, 1950; Peryam and Pilgrim, 1957; Sukanya and Michael, 2015). Researchers treat these numbers as equally spaced due to their need in accessing consumers as it is thought to not cause any major issues (Sukanya and Michael, 2015). Sukanya and Michael (2015) further explain additional cautions when numbers are obtained from categorical scales. Consumers are affected by what psychologists call an end effect or termed as timidity by consumer sensory scientists (Meilgaard et al., 2016). This causes consumers to be reluctant to use the end of scales, such as an 8 or a 9. It is thought that more cognitive effort is required for a consumer to pass from an 8 to a 9 compared to the middle portion of the scale as somehow the distance feels greater towards the end. It is argued that this creates a scale that cannot be considered an interval scale, as the consumers do not space the numbers the same way. Sukanya and Michael (2015) concluded that the scale is at least ordinal, but does provide more information because consumers use the numbers to create a spacing between the ranks. But this does not qualify the data as interval data. Therefore, the data are better than ordinal, but not as good as interval. Sukanya and Michael (2015) further state that numbers assigned to "words only scales" have the same property as the words. They question how this reassignment into a number creates a normal distribution that is analyzed through parametric analysis when the ordinal nature of the scale would distort a normal distribution. The authors exemplify this thought by stating "the simplest illustration that the assigned numbers are merely new labels is that if 'eight' is subtracted from 'nine', the answer is 'one'. Yet, if 'like very much' is subtracted from 'like extremely', the answer is hardly likely to be 'dislike extremely'. They further acknowledge the benefits of using this scale and note there is no problem with its use as long as the researcher understands its true nature and treat the data accordingly.

The objective of the study should be on the forefront of the researcher's mind when determining the appropriate type of analysis to apply to their data. This will aid in identifying the method that suits the need of the researcher. There is not a clear right or wrong way of analyzing data. It is up to the researcher to determine and justify their reasoning for the procedures in which they apply to their data.

Regression Analysis

From a broad perspective, regression analysis is applied to understand the influence of a dependent variable toward one or more independent variables. Within the field of regression analysis, numerous variations exist and therefore requires the understanding of what they entail, how they differ, and when or when not to use them. This is the foundation for a researcher to justify their approach to their data analysis. A researcher may narrow their options for their choice of analysis by answering what level of interpretability and prediction accuracy they desire from their model. James et al. (2013) explains that a model high in its prediction accuracy and also easily interpretable is not possible as there is a trade-off between these two characteristics. For example, a simple linear fit to data allows for a highly interpretable relationship of the independent and dependent variables. The predictive accuracy of the model may suffer though as the fit is not flexible because it is just a simple line drawn within the variables. If the researcher is focused on developing a model strictly for prediction purposes, they should choose one lower in its interpretability but greater in its flexibility, as the need to understand the relationship among the variables is minimal. An additional concept discussed by James et al. (2013) is the bias-variance trade-off. This theory is derived from the concept that in order to minimize the test error, a method must ideally simultaneously achieve low variance and low bias. Variance refers to the amount the model would change if it were reproduced with another set of data and bias is the error produced from attempting to estimate a complicated, unknown real-life scenario with an equation that does not encompass the true complexity. Therefore, as a model increases in its flexibility, the variance will increase and the bias will decrease. This concept is tied to the increase and decrease in the mean square error (MSE), which is commonly used to access the performance of models (James et al., 2013). The true function of the real-life situation the data are derived from is not known therefore this relationship can only be estimated. Regardless, the theory of this concept represents one of the important factors to consider when choosing between models of differing flexibility and interpretability.

A review by Poole and O'Farrell (1971) provides a concise description of the assumptions for the linear regression model. The authors emphasize the need to clear the misunderstandings of the assumptions by identifying specific, highly regarded work in their field at the time that failed to report whether the assumptions were verified. In some cases, only a portion of the assumptions was checked while some noted the validation of assumptions that were not truly assumptions. The authors begin by defining the general single-equation linear regression model:

$$Y = a + \sum_{i=1}^{k} b_i X_i + u$$

Where Y is the dependent variable; $X_1, X_2 \ldots X_k$ are k independent variables; a and b_i are regression coefficients that represent the parameters of the model for a specific population, and u is a stochastic disturbance-term that may be interpreted as occurring from the effect of an independent variable or a specified random element in the model. This equation represents both, simple regression and multiple regression. The difference in the two sets is defined by the X_i independent variable. In one set, the independent variables are held constant through experimental conditions resulting in a fixed value. The other scenario consists of randomly selected independent variables. In both cases the Y variable is random. The authors refer to the two models as the "fixed X model" and the "random X model." This concept is important because correlation analysis is valid for only the "random X model." Further, Poole and O'Farrell (1971) explain that regression model usage can be categorized into three groups of either the computation of point estimates, the calculation of confidence intervals, or hypothesis testing. The goal of the experiment will determine which group the analysis is categorized as, and thus will determine what assumptions must be met. The assumptions are:

1) Each value of the independent and dependent variables is observed without measurement error.
2) The dependent variable is linear in relation to each independent variable.
3) Each conditional distribution of u has a mean of zero.
4) Homoscedasticity: the variance of the expected distribution of u is constant for all distributions.
5) Autocorrelation: the values of u are serially independent, meaning the values of u are independent of each other and their covariance is zero.
6) The independent variables are linearly independent of each other. Failure of this assumption indicates multicollinearity.

7) The fixed *X* model requires the dependent variable is randomly selected and has a normal distribution while the random *X* model requires both, the independent and dependent variables are random selections that are normally distributed.

The authors state that the first six assumptions are critical. Assumptions three, four, and five are related to the disturbance-term. The conditional distributions of the disturbances need to hold for differing values depending on if the models are "fixed *X*" or "random *X*." The first five assumptions are for both, simple and multiple regression while the sixth is only for multiple regression. If the model's usage involves regression analysis for prediction, interval estimation, or hypothesis testing then the first 6 assumptions are required. The seventh is required in addition if the model is used for interval estimations and hypothesis testing, as they are necessary for inferential interpretation of the model. For point estimates, neither assumption for normality is required.

In regards to the optional seventh assumption of normality, if the number of observations in relation to the number of parameters satisfies the law of large numbers and the central limit theorem then the data may be considered normally distributed (Dabney). If data are not normally distributed, tools such as logarithmic transformation or polynomial regression may be applied while still allowing the data to fit these listed assumptions. Simply evaluating the p-value cannot inform you if the distribution is considered normal. This is an informal process that should be made through interpreting the context of your data (asking if it makes sense that a variable influences another) and does not require any data analysis (Dabney, 2018). Next, developing visuals of the data is recommended. One form of visualization includes quantile-quantile plots (Q-Q plot). This determines if the data came from a univariate normal distribution in which the sample quantiles are plotted against their corresponding quantiles from a standard normal distribution. Non-normal data will reflect nonlinear patterns (Dabney, 2018). Formal tests may be used, but should not be referred to first, an assessment of visual plots of the data are more reliable. The presented emphasis of the assumptions of the linear regression model is necessary as this serves as the foundation to determining if linear regression is appropriate for a researcher's statistical analysis. The awareness of the whether the data meet these assumptions or not impact the validity of the model. If violations are discovered, appropriate measures may be taken to accommodate.

Least-Squares Regression

Least-squares regression (LSR) is an adaptation of LR where the beta coefficients are determined through the ordinary least squares (OLS) method. The OLS estimates are considered the best linear unbiased estimate (often referred to as BLUE) derived from the Gauss-Markov Theorem. The fitted line is selected based on the path that minimizes the sum of squared errors. A notable characteristic of LSR is that it is an unbiased estimation method. This is a major assumption of LSR, as the expected value of beta is equal to the true (population) beta. The flexibility of LSR is low as expected because a linear line drawn through a plot of data will not pass through each data point. Although the flexibility of the model is low, often times researchers find the level of predictability as a beneficial feature of LSR. Due to its low flexibility, LSR is high in its level of interpretability. This is an attractive feature for researchers who want to understand the relationship between the variables. One drawback for this method is if there are a large number of predictor variables in the model. This causes the level of difficulty of interpretation to increase as it becomes unclear as to what is predicting or influencing the dependent variable. The model can be improved through forms of model selection, but in order to do so the ordinary least squares fitting would need to be replaced (James et al., 2013). In theory, if similar data set were used in place of the original data used to develop a LSR, it most likely would not result in a large change to the model. In other words, because LSR is low in its flexibility, the new data set would fit similarly to the data that created the regression. This results in low variance between the two sets. Consequently, the low variance is associated with a higher level of bias as expected, as it is conceptually difficult to accept that such a simple LR can explain the real-world phenomenon it is representing to a high degree of accuracy.

Least-squares regression is sensitive to outliers as it causes the estimates from the model to not be truly reflective of the reality it is predicting (Casson and Farmer, 2014). This is because the outliers cause the placement of the line to be pulled towards them. Outliers may be identified through scatterplots, box plots, and Q-Q plots but with some limitations that are discussed later in this paper. Arguably, the greatest disadvantage of LSR is its subjectivity to issues of multicollinearity. This occurs when a correlation exists among the independent variables, which causes a substantial decrease in the quality of the model. Under this condition, the model suffers from untrustworthy regression coefficients. This causes inflated standard errors and possible incorrect signs of the coefficients (Lauridsen and Mur, 2006) regardless of if high R-squared statistic is present, as this may still occur with multicollinearity (Yeniay and Goktas, 2002).

Hastie et al. (2017) argued that using an unbiased estimation method may not be the most beneficial method as there may be a biased estimator with a smaller MSE. If the researcher were to allow a small amount of bias then a larger reduction is variance may be achieved. The best model can be selected by balancing bias and variance (Hastie et al., 2017). This concept has increased the acceptance of using biased estimation methods to combat the issues of imprecise predictions that commonly occur through methods such as LSR.

Principal Component Regression

Principal component regression (PCR) is a type of model selection that uses dimension reduction. Dimension reduction is defined as when a large number of variables are minimized to a relatively small number of components to model the information of the original data set. This method is beneficial for data sets that yield unclear results from LSR when too many variables are included in the model. The inclusion of too many independent variables leads to over-fitting (Tobias, 1995). Principal component analysis (PCA) is a prerequisite to performing PCR. PCA is an unsupervised learning technique that allows the visualization of numerous variables through dimension reduction. This approach is considered unsupervised as it does not define a response variable, Y, but is useful for deriving variables for later use in supervised learning techniques like PCR. PCA allows researchers to maximize the amount of variation explained from a large data set in a low-dimension setting. It is highly recommended that the data are centered and scaled before this analysis. This is critical because data that have higher variances due to the inherent nature of their unit of measurement will be weighted with greater importance compared to data with smaller variance. Centering and scaling the data allows them to have equal importance when they are evaluated by their variance. If PCA is computed with unstandardized variables, then the eigen decomposition is applied to the covariance matrix. Eigen decomposition applied to the correlation matrix results in standardized variables. Next, PCA identifies the linear combination of variables that account for the largest sample variance for the first principal component (PC). The determined coefficients are referred to as the loading vectors or factor loadings of the PC. The second PC is the linear combination of variables that explain the next greatest amount of sample variance that is uncorrelated/orthogonal to the first PC. Additional PCs are computed until the cumulative proportion of variance is fully explained (James et al., 2013). There is not an objective method for determining the number of principal components that should be considered for a given set of data. Often, with the use of scree plots, researchers define the number of factor loadings that significantly contribute to the explanation of the variance.

The PCR method uses the PC as predictors in a linear regression model that is fit through the use of least squares. This procedure assumes the direction of the independent variables and shows the most variation associated with the dependent variable. There is no guarantee that best direction for the predictors is the same as the best direction for the predictors to estimate the response (James et al., 2013).

Partial Least Squares Regression

Similar to PCR, partial least squares regression (PLSR) is considered a flexible approach that can be applied to several shapes of data sets including wide (more predictor variables than observations), tall (more observations in relation to predictor variables), and square (similar number of predictor variables and observations). As with PCR, collinear variables and noisy data are acceptable for this method (Cox and Gaudard, 2013). Partial least squares regression is not an appropriate tool for screening out variables that do not contribute to the response variable (Tobias, 1995); Sawatsky et al. (2015) explains that the data should be relatively normally distributed and should be assessed for influential outliers before applying the analysis. Both of these issues may be corrected through log transformation, if needed. The data should be centered and scaled for the same reasonings as discussed with PCR. Similar to PCR, PLSR utilizes the model selection form of dimension reduction and controls for the collinearity among the variables through orthogonal linear combinations. The only difference between the two methods is that the PLSR model identifies the direction within the independent variables that explain the maximum amount of variation in the dependent variable. This allows for the extracted factors to account for both the predictor and response variation (Sawatsky et al., 2015). In a comprehensive comparison by Wentzell and Vega Montoto (2003), the researchers revealed several "perceived" advantages of PLSR over PCR regarding work by chemists. The four most occurring perceived reasons the authors found were: PLSR may have an advantage in its ability to predict because correlations with the dependent variable are considered in its development; PLSR requires fewer latent variables compared to PCR and therefore should be more parsimonious; PLSR factor loadings are more readily interpretable, and PLSR should handle nonlinearities better than PCR. The authors then progress beyond the scope of how previous literature perceived the comparison of the two methods to a literature review that critiques the methods when they were utilized and compared within in others' studies as an objective of comparison. Additionally, the authors created simulation of their own involving varying levels of complexity in multivariate calibration systems. Wentzell and Vega Montoto (2003) concluded from their simulation work and the conclusions made by other researchers regarding their respective findings, that none of the conditions provided significant differences between the predictive ability of PLSR and PCR when the number of latent variables was unconstrained. Their findings refuted the theories proposed in previous literature but they note that this does not mean there may not be particular circumstances where one method is more useful in another's research. Additionally, they cannot disprove that PLSR provides greater interpretability compared to PCR. Overall, it appears the application of either PLSR or PCR is dependent on the parameters of the researcher's study and the efficacy is study dependent. Although understanding the relationship of the variables is not an emphasis of PLSR, if interpretability is of importance to the research then PLSR have an advantage over PCR.

Ridge Regression

Ridge regression (RR) is a constrained version of least squares (Yan and Su, 2009) that is considered a biased estimator method that uses shrinkage or regularization as its model selection approach. It represents a form of LR that shrinks the regression coefficient estimates relative to the least squares estimates that have little effect on the model towards zero, ultimately reducing the variance (James et al., 2013). Therefore, this method is an alternative for when LSR fails to produce a clear indication of variables that influence the dependent variable or if there is an issue of multicollinearity. This is crucial because when multicollinearity exists in a LR model the assumptions are violated and may result in the coefficients suffering from high variance, ultimately yielding poor estimates. Ridge regression is also useful when all of the coefficients have roughly the same order of magnitude but is not applicable to "sparse" data sets (missing data points or data points entered as zero). Because RR is based on least squares estimates, it is sensitive to outliers and high leverage points (Maronna et al., 2018). While the least squares fitting process estimates the coefficients that result in the minimized residual sum of squares (RSS), the RR applies an additional coefficient to reduce the RSS further. The term referred to as a shrinkage penalty and is also accompanied by a tuning parameter, referred to as λ (James et al., 2013). The shrinkage term is imposed to create a penalty to the regression coefficients based on their size. The tuning parameter serves to control the relative impact of itself and the shrinkage penalty towards the coefficient estimates and is determined through cross-validation (Hastie et al., 2017). An important note is that RR is influenced by the scaling of the inputs. Therefore, the inputs and the responses need to be standardized (Yan and Su, 2009). One major disadvantage to the RR is that a subset of variables is not chosen. Instead, all of the variables remain in the final model (James et al., 2013). In terms of bias-variance trade-off, RR is viewed as superior to least squares regression. Compared to previous discussed predictive models, RR is an alternative to LSR when multicollinearity exists and is optimal when a shrinkage model selection tool is desired. In terms of flexibility and robustness discussed thus far, RR is a strong competitor for PLSR, but their approach to model selection is different (Tobias, 1995).

As discussed by Frank and Friedman (1993), RR, PCR, and PLSR all operate as an alternative to the OLS approach as they pull the solution coefficients away from the OLS solution and towards the direction of where the predictor variables have a large spread. All help to alleviate the issues of multicollinearity where the variance is greater than the bias. They differ in regards to the directions they shrink the coefficients as PLSR and PCR will shrink away from areas of the low spread while RR applies its shrinkage in an equal manner. This indicates that PLSR and PCR assume that the true population parameters are preferentially aligned with the areas of high spread of the sample distribution. The level of bias each of these methods impose is dependent on the value of the model selection parameter. For RR, this the tuning parameter and for PLRS and PCR, it is the number of PC used.

Robust Regression

Outliers are defined as an unusual observation seen in the response variable given the predictor variable. High leverage points occur when an unusual value in the predictor variable occurs (Hastie et al., 2017). When outliers are leverage points, they cannot be discovered by observing the least squares residuals (Rousseeuw and Leroy, 2005). Maronna et al. (2018) demonstrated that observing Q-Q plots for residuals with least squares estimates may cause the researcher to conclude that the data are normally distributed with no outliers. The same data reported in a Q-Q plot with robust fits indicated that the majority of the residuals were non-normal. The difficulty with identifying leverage points increases as the dimensionality increases, as the relationships among multiple explanatory variables cannot be visualized. Two methods are available to account for regression outliers. The most well-known method is to construct regression diagnostics to pinpoint the influential points in the data set. This method allows for the removal or correction of the points and still maintains the least squares analysis on the remaining data. When there is more than one influential outlier, the diagnostics become complex. This leads to the second alternative of robust regression (ROR) (Rousseeuw and Leroy, 2005). As an alternative to LSR, ROR does not focus on minimizing the sum of squared residuals but instead gives less weight to high leverage points and outliers in the fitting procedure. This results in a form of regression that is not affected by extreme data points (Chatterjee and Simonoff, 2012). Therefore, it is recommended that researchers take advantage of the available regression diagnostics to identify if the high leverage outliers are present and to determine if a robust fit is necessary to produce an accurate model. If this is not investigated and is simply assumed by the researcher that the residuals are normally distributed, as in the case demonstrated by Maronna et al. (2018), a model yielding erroneous conclusion may occur. This form of regression is unique compared to the previously discussed methods as it identifies and helps correct influential data points that would otherwise induce bias on a regression model. This model is superior in terms of its robustness compared to the previously discussed models.

The utmost important decisions for conducting the statistical analysis of a research project begins before the project commences. The goal of the researcher must be clearly identified. This objective should determine the amount of predictability accuracy and interpretation is desired from the experimental design. Additionally, the design on the study, such as the determination of the response and predictor variables and the manner in which they are collected or observed, will determine whether the assumptions or linear regression hold. Undoubtedly, a high level of preplanning and understanding of the available statistical research methods are required before beginning any data collection.

Regardless of the statistical analysis chosen for the interpretation of consumer preference data, it is important to note the limitations of the interpretation. Measuring consumer liking or preference captures a snapshot of a consumer's conscious comparison of the presented product constrained to particular place and time. From a cognitive science perspective, there are background decision making processes occurring that are overlooked as they become summarized by the consumer's check marked option within a 9-point scaled parameter. Several fields of science have combined the benefits of Likert scale data with biometric data in order to create a more holistic perspective of consumer preference. These types of data require an understanding of human perception processing as they are related to the subconscious actions of consumers. A basic understanding of these processes could aid researchers in understanding the effect of biases that may be introduced into their ballot or study design. A basic overview of the visualization process is discussed.

Understanding Consumer Behavior

Human Visualization

A simple processing model of human visual perception divides the intake of information into three stages (Ware, 2012). Stage 1 is described as parallel processing that occurs subconsciously. Billions of neurons work in parallel to extract low-level properties of the visual field simultaneously. These low levels are extractions of features, orientation, color, texture, and movement patterns. Therefore, if information is needed to be understood quickly, it should be presented in conjunction with the method of processing that occurs in the brain. Stage 2 of visual processing identifies patterns in the large mass of data being processed in order to organize the information into groupings. Patterns may be identified through similar contours, color, and textures. This stage occurs rapidly, but is slower in terms of processing because the visual system identifies and “binds” up to three patterns that will capture one’s attention for a few seconds. The low-level system (Stage 1) is constantly seeking a stimulus to provide a focus for the eye. This is how a person may view or perceive a shape of an object, but not consciously identify it. If the person has an inherent interest in the object, the data interpreted by the visual system in Stage 1 may be further synthesized in a manner where the shape of the object will advance to the attention of the conscious mind. If the object is not further recognized, the data captured during Stage 1 of processes will dissipate (Malamed, 2009). Stage 1 and 2 are driven by bottom-up processing where visual perception is motivated by external stimuli. Stage 3, the highest level of perception, is classified as top-down processing. This stage is reached through the need of active visual attention where stimuli are held in visual working memory. Long-term memory related to a task is used in this stage to undergo visual search strategies. This final stage is characterized by its influence of prior knowledge, goals, and expectations. Bottom-up flow of processing that is inherent to our processes of visualizing interacts and influences our top-down method of visual processing. When introduced to a new image or scene is introduced to someone, information can only flow in sequential order of the stages. The system is quickly able to adapt to a conservative strategy where we utilize the stage that is most beneficial to us and our expectations. The level of attention increases with the increasing stage that is being utilized. The preattentive processes may be arranged and manipulated to increase the likelihood of successful comprehension. If they are not considered, the audiences' perception, interpretation, and acceptance of the visual may fail the intended goal of the presenter.

The relationship of cognitive load and working memory are crucial in considering how to present information to an intended audience. All tasks we perform impact our working memory to different degrees relevant to the amount of cognitive effort required to complete them. Taxing activities may include encountering new situations, recalling previously learned information, and inhibiting irrelevant information (Malamed, 2009). The resources we employ to complete these activities placed on our working memory are called a cognitive load. When the cognitive load exceeds the capacity of the working memory, the ability to adequately process information diminishes. This results in the misunderstanding, misinterpretation, and the overlooking of information. Graphical techniques may be applied through the design of visual communication to reduce the cognitive load.

Usage of Eye-Tracking

Eye-tracking has been applied to a wide array of genres including heavily cited work investigating the eye movements of schizophrenic patients (Holzman et al., 1973), the relationship of human and computer interactions (Jakob, 1998), and individual's responses to advertisements (Lohse, 1997). Its benefits are utilized across many disciplines as described by work of Duchowski (2002) as it has extended to the fields of psychology, engineering, and marketing. Eye-tracking data aids companies and researchers in identifying what captures an individual's visual attention. This method may not be able to define all cognitive processes such as why a person is drawn to something specific, but it can identify what captures the consumer's attention the most and the path of their visualization. This information can reveal the brain's underlying processing decisions. Its usage has increased within recent years due to growth in technological innovation causing a decrease in the time commitment and costs that were originally required to use this technology.

Understanding the basic anatomy of the eye is necessary for the application of eye tracking in human behavioral research. The changing structure of the eye is quite complex. Eye movement can be defined by two basic categories of either smooth pursuits or saccadic movements (Wright, 2003). Smooth pursuit eye movements are the slow and accurate movements the eyes make that require visual feedback. Pursuit eye movements follow visual targets up to 30 degrees per second while saccadic eye movements are rapid with velocities commonly occurring within the range of 200 to 700 degrees per second. Saccadic movements are utilized once a target exceeds velocities beyond the capability of smooth pursuit eye movements. Wright (2003) describes that saccadic movements can be voluntarily initiated although they are not voluntarily controlled. This type of eye movement is termed "ballistic" due to the neuronal signals consisting of pulses that contribute to contraction and relaxation of the six extraocular muscles. During saccadic movements vision is suppressed and therefore limits individuals from comprehending new information (Matin, 1974). Between saccade movements our eyes have the ability to remain relatively still for small periods of time (200-300 milliseconds) in states called fixations. It is during this fixation time that information is gathered from the text (Gilchrist et al., 1997). Russo (1978) explains that fixation points from the eyes are the most efficient method in monitoring human reactions to their environment as they are extremely accurate and fast. As explained by this researcher, a typical 5 to 6-degree eye movement occurs in 30 milliseconds. Within this time frame, 5% of the time is devoted to the eye movement itself, while the other 95% accounts for fixation time.

Rayner (1998) defines two eye movements in addition to a smooth pursuit that are crucial in the application of eye tracking research called vergence and vestibular. Vergence movements are when we move our eyes inward to focus on a nearby object. Vestibular movements are defined as when the eyes rotate to compensate for head and body movement in order to maintain the same direction of vision. Rayner (1998) further defines three types of fixations of the eyes called nystagmus, drifts, and microsaccades.

Although the term "fixations" may infer the eyes are momentarily still, they actually are not. Nystagmus is the constant, small tremors that occur in eyes. Drifts and microsaccades are slightly larger movements that are thought to occur when the eyes drift due to imperfect control of the oculomotor system within the nervous system. As this occurs, a microsaccade returns the eyes to their original position. Researchers involved in eye-tracking movements often categorize these movements as “noise” and adopt analytical methods to ignore them.

The types of movements required to analyze eye movement including fixations, smooth pursuits, and saccades. This assumes that these movements are evidence of intentional and apparent visual attention and fixations imply an individual’s desire to maintain their gaze on what they are interested in. Pursuits are similar, but they occur in a smooth motion while saccades represent moments of one’s desire to willingly change their direction of focus (Duchowski, 2017). Additionally, the nature of eye movements varies depending on the task of the individual. Eye tracking studies are commonly separated into reading, scene perception, and visual search studies. Rayner (2009) cautions those involved with eye-tracking research do not assume the three tasks evoke similar results. The saccade length and duration of fixation do not correlate with each other during reading, scene perception, or visual search studies (Rayner and McConkie, 1976). Recent literature also agrees fixation durations and saccade lengths during the reading process do not correlate with the measurements obtained during scene perception and search (Rayner et al., 2007).

The relationship between the variations of eye movements influence the muscles involved and overall contribute to one's ability to view information that then allows the interpretation of what is perceived. While individuals read a text, there is a pattern of saccadic eye movements and fixations. Eye movement is required for visualization due to the anatomy of the eye. The area of what is viewed is determined by the fovea. The area outside of the fovea's span is limited in visual acuity. Therefore the movement of the eyes allows for the increased acuity by relocating the view of the fovea, allowing for clearer perception. Gilchrist et al. (1997) encountered an opportunity to test their hypothesis of what occurs when a subject cannot produce eye movements. In their study, the subject had a congenital extraocular muscular fibrosis condition that resulted in a lack of eye movement since birth. Despite this condition, the subject had no reports of major vision problems and required no additional assistance with her academic studies. Through monitoring her eye movements while reading text, they discovered the number of words she read per minute was classifiable as slow, but not of abnormal reading speed. The researchers concluded this was achieved by her head movements working in a saccadic pattern as she read left to right through the text. These findings further emphasize the importance of saccadic eye movement for scanning text for information.

An explanation of how eye-tracking equipment operates is summarized by Walker and Federici (2018). The authors explained that data is captured from small infrared cameras that are positioned at differing angles to track the movements of an individual's eye path. The eye tracker identifies the point of gaze based on the eye's pupil center corneal reflection (Farnsworth, 2018). The intervals the cameras capture this information is determined by their frequency. A common frequency setting is 60 Hz, which allows the eye tracker to capture the eye's position 60 times per second. These data points are essentially translated into a position that is defined by an XYZ axis where X corresponds with the horizontal axis of the screen, Y with the vertical axis of the screen, and Z as the distance the individual's eye are away from the screen. This plane allows for the data to be interpreted through several visualization methods that reveal fixation clustering. In the realm of eye tracking data collection, fixations are defined as when an individual's gaze remains fixed in the same location for longer than a predetermined time duration. This is defined as pixels in the software and can vary depending on the characteristics of an individual or the type of stimulus being observed. Fixations can be visualized through several metrics as explained by Farnsworth (2018). Areas of interest (AOI) allow researchers to define specific regions of the stimuli either before testing or after. Several calculations within each AOI can be made including the time it took for the subject to first view the defined region, the time they spent viewing the region, the number fixations, the number of revisits to the area, and the ratio of individuals who viewed the area (in the case that multiple subjects were tested). Heatmaps may be generated by overlaying the fixations overtime over the stimuli. This creates a visual technique of understanding where either a group of viewers focused their attention either through the aggregation of the data or the attention individual subjects. Fixation sequences can be developed to understand the viewing path of the subjects defined by their number of fixations. This is useful to see where the subject's attention was captured initially and where their focus traveled over time. Eye trackers also have the capability of capturing the diameter of the pupils that can be used for cognitive effort measurements.

Research within the field of marketing has used eye tracking to investigate consumer interaction with topics including, but not limited to, choice and search behavior, print advertising, commercials, and website usability. In order to optimize the impact of their marketing, leaders understand that their strategies to attract the attention of consumers are built around the concept that the amount of information processed through the optic nerve exceeds the brain's processing capability. The brain has a limited capacity of visual working memory as it is constantly making decisions of where to look, what is most important to focus on, and what it should remember. Because of this unbalance, the brain has learned to focus only on what it deems as relevant by enhancing this selection of information while suppressing the remaining. An individual's gaze is directed to only one area at a time and allows their visual attention to narrow and fixate within this defined area (Droll and Hayhoe, 2007). This allows the brain to shift its usage of visual working memory to relying on fixations in decision making processes. This shift is desired because it requires less work for the brain.

Exploratory search behavior is defined as when consumers are faced with numerous pieces of information (i.e. catalog page and visual merchandising) and do not have a lot of stored knowledge about how to proceed with interpreting the information (Janiszewski, 1998). Information searching occurs through a combination of techniques called top-down decisions, where and how to find information, and bottom-up decisions, how to visually explore a new environment (Groner et al., 1984). Marketing jargon defines the traits of consumers as a goal-oriented process or as a “top-down” factor. Examples include customer familiarity, expectations, and viewing time. The characteristics of the visual marketing stimulus are referred to as “bottom-up” factors and are described as the physical features of the product. Malhotra (2008) describes how marketers use the bottom-up factors to capture the attention of their consumers. A target object is made to stand out from its competitors because of a single perceptual feature (i.e. color of the product, labeling characteristics) with the intention to capture the first eye fixation from the consumer. This varies from a consumer’s voluntary top-down frame of mind and the interaction of the two influences attention overall. For example, as a consumer is searching a retail shelf for a specific item, they may refer to their memory to recall the shape or color the container they routinely purchase of the good they want to find. The brain enhances the details that will aid in finding the specific item and will suppress those that will not assist. This process, combined with the bottom-up factors, will influence the attention of the consumer.

Marketing research has focused on consumers’ conceptual analyses of marketing stimuli but have overlooked the importance of perceptual analysis (Pieters and Warlop, 1999). As a consumer stands in front of a shelf of a product with variations of brands and attributes to select from, they will use conceptual analysis to refer to their current knowledge of the product in order to relate to the stimulus and rationalize how it may or may not satisfy their needs. Before and during conceptual analysis, the consumer’s focal attention is driven to undergo perceptual analysis where the consumer evaluates the sensory features of the objects of concern (Greenwald and Leavitt, 1984). This may be the container's shape, color, size, or packaging material. The brain categorizes these features into sub groups in order for the consumer to identify which product has the best combination of features to meet their needs.

Consumers' decisions towards product purchasing are driven by different motivations depending on the circumstance and the product. The attitude of consumers are often classified as driven by gratification based on sensory attributes of a product or as a functional, utilitarian perspective driven by non-sensory attributes (Batra and Ahtola, 1991). The distinction of these classes is critical in considering purchasing decisions because consumers will approach the buying process differently depending on this factor. Whitley et al. (2018) researched situations of hedonic verses utilitarian motivations in consumer decision making in regards to preference of size assortment of options. Consumers with a hedonic purchase motivation preferred to choose from a larger assortment of options compared to those influenced by utilitarian motivations. If retailers do not understand which category their product(s) fit into from their consumers' perspective then negative results may occur such as increased dissatisfaction or increased levels of frustration from their targeted cliental.

Time Pressure and Task Motivation

Another important concept investigated by researchers includes defining the influence of time pressure and task motivation on consumer decision making. In most situations, consumers are not able to leisurely make purchasing decisions. Whether the circumstance is a mother grocery shopping with a small child on a busy weekend, or a family making a purchase of their first home, consumers are often undergoing at least a minimal amount of pressure to make their decision. This concept is seen often in marketing as “limited-time only” sales as a means to emphasize the scarcity of a product. Task motivation is characterized as the consumer’s involvement in the product stimuli (Celsi and Olson, 1988). Consumers make decisions differently when task motivation is high, as they spend more time acquiring information of the product (Celsi and Olson, 1988). Pieters and Warlop (1999) confirmed their theory through eye-tracking that consumers react differently under these two conditions and adapt their information processing patterns through systematic methods. Consumers who were under time pressure decreased their average duration of their eye fixations which indicated they accelerated their information scanning. They also filtered information by skipping information related to the brand and instead focused more of their attention to the attributes of the products, indicated by their inter-brand saccades. Consumers classified as highly motivated decreased in their information processing time as their average fixation durations increased and also revealed lower inter-brand saccades. This group skipped less of the brand name information and more of the pictorial elements of the products.

Optimizing Product Presentation

Several studies have validated that when a product is viewed for longer amount of time or repeatedly viewed, the likelihood of the product being purchased increases (Armel et al., 2008; Milosavljevic et al., 2012; Pärnamets et al., 2015; Gidlöf et al., 2017). This is the basis of why product developers and retailers have built an industry around a motive to capture consumer’s visual attention. Large manufacturers are willing to pay large sums of money to ensure their products are placed at what is considered prime shelf space as they believe the position of their product will influence consumers' willingness to purchase (Forster, 2002). Retailers use consumer behavior concepts to make decisions regarding store layout and shelf facings in order to increase sales. Retailers display larger facings of certain products in order to create larger visual appeal as this concept has been confirmed to increase consumer's visual attention (Chandon et al., 2009; Peschel and Orquin, 2013; Gidlöf et al., 2017).

Research has shown that consumers tend to look at the center shelves more often (Atalay et al., 2012). Further, consumers have been shown to hold beliefs that retailers organize shelf space in a specific manner as they associate the center shelf with popular, high turn-over items and the top shelf with expensive items (Wright, 2002). Work by Valenzuela et al. (2013) refutes this concept as it found retailer layouts contradicted consumer beliefs for certain commodities. The authors hypothesize benefits and repercussions of this mismatch of consumer perception and the reality of retailer layouts. Sales may be jeopardized if products are not where consumers "expect" them to be placed, as they may increase their level of frustration and therefore decrease in their satisfaction of the retailer. Alternatively, this may cause the consumer to spend more time searching retail space and as their attention increases they may purchase more items.

A valid question regarding the effect of exposing consumers to a large amount of options for a single type of product is whether or not they become overwhelmed and how this affects their purchasing decision. A common thought is that as the number of options increases, consumers will become stricter in the attributes they pay attention to in order to make their selection. An extensive review of the choice overload hypothesis was discussed by Scheibehenne et al. (2010), where 50 published and unpublished experiments of this topic are analyzed. The authors acknowledge that adverse consequences may occur including a decrease in motivation to make a choice or a decrease in overall satisfaction. Several viable arguments against the choice overload hypothesis have been considered, especially in the retail market setting. Concepts include studies showing a large variety of options increased the likelihood of satisfying a diverse demographic of consumers (Anderson, 2006), more choices lead to a competitive advantage over those who offer less (Arnold et al., 1983), and that consumers associate large product lines with minute differences between products of higher quality (Berger et al., 2007). This area of research has been identified as one needing further investigation and could benefit from the application of eye-tracking methods. Adding the concept of hedonic or utilitarian classification, as motivational factors of consumers, to the concept of product exposure in the retail setting would add a new dimension of understanding of consumer behavior as well.

Eye Tracking Application to Product Packaging

The visual appearance of a product in relation to its product category and its competing products influence consumer perception. A product's saliency is described as its low-level visual features of color, intensity, contrast, and edge orientation (Gidlöf et al., 2017). This term describes to what extent the product stands out from the adjacent, competing products. A study by Milosavljevic et al. (2012) showed that when participants were shown two snack options on a computer monitor that the saliency of the products were a larger driver for the participants selection compared to their personal preference when placed under a time pressure situation. Therefore, manufactures and retailers may use this attribute of a product to draw consumer's visual attention. Gestalt psychology was founded in 1912 by Max Wertheimer. Wertheimer developed the foundation of the Gestalt laws that serve to describe how humans group elements to see shape. It is important to note that the Gestalt theory focuses on cognitive perception of the human mind and does not address one's belief or emotional response. In other words, the theory does not imply anything towards a design's rhetoric value. These principles may be used to increase the effectiveness of designs and in some circumstances, the rhetoric of the design may be of high importance and may be understood through using the Gestalt theory (Moore and Fitz, 1993). Pilelienė and Grigaliūnaitė (2016) described these principles in detail.

In the food production industry companies place emphasis in their research and development sector to understand if the flavor, textural, and visual appraisal of the product will determine the satisfaction and repeat purchase of the customer. In order to reach the point where the customer makes this critique, they must be drawn to the product as it is displayed on the retail shelf. The packaging of the product serves as possibly one of the most important marketing tools for the product but is often overlooked. The packaging of the product enables the company to communicate the qualities of the product to the consumer. This communication is critical as the company could in theory develop the highest quality and most appetizing product available on the market, but if the packaging does not attract the consumer then the product's likelihood of failing increases substantially. Eye tracking methodology has recently shown to be beneficial in observing the visual attention of differing packaging features (Bialkova and van Trijp, 2010; Bialkova et al., 2013; Clement et al., 2013; Husić-Mehmedović et al., 2017). Research has shown that limited cognitive capacity affects consumers when they view multiple visual stimuli. Consumers will reduce the number of factors in their visual search in order to make a choice. This makes the packaging of a product more crucial in attracting the consumer's attention. The product name, symbols, and slogans of well-known brands create an anchor in consumer's minds (Underwood and Klein, 2002). The positive aspect of this concept can be minimized by the proposed thought that objects that are seen regularly will ultimately receive less visual attention over time (Rosbergen et al., 1997). Manufactures must be careful when adjusting packaging appearances, as too drastic of changes may be disapproved by consumers resulting in a financial loss for the company. Clement et al. (2013) recognized that the current research literature at the time recognized the visual stimulation of products influenced the decision-making processes. However, the literature failed to describe when and which visual elements affected the consumer's choice. The researchers designed an eye tracking experiment to take place in a realistic grocery retail setting where consumers viewed a variety of 95 jam products. Clement et al. (2013) wanted to evaluate the influence of bottom-up processing and if the number of features on the label influenced the consumer's visual attention. The design features of the jams, such as the shape of the container, initiated the first-eye contact from consumers, not the test descriptions of the brand attributes.

Therefore, utilizing the design features of the product may reduce the chances of being overlooked. It is important to note that consumers do need the higher-level design features like the brand and text elements as well as the brand colors as they use this information to understand the product completely. If the consumer's attention is not attracted to the product through the bottom-up features, then the consumer will never reach the point to interpret these higher-level features.

Husić-Mehmedović et al. (2017) acknowledged that packages compete for consumers' attention within their respective category. Consequently, research and interpretation must be conducted within the actual product category and cannot be applied across commodities to gain insight. Husić-Mehmedović et al. (2017) studied consumer's visual attention for canned beer. An important feature of the beer products was that the containers were of similar size and shape. This was unlike the jam jars aforementioned in the experiment by Clement et al. (2013), which was concluded to have influenced consumer perception. Without this feature difference in canned beer products, the color and semantic features represented the decisive factors for attracting consumer attention. For the final phase of the study, participants were surveyed on the likability and recall of the beer products they viewed during the previous phases. The researchers were interested in comparing the packages that attracted the most attention (collected from eye-tracking data) to the responses of the survey. Interestingly, packages that preformed the highest for attention received under average likeability scores. The researchers acknowledge that brand familiarity did appear to play a role in the likability scores of the packaging design. These results emphasize the need for packaging research to be conducted for specific products as the unique features of the product category can influence overall conclusions and inferences.

Overall, the literature provided associated with product packaging design implicates an area of missed opportunity for manufacturers. From the limited amount of information present, eye tracking appears to be a method that is able to capture a significant amount of insight towards consumer's perception of product appearance. This subject represents an opportunity researchers and companies should acquire for a means to gain market share in their product's category.

Accessing Human Emotional Response

Facial coding is the process of measuring human emotions through their facial expressions. Emotions are interpreted through subtle facial expressions referred to as action units. Examples of action units include lifting of an eyebrow or wrinkling of the nose. Expressions can be classified as macroexpressions, microexpressions, or subtle expressions. Macroexpressions occur frequently and last between 0.5 – 4 s. Microexpressions last less than 0.5 s and occur when we consciously or non-consciously attempt to conceal an emotion. Subtle expressions refer to the intensity of an underlying emotion, such as when a person has an extreme smile and it begins to fade, as we do not hold these expressions constantly. People universally recognize the emotions of happiness, sadness, fear, anger, disgust, and surprise (Ekman et al., 1987). The understanding of these emotions across cultures supports what researchers term as the "Universality Hypothesis" (iMotions, 2015). Facial expression analysis allows researchers to quantify facial expressions that are then used to measure the emotional response of respondents.

Although there are multiple emotion recognition engines available, all are comprised of the same steps to undergo automatic facial coding. These steps are explained in further detail by iMotions (2017). First, the position of the respondent's face is detected through the programs algorithm, resulting in a face box framing the detected face. The features of the respondent's face are then detected, such as their eyes, brows, and the corners of their mouth. As the respondent's face moves the pinpointed features shift as well. The position and orientation information of the respondent's features are then fed into a classification algorithm. The features are translated into action units and emotional states. These translations are computed statistically, as they are compared to a database that contains distributions of all feature characteristics from respondents representing multiple geographic locations and demographic profiles. Emotional states are classified based on a probability that reflects the likelihood that the expression is reflected of the stated emotion.

Other Human Biometric Analyses

Electrodermal activity (EDA), also known as galvanic skin response (GSR) measures the level of sweat secretion from the sweat glands in the skin of our finger palms (iMotions, 2017). As the level of the secretion of our sweat increases there is an increase in our skin's conductivity. Skin conductance is controlled on a subconscious level and therefore serves as an unbiased method to measure emotional arousal.

Electroencephalography (EEG) is a form of neuroimaging that measures the electrical activity generated by the brain. Portable sensors and amplifier systems are placed on the scalp surface to measure these data. Electroencephalography decodes which parts of the brain are activated when a respondent is exposed to stimuli. This tool can give insights towards ones' subconscious engagement, motivation, frustration, and cognitive workload (iMotions, 2017).

Potential Application to the Beef Industry

The beef industry relies on the quality attributes of the product (e.g. color and marbling) to attract the visual attention of consumers. Contrary to the stability of packaging of non-perishable foods, intrinsic factors of the meat control the visible appearance of the meat products. These to a large extend are out of the control of the retailers (Suman et al., 2014). Although this may be a large obstacle to overcome, factors are still available to increase attention to these products. Literature relating to consumer beef satisfaction has focused on the influence of beef palatability on consumer perception in regards to a number of topics. These include, but are not limited to, USDA maturity group (Smith et al., 1982), tenderness level and beef cut (Morgan et al., 1991; Brooks et al., 2000; Voges et al., 2007; Guelker et al., 2013; Martinez et al., 2017), variation in marbling amount (Savell et al., 1987), beef flavor (Kerth and Miller, 2015), regional influence (Neely et al., 1998; Lorenzen et al., 1999; Savell et al., 1999), cooking method and degree of doneness (Lorenzen et al., 1999). The application of eye tracking software to monitor the effect of these intrinsic factors on consumer satisfaction would add an additional perspective to these topics.

Extrinsic factors, such as branding, are present in a portion of fresh meat products available to consumers. Fresh beef branding segregates product through Certified Beef Programs and audited programs that define claims such as grass fed, tenderness claims, non-hormone, and humanely raised (USDA, 2019b). Additionally, a large portion of the beef industry is represented by processed meat products. This sector does have the advantage of shelf space and packaging applications that may be manipulated to attract consumer visual attention. This adds an additional portion of the industry where eye tracking application would be useful in order to gain further insight into the reaction of consumers. Fresh and processed meat products may be improved by the application of eye-tracking software in research experiments to understand consumers perception of these products. These research tools have the ability to gain perspective on consumers' cognitive processing that is not obtainable through surveys, focus groups, or observation. Additionally, these tools may be beneficial in improving communication with the public regarding agricultural practices.

CHAPTER II

UPDATING CONSUMER TENDERNESS AND JUICINESS THRESHOLDS

Introduction

Shackelford et al. (1991) analyzed the population of A and B maturity carcasses (n = 678) from the study of Smith et al (1982) that included product representative of marbling scores from Practically Devoid to Moderately Abundant. The average WBSF value was 3.8 kg with a standard deviation (SD) of 1.3 kg. Shackelford et al. (1991) used “slightly tough,” “slightly tender,” “moderately tender,” and “very tender” in association with 4, 5, 6, and 7 values on an 8-point scale, respectively. These data were used in regression analyses of trained sensory panel overall tenderness ratings of beef top loin steaks on Warner–Bratzler shear force (WBSF) values to determine confidence levels of 50, 68, and 95% for the WBSF values associated with overall tenderness ratings from the trained sensory panel corresponding to “slightly tender”. An average (50% confidence level) WBSF value of 4.6 kg was predicted from evaluating their equation using “slightly tender” value of 5. With a chosen SD of 0.7 kg, a reduction to 3.9 kg (-1 SD) was required to achieve a confidence level of 68% and 3.2 kg (-2SD) achieved a 95% confidence level. To verify the accuracy of their proposed thresholds, Shackelford et al. (1991) evaluated the confidence levels against the trained sensory panel overall tenderness ratings from Smith et al. (1982) and the National Consumer Retail Beef Study (Savell et al., 1987). In addition, household consumer data from the National Retail Beef Study was used to validate thresholds. The study recommended using a confidence level of 50%, 4.6 kg, as a benchmark to evaluate beef tenderness. Later research used the confidence intervals developed by Shackelford et al. (1991) to create classifications of tenderness of "very tender" (WBS < 3.2 kg), "tender" (3.2 < WBS < 3.9 kg), "intermediate" (3.9 < WBS < 4.6 kg), and "tough" (WBS > 4.6 kg) to categorize 40 bovine muscles (Belew et al., 2003).

Since the publication of Shackelford et al. (1991), these thresholds have been extensively used in development of instrument grading for tenderness in order to segment beef. The ASTM (2011) established tenderness thresholds for label verification for "Certified Tender" and "Certified Very Tender" product label claims. However, there is concern that consumer thresholds have changed in the last 30 years. Additionally, beef tenderness has improved and is less variable based on beef tenderness surveys conducted since 1989 (Morgan et al., 1991; Brooks et al., 2000; Voges et al., 2007; Guelker et al., 2013; Martinez et al., 2017). The most recent of these surveys reported 95.93% of boneless, top loin strip steaks met the classification of "very tender" (Martinez et al., 2017). As beef has slowly improved in tenderness and tenderness variation is less, consumer thresholds for tenderness may have changed. While consumer trends change slowly, it is not unreasonable to hypothesize that beef tenderness thresholds have changed in the last 30 years. The percentage distribution of beef cuts based on tenderness classification has become right skewed, as a majority of cuts fall into the "very tender" threshold and few are categorized as "tough." In order to make advances and track the progress of consumer beef satisfaction, a redistribution of the tenderness thresholds was necessary to create more room to progress. The objective of this study was to establish tenderness and juiciness thresholds using consumer and trained descriptive tenderness and juiciness attributes, and WBSF to propose updated confidence levels to evaluate beef tenderness and juiciness.

Materials and Methods

Data analyzed for this project were previously collected through two Beef Checkoff projects. The materials and methods for these studies included additional analyses including gas chromatography-mass spectrometry-olfactometry, fatty acid composition, non-heme iron and myoglobin content, pH, and fat and moisture analysis. These data were excluded from our analysis, as it did not relate to the objective of this project. Additional information regarding the specific protocols for each of these studies are stated in the respective thesis, which may be provided upon request of the corresponding author.

Overview of Data

The objectives of the first study, Luckemeyer (2015), were to characterize beef flavor attributes as positive or negative across consumer segments, specifically consumers classified as light beef eaters (eat beef twice a week or less). Choice strip loins, high pH strip loins (pH ≥ 6.0), Select top sirloins, Choice tenderloins, Select bottom rounds, and Choice bottom rounds from 10 beef carcasses were collected and cut into steaks (Choice top loin, high pH top loins, Select top sirloin, Choice tenderloin) and roasts (Select and Choice bottom round). Top loin steaks were cooked to 58 °C or 80 °C utilizing a George Forman grill (Choice top loin, High pH top loin, Select top sirloin and Choice tenderloin steaks) set at 191 °C, a flat food-service grill at 232 °C (Choice top loin, High pH top loin, Select top sirloin and Choice tenderloin steaks), or crock-pot (Select and Choice bottom round roasts). These data were defined as Study 1.

Study 2 data were obtained from Laird (2015) and were analyzed similarly to Study 1. The objectives of Study 2 were to identify and select four consumer groups of millennials and non-millennials that were either light (eat beef 2 to 4 times per month) or heavy (eat beef 3 or more times per week) beef eaters to determine perceptions of overall liking of beef, chicken and pork cooked differently to create differences in flavor. USDA Choice beef top strip loin (cooked to 58 or 80°C on a commercial electric flat grill); Select bottom round flat roasts (approximately 0.9 kg; cooked to 58 or 80°C in a crockpot); chicken breast (cooked to 62 or 80°C on a commercial electric flat grill); thigh meat (not enhanced; cooked to 62 or 80°C in a crockpot); boneless pork loins (cooked to 62 or 80°C on a commercial electric flat grill); and inside ham roasts (not enhanced; cooked to 62 or 80°C in a crock pot) were purchased commercially. Top loin steaks, chicken breasts and pork chops were cooked on a commercial electric grill (StarMax 536GF 36 inch Countertop Electric Griddle, Star Manufacturing International, Inc., St. Louis, MO) set at 232 °C. Data used for analysis were evaluated in two sets. One set was limited to top strip loin steaks, as both Study 1 and 2 evaluated this cut. The second set included all beef cuts used in both studies in order to generate analyses of a wide variation of beef products industry produces for consumer purchase.

Trained Descriptive Beef Flavor Analysis

Steaks and roasts from Study 1 and Study 2 were evaluated by a trained beef-flavor descriptive attribute panel that helped develop and validate the beef lexicon

(Adhikari et al., 2011). Before each study, the panel was retrained using the beef lexicon for 14 d. Beef flavor attributes were measured using the beef lexicon (0 = none and 15 = extremely intense). After cooking, samples were placed in a food warmer set at 60°C (Alto-Shaam, Model 750-TH-II, Milwaukee, WI) for no longer than 20 min. Samples were cut into 1.27 cm cubes and served immediately to assure samples were approximately 37°C at time of serving (AMSA, 2016). Two cubes per sample were served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Samples were identified with random three-digit codes and served in random order. Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm-up" sample that was evaluated and discussed orally. After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each beef flavor lexicon attribute. Double-distilled water, unsalted saltine crackers and ricotta cheese were available for cleansing the palette between samples. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights. In order to prevent taste fatigue, samples were served at least four minutes after the completion of the prior sample with the exception of a ten-minute break that divided each test day into two sessions.

Consumer Evaluation

In Study 1, consumers (n = 80 per city) were randomly selected in three cities (Olathe, KS; State College, PA; and Portland, OR). Study 2 included consumers (n = 120 per city) randomly selected in four cities (Griffin, GA; Olathe, KS; State College, PA; and Portland, OR). Cities were selected to include the Southeast (Study 2 only), the Midwest, the east coast, and the west coast. Study 1 held four consumer sessions and Study 2 conducted six consumer sessions, with approximately 20 consumers per session in each city surveyed. For both studies, consumer panelists were recruited by the individual research institution in each city and all panelists were required to pass a consumer screener guaranteeing them to be over 18 years of age and have no food allergies. Specifically, for Study 1, consumer recruitment was limited to individuals who consumed beef a maximum of one or two times per week (including ground beef). Study 2 did not have a standard for consumer beef consumption, therefore consumers were defined as either heavy or light beef eaters based on collected demographic data. On the day of evaluation, recruited consumer panelists were asked to sign an informed consent document. An instructional document, demographic ballot and ten individual sample ballots were provided to the consumer upon entering the testing room. Consumer demographics for age, sex, income, household size, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, and meat shopping habits were determined. The sample ballot included overall liking, overall flavor liking, beefy-flavor liking, grilled-flavor liking, juiciness liking, and tenderness liking using end- and middle-anchored 9-point hedonic scales. Panelists were provided ten pre-identified random samples in a pre-determined random order at least four minutes apart after the evaluation of the previous sample. Samples were served in clear plastic soufflé cups labeled with a random three-digit number corresponding to their ballot. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis.

Warner-Bratzler Shear Force

For both, Study 1 and Study 2, steaks and roasts for Warner-Bratzler shear force were cooked in the same manner and at the same time as trained descriptive beef flavor analysis steaks. Cooking yield percentages were determined from weights recorded before and after cooking and total cooking time was recorded for individual steaks and roasts. Steaks and roasts were trimmed of visible connective tissue to expose muscle fiber orientation. Six-1.3 cm diameter round cores were removed from each muscle. Roasts were cut in 2.54 cm sections and then cores were removed. Cores were removed parallel to the muscle fibers and sheared once, perpendicular to the muscle fibers, on a United Testing machine (United SSTM-500, Huntington Beach, CA) at a cross-head speed of 200 mm/min using a 500 kg load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak. The peak force (kg) needed to shear each core was recorded, converted to Newtons (N), and the mean peak shear force of the cores was used for statistical analysis. Values were converted using the following equation: WBSF (N) = WBSF (kg) × 9.81.

Statistical Analysis

For each hypothesis, regression equations were calculated using either consumer tenderness liking, juiciness liking, and overall liking; trained descriptive attribute sensory muscle fiber tenderness, connective tissue amount, juiciness and overall tenderness; or Warner-Bratzler shear force. The PROC MEANS (9.4, SAS Institute Inc., Cary, NC) function was used to calculate means, minimum, and maximum values for all variables used in the displayed regression equations. Least squares means were calculated for WBSF of each category for each demographic section within each hypothesis. Predicted WBSF values using defined regression equations and the subsequent 95, 68 and 50% confidence intervals were calculated.

Results and Discussion

Table 1 describes definitions and references for trained descriptive sensory attributes adapted from AMSA (2016). Table 2 displays the descriptive statistics for the combined data from Study 1 and Study 2 for top loin strip steaks and all beef cuts separately. For top loin steaks, consumers rated juiciness, tenderness, flavor, and overall liking averaged 6.6, 6.4, 6.9, and 6.8, respectively, using a 9-point hedonic scale. The average WBSF value was 2.88 kg for all beef cuts and 2.69 kg for top loin steaks. Therefore, the average beef cut and top loin steak would be classified as “very tender” according to the tenderness thresholds developed by Shackelford et al. (1991) and (Belew et al., 2003).

Table 1. Definition and reference standards for meat descriptive sensory attributes and their intensities where 1 = none; 15 = extremely intense adapted from AMSA (2016).

Attribute	Definition	Reference
Juiciness	The amount of perceived juice that is released from the product during mastication.	Carrot = 8.5; Mushroom = 10.0; Cucumber = 12.0; Apple = 13.5; Watermelon = 15.0 Choice top loin steak cooked to 58ºC = 11.0 Choice top loin steak cooked to 80ºC = 9.0
Muscle fiber tenderness	The ease in which the muscle fiber fragments during mastication.	Select eye of round steak cooked to 70ºC = 9.0 Select tenderloin steak cooked to 70ºC = 14.0
Connective tissue amount	The structural component of the muscle surrounding the muscle fiber that will not break down during mastication.	Cross cut beef shank cooked to 70ºC = 7.0 Select tenderloin cooked to 70ºC = 14.0
Overall tenderness	Average of the muscle fiber tenderness and connective tissue amount when connective tissue is a 6 or less. When connective tissue is 7 or more, overall tenderness is equal to muscle fiber tenderness.	

Table 2. Descriptive statistics of consumer evaluations for juiciness, tenderness, flavor, and overall liking, Warner–Bratzler shear force values (kg), and trained, descriptive sensory panel ratings for muscle fiber tenderness, connective tissue amount, juiciness, and overall tenderness.

Variable	Mean	SD	Minimum	Maximum
Top loin steaks (*n* =273)				
Juiciness liking[a]	6.6	1.42	1.75	9.00
Tenderness liking [a]	6.4	1.39	1.75	9.00
Flavor liking [a]	6.9	1.29	1.00	9.00
Overall liking[a]	6.8	1.33	1.00	8.75
Warner–Bratzler shear force, kg	2.69	0.802	1.33	5.59
Muscle fiber tenderness[b]	11.5	1.08	7.20	13.40
Connective tissue amount[b]	12.2	0.71	10.25	13.67
Juiciness[b]	10.7	1.28	7.25	13.00
Overall tenderness[b]	11.6	1.10	7.20	13.40
All beef cuts (*n*=792)				
Juiciness liking	5.9	1.75	1.25	9.00
Tenderness liking	5.9	1.71	1.00	9.00
Flavor liking	6.1	1.49	1.00	9.00
Overall liking	6.0	1.54	1.00	9.00
Warner–Bratzler shear force, kg	2.88	0.949	1.23	5.97
Muscle fiber tenderness	11.1	1.58	6.20	14.20
Connective tissue amount	11.7	1.41	5.80	14.20
Juiciness	10.0	1.52	6.40	13.00
Overall tenderness	11.0	1.64	6.00	14.20

[a]Consumer sensory juiciness, tenderness, flavor, and overall liking were evaluated where 1=dislike extremely and 9= like extremely, respectively.

[b]Trained descriptive attributes for muscle fiber tenderness, connective tissue amount, juiciness, and overall tenderness were evaluated where 1=extremely tough, extremely abundant, extremely dry and extremely tough and 15=extremely tender, none, extremely juicy, and extremely tender, respectively.

Average trained, descriptive sensory panel ratings for overall tenderness of top loin steaks (11.6) and of all beef cuts (11.0) were classified as “moderately tender”. This indicated the need to increase the WBSF threshold criteria from “slightly tender” to “moderately tender” in order to base new classification standards on the updated average panelists rating. For all beef cuts, the average trained, descriptive sensory panel ratings for juiciness was reported as 10.0, between “slightly juicy” and “moderately juicy”. This suggests a juiciness threshold be established at “slightly juicy”. When all beef cuts were analyzed, mean consumer sensory ratings were lower and descriptive sensory mean attributes were slightly lower than when top loin steaks were analyzed, soley. However, the range of values for descriptive sensory attributes was greater, indicating that development of regression equations using all beef cuts may provide more accurate prediction of beef tenderness and juiciness as it encompasses a more applicable, wider array of beef products.

Correlation coefficients for all beef cuts and top strip steaks data sets are shown in Table 3. For top loin steaks, insignificant ($P > 0.05$) relationships among consumer attributes of overall, juiciness, tenderness, and flavor liking with trained, descriptive sensory panel attributes of overall tenderness and juiciness were reported with the exception of juiciness liking and juiciness, which had a weak, positive relationship ($P < 0.05$). These results were expected as previously reported by Shackelford et al. (1991). The strength of the relationships between consumer attributes and trained, descriptive sensory attributes increased when all beef cuts were analyzed. All coefficient values were reported as significant ($P < 0.001$) at either weak or moderate strength. Correlation coefficients for WBSF values, and trained, descriptive sensory attributes of overall tenderness (r = -0.49) and juiciness (r = -0.41) were reported as moderate in strength and negative in direction ($P < 0.001$). For consumer attributes, only flavor liking was reported as having a significant relationship ($P < 0.05$) with WBSF (r = -0.12). For all beef cuts, negative, weak relationships ($P < 0.001$) were reported for WBSF and consumer overall and flavor liking, while consumer tenderness and juiciness liking and trained panel overall tenderness reported negative, moderate relationships ($P < 0.001$). Trained panel juiciness was positive and moderate in relationship to WBSF ($P < 0.001$). Further, positive, strong relationships among the consumer attributes of overall, juiciness, tenderness, and flavor liking ($P < 0.001$) were reported. Notably, overall and flavor liking reported an r value of 0.92 for all beef cuts and 0.93 for top loin steaks, aligning with the findings of previous research (Huffman et al., 1996; Neely et al., 1998; Killinger et al., 2004; O'Quinn et al., 2012). These findings indicate a strong, positive relationship between consumers' overall liking and flavor liking of beef products. Additionally, assessment of possible issues of multicollinearity was addressed by observing correlation coefficients. Multicollinearity occurs when a correlation exists among independent variables. If present, a substantial decrease in the quality of the model would have occurred, causing untrustworthy regression coefficients, inflated standard errors and possible incorrect signs of the coefficients (Lauridsen and Mur, 2006), regardless if high R-squared statistics were present (Yeniay and Goktas, 2002).

Variables with strong correlations must be avoided in concurrent usage as independent variables in regression equation development.

In order to identify suitable regression equations to update consumer beef tenderness thresholds and to develop consumer juiciness thresholds, different response variables were investigated. Table 4 reported consumer attributes as the response variable with explanatory variables of either WBSF or other consumer attributes. Due to high correlation values among consumer attributes, multiple linear regression equations were not investigated. Predicting consumer overall, tenderness, and juiciness liking using consumer sensory attributes resulted in regression equations with moderate to high predictability, as expected due to previously discussed correlation coefficients. Equations that included consumer flavor liking as a predictor of consumer overall liking had the highest adjusted r^2 values, indicating that flavor was a greater driver of consumer liking than either tenderness or juiciness liking. Warner–Bratzler shear force was a poor predictor of overall, tenderness, and juiciness liking consumer sensory attributes. Therefore, the use of consumer attributes in the development of tenderness thresholds were not further investigated. This was similarly reported by Shackelford et al. (1991).

Table 3. Correlation coefficients for trained, descriptive sensory panel attribute, consumer liking attributes, and Warner–Bratzler shear force.

	Overall Tenderness	Juiciness	Overall liking	Juiciness liking	Tenderness liking	Flavor liking	WBSF
Overall tenderness[a]	—	0.55**	0.31**	0.32**	0.41**	0.29**	-0.60**
Juiciness[a]	0.57**	—	0.33**	0.45**	0.41**	0.35**	0.42**
Overall liking[b]	0.02	0.00	—	0.72**	0.75**	0.92**	-0.25**
Juiciness liking[b]	0.08	0.20*	0.74**	—	0.83**	0.65**	-0.34**
Tenderness liking[b]	0.08	0.12	0.76**	0.83**	—	0.65**	-0.36**
Flavor liking[b]	0.12	-0.06	0.93**	0.65**	0.65**	—	-0.21**
WBSF	-0.49**	-0.41**	-0.08	-0.10	-0.10	-0.12*	—

Correlation coefficients above the diagonal represent correlations of all beef cuts (n = 792); coefficients below the diagonal represent correlations of top loin steaks (n = 273).

**Significant at $P < 0.001$

*Significant at $P < 0.05$

Table 4. Regression equations to predict consumer overall, tenderness, and juiciness liking ratings.

			Dependent variables					
	Intercept	Shear Force	Overall liking	Tenderness liking	Juiciness liking	Flavor liking	Adjusted R^2	RMSE
All beef cuts								
Overall liking	7.417*	-0.491*					0.08	1.473
Overall liking	1.825*			0.706*			0.60	0.963
Overall liking	2.091*				0.658*		0.55	1.027
Overall liking	0.061					0.961*	0.85	0.593
Tenderness liking	8.039*	-0.738*					0.16	1.561
Tenderness liking	0.729*		0.864*				0.60	1.066
Tenderness liking	1.190*				0.795*		0.66	0.988
Tenderness liking	1.185*					0.765*	0.44	1.276
Juiciness liking	7.835*	-0.657*					0.12	1.639
Juiciness liking	0.858*		0.847*				0.55	1.165
Juiciness liking	0.995*			0.836*			0.66	1.013
Juiciness liking	1.068*					0.789*	0.44	1.304
Top loin strip steaks								
Overall liking	7.750*	-0.413*					0.04	1.331
Overall liking	2.048*			0.734*			0.57	0.882
Overall liking	2.307*				0.675*		0.53	0.924
Overall liking	0.204					0.947*	0.85	0.523
Tenderness liking	7.805*	-0.579					0.08	1.352
Tenderness liking	0.993*		0.792*				0.57	0.916
Tenderness liking	1.157*				0.794*		0.69	0.783
Tenderness liking	1.352*					0.721*	0.45	1.043
Juiciness liking	7.721*	-0.486*					0.05	1.443
Juiciness liking	1.094*		0.802*				0.53	1.007
Juiciness liking	0.951*			0.874*			0.69	0.822
Juiciness liking	1.387*					0.740	0.43	1.114

[a]RMSE = Root Mean Square Error.
*Significant at $P < 0.05$

Regression equations using descriptive, trained panel attributes as response variables are reported in Table 5. When all beef data were used, r^2 values were slightly higher for respective regression equations, especially when juiciness was involved. The stronger predictability of WBSF using descriptive juiciness and tenderness attributes may have resulted from the use of a trained descriptive sensory panel trained to separate tenderness and juiciness attributes where consumers most likely were not able to. It was most likely that the addition of the other beef cuts increased the variability in juiciness and provided greater predictability. When juiciness was used in combination with WBSF to predict overall tenderness of top loin steaks, the predictability was similar to when WBSF was used as the single predictor. Based on adjusted r^2 values, equations using overall tenderness as the response variable and WBSF as the explanatory variable were identified as the simple regression equation for all beef cuts and top loin steaks with the greatest predictability. When juiciness was added to create a multiple variable equation, a notable increase in the adjusted r^2 value occurred. The simple regression equation was used for predictability assessment as it included the same variables as the beef tenderness thresholds developed by Shackelford et al. (1991).

Table 5. Regression equations to predict trained, descriptive sensory panel overall tenderness or juiciness attributes.

		Dependent variables				
	Intercept	Shear Force	Juiciness	Overall tenderness	Adjusted R^2	RMSE
All beef cuts						
Overall tenderness	14.052*	-1.074*			0.36	1.316
Overall tenderness	9.213*	-0.768*	0.396*		0.47	1.204
Juiciness	12.193*	-0.770*			0.22	1.344
Juiciness	6.373*	-0.326*		0.414*	0.34	1.230
Top loin strip steaks						
Overall tenderness	13.718*	-0.878*			0.31	0.946
Overall tenderness	11.957*	-0.817*	0.150*		0.34	0.929
Juiciness	11.680*	-0.404*			0.04	1.278
Juiciness	7.911*	-0.162		0.274*	0.08	1.254

[a]RMSE = Root Mean Square Error.

*Significant at $P < 0.05$

Three regression equations were selected from Table 5 to update and develop tenderness and juiciness thresholds. Table 6 reports the predicted average WBSF for each point within the overall tenderness descriptive attribute scale (1 = extremely tough; 15 = extremely tender) by using the previously develop equation for top loin steaks. Table 7 reports this same relationship, but all beef cuts were used. Similarly, Table 8 shows the predicted average WBSF corresponding with each point on the trained, descriptive juiciness scale. As overall tenderness descriptive panel ratings increased, predicted WBSF values decreased. For top loin steaks, a WBSF of 3.10 kg was associated with the 50% CL for the overall tenderness value of "moderately tender," indicating steaks with WBSF of 3.10 kg or less were considered moderately tender or more tender. A beef cut with WBSF values of 2.84 kg or less would be considered moderately tender or more tender. These different predictions would be expected as samples from the additional beef cuts included beef tenderloin steaks, top sirloin steaks, and bottom round steaks derived from bottom round roasts, creating a more variable data set. A beef cut with a WBSF of 4.15 kg or less was predicted to be slightly juicy or juicier.

Table 6. Predicted trained, descriptive sensory panel overall tenderness from regression equation (Trained, descriptive overall tenderness = 13.718 – 0.878 * WBSF (kg)) for top loin strip steaks.

Overall Tenderness Descriptive Attribute	Predicted Mean
1-extremely tough	14.49
2	13.35
3-very tough	12.21
4	11.07
5-moderately tough	9.93
6	8.79
7-slightly tough	7.65
8	6.51
9-slightly tender	5.37
10	4.23
11-moderately tender	3.10
12	1.97
13-very tender	0.82
14	-0.32
15-extremely tender	-1.46

Regression equation developed with $n = 182$ randomly selected observations used as training subset.
Predicted WBSF values estimated with remaining $n = 91$ observations used as validation subset.

Table 7. Predicted trained, descriptive sensory panel overall tenderness from regression equation (Trained, descriptive overall tenderness = 14.052 – 1.074* WBSF (kg)) for all beef cuts.

Overall Tenderness Descriptive Attribute	Predicted Mean
1-extremely tough	12.15
2	11.22
3-very tough	10.29
4	9.35
5-moderately tough	8.42
6	7.50
7-slightly tough	6.57
8	5.63
9-slightly tender	4.70
10	3.77
11-moderately tender	2.84
12	1.91
13-very tender	0.98
14	0.48
15-extremely tender	-0.88

Regression equation developed with n = 530 randomly selected observations used as training subset. Predicted WBSF values estimated with remaining n = 262 observations used as validation subset.

Table 8. Predicted trained, descriptive sensory panel juiciness from regression equation (Trained, descriptive juiciness = 12.193 – 0.770* WBSF (kg)) for all beef cuts.

Juiciness Descriptive Attribute	Predicted Mean
1-extremely dry	14.54
2	13.24
3-very dry	11.94
4	10.64
5-moderately dry	9.34
6	8.04
7-slightly dry	6.74
8	5.45
9-slightly juicy	4.15
10	2.85
11-moderately juicy	1.55
12	0.25
13-very juicy	-1.05
14	-2.35
15-extremely juicy	-3.65

Regression equation developed with n = 530 randomly selected observations used as training subset.
Predicted WBSF values estimated with remaining n = 262 observations used as validation subset.

Figure 1 displays the plot of descriptive, trained panel tenderness ratings regressed on WBSF of top loin steaks. In order to find the 68 and 95% CL WBSF means, the WBSF standard deviation of top loin steaks was used (SD = 0.802). Therefore, the WBSF corresponding to the -1SD (68% CL) was 2.30 kg and the -2SD (95% CL) was 1.50 kg. These values may be interpreted as: a top loin steak with a WBSF of 3.10 kg or lower is 50 % certain to be 'moderately tender' or more tender; a top loin steak with a WBSF of 2.30 kg or lower is 68% certain to be 'slightly tender' or more tender; and a top loin steak with a WBSF of 1.50 kg or lower is 95 % certain to be 'slightly tender' or more tender. The WBSF associated with the 50% CL was lower when all beef cuts were used (Figure 2). The interpretation of the CL associated with the tenderness of all beef cuts was similar to Figure 1, with the exception that the WBSF SD of all beef cuts was slightly higher, at 0.949. Therefore, the WBSF thresholds associated with the 50, 68, and 95% CL were 2.84, 1.89, and 0.94 kg, respectively. Figure 3 showed the plot for trained, descriptive panel ratings for juiciness regressed on WBSF. Warner-Bratzler shear force values of 4.15, 3.20, and 2.25 kg were associated with 50, 68, and 95% CL, respectively for a beef cut evaluated as slightly juicy or juicer.

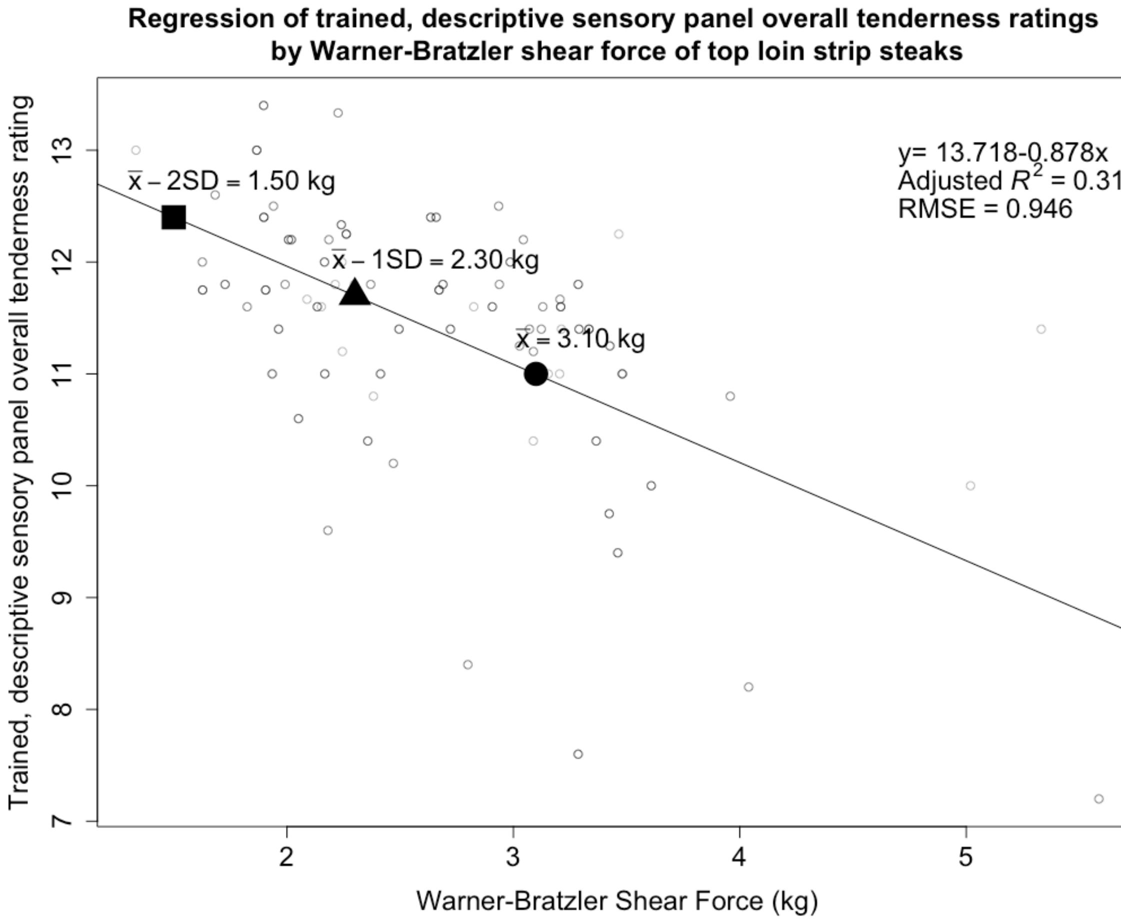


Figure 1. Determination of tenderness threshold values for top loin steaks. The average WBSF corresponding to "moderately tender" was 3.10 kg (●; 50% CL). The population SD (0.802) of WBSF for top loin steaks determined 2.30 (▲; 68% CL) and 1.50 kg (■; 95% CL) as additional threshold values.

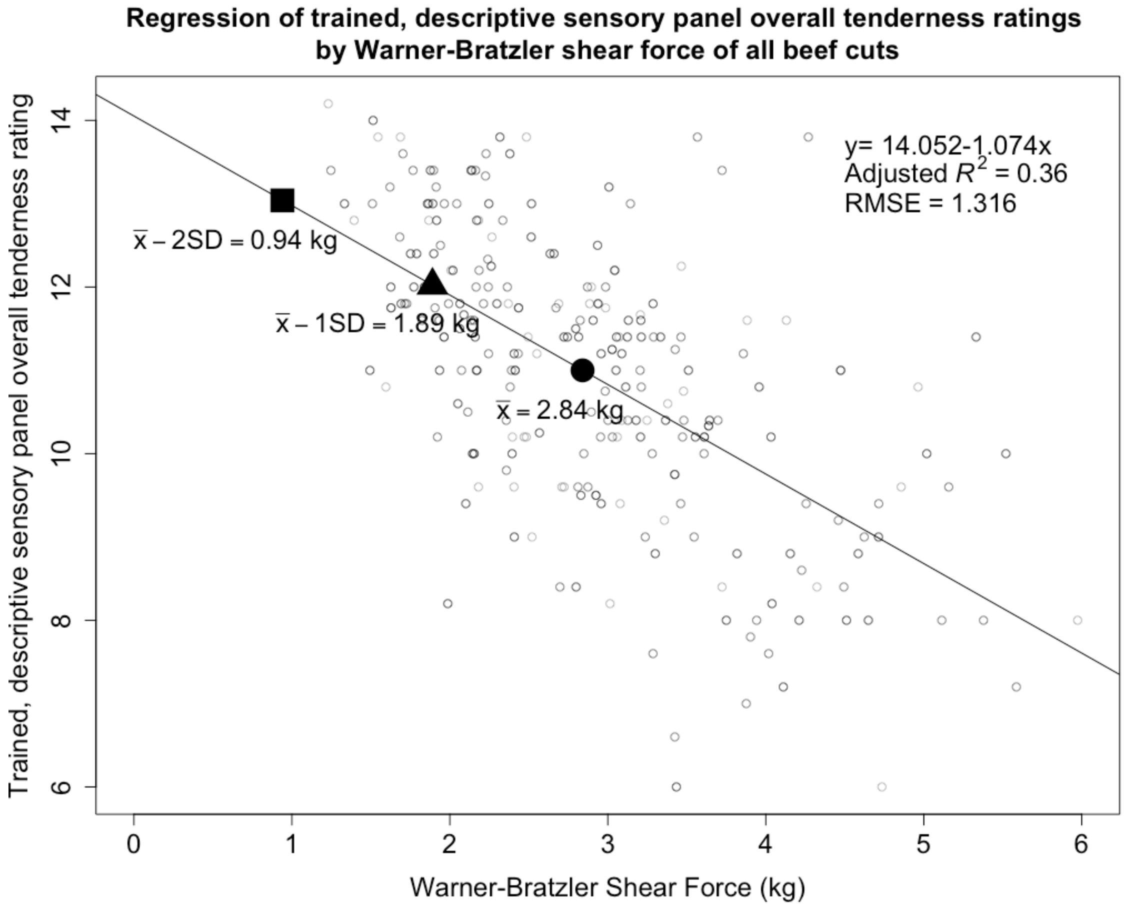


Figure 2. Determination of tenderness threshold values for all beef cuts. The average WBSF corresponding to "moderately tender" was 2.84 kg (●; 50% CL). The population SD (0.949) of WBSF for all beef cuts determined 1.89 (▲; 68% CL) and 0.94 kg (■; 95% CL) as additional threshold values.

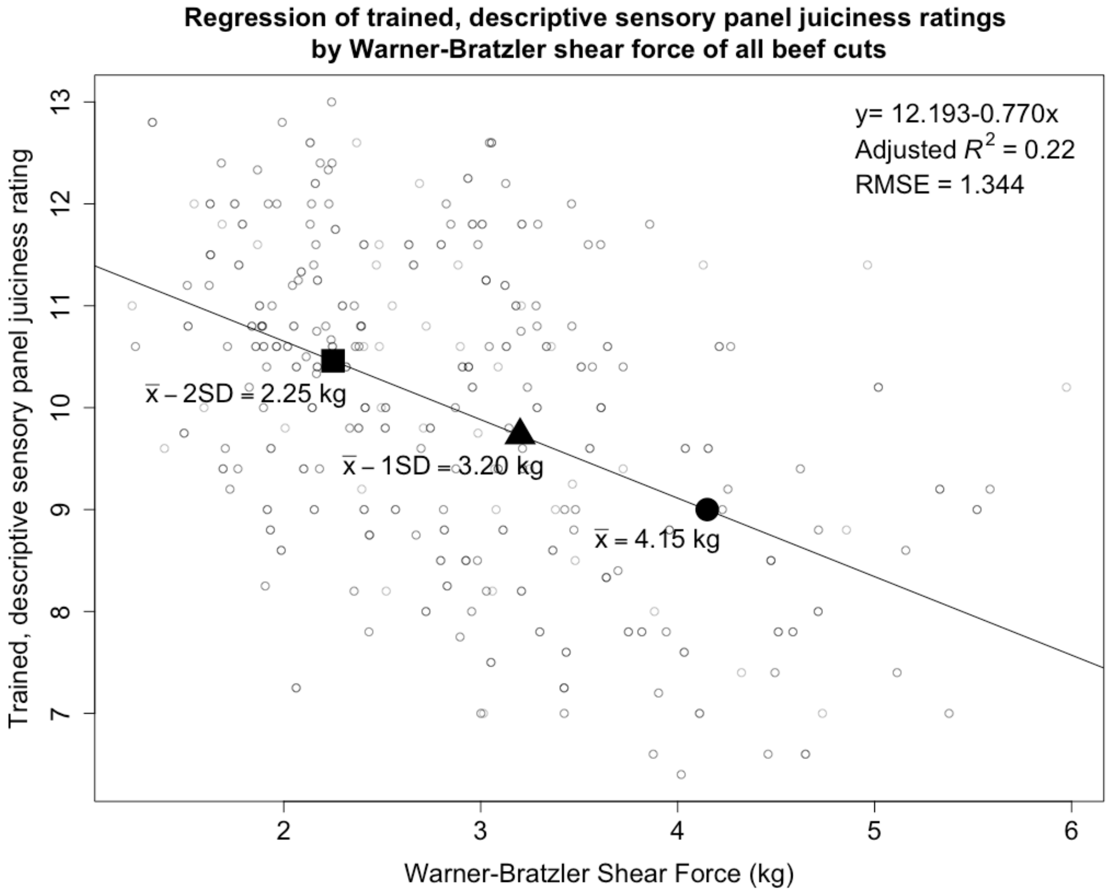


Figure 3. Determination of juiciness threshold values for all beef cuts. The average WBSF corresponding to "slightly juicy" was 4.15 kg (●; 50% CL). The population SD (0.949) of WBSF for all beef cuts determined 3.20 (▲; 68% CL) and 2.25 kg (■; 95% CL) as additional threshold values.

Tables 9, 10, and 11 corresponds with Figures 1, 2, and 3, respectively. In order to evaluate the prediction accuracy of the regression equations, the trained, descriptive attribute was calculated for each WBSF threshold level within each equation. This resulted in a predicted threshold value in terms of the trained panel attribute. The trained, descriptive attribute values were then predicted using the developed equations and the validation data set. The predicted values were compared to the actual, known values to determine if the regression equations were accurate. Table 9 reported the percentage of correctly identified tough and tender top loin steaks (50% CL, 70.33; 68% CL, 64.84; 95% CL, 90.11%). These results were most comparable to those reported by Shackelford et al. (1991) as the current thresholds were also developed from top loin steaks. Table 10 reported the prediction accuracy for all beef cuts. The percent predicted correctly for the 50, 68, and 95% CL were 68.7, 77.48, and 90.84 %, respectively. The accuracy of the juiciness threshold predictions reported in Table 11 are lower than the previously reported tenderness thresholds. This was a result of the lower amount of variation explained by the regression equation. Never the less, the percentage of beef cuts predicted correctly was similar to the percentages reported by Shackelford et al. (1991) for tenderness thresholds, indicating promise and ability in applying these newly developed tenderness and juiciness thresholds.

Table 9. Prediction of whether descriptive, trained sensory panel overall tenderness ratings of top loin strip steaks were "moderately tender" or more tender for validation data (*n* = 91).

	Confidence level[a]		
	50%	68%	95%
Predicted correctly	70.33	64.84	90.11
Predicted incorrectly	29.67	35.16	9.89
Predicted tough, were tough[b]	8.79	41.76	90.11
Predicted tender, were tender[c]	61.54	23.08	0.00
Predicted tough, were tender	21.98	18.68	9.89
Predicted tender, were tough	7.69	16.48	0.00

[a]Associated average WBSF (kg) for each CL were: 50%, 3.10; 68%, 2.30; and 95%, 1.50.

[b]Steaks defined as tough were less than "moderately tender".

[c]Steaks defined as tender were "moderately tender" or more tender.

Table 10. Prediction of whether descriptive, trained sensory panel overall tenderness ratings of all beef cuts were "moderately tender" or more tender for validation data (*n* = 262).

	Confidence level[a]		
	50%	68%	95%
Predicted correctly	68.70	77.48	90.84
Predicted incorrectly	31.30	22.52	9.16
Predicted tough, were tough[b]	30.92	63.36	89.69
Predicted tender, were tender[c]	37.79	14.12	1.15
Predicted tough, were tender	19.08	8.78	7.63
Predicted tender, were tough	12.21	13.74	1.53

[a]Associated average WBSF (kg) for each CL were: 50%, 2.84; 68%, 1.89; and 95%, 0.94.

[b]Beef cuts defined as tough were less than "moderately tender".

[c]Beef cuts defined as tender were "moderately tender" or more tender.

Table 11. Prediction of whether descriptive, trained sensory panel overall tenderness ratings of all beef cuts were "slightly juicy" or juicer for validation data (*n* = 262).

	Confidence level[a]		
	50%	68%	95%
Predicted correctly	74.05	66.79	65.27
Predicted incorrectly	25.95	33.21	34.73
Predicted dry, were dry[b]	7.25	22.14	45.80
Predicted juicy, were juicy[c]	66.79	44.66	19.47
Predicted dry, were juicy	3.44	12.21	22.90
Predicted juicy, were dry	22.52	20.99	11.83

[a]Associated average WBSF (kg) for each CL were: 50%, 4.15; 68%, 3.20; and 95%, 2.25.
[b]Beef cuts defined as dry were less than "slightly juicy".
[c]Beef cuts defined as juicy were "slightly juicy" or juicier.

Table 12 presents the comparison of the percentages of beef cuts stratified by current and proposed beef tenderness categories. Using current classification standards, two thirds of all the beef cuts were considered “very tender” while the remaining one third of beef cuts decreased in their category placement as tenderness levels increased in toughness. A shift in the distribution of tenderness categories was reported with the proposed tenderness categories. As the requirements for the tenderness classes were more stringent, a lower percentage of cuts achieved the “very tender” assessment. The remaining “tender,” “intermediate,” and “tough” classes each represented roughly one third of the remaining percentage of cuts.

Conclusion

Beef tenderness perception by consumers has changed and tenderness variation has decreased over the last 30 years. Today, the average WBSF value for top loin steaks is 2.69 kg while 3.8 kg was reported by Shackelford et al. (1991). Updating previous WBSF thresholds based on trained descriptive sensory evaluations that meet the classification of “moderately tender” was imperative as average WBSF values have decreased (become more tender) within the last 30 years. The WBSF thresholds should be adjusted to current data. In conclusion, the implementation of these updated tenderness threshold categories and introduction of juiciness threshold categories created modernized standards for the beef industry to measure consumer acceptance for products produced by the beef industry.

Table 12. Percentage distribution of beef cuts (*n* = 792) stratified into tenderness categories adapted from Belew et al. (2003) and proposed categories[a].

	Very tender	Tender	Intermediate	Tough
Current categories[b]				
Flat	58.30	24.38	10.60	6.71
Strip	73.63	20.15	2.56	3.66
TB	46.55	17.24	15.52	20.69
Tender	90.00	7.50	2.50	0.00
All Cuts	66.67	19.32	7.32	6.69
Proposed categories[c]				
Flat	1.41	22.26	32.16	44.17
Strip	1.10	41.39	27.47	30.04
TB	0.00	10.34	33.62	56.03
Tender	7.50	55.00	25.00	12.50
All Cuts	2.02	32.07	29.67	36.24

[a]Proposed thresholds use the moderately tender WBSF value from the regression equation predicting overall tenders from WBSF of top loin steaks.

[b]Very Tender, WBSF < 3.2 kg, Tender, 3.2 kg < WBSF < 3.9 kg, Intermediate, 3.9 kg < WBSF < 4.6 kg, Tough, WBSF > 4.6 kg

[c]Very Tender, WBSF < 1.5 kg, Tender, 1.5 kg < WBSF < 2.3 kg, Intermediate, 2.3 kg < WBSF < 3.1 kg, Tough, WBSF > 3.1 kg

TB = top sirloin steaks; flat = bottom round steaks from bottom round roasts; strip = top loin steaks; tender = tenderloin steaks.

CHAPTER III

DEVELOPMENT OF STATISTICAL MODEL TO PREDICT CONSUMER LIKING OF BEEF SUBPRIMALS

Introduction

Multiple factors impact flavor in beef. Researchers have been extensively involved in first defining what flavors are present in beef whole muscle cuts by developing the beef whole muscle flavor lexicon (Adhikari et al., 2011). Then the team examined the effect of cooking method, degree of doneness, and cut on beef flavor attributes and consumer liking. They have determined perceptions of millennials, non-millennials, heavy beef-eaters, and light beef-eaters through consumer studies including Central Location Tests and In-Home Use Tests to assess consumer liking. While each of these data sets (4 total) have addressed the objectives and hypotheses presented, combining the data sets to model beef flavor has not been completed. Our objective was to develop a beef flavor model to understand the major positive and negative flavors for beef of whole muscle cuts using trained descriptive flavor and texture attributes, consumer liking attributes, volatile aromatic compounds, and chemical data.

Materials and Methods

While differences were present between these studies, a large portion of the materials and methods were similar. A general overview is presented. The data that was included in the preceding chapter of this dissertation included work by Luckemeyer (2015) and Laird (2015) is referred to as Study 1 and Study 2, respectively. The current chapter work also uses these same data in addition to work by Glascock (2014) is Study 3. All studies conducted trained, descriptive beef flavor and texture attribute sensory evaluation in accordance to AMSA (2015); gas chromatography-mass spectrometry-olfactometry (GC-MS-O); fatty acid composition; non-heme iron and myoglobin content; and fat and moisture analysis. These specific analytical procedures are discussed in subsequent paragraphs.

For review, Study 1 used Choice strip loins, high pH strip loins (pH ≥ 6.0), Select top sirloins, Choice tenderloins, Select bottom rounds, and Choice bottom rounds collected from 10 beef carcasses and cut into steaks (Choice top loin, high pH top loins, Select top sirloin, Choice tenderloin) and roasts (Select and Choice bottom round). Top loin steaks were cooked to 58°C or 80°C utilizing a George Forman grill (Choice top loin, High pH top loin, Select top sirloin and Choice tenderloin steaks) set at 191°C, a flat food-service grill at 232°C (Choice top loin, High pH top loin, Select top sirloin and Choice tenderloin steaks), or crock-pot (Select and Choice bottom round roasts). Consumer evaluations were collected through central location testing (n = 80 per city in Olathe, KS; State College, PA; and Portland, OR) where participants that ate beef one or two times per week were considered light beef eaters. In each city, four consumer sessions, with approximately 20 consumers per session, were conducted. The overall objective of this study was to create varying levels of positive and negative beef flavor attributes to measure consumer liking for light beef eaters.

Study 2 was conducted similarly to Study 1. In Study 2, millennial and non-millennial consumers that were either light (eat beef 2 to 4 times per month) or heavy (eat beef 3 or more times per week) beef eaters in four cities (n = 120 per city; Portland, OR; Olathe, KS; College Park, PA; Atlanta, GA) were used. In each city, six consumer sessions with approximately 20 consumers per session were conducted. The Choice beef top strip loin (cooked to 58°C or 80°C on a commercial electric flat grill); Select bottom round flat roasts (cooked to 58°C or 80°C in a crockpot); chicken breast (cooked to 62°C or 80°C on a commercial electric flat grill); thigh meat (not enhanced; cooked to 62°C or 80°C in a crockpot); boneless pork loins (cooked to 62°C or 80°C on a commercial electric flat grill); and inside ham roasts (not enhanced; cooked to 62°C or 80°C in a crockpot) were purchased commercially. Top loin steaks, chicken breasts, and pork chops were cooked on a commercial electric grill (StarMax 536GF 36-inch Countertop Electric Griddle, Star Manufacturing International, Inc., St. Louis, MO) set at 232°C. The objectives of this study were to select consumer groups differing in age category and frequency of beef consumption to determine the perception of overall liking for three protein sources (evaluated independently).

Study 3 data used the same treatments and cooking methods as described in Study 1, with the exception that tenderloin steaks were not examined. Consumer evaluations were collected through central location testing (n = 80 per city in Houston, TX; Olathe, KS; Philadelphia, PA; and Portland, OR) where consumers were defined as moderate to heavy beef eaters if they ate beef three or more times per week. In each city, four consumer sessions, with approximately 20 consumers per session were conducted. The objective of this project was to understand factors, whether they were chemical, volatile, or trained descriptive attributes, that drive consumer liking in moderate to heavy beef eaters.

Trained, Descriptive Beef Flavor Analysis

Steaks and roasts within all studies were evaluated by a trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon (Adhikari et al., 2011). The complete list of attributes and their respective references adapted from AMSA (2016) can be found in the appendix. Beef flavor attributes were measured using the beef lexicon where 0 = none and 15 = extremely intense. After training was complete, panelists were presented multiple test samples per day. The number of samples presented per day varied among studies (Study 1,12; Study 2,12; Study 3,17). After cooking, samples were placed in a food warmer set at 60°C (Alto-Shaam, Model 750-TH-II, Milwaukee, WI) for no longer than 20 min. Steaks and roasts were cut into 1.27 cm cubes. Two cubes per sample were served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Samples were cut and served immediately to assure samples were approximately 60°C upon the time of serving (AMSA, 2016). Samples were identified with random three-digit codes and served in random order. Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm-up" sample that was evaluated and discussed orally. Double-distilled water, unsalted saltine crackers, and ricotta cheese were available for cleansing the palate between samples. During the evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served at least four minutes after evaluation of the previous sample.

Consumer Evaluation

Details including the specific cities, number of sessions, and numbers of consumers recruited per session are described in previous paragraphs for each study. Consumer panelists were recruited by the individual research institution in each city and were required to pass a consumer screening questionnaire guaranteeing them to be over 18 years of age and to have no food allergies. On the day of evaluation, recruited consumer panelists were asked to sign an informed consent document. An instructional document, demographic ballot, and individual sample ballots were provided to the consumer upon entering the testing room. Consumer demographics for age, sex, income, household size, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, and meat shopping habits were determined. Ballots in Study 1, 2, and 4 included overall, overall flavor, beefy flavor, grilled flavor, juiciness, and tenderness liking. Study 3 was the limiting study as the questions in common with the other studies included overall, overall flavor, and overall grilled flavor liking. Consumers evaluated samples by using middle- and end-anchored 9-point hedonic scales. Panelists were provided pre-identified random samples in a predetermined random order at least four minutes after evaluation of the previous sample. Samples were served in clear plastic soufflé cups labeled with a random three-digit number corresponding to their ballot. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis.

Warner-Bratzler Shear Force

Studies 1, 2, and 3 cooked samples for WBSF in the same manner and at the same time as trained descriptive beef flavor analysis steaks. Cooking yield percentages were determined from weights recorded before and after cooking and total cooking time was recorded for individual steaks and roasts. Steaks and roasts were trimmed of visible connective tissue to expose muscle fiber orientation. Six 1.3-cm-diameter round cores were removed from each muscle. Roasts were cut in 2.54-cm sections and then cores were removed. Cores were removed parallel to the muscle fibers and sheared once, perpendicular to the muscle fibers, on a United Testing machine (United SSTM-500, Huntington Beach, CA) at a cross-head speed of 200 mm/min using a 500 kg load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak. The peak force (kg) needed to shear each core was recorded, converted to Newtons (N), and the mean peak shear force of the cores was used for statistical analysis. Values were converted using the following equation: WBSF (N) = WBSF (kg) × 9.81.

Cooked Beef Volatile Flavor Evaluation

Fatty acid composition, myoglobin content, and non-heme iron content were determined from each raw muscle within carcass from Studies 1, 2, and 3. Fatty acid methyl esters (FAME) were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately 3 to 5 g of ground beef was combined with 1 mL of 0.5 KOH in MeOH and heated at 70°C for 10 min. After cooling, 1 mL of boron trifluoride (BF_3; 14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70°C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC-grade hexane and 2 mL of saturated NaCl were added to the samples and vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. Each sample was evaporated to dryness at 60°C under N_2 gas, subsequently reconstituted with HPLC-grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 autosampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 (100 m x 0.25 mm [i.d.]; Chrompack Inc., Middleburg, The Netherlands), with helium as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180 °C, the oven temperature was increased at 20 °C/min to 225°C and held for 13.75 min. Total run time was 48 min. Injector and detector temperatures were at 270°C and 300°C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

Myoglobin concentration determination was done according to Rickansrud and Henrickson (1967) with modification to be read using a 96-well plate reader. Duplicate 25g samples were blended with 100 mL of double distilled H_2O for 3 min and centrifuged at 2000 x *g* at 6°C for 15 min. The supernatant was filtered through

Whatman No. 3 filter paper and brought to volume in a 200 mL volumetric flask. From this 200 mL portion, duplicate 5 mL portions were taken and adjusted to a pH of 7.1 using 0.5 M phosphate buffer. Then, 1.25 mL of saturated lead acetate was added to the tube and centrifuged at 2000 x *g* for 15 min. Finally, 2.5 mL of the supernatant was combined with a mixture of mono- and di-basic phosphate to bring the phosphate concentration to 3M and the pH to 6.6. and was again centrifuged at 2000 x *g* for 15 min. One milliliter of the supernatant was combined with 0.7 mL of potassium ferricyanide and 0.7 mL of potassium cyanide to convert all forms of myoglobin to cyanmetmyoglobin. The samples were again centrifuged at 2000 x *g* for 15 min to ensure that all myoglobin had been transformed, and 200 µL were pipetted in triplicate on a 96 well plate and read at 520 nm on a plate reader (BioTek, Epoch, Winooski, VT).

For non-heme iron, samples were prepared following the procedures described by Rhee and Ziprin (1987) and read at 540 nm using a Cary 100 Varian UV/Visual Spectrophotometer (Varian Instruments, Sugarland, TX). To determine total non-heme iron, final absorbance of each sample was calculated by subtracting the absorbance of the incubated liquid phase with no color reagent added from the absorbance of the incubated liquid phase with a color reagent added. Next, final concentration was calculated by subtracting the intercept of the standard curve from the final absorbance and dividing by the slope of the standard curve. Finally, non-heme iron was calculated as follows:

µg non-heme Fe/g meat = concentration (µg/mL) x ((15 + 0.2 + moisture in 5g meat))/5g x 1mL

Raw Chemical Analyses

Fatty acid composition, myoglobin content, and non-heme iron content were determined from each raw muscle within carcass from Studies 1, 2, 3, and 4. Fatty acid methyl esters (FAME) were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately 3 to 5 g of ground beef was combined with 1 mL of 0.5 KOH in MeOH and heated at 70°C for 10 min. After cooling, 1 mL of boron trifluoride (BF_3; 14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70°C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC-grade hexane and 2 mL of saturated NaCl were added to the samples and vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. Each sample was evaporated to dryness at 60°C under N_2 gas, subsequently reconstituted with HPLC grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 autosampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 (100 m x 0.25 mm (i.d.); Chrompack Inc., Middleburg, The Netherlands), with helium as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180 °C, the oven temperature was increased at 20 °C/min to 225°C and held for 13.75 min. Total run time was 48 min. Injector and detector temperatures were at 270°C and 300°C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

Myoglobin concentration determination was done according to Rickansrud and Henrickson (1967) with modification to be read using a 96-well plate reader. Duplicate 25g samples were blended with 100 mL of double distilled H_20 for 3 min and centrifuged at 2000 x *g* at 6°C for 15 min. The supernatant was filtered through Whatman No. 3 filter paper and brought to volume in a 200 mL volumetric flask. From this 200 mL portion, duplicate 5 mL portions were taken and adjusted to a pH of 7.1 using 0.5 M phosphate buffer. Then, 1.25 mL of saturated lead acetate was added to the tube and centrifuged at 2000 x *g* for 15 min. Finally, 2.5 mL of the supernatant was combined with a mixture of mono- and di-basic phosphate to bring the phosphate concentration to 3M and the pH to 6.6. and was again centrifuged at 2000 x *g* for 15 min. One milliliter of the supernatant was combined with 0.7 mL of potassium ferricyanide and 0.7 mL of potassium cyanide to convert all forms of myoglobin to cyanmetmyoglobin. The samples were again centrifuged at 2000 x *g* for 15 min to ensure that all myoglobin had been transformed, and 200 μL were pipetted in triplicate on a 96 well plate and read at 520 nm on a plate reader (BioTek, Epoch, Winooski, VT).

For non-heme iron, samples were prepared following the procedures described by Rhee and Ziprin (1987) and read at 540 nm using a Cary 100 Varian UV/Visual Spectrophotometer (Varian Instruments, Sugarland, TX). To determine total non-heme iron, final absorbance of each sample was calculated by subtracting the absorbance of the incubated liquid phase with no color reagent added from the absorbance of the incubated liquid phase with a color reagent added. Next, final concentration was calculated by subtracting the intercept of the standard curve from the final absorbance and dividing by the slope of the standard curve. Finally, non-heme iron was calculated as follows:

μg non-heme Fe/g meat = concentration (μg/mL) x ((15 + 0.2 + moisture in 5g meat))/5g x 1mL

Data from Studies 1, 2, and 3 were analyzed to answer the following objectives:

1. Identify commonality of variables between all studies.
2. Analyze wide array of data from trained descriptive panel attribute scores, chemical assays, fatty acid analysis, and aromatic volatiles for which variables are likely to contribute to predicting consumer overall liking of beef.
3. Identify the affects these variables have on consumer perception of beef.
4. Use principal component analysis and partial least squares regression to create bi-plots and regression equations.
5. Build an overall statistical model to predict consumer overall liking of beef products.

Statistical Analysis

Five analysis groups for whole muscle beef cuts were developed and are described as:

Analysis 1: USDA Select and Choice bottom round roasts from Study 1 and 3.

Analysis 2: USDA Choice bottom round roasts and USDA Choice top loin steaks from Study 1 and 3.

Analysis 3: Top sirloin steaks differing in cook methods of either open flat grilled or grilled though the use of a clam-shell style grill from Study 1 and 3.

Analysis 4: Top loin steaks differing in cook methods of either open grilled or grilled though the use of a clam-shell style grill from Study 1, 2, and 3.

Analysis 5: USDA Select bottom round steaks from Study 1, 2, and 3.

Data from Studies 1, 2, and 3 were analyzed as followed:

1. Identified commonality of variables between all studies to create Analysis groups.

2. Analyze wide array of data from trained descriptive panel attribute scores, chemical assays, fatty acid analysis, and aromatic volatiles within each analysis group for which variables are likely to contribute to predicting consumer overall liking of beef. Within analysis, respective main effects and interactions were observed through descriptive summary analysis and least squares means comparisons.

3. Within analysis, identify the affects these variables have on consumer perception of beef and which were contributing to differences in consumer overall liking. Contributing variables were identified and used for additional analysis methods.

4. Partial least squares regression was used to create bi-plots and regression equations.

These analysis groups allowed for the comparison of differences in cut, quality grade, and cook method and were used to validate their inclusion in model development. Statistical procedures were conducted through SAS (version 9.4, SAS Institute, Cary, NC). A predetermined alpha of 5% was used in each analysis when appropriate for the current analyses of the data and any prior analyses conducted during the time of each study. Previous analysis of each data set evaluated the trained panel data by analysis of variance and PROC GLM procedures. For trained panel, the data were averaged across panelists after testing for panelist by treatment interactions to validate the panelists with sensory day and order served defined as random variables. Previous analysis of each data set also analyzed the consumer data through the same statistical procedures by classifying the city and treatment as the main effects, the interaction of the main effects, and the order the consumers were served as the random variable.

For the current study, PROC CORR was used to identify the strength and direction of the relationships between all variables considered in model development to identify potential sources of multicollinearity. The PROC MIXED analysis was used to measure descriptive summary statistics for consumer responses, trained descriptive sensory panel results, chemical analyses (fatty acid percentages, myoglobin content, non-heme iron content, and fat and moisture analysis). Consumer responses were first analyzed individually (data were not evaluated by averaged consumer response per steak/roast) to identify the level of variability among consumers. Treatment and endpoint temperature were considered fixed effects while the consumer within the study and within city, city, and study were classified as random effects. For each Analysis, consumer overall liking, overall flavor liking, and grill flavor liking were preformed separately. Trained panel data were evaluated with the panelist scores averaged per sample, similar to the statistical analysis conducted within each original study. For each treatment, attributes were evaluated individually in order to understand the variation in the data to verify their use in future model development. Study session and sample order served as random variables. When necessary, least squares means were calculated and differences between least squares means were determined using the PDIFF function. Final model development was conducted with PROC GLMSELECT with the STEPWISE option.

Partial least squares regression modeling (v 20.2, XLSTAT, Addisoft, New York, NY) was used to develop prediction models for whole muscle beef cuts (Luckemeyer, 2015; Laird, 2015; and Glascock, 2014). Biplots were presented and Variable Importance in the Projection (VIP) values were evaluated to determine variables to remain in the final PLSR models. Variables with initial VIP values < 0.50 were removed from the analysis. Variables continued to be removed through multiple evaluations of VIP values. As evaluations progressed, the stringency for variables to remain in the final model increased to VIP values < 0.8. Volatile aromatic compounds were normalized through Box-Cox transformation (Box and Cox, 1964) through JMP Pro (version 14.0.0, SAS Institute, Cary, NC) using the following equation for when $\lambda \neq 0$:

$$Y_\lambda = \frac{\gamma^\lambda}{\lambda \gamma^{\lambda - 1}}$$

After least squares means comparisons of volatile aromatic compounds, significant variables were used for PLSR to predict consumer overall liking.

Results

Modeling Beef Flavor Using Analyses 1 Through 5

Table 13 presents the descriptive summary statistics for consumers for overall, overall flavor, and grill flavor liking for each treatment. Consumer averages were not collapsed by steak/roast within each treatment. Therefore, *n* is reflective of the number of consumer observations within each treatment. Within each analysis, no interactions were significant ($P \geq 0.086$). In Analysis 1, USDA Choice and Select bottom from Study 1 and 3 were compared as cut and cooking methods were consistent. Quality grade did not affect consumer liking attributes with the exception of grill flavor liking as it was slightly higher for Choice bottom round roasts. Roasts were cooked in crock pots with no grilling. Consumers liked beef bottom round roasts cooked to 58°C compared to roasts cooked to 80°C.

Table 13. Descriptive summary statistics for least squares means and SEM for consumer response for overall liking, overall flavor, and grill flavor liking by treatment[1].

Consumer attribute	*n*	Treatment		SEM	Endpoint Temp		SEM	*P*-value[2]	
					58°C	80°C		Trt	Temp
BR/Se x BR/Ch		Se	Ch						
Overall liking	1048	4.7	4.8	0.14	4.9	4.6	0.14	0.229	0.006
Overall flavor liking	1048	4.8	5.1	0.10	5.1	4.8	0.10	0.060	0.028
Grill flavor liking	1049	4.1	4.4	0.09	4.2	4.3	0.09	0.014	0.328
BR/Ch x TL/Ch		BR	TL						
Overall liking	1572	4.8	6.5	0.19	5.9	5.5	0.19	< 0.001	0.002
Overall flavor liking	1573	5.1	6.6	0.10	5.9	5.7	0.10	< 0.001	0.041
Grill flavor liking	1573	4.4	6.2	0.11	5.3	5.3	0.11	< 0.001	0.607
TS/grilled x TS/CS		Grilled	CS						
Overall liking	1044	6.4	5.6	0.18	6.4	5.6	0.18	< 0.001	< 0.001
Overall flavor liking	1045	6.6	5.6	0.16	6.4	5.8	0.16	< 0.001	< 0.001
Grill flavor liking	1044	6.5	5.0	0.17	5.8	5.7	0.17	< 0.001	0.315
TL/Ch/grilled x TL/Ch/CS		Grilled	CS						
Overall liking	1500	7.1	6.1	0.15	6.7	6.4	0.15	< 0.001	0.002
Overall flavor liking	1500	7.2	6.1	0.14	6.8	6.5	0.13	< 0.001	0.020
Grill flavor liking	1500	7.1	5.3	0.10	6.3	6.2	0.10	< 0.001	0.913
BR/Se									
Overall liking	965	——	——		5.1	4.6	0.23	——	< 0.001
Overall flavor liking	964	——	——		5.2	4.9	0.28	——	0.013
Grill flavor liking	966	——	——		4.2	4.3	0.18	——	0.435

[1]Consumer liking attributes where 0=extremely dislike and 9=extremely like.
SEM = standard error mean; n = number of consumer responses; BR = bottom round; Se = USDA Select; Ch = USDA Choice; TL = top loin steaks; TS = top sirloin steaks; Trt = treatment; Temp = temperature; Grilled = open flat grilled; CS = clam-shell style grill.
[2]Interations of Trt x Temp not presented; $P \geq 0.086$.

To understand the effect of cut, Choice round roasts and Choice top loin steaks were evaluated. Cooking methods differed as bottom round roasts were cooked in crock pots and top loin steaks were grilled using clam-shell style or open flat grill. Grilled top loin steaks were rated higher for consumer liking attributes compared to bottom round roasts cooked in crock pots. Again, consumer ratings were higher for overall liking in steaks and roasts cooked to 58°C. Top sirloin steaks from studies 1 and 3 cooked on an open flat grill or clam-shell style grill differed in consumer sensory attributes. Consumers rated open flat grilled top sirloin steaks higher for consumer liking attributes. Additionally, consumers liked the overall flavor and overall liking of TS steaks cooked to 58°C compared to steaks cooked to 80°C. Data from studies 1, 2, and 3 were combined to analyze USDA Choice top loins differing in cook methods of either open flat grilled or clam-shell style grilled. Consumers preferred top loin steaks cooked using the open flat grill method and they had higher overall and overall flavor liking for top loin steaks cooked to a lower temperature endpoint. However, endpoint temperature did not affect consumer preference in grill flavor liking. All three studies had data for USDA Select bottom round roasts cooked in crock pots. The impact of cooking to either 58 or 80°C on consumer attributes of Select bottom round roasts cooked in crock pots was examined. Select bottom round roasts cooked to 58°C had higher overall and overall flavor liking. Grill flavor liking was not affected by endpoint temperature although an impact was seen previously when bottom rounds of differing USDA quality grade were compared. These differences were as expected and showed that these data were acceptable to use for predictive consumer overall liking.

Table 14 reports the covariance parameter values and the respective percentage of explained and unexplained variation for each analysis group for consumer overall liking. It was well understood that consumer opinion was variable. Analyzing and accounting for consumer data was challenging as the objective of each study was to quantify differences between defined treatments. Therefore, the steak or roast sample was defined as the experimental unit. The design on the experiments allowed for multiple consumers to evaluate multiple steaks across multiple cities. Due to steak being the defined experimental unit, the consumer hedonic ratings for consumer liking scores were collapsed based on the original primal from which the steaks where cut from based on the assigned treatment. Table 14 served to quantify the variation accounted for each particular consumer within each study and city combination.

Across the five analysis groups, the range for the amount of variation explained by the singular consumer participants was from 10.48 to 22.49% for their overall liking scores. This large amount of variation would indicate that individual consumers should be accounted for in further developed models for each analysis group as they influenced the overall liking score. The difficulty in this was that the form of statistical analysis would need to be altered as this would change the dependent variable from a continuous value to an integer form. As this exceeded the scope and intent of this study, this left an important area of further consideration for how to address this issue statistically in order to account for consumer variation in future statistical modeling.

Table 14. Amount of variation explained with each analysis group for consumer overall liking.

	Covariance parameter values					Percentage of explained variation			
Analysis group	Consumer (study x city)	City	Study	Residual	Total	Consumer (study x city)	City	Study	Unexplained
BR/Se x BR/Ch	1.07	0.00	0.02	3.67	4.76	22.49	0.00	0.41	77.10
BR/Ch x TL/Ch	0.45	0.00	0.05	3.82	4.33	10.48	0.00	1.24	88.27
TS/grilled x TS/CS	0.71	0.02	0.04	2.95	3.71	19.03	0.57	0.99	79.41
TL/Ch/grilled x TL/Ch/CS	0.52	0.01	0.04	2.83	3.40	15.32	0.32	1.08	83.28
BR/Se	0.93	0.04	0.09	3.57	4.62	20.06	0.73	1.95	77.27

BR = bottom round; Se = USDA Select; Ch = USDA Choice; TL = top loin steaks; TS = top sirloin steaks; grilled = open flat grilled; CS = clam-shell style grill.

Multicollinearity occurs when two or more predictor variables in a regression model are highly correlated with one another. Identifying whether or not this relationship was present between variables was critical as multicollinearity results in linear dependency among predictor variables and ultimately, leads to unreliability in the statistical model. One method to identify multicollinearity was to examine the simple correlation coefficients between consumer sensory attributes, trained descriptive sensory panel flavor attributes, fatty acids, and chemical analyses (Table 15). As expected, consumer overall liking was positively and strongly correlated to flavor liking and grill flavor liking with r-values of 0.89 and 0.74, respectively. Not only was the correlation strong between flavor liking and grill flavor liking ($r = 0.76$), but the correlation was strong with the dependent variable, overall liking. If overall flavor liking and grill flavor liking were to be included in the final model, multicollinearity would occur, decreasing the strength of the prediction model. Several variables reported moderate correlation with one another, but were still considered for final model development as only variables reported strong correlations were excluded. Strongly correlated variables were those with reported r values greater than or equal to 0.67 and included bloody/serumy and metallic ($r = 0.69$), lipid and moisture percentages ($r = -0.85$), and 18:2 and 20:4 fatty acids ($r = 0.79$). In order to avoid the linear dependency of the predictor variables, only one these variables within the three correlations were used.

Table 15. Simple correlation coefficients between chemical measures and trained descriptive sensory panel flavor attributes.

Effect	Overall liking	Flavor liking	Grill flavor liking	Beef identity	Brown/ roasted	Bloody/ serumy	Umami	Livery	Cardboard	Fat-like	Metallic	Overall Sweet	Sweet
Overall liking	1.00	0.89	0.74	0.09	0.26	0.11	0.11	-0.16	-0.16	0.19	0.08	0.17	0.16
Flavor liking		1.00	0.76	0.05	0.25	0.07	0.10	-0.15	-0.14	0.17	0.06	0.17	0.15
Grill flavor liking			1.00	0.09	0.38	0.04	0.16	-0.19	-0.18	0.22	0.02	0.21	0.18
Beef identity				1.00	0.34	0.33	0.33	-0.28	-0.28	0.22	0.24	0.34	0.38
Brown/roasted					1.00	-0.16	0.51	-0.30	-0.28	0.32	-0.18	0.45	0.29
Bloody/serumy						1.00	-0.25	-0.06	-0.23	0.22	0.69	-0.15	-0.10
Umami							1.00	-0.14	-0.05	0.28	-0.35	0.64	0.37
Livery								1.00	0.22	-0.15	-0.14	-0.14	-0.19
Cardboard									1.00	-0.26	-0.18	-0.17	-0.26
Fat-like										1.00	0.05	0.31	0.17
Metallic											1.00	0.56	0.05
Overall Sweet												1.00	0.56
Sweet													1.00

[a]Simple correlation coefficients ≥ 0.04 are significant ($P \leq 0.05$)

Table 15 Continued.

Effect	Sour	Salty	Bitter	Sour aromatics	Non-heme	Myo-globin	Lipid	Moisture	14:0	16:0	16:1	18:1	18:2	20:4	20:5
Overall liking	0.06	0.20	0.07	-0.13	-0.00	-0.05	0.18	-0.16	0.04	0.18	-0.08	0.01	-0.13	-0.14	-0.02
Flavor liking	0.04	0.19	0.07	-0.12	0.00	-0.06	0.17	-0.15	0.03	0.17	-0.07	0.02	-0.14	-0.14	-0.02
Grill flavor liking	-0.01	0.22	0.05	-0.12	0.02	-0.02	0.21	-0.18	0.06	0.16	-0.08	-0.01	-0.15	-0.16	-0.01
Beef ID	-0.00	-0.02	-0.05	-0.13	-0.15	0.37	0.08	-0.21	-0.09	0.07	-0.33	-0.02	0.08	0.04	0.03
Brown/Roasted	-0.25	0.33	0.00	-0.09	-0.03	0.08	0.28	-0.29	0.07	0.16	-0.15	-0.04	-0.15	-0.14	-0.02
Bloody/Serumy	0.61	-0.15	0.08	-0.10	-0.02	0.08	0.07	-0.16	-0.01	-0.02	-0.24	-0.18	0.07	0.14	0.13
Umami	-0.42	0.31	-0.22	-0.06	-0.02	0.07	0.31	-0.30	0.15	0.16	0.08	0.08	-0.18	-0.22	0.03
Livery	0.04	-0.22	0.03	0.17	-0.02	-0.07	-0.12	0.15	0.13	-0.13	0.19	-0.16	0.07	0.16	0.07
Cardboard	-0.05	-0.16	-0.09	0.18	0.02	-0.03	-0.16	0.11	-0.01	-0.12	0.15	-0.03	0.12	0.12	0.10
Fat-like	-0.02	0.23	-0.08	-0.05	0.05	0.04	0.37	-0.33	0.13	0.06	-0.04	-0.06	-0.17	-0.15	0.05
Metallic	0.59	0.04	0.33	-0.11	-0.10	-0.05	-0.08	-0.01	-0.08	0.04	-0.23	-0.12	0.13	0.22	0.00
Overall Sweet	-0.36	0.42	-0.04	-0.12	-0.01	0.02	0.35	-0.33	0.10	0.24	0.00	0.08	-0.20	-0.21	-0.06
Sweet	-0.22	0.45	0.22	-0.14	-0.20	-0.08	0.17	-0.20	-0.03	0.33	-0.07	0.25	-0.18	-0.19	-0.17
Sour	1.00	-0.08	0.38	-0.02	-0.09	-0.05	-0.17	0.05	-0.08	0.07	-0.23	-0.16	0.12	0.17	-0.03
Salty		1.00	-0.15	-0.14	-0.00	-0.23	0.29	-0.23	0.13	0.32	0.13	0.15	-0.25	-0.25	-0.15
Bitter			1.00	-0.13	-0.17	-0.21	-0.18	0.10	-0.05	0.30	-0.10	-0.00	0.06	0.09	-0.21
Sour Aromatics				1.00	0.07	-0.08	-0.01	0.04	0.02	-0.02	0.03	-0.03	0.04	0.02	0.03
Non-heme iron					1.00	0.17	0.16	-0.15	-0.03	-0.14	-0.05	-0.00	0.08	0.00	0.11
Myoglobin						1.00	0.03	-0.06	-0.07	-0.22	-0.10	-0.03	0.09	0.00	0.02
Lipid							1.00	-0.85	0.37	0.17	0.20	0.12	-0.54	-0.54	0.15
Moisture								1.00	-0.29	-0.16	-0.13	-0.14	0.49	0.48	-0.10
14:0									1.00	0.19	0.54	-0.43	-0.32	-0.24	-0.00
16:0										1.00	-0.06	0.14	-0.27	-0.36	-0.21
16:1											1.00	0.21	-0.39	-0.26	-0.02
18:1												1.00	-0.48	-0.53	0.00
18:2													1.00	0.79	-0.01
20:4														1.00	-0.02
20:5															1.00

[a]Simple correlation coefficients ≥ 0.04 are significant ($P \leq 0.05$)

Analysis 1

Table 16 reports the trained descriptive flavor attributes for Select and Choice bottom round roasts cooked to either 58 or 80°C. The importance of noting the differences of quality grade within the bottom round may justify acknowledgement of USDA quality grade in statistical modeling to predict consumer overall liking. Trained descriptive panel session and order random effects were presented for each attribute to justify the ability to combine date sets as no impacts were found ($P > 0.05$). Quality grade and cook temperature endpoint affected ($P < 0.05$) descriptive beef flavor attributes while interactions between these main effects did not ($P > 0.05$). USDA Choice bottom round roasts were higher in fat-like and lower in salt intensity compared to USDA Select bottom round roasts. Regardless of quality grade, roasts cooked to 58°C were lower in brown/roasted, overall sweet, and warmed-over flavor and higher in bloody/serumy, metallic, and sour flavor attribute intensities. While differences may not singly affect differences, beef flavor is multivariate and these differences may be more apparent with multivariate analysis.

Table 17 reports the analysis of the chemical components for Analysis 1. Study was included as a random effect and did not report a significant impact ($P > 0.05$) on least squares means comparisons of the quality grade treatment. USDA Select and Choice bottom round roasts did not differ ($P > 0.05$) in 20:5 fatty acid, 20:4 fatty acid, moisture percentage, non-heme iron, or myoglobin concentration. As expected, USDA

Choice bottom round roasts reported higher percent lipid (*P* = 0.004). USDA Select bottom round roasts reported lower amounts (units of g per 100g meats) of 14:0, 16:0, 16:1, 18:1, and 18:2 fatty acids. Chemical components that reported significant differences between treatment groups were identified for later PLSR development to understand their impact of consumer overall liking.

Table 16. Least squares means and SEM values for trained descriptive flavor attributes for crock pot cooked beef bottom round roasts from Studies 1 and 3 (n = 80).

Attribute[1]	USDA Select		USDA Choice			*P*-value			Random effects	
	58°C	80°C	58°C	80°C	SEM	Trt	Temp	Trt x Temp	Session	Order
Major										
Beef identity	6.8	7.9	7.4	8.1	0.70	0.510	0.124	0.731	0.149	0.180
Brown/roasted	0.5	0.8	0.5	0.9	0.12	0.359	0.003	0.783	0.163	—
Bloody/serumy	1.8	0.7	1.9	0.8	0.19	0.519	< 0.001	0.932	—	0.369
Umami	0.6	1.0	0.8	0.9	0.11	0.552	0.050	0.116	0.192	0.177
Liver-like	0.4	0.4	0.4	0.3	0.11	0.573	0.878	0.736	0.048	—
Cardboard	0.4	0.3	0.3	0.4	0.08	0.989	0.654	0.557	0.325	0.472
Minor										
Fat-like	0.9	0.8	1.1	1.0	0.07	0.007	0.262	0.494	—	—
Metallic	2.2	1.7	2.2	1.6	0.11	0.963	< 0.001	0.611	—	—
Overall sweet	0.3	0.6	0.5	0.6	0.08	0.088	< 0.001	0.341	0.196	0.127
Sweet	0.2	0.4	0.3	0.4	0.08	0.338	0.083	0.472	0.266	0.146
Sour	2.2	1.4	2.0	1.5	0.10	0.720	< 0.001	0.188	0.207	—
Salty	1.2	1.1	1.3	1.3	0.05	0.001	0.799	0.890	0.462	0.411
Bitter	1.5	1.4	1.5	1.4	0.08	0.872	0.137	0.770	0.289	—
Sour aromatics	0.1	0.1	0.1	0.0	0.05	0.861	0.352	0.093	0.099	0.123
Soapy	0.0	0.0	0.0	0.0	0.01	0.121	0.382	0.388	0.428	—
Warmed over flavor	0.0	0.1	0.0	0.2	0.05	0.211	0.003	0.561	0.105	0.402

[1]Trained descriptive flavor attributes were evaluated where 0 = none and 15 = extremely intense.

[a-c]Means with different superscripts are significantly different ($P < 0.05$) within row.

SEM = standard error mean; Trt = treatment; Temp = temperature.

Table 17. Least squares means and SEM values for chemical components for Analysis 1; beef bottom roasts from Studies 1 and 3 (*n* = 38).

				P-value	
Component	BR/Se	BR/Ch	SEM	Trt	Study
14:0[1]	0.06	0.09	0.015	0.008	0.2878
16:0	0.46	0.80	0.144	0.002	0.266
16:1	0.06	0.11	0.017	0.001	0.304
18:1	0.76	1.38	0.336	0.001	0.255
18:2	0.15	0.19	0.029	0.030	0.266
20:4	0.03	0.04	0.007	0.184	0.276
20:5	0.00	0.00	0.001	0.293	0.250
Moisture (%)	74.17	72.64	1.573	0.115	0.263
Lipid (%)	2.20	4.29	0.975	0.004	0.272
Non-heme	3.30	3.38	0.215	0.782	——
Myoglobin	2.90	2.93	0.079	0.775	——

[1]Fatty acids are presented as g per 100 g meat.
n = number of observations; BR = bottom round roasts; Se = USDA Select; Ch = USDA Choice; SEM = standard error mean; Trt = treatment.

Least squares means of volatile, aromatic compounds detected in USDA Select and Choice bottom round roasts cooked to 58 or 80°C were reported in Table 18. Volatile, aromatic compounds were compared to detect those that differed between treatments in Analysis 1. The temperature, duration, and type of cookery method for beef product influenced the presence and intensity of flavor compounds. The volatiles that reported significant difference ($P < 0.05$) were acetic acid, 1-hexanol, 1-butanol, 1-heptanol, 1-octen-3-ol, 1-octanol, 2,3-butanedione, nonenal, and benzaldehyde.

Acetic acid reported a significant interaction ($P = 0.041$) between quality grade and endpoint temperature. USDA Select roasts cooked to 80°C and USDA Choice roasts cooked to 58°C had greater acetic acid levels compared to USDA Select roasts cooked to 58°C and USDA Choice roasts cooked to 80°C. 1-Hexanol reported a significant interaction (P = 0.045). An interaction was reported between temperature endpoint and quality grade for 1-Heptanol (P = 0.048). Quality grade influenced levels of 1-Octen-3-ol as USDA Choice bottom round roasts had greater amounts compared to USDA Select. 2,3-Butanedione levels were higher in USDA Choice bottom round roasts compared to USDA Select (P = 0.013). Roasts cooked to higher endpoint temperatures of 80°C reported higher levels of Benzaldehyde (P = 0.004).

Table 18. **Transformed volatile, aromatic least squares means and SEM values Analysis 1; crock pot cooked beef bottom round roasts.**

		USDA Select		USDA Choice			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	Temp	QG	Temp x QG	Study
Acids										
Acetic acid	56	148,813[b]	170,866[a]	171,473[a]	158,051[b]	9,462.6	0.613	0.564	0.041	——
Hexanoic acid	41	279,253	319,268	327,468	316,444	17,766.0	0.312	0.116	0.078	0.440
Octanoic acid	18	44,581	45,672	46,307	45,602	2,254.0	0.909	0.625	0.597	——
Heptanoic acid	9	64,441	61,449	58,811	66,196	7,382.6	0.760	0.949	0.473	0.456
Alcohols										
1-Heptanol	33	754,119[a]	755,180[a]	763,021[b]	735,010[a]	11,377.0	0.062	0.420	0.048	0.277
1-Octen-3-ol	44	1,971,703	1,964,267	2,006,790	1,996,723	34,301.0	0.591	0.044	0.935	0.257
1-Pentanol	10	720,024	706,177	714,242	717,208	29,586.0	0.847	0.925	0.766	——
1-Octanol	40	1,097,074	1,083,367	1,101,912	1,075,450	12,551.0	0.014	0.841	0.411	0.292
1-Hexanol	38	1,087,874	1,098,551	1,096,107	1,083,987	8,669.4	0.897	0.569	0.045	0.285
1-Butanol	24	490,413	558,795	579,366	519,505	22,332.0	0.828	0.214	0.003	——
Tetradecanal	20	325,143	325,532	299,523	324,639	25,534.0	0.452	0.431	0.461	0.288
Aldehydes										
Pentanal	49	287,184	346,620	333,418	332,065	48,207.0	0.150	0.431	0.132	0.255
2-Decenal	12	2,506,927	2,538,726	2,503,047	2,545,239	44,225.0	0.208	0.962	0.856	0.312
Benzaldehyde	61	1,519,738	1,895,937	1504,567	1,909,303	516,882.0	0.004	0.994	0.913	0.243
Hexanal	76	3,314,373	3,540,872	3,465,724	3,250,360	646,219.0	0.985	0.823	0.478	0.255
Nonanal	72	1.96E+08	1.96E+08	1.96E+08	1.96E+08	156,838.0	0.850	0.181	0.850	0.275
Nonenal	52	282,352	285,117	280,208	266,576	10,584.0	0.294	0.049	0.116	0.258
Octanal	76	959,633	851,840	916,382	867,421	145,794.0	0.177	0.810	0.610	0.249
2-Heptenal	14	240,599	218,548	234,862	243,523	9,301.2	0.461	0.297	0.111	——
Dodecanal	14	33,921,664	33,920,537	33,916,034	33,916,499	8,676.5	0.941	0.298	0.859	0.316
Phenylacetaldehyde	20	72,707	84,906	77,255	74,749	7,575.1	0.254	0.503	0.094	0.268
Tridecanal	8	138,454	113,931	128,857	143,816	16,866.0	0.729	0.475	0.200	——
Alkanes										
Thiobis-methane	43	609,166	614,729	623,764	612,610	9,168.3	0.581	0.222	0.105	0.262
Hentriacontane	11	148,813	170,866	171,473	158,051	9,462,6	0.338	0.880	0.344	——
Octacosane	15	8,879	9,106	6,805	7,524	3,274.6	0.750	0.234	0.867	0.301
Pentadecane	6	33,211	47,357	13,459	31,695	14,871.0	0.414	0.372	0.890	0.422

Table 18 Continued.

Compound	*n*	USDA Select 58°C	USDA Select 80°C	USDA Choice 58°C	USDA Choice 80°C	SEM	*P* - value Temp	*P* - value QG	*P* - value Temp x QG	Random effect Study
Dodecane	17	3,034,066	2,943,869	2,990,860	2,973,509	33,505.0	0.125	0.838	0.286	——
Alkenes										
1,3-Octadiene	10	129,547	124,529	120,856	111,609	31,888.0	0.786	0.683	0.935	——
Furans										
2-Pentylfuran	45	515,512	519,560	502,868	529,615	30,706.0	0.266	0.925	0.409	0.253
Hydrocarbons										
DL-Limonene	7	174,821	303,930	437,365	157,569	131,225.0	0.520	0.614	0.143	——
Ketones										
3-Hydroxy-2-butanone	50	826,310	906,917	1,077,943	910,243	122,052.0	0.517	0.062	0.070	0.272
2,3-Octanedione	37	2,896,352	2,949,299	2,924,773	2,931,257	26,506.0	0.062	0.733	0.135	0.273
2,3-Butanedione	38	622,198[a]	746,807[b]	785,997[b]	762,905[b]	39,295.0	0.149	0.013	0.039	——
2-Pentanone	33	676.42	672.93	712.3	784.99	390.6	0.579	0.234	0.539	0.241
Polymers										
Styrene	30	2,618,257	2,596,678	2612,882	2,597,707	21,123.0	0.345	0.910	0.868	——
Sulfur-containing										
Sulfur dioxide	9	30,341	68,755	52,298	5,8259	26,398.0	0.273	0.756	0.419	0.340

All initial trained, descriptive sensory flavor attributes, chemical components, and volatile, aromatic flavor compounds that reported a significant difference in treatment, endpoint temperature, or treatment x endpoint temperature were analyzed with PLSR to evaluate their VIP value. The variable of importance factor was evaluated through several rounds where variables continued to be removed. The threshold VIP value increased after each evaluation until all variables remaining reported a VIP value of 0.8 or greater within at least one of the first two components. Final variables and their VIP values were reported in Table 19. A variable with a higher value of VIP score shows that it was more relevant in predicting the dependent variable (Akarachantachote et al., 2014). Setting thresholds for VIP values were debated among researchers across fields (Akarachantachote et al., 2014; Tran et al., 2014) as most agree that the same cut off threshold should not be the same in different types of data structures. While most use a VIP value of 1 as a cut off basis (due to the average of the squared values of the VIPs equal 1) this worked used a less stringent value of 0.8. If was because if too high of a VIP cutoff score was chosen, some crucial variables would be eliminated from the final model. It was noted that the variables above 1 for t1 and t2 were 18:2, salty, and bloody/serumy while benzaldehyde's VIP score was above 1 for t1.

The final model parameters were reported in Table 20. All coefficients were positive and therefore increased consumer overall liking as their presence/level increased with the exception of 18:1 and 18:2. 18:2 reported the largest coefficient in the final equation and negatively impacted consumer overall liking.

Table 19. Variable Importance in the Projection (VIP) for the partial least squares regression predicting consumer overall liking for Analysis 1; USDA Choice and Select bottom round roasts cooked to 58 or 80°C using consumer, trained descriptive flavor attributes, chemical components, and volatile, aromatic flavor compounds.

Variable	VIP for t1	SD	Lower bound (95%)	Upper bound (95%)	VIP for t2	SD	Lower bound (95%)	Upper bound (95%)
18:2	0.00	0.600	-1.176	1.176	1.32	0.357	0.622	2.021
Salty	1.44	0.376	0.702	2.176	1.22	0.393	0.453	1.993
Bloody/serumy	1.45	0.311	0.838	2.057	1.13	0.266	0.613	1.654
Benzaldehyde	1.12	0.490	0.155	2.074	0.99	0.262	0.472	1.501
Lipid (%)	0.98	0.772	-0.528	2.497	0.77	0.276	0.231	1.313
1-Butanol	0.69	0.801	-0.876	2.265	0.84	0.826	-0.779	2.458
18:1	0.62	0.491	-0.342	1.583	0.85	0.269	0.323	1.375
Sour	0.87	0.469	-0.049	1.788	0.69	0.320	0.063	1.319

SD = standard deviation.

Table 20. Prediction equation for the partial least squares regression for Analysis 1; USDA Choice and Select bottom round roasts cooked to 58 or 80°C using consumer, trained descriptive flavor attributes, and chemical components, and volatile, aromatic volatiles to predict consumer overall liking.

Variable	Consumer overall liking[1]
Intercept	2.658
Bloody/serumy	0.105
Sour	0.042
Salty	0.649
Lipid (%)	0.044
18:1	-0.008
18:2	-2.007
1-Butanol	0.000
Benzaldehyde	0.000

[1]Consumer liking attributes where 0=extremely dislike and 9=extremely like.

The biplot of the final PLSR is reported in Figure 4 where the dependent variable, consumer overall liking, was represented on the c vectors and the explanatory variables on the w* vectors. The w* was related to the weights of the variables produced by the model. These are similar to the factor loadings used for principal component analysis. This arrangement of the PLSR biplot allows for the visualization of the global relationship between the variables. Within the first two plotted components, the cumulative R^2 X values were 52.3 % and the cumulative R^2 Y values were 21.0%. Therefore, when interpreting the locations of the variables in comparison to the placement of the consumer overall liking dependent variable, more emphasis was placed on the relations along the X-axis, as more variation was explained. Consumer overall liking scores were associated with 18:1 fatty acid, 1-butanol, sour intensity, and lipid percentage. Benzaldehyde was less associated with consumer overall liking. Benzaldehyde was associated with fatty and broth flavor notes in cooked, cured pork and was considered to positively contribute to flavor (Benet et al., 2016). Benzaldehyde had previously been identified in beef aromas associated with almond oil, bitter almond, or burning aromatic taste (Calkins and Hodgen, 2007). Based on the final model coefficients in Table 20, it can be concluded that presence of benzaldehyde may contribute positively to consumer overall liking, but of the variables present in the final model, it was not the most influential. Although the variation along the Y axis was lower, it still represented an amount that explained a portion of the variation due to understanding consumer overall liking. The variables most associated with consumer overall liking were blood/serumy, benzaldehyde, lipid percentage, 1-butanol, salty, and sour. 18:2 was furthest from consumer overall liking, as expected due to the negative impact on consumer overall liking denoted by its coefficient value reported in Table 20.

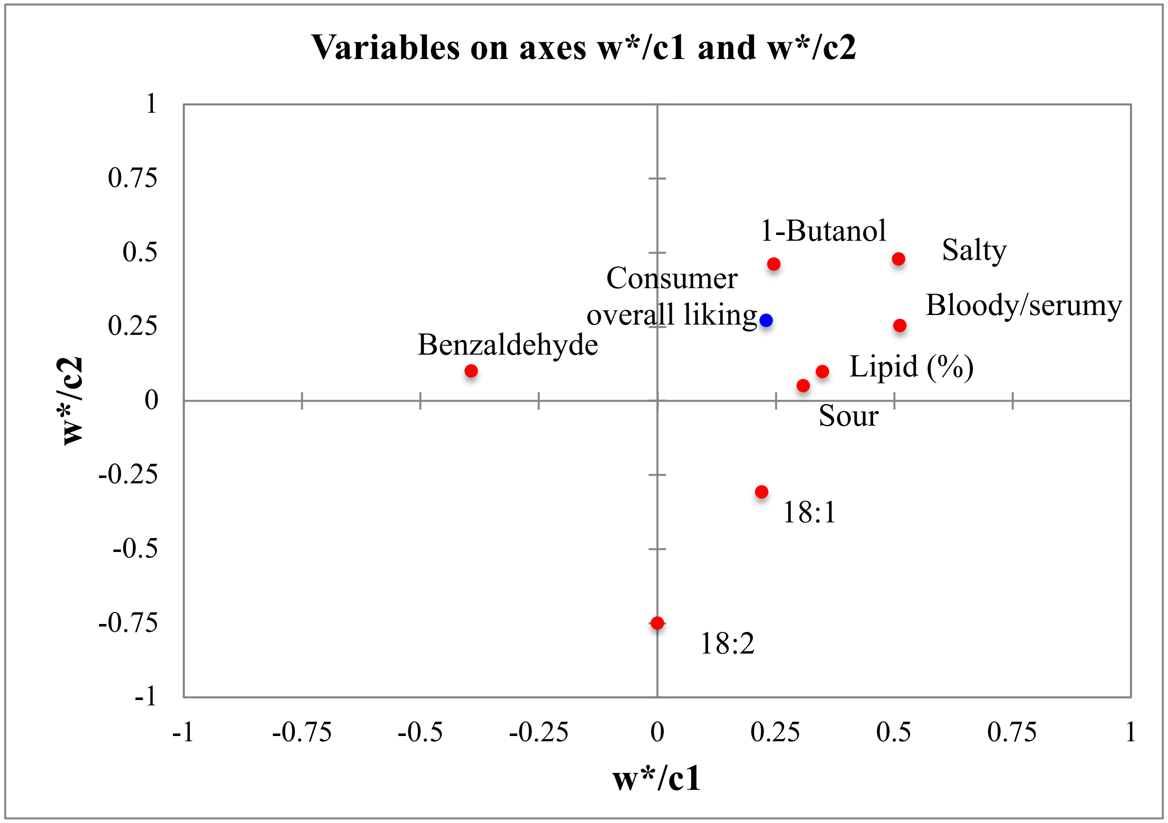


Figure 4. Partial least squares regression biplot for Analysis 1 USDA Choice and select bottom round roasts cooked to 58 or 80 °C. Consumer overall liking was defined as the dependent variable and consumer, trained descriptive attribute flavor, chemical attributes, and volatile, aromatic flavor compounds were defined as independent variables (*n* = 80). Component 1 R^2 Y and R^2 X values were 12.8 and 34.9%, respectively. Component 2 R^2 Y and R^2 X values were 8.2 and 17.4%, respectively.

Analysis 2

Table 21 reported the trained descriptive flavor attributes for USDA Choice bottom round roasts and USDA Choice top loin steaks cooked to either 58 or 80°C. Bottom round roasts were cooked in a crock-pot and while top loin steaks were cooked either on an open flat top or CS grill. Analyzing differences between subprimal cuts with their respective cooking methods may support the need to include these variables in the development of a statistical model to predict consumer overall liking. The session and order of the trained descriptive panel testing did not affect the model ($P > 0.05$). Subprimal cut and cook temperature endpoint affected ($P < 0.05$) descriptive beef flavor attributes. Top loin steaks reported higher levels of brown/roasted, bloody/serumy, and fat-like. Roasts or steaks cooked to 58°C had higher brown/roasted, metallic, and sour flavor intensities. An interaction was reported for umami as intensity was similar for bottom round roasts cooked to 58 and 80°C, but top loin steaks cooked to 80°C were higher than those cooked to 58°C ($P < 0.05$).

Table 21. Least squares means and SEM values for trained descriptive flavor attributes for Analysis 2; crock pot cooked USDA Choice bottom round roasts and either clam style or open flat grilled USDA Choice top loin steaks (*n* = 120).

	Bottom round roasts		Top loin steaks			*P*-value			Random effects *P*-value	
Attribute[1]	58°C	80°C	58°C	80°C	SEM	Trt	Temp	Trt x Temp	Session	Order
Major										
Beef identity	7.3	8.0	8.0	8.7	0.61	0.160	0.188	0.999	0.221	——
Brown/roasted	1.9	0.8	2.5	1.3	0.15	< 0.001	< 0.001	0.890	——	——
Bloody/serumy	0.6	0.9	1.2	1.7	0.17	< 0.001	0.006	0.525	——	——
Umami	0.9[ab]	0.8[ab]	0.7[b]	1.1[a]	0.10	0.745	0.032	0.030	0.359	0.125
Liver-like	0.4	0.3	0.2	0.2	0.08	0.014	0.914	0.417	0.206	——
Cardboard	0.3	0.4	0.1	0.2	0.07	< 0.001	0.417	0.593	——	——
Minor										
Fat-like	1.1	1.0	1.6	1.4	0.10	< 0.001	0.086	0.909	——	0.211
Metallic	2.2	1.6	2.2	2.3	0.10	0.064	< 0.001	0.875	0.162	——
Overall sweet	0.4	0.6	0.6	0.7	0.07	0.058	0.051	0.529	0.261	——
Sweet	0.3	0.4	0.4	0.5	0.07	0.157	0.184	0.846	0.181	——
Sour	2.0	1.5	2.0	1.7	0.08	0.193	< 0.001	0.244	——	——
Salty	1.3	1.3	1.4	1.4	0.05	0.120	0.942	0.853	0.201	0.445
Bitter	1.4	1.4	1.3	1.4	0.08	0.343	0.741	0.244	0.251	——
Sour aromatics	0.2[a]	0.1[bc]	0.0[c]	0.1[ab]	0.04	0.059	0.564	0.003	0.304	——
Soapy	0.0	0.0	0.0	0.0	0.01	0.471	0.489	0.471	0.429	——
Warmed over flavor	0.1	0.2	0.0	0.1	0.03	0.002	0.002	0.152	0.442	0.331

[1]Trained descriptive flavor attributes were evaluated where 0 = none and 15 = extremely intense.

[a-c]Means with different superscripts are significantly different ($P < 0.05$).

SEM = standard error mean; Trt = treatment; Temp = temperature.

As presented in Table 22, top loin strip steaks had greater amounts of 14:0, 16:0, 16:1, 18:1, 20:4, and 20:5 fatty acids (*P* < 0.05). Bottom round roasts had a higher percentage of moisture (*P* < 0.001) and lower percentage of lipid (*P* < 0.001) compared to top loin steaks. Due to these differences noted in chemical composition between subprimal cut, these variables were included in a statistical model to predict consumer overall liking of Analysis 2 treatments.

Table 22. Least squares means and SEM values for chemical components for Analysis 2; USDA Choice bottom round roasts and USDA Choice top loin steaks (*n* = 38).

					Random effects
Chemical component	Bottom round roasts	Top loin steaks	SEM	*P*-value	Study
14:0	0.09	0.26	0.047	< 0.001	0.285
16:0	0.80	1.77	0.164	< 0.001	0.328
16:1	0.12	0.24	0.370	< 0.001	0.288
18:1	1.36	2.64	0.194	< 0.001	——
18:2	0.19	0.34	0.053	< 0.001	0.264
20:4	0.04	0.06	0.012	0.019	0.272
20:5	0.00	0.01	0.003	0.011	——
Moisture (%)	72.64	68.61	0.748	< 0.001	——
Lipid (%)	4.29	7.99	0.696	< 0.001	——
Non-heme	3.38	4.06	0.550	0.154	0.289
Myoglobin	2.93	3.05	0.134	0.512	0.426

[1]Fatty acids are measured as a g per 100g meat.
n = number of observations; SEM = standard error mean.

Transformed aromatic volatile compound least squares means for bottom round roasts and top loin steaks cooked to endpoints of 58 and 80°C are reported in Table 23. Lower endpoint temperatures created a greater amount of 1-heptanol ($P = 0.007$) and thiobis-methane ($P < 0.001$). Cut within the treatment was responsible for many differences in volatiles ($P < 0.05$). Top loin steaks had greater amounts alcohol compounds of 1-heptanol, 1-octanol, 1-hexanol, and 1-butanol. Bottom round roasts had a greater amount of acetic acid, tetradecanal, and thiobis-methane, 3-hydroxy-2-butanone and heptanal. An interaction of endpoint temperature and subprimal cut was reported for benzaldehyde and DL limonene. Volatile aromatic compounds that reported significant differences were retained for PLSR to assess their relationship to consumer overall liking.

Table 23. Transformed volatile, aromatic least squares means and SEM values for Analysis 2; crock pot cooked USDA Choice bottom round roasts and either clam style or open flat grilled USDA Choice top loin steaks.

		Bottom round roasts		Top loin steaks			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	Temp	Cut	Temp x Cut	Study
Acids										
Acetic acid	78	212,365	197,190	220,767	197,522	10,473.0	0.632	0.038	0.658	——
Hexanoic acid	58	295,998	282,664	287,089	283,268	15,305.0	0.771	0.549	0.739	——
Pentanoic acid	8	75,318	63,718	72,820	71,141	4,930.4	0.579	0.179	0.291	——
Octanoic acid	26	101,501	100,760	101,609	99,314	2,679.6	0.769	0.507	0.733	——
Heptanoic acid	16	213,813	222,285	224,224	217,605	7,455.3	0.641	0.879	0.233	——
Alcohols										
1-Heptanol	53	1,540,853	1,493,906	1,552,703	1,533,571	14,376.0	0.007	< 0.001	0.138	0.295
1-Octen-3-ol	60	792,040	785,056	793,638	762,968	28,153.0	0.581	0.311	0.525	0.296
1-Pentanol	19	7,010,098	7,024,696	7,123,163	7,089,759	55,410.0	0.082	0.846	0.622	——
1-Octanol	69	394,505	366,134	395,313	380,708	8,905.6	0.184	< 0.001	0.234	0.293
1-Hexanol	64	206,118	188,490	222,558	195,588	13,986.0	0.108	0.003	0.520	0.259
1-Butanol	37	566,326	486,363	519,082	503,937	30,002.0	0.506	0.038	0.151	——
Aldehydes										
Tetradecanal	15	349,483	366,784	338,287	356,432	11,296.0	0.106	0.014	0.945	0.264
Pentanal	62	417,437	416,267	392,502	398,926	55,713.0	0.272	0.890	0.842	0.249
2-Decenal	21	1,032,747	1,054,998	1,038,421	1,028,740	15,058.0	0.292	0.515	0.110	——
Benzaldehyde	80	1,500,978[a]	1,900,689[b]	1,632,012[ab]	1,463,745[a]	411,992.0	0.138	0.260	0.006	0.243
Hexanal	108	2,162,716	2,057,769	1,666,962	1,998,302	602,321.0	0.068	0.454	0.150	0.243
Nonanal	103	1,679,851	1,658,049	1,621,364	1,575,793	135,750.0	0.342	0.649	0.872	0.262
Nonenal	79	258,644	244,940	262,312	258,634	8,354.6	0.063	0.063	0.288	0.261
Octanal	106	609,295	563,979	502,703	544,627	127,555.0	0.116	0.966	0.275	0.245
2-Heptenal	24	129,865	135,446	127,178	133,160	12,260.0	0.782	0.510	0.981	0.338
Dodecanal	16	4,519,954	4,520,236	4,518,719	4,523,236	8,959.6	0.861	0.635	0.675	0.287
Phenylacetaldehyde	26	95,978	9,3560	103,478	94,794	7,545.8	0.272	0.186	0.429	0.263
Tridecanal	8	58,803	73,449	63,225	59,093	9,009.8	0.610	0.590	0.356	——
Heptanal	46	173,056	158,429	172,131	156,367	7,069.6	0.811	0.019	0.927	0.494

Table 23 Continued.

		Bottom round roasts		Top loin steaks			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	Temp	Cut	Temp x Cut	Study
Alkanes										
Thiobis-methane	39	194,844	186,619	177,330	168,784	7,454.0	<.0001	0.019	0.963	0.254
Hentriacontane	19	210,188	210,817	211,068	211,074	4,394.8	0.834	0.916	0.913	0.285
Octacosane	18	13,351	14,745	17,115	14,961	3,934.0	0.311	0.843	0.364	0.319
Dodecane	26	1,247,016	1,233,626	1,234,229	125,0738	32,996.0	0.922	0.944	0.507	0.290
1,3-Octadiene	13	182,408	174,469	190,792	178,948	174,469.0	0.761	0.642	0.926	——
Furans										
2-Pentylfuran	59	411,692	434,137	416,483	411,056	22,033.0	0.380	0.413	0.179	0.256
Furfural	10	609,062	607,516	614,714	609,680	10,119.0	0.560	0.622	0.786	0.295
DL-Limonene	11	4,630,138[b]	4,328,142[a]	4,427,601[ab]	4,497,242[ab]	95,598.0	0.814	0.139	0.034	——
3-Hydroxy-2-butanone	66	1,241,859	1,080,706	1,212,018	978,947	78,599.0	0.282	0.001	0.555	0.370
2,3-Octanedione	50	1,638,674	1,646,241	1,634,544	1,649,330	22,146.0	0.970	0.424	0.794	0.277
2,3-Butanedione	43	578,338	552,781	532,001	477,569	38,045.0	0.091	0.261	0.682	——
2-Pentanone	37	1,588	1,722	1,586	1,593	1,028.9	0.669	0.645	0.688	0.241
Polymers										
Styrene	43	1,819,435	1,802,160	1,840,742	1,812,493	23,638.0	0.410	0.238	0.774	——
Sulfur-containing										
Sulfur dioxide	7	73,109	87,764	115,485	20,550	26,765.0	0.636	0.216	0.135	——
2-Acetyl-2-thiazoline	14	740,749	745,554	742,436	745,614	25,857.0	0.929	0.643	0.917	0.249

The variable importance in the projection for Analysis 2 were reported in Table 24. Brown/roasted, 18:1, 16:0, tetradecanal, and moisture percentage reported VIP >1 scores for t1 and t2. Thiobis-methane, DL-Limonene, and fat-like reported VIP > 1 scores for t2. These variables were strong contributors to predicting consumer overall liking. Remaining variables met the VIP > 0.8 cutoff value and were considered to contribute to the final model.

Table 24. Variable Importance in the Projection (VIP) for the partial least squares regression for Analysis 2; crock pot cooked USDA Choice bottom round roasts and either clam style or open flat grilled USDA Choice top loin steaks using trained, descriptive panel attributes, chemical components, and volatile, aromatic compounds to predict consumer overall liking.

Variable	VIP for t1	SD	Lower bound (95%)	Upper bound (95%)	VIP for t2	SD	Lower bound (95%)	Upper bound (95%)
Brown/roasted	1.17	0.341	0.499	1.834	1.15	0.321	0.516	1.774
18:1	1.22	0.272	0.687	1.754	1.10	0.205	0.700	1.504
DL-Limonene	0.88	0.907	-0.895	2.660	1.04	1.028	-0.979	3.051
16:0	1.16	0.300	0.568	1.744	1.09	0.203	0.690	1.487
Tetradecanal	1.21	0.824	-0.405	2.825	1.06	0.730	-0.369	2.493
Moisture (%)	1.11	0.342	0.437	1.777	1.00	0.253	0.507	1.498
Thiobis-methane	1.19	0.374	0.375	1.841	0.99	0.342	0.324	1.665
Fat-like	1.09	0.244	0.614	1.571	0.96	0.240	0.487	1.426
16:1	0.63	0.375	-0.106	1.363	0.92	0.235	0.461	1.381
Liver-like	0.83	0.200	0.436	1.221	0.88	0.231	0.424	1.330
20:05	0.38	0.417	-0.434	1.201	0.90	0.206	0.499	1.307
Bloody/serumy	0.83	0.486	-0.119	1.787	0.87	0.418	0.046	1.685

SD = standard deviation.

The final model was reported in Table 25. Most notably of all the variables, 20:5 was the most impactful towards predictive consumer overall liking ratings. For every gram of 20:5 per 100 gram of meat sample, consumer overall liking was expected to decrease by -8.356. Although not as severe, 16:1, moisture percentage, and liver-like also negatively impacted consumer overall liking. The variables that contributed most to consumer overall liking were brown/roasted and fat-like.

Table 25. Prediction equation for the partial least squares regression for Analysis 2; crock pot cooked USDA Choice bottom round roasts and either clam style or open flat grilled USDA Choice top loin steaks using consumer, trained descriptive flavor attributes, and chemical components to predict consumer overall liking.

Variable	Consumer overall liking
Intercept	21.369
Brown/roasted	0.265
Bloody/serumy	0.201
Fat-like	0.256
Liver-like	-0.316
Moisture (%)	-0.023
16:0	0.091
16:1	-0.562
18:1	0.078
20:5	-8.356
Thiobis-methane	0.000
Tetradecanal	0.000
DL-Limonene	0.000

The biplot for the PLSR-DA analysis predicting Analysis 2 treatments using trained, descriptive flavor attributes, chemical components, and volatile, aromatic compounds was shown in Figure 5. The cumulative R^2 Y and R^2 X for the first two components within the biplot accounted for 49.0 and 54.65, respectively. Since the amount of variation explained on each axis are similar numerically, near equal emphasis was placed in interpreting the placement of the variables on each axis. Overall, consumer overall liking clustered near bloody/serumy, brown/roasted, and fat-like.

There was limited mention of the tetradecanal compound in meat science literature. In general, tetradecanal was a long-chain fatty aldehyde commonly found in ceylan cinnamon and has been isolated from lemon oil (PubChem, 2019). The placement of DL-limonene near liver-like was interesting as this compound has previously been associated with liver-like samples. Although limonene was known for its citrus aroma, the compound was observed in higher concentrations in liver-like samples (Ho et al., 2003; Hodgen, 2006). Thiobis-methane was negatively associated with beef flavor as this compound was responsible for irradiation off-odor (Fan et al., 2002). These compounds were referred to as “sulfide” and were distinctly different from odors characteristic of oxidation (Flores, 2017). Thiobis-methane, liver-like, and DL-limonene were understandably located in the opposite quadrant from consumer overall liking and were near one another.

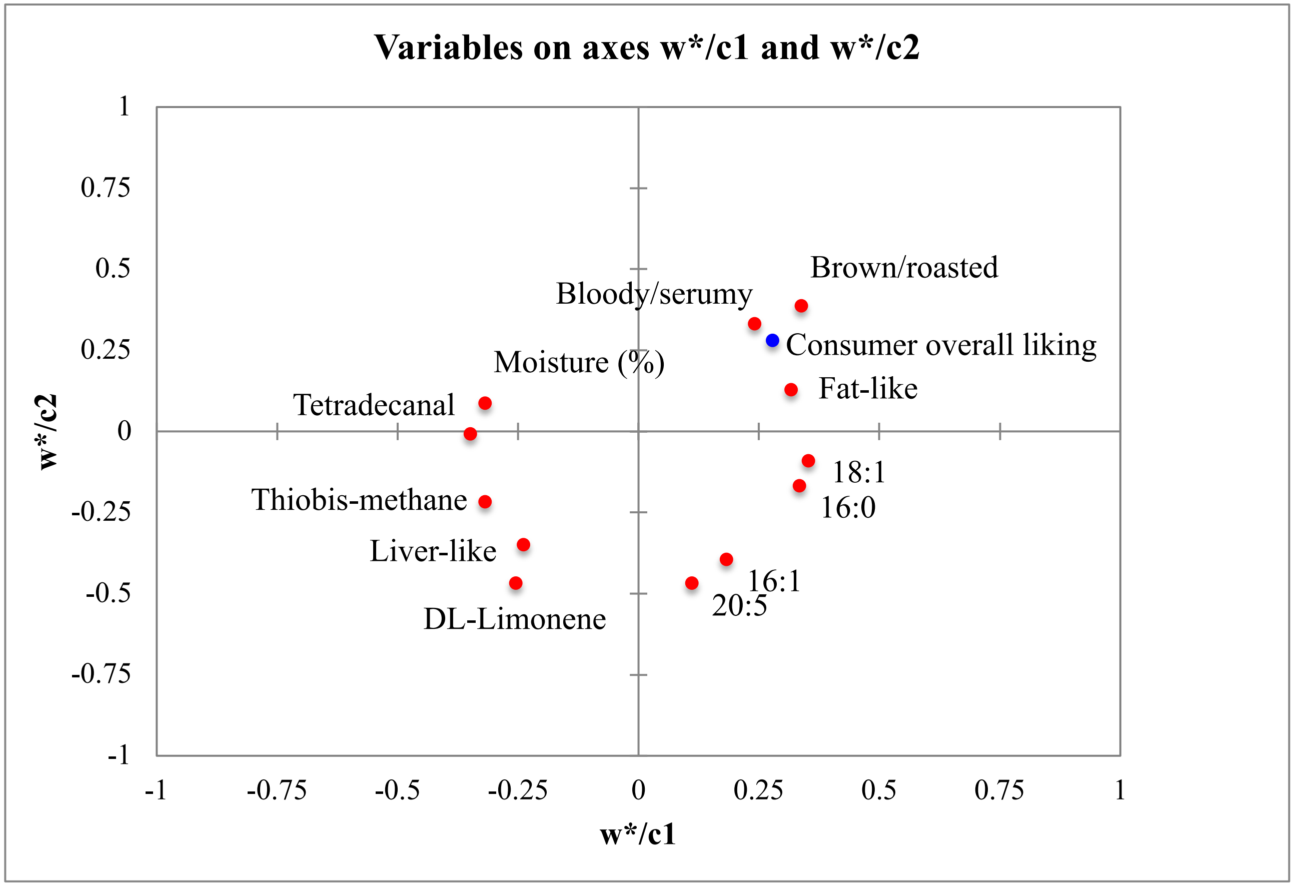


Figure 5. Partial least squares regression biplot for Analysis 2; crock pot cooked USDA Choice bottom round roasts and either clam-shell style or open flat grilled USDA Choice top loin steaks. Consumer overall liking was defined as the dependent variable and volatile, aromatics, were defined as independent variables. Component 1 R^2 Y and R^2 X values were 37.2 and 39.4%, respectively. Component 2 R^2 Y and R^2 X values were 11.8 and 15.2%, respectively.

Analysis 3

Table 26 reported trained descriptive flavor attribute comparisons for USDA Choice and Select top sirloin steaks cooked on either an open flat or CS grill to end point temperatures of 58 or 80°C. Analysis 3 served to determine if cooking method effects differences in trained descriptive flavor attribute levels and may ultimately serve as a variable that impacted consumer overall liking. Cooking with a CS grill represented an intermediate form of moist cooking where moisture was retained in the environment allowing for the steam to serve as a component of heat transfer. Grilling represents a form of dry-heat cookery which uses higher temperatures and results in the dehydration of the meat's surface which leads to the initiation of the Maillard reaction (Kerth and Miller, 2015). Therefore, it was reasonable to hypothesize cooking method must be considered in determining the differences in attributes of beef cuts. Brown/roasted was the only attribute that reported a significant interaction ($P < 0.05$) between cook method and temperature. Open flat grilled top sirloin steaks were higher in brown/roasted compared to CS for both end point temperatures. Open flat grilled steaks cooked to 58°C had higher levels than those cooked to 80°C. Open flat grilled top sirloin steaks reported higher levels of umami ($P < 0.05$). Numerous differences in attribute levels were reported due to temperature effects ($P < 0.05$). Most notably, top sirloin steaks cooked to 58°C were higher in bloody/serumy, fat-like, and metallic.

Table 26. Least squares means and SEM values for trained descriptive flavor attributes for Analysis 3; USDA Choice top sirloin steaks either open flat or clam-shell style grilled (n = 79).

	Grilled		CS			*P*-value			Random effects	
Attribute[1]	58°C	80°C	58°C	80°C	SEM	Trt	Temp	Trt x Temp	Session	Order
Major										
Beef identity	7.5	8.9	7.3	7.6	0.56	0.170	0.169	0.377	——	——
Brown/roasted	1.3[b]	2.3[a]	0.8[c]	0.9[c]	0.12	< 0.001	< 0.001	< 0.001	0.194	——
Bloody/serumy	2.7	1.4	2.6	1.4	0.18	0.740	< 0.001	0.743	——	0.344
Umami	0.5	0.9	0.4	0.6	0.07	0.030	< 0.001	0.053	0.227	——
Liver-like	0.1	0.1	0.3	0.3	0.06	0.005	0.880	0.540	0.291	——
Cardboard	0.2	0.2	0.2	0.3	0.06	0.481	0.123	0.359	——	——
Minor										
Fat-like	1.2	1.0	1.2	0.9	0.09	0.165	< 0.001	0.552	——	0.356
Metallic	2.5	1.9	2.4	1.9	0.12	0.676	< 0.001	0.355	0.347	0.161
Overall sweet	0.4	0.5	0.4	0.5	0.07	0.972	0.042	0.893	0.157	——
Sweet	0.2	0.4	0.2	0.3	0.06	0.305	0.020	0.885	——	——
Sour	2.5	1.9	2.4	2.0	0.11	0.905	< 0.001	0.291	0.420	0.207
Salty	1.2	1.3	1.3	1.2	0.05	0.601	0.830	0.057	0.356	——
Bitter	1.6	1.6	1.7	1.5	0.09	0.827	0.183	0.512	0.057	0.072
Sour aromatics	0.0	0.0	0.0	0.1	0.03	0.008	0.073	0.129	0.340	——
Soapy	0.0	0.0	0.0	0.0	0.01	0.471	0.489	0.471	0.429	——
Warmed over flavor	0.0	0.0	0.0	0.1	0.03	0.249	0.019	0.096	0.225	0.422

[1]Trained descriptive flavor attributes were evaluated where 0 = none and 15 = extremely intense.

[a-c]Means with different superscripts are significantly different ($P < 0.05$).

SEM = standard error mean; Grilled = open flat grilled; CS = clam-shell style grill; Trt = treatment; Temp = temperature.

Descriptive summary statistics for Analysis 3 were reported in Table 27. Least squares means for volatile, aromatic compounds in top sirloin steaks cooked with either an open flat or clam-shell style grill to endpoint temperatures of 58 or 80°C are reported in Table 28. Multiple volatile aromatic compounds differed due to cooking method (P < 0.05). Open flat grilled, representative of a dry heat form of cookery, reported higher levels of hexanal and 2-acetyl-2-thiazoline. Clam-shell style grilled, an intermediate form of dry heat and moist heat cookery, reported higher levels of 1-octanol, and octanal compounds. Lower temperature endpoints reported higher levels of heptanoic acid (P = 0.015) and 2-heptenal (P = 0.015). Higher levels of hentriacontane was reported for higher endpoint temperatures (P = 0.040). Interactions of endpoint temperature and cooking method were reported for 2-decenal (P = 0.025) and phenylacetaldehyde (P = 0.039). These volatile, aromatic compounds that were significantly different in their level of presence were used for additional PLSR analysis.

Table 27. Least squares means and SD values for chemical analysis for Analysis 3; USDA Choice top loin steaks (n = 30).

Chemical component	Top sirloin steak	SD	Min	Max
14:0[1]	0.11	0.610	0.03	0.28
16:0	0.90	0.413	0.38	2.06
16:1	0.09	0.045	0.02	0.24
18:1	1.23	0.491	0.50	2.35
18:2	0.23	0.103	0.00	0.01
20:4	0.05	0.021	0.02	0.11
20:5	0.00	0.004	0.00	0.01
Moisture (%)	72.32	1.337	70.06	74.68
Lipid (%)	3.99	1.710	1.78	8.21
Non-heme	3.61	1.097	1.99	7.47
Myoglobin	3.07	0.638	2.24	4.99

[1]Fatty acids are measured as a g per 100g of meat.

SD = standard deviation.

Table 28. **Transformed volatile, aromatic least squares means and SEM values for Analysis 3; top sirloin steaks cooked with either an open flat or clam-shell style grill to 58 or 80°C.**

		Open flat		Clam-shell style			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	CM	Temp	CM x Temp	Study
Acids										
Acetic acid	57	326,214	342,451	340,963	362,035	16,307.0	0.186	0.151	0.851	——
Hexanoic acid	33	236,323	245,607	252,996	206,366	25,192.0	0.617	0.410	0.221	——
Octanoic acid	21	235,444	227,907	230,172	229,149	2,602.7	0.393	0.080	0.175	——
Heptanoic acid	21	35,082,348	35,070,969	35,077,788	35,069,964	5,174.3	0.445	0.015	0.623	0.340
Alcohols										
1-Heptanol	49	73,046	64,024	88,948	87,396	10,284.0	0.003	0.410	0.556	0.279
1-Octen-3-ol	45	466,446	477,132	477,426	435,701	24,251.0	0.281	0.264	0.062	0.267
1-Pentanol	8	1,098,102	1,076,540	1,130,086	1,137,291	66,055.0	0.410	0.893	0.789	——
1-Octanol	50	201,405	191,668	222,992	209,136	10,027.0	0.037	0.199	0.821	0.424
1-Butanol	26	1,246,513	1,198,952	1,156,439	1,198,275	38,604.0	0.165	0.928	0.171	——
Aldehyes										
Pentanal	37	277,506	280,219	285,693	288,616	38,898.0	0.651	0.877	0.995	0.272
2-Decenal	20	315,087[ab]	276,842[a]	325,101[b]	343,290[b]	21,105.0	0.003	0.408	0.025	0.263
Benzaldehyde	55	2,523,606	2,807,097	2,627,312	2,792,052	606,695.0	0.787	0.183	0.718	0.244
1-Hexanol	38	128,576	129,601	132,243	126,133	10,668.0	0.987	0.697	0.585	0.272
Hexanal	72	2,135,915	2,255,067	1,852,266	1,795,948	474,321.0	0.044	0.863	0.631	0.249
Nonanal	68	58,010,354	58,066,504	58,113,243	58,014,951	413,077.0	0.838	0.866	0.538	0.245
Nonenal	51	201,288	193,951	207,698	193,673	12,225.0	0.624	0.093	0.594	0.259
Octanal	73	734,972	819,116	964,678	877,607	194,896.0	0.034	0.982	0.203	0.247
2-Heptenal	9	95,739	85,080	93,883	75,357	4,336.3	0.186	0.015	0.359	0.421
Dodecanal	23	2,483,237	2,481,203	2,479,416	2,476,282	12,751.0	0.323	0.566	0.901	0.247
Phenylacetaldehyde	17	57,963[a]	69,580[ab]	74,654[b]	64,014[ab]	6,441.2	0.244	0.914	0.039	0.294
Heptanal	28	76,173	68,713	73,734	71,345	6,061.2	0.986	0.393	0.658	——
Alkanes										
Thiobis-methane	44	279,599	282,654	286,395	280,648	9,167.4	0.556	0.740	0.281	0.252
Hentriacontane	15	7,867	10,650	7,186	10,363	2,141.4	0.709	0.040	0.879	0.273
Octacosane	13	14,163	14,013	13,823	14,720	4,137.9	0.906	0.812	0.739	0.272
Dodecane	19	6,948,262	6,880,483	6,911,554	6,970,904	61,745.0	0.542	0.923	0.156	0.402

Table 28 Continued.

		Open flat		Clam-shell style			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	CM	Temp	CM x Temp	Study
1,3-Octadiene	17	418,893	403,555	411,502	422,169	22,909.0	0.678	0.862	0.344	0.371
Furans										
2-Pentylfuran	43	499,647	504,610	494,862	492,657	17,326.0	0.368	0.881	0.700	0.263
Furfural	10	79,767	82,853	87,454	86,299	5,375.8	0.205	0.788	0.560	0.295
Hydrocarbons										
DL-Limonene	14	1,980,457	1,957,163	1,879,758	1,962,959	34,405.0	0.142	0.337	0.105	——
Ketones										
3-Hydroxy-2-butanone	47	674,627	843,857	795,228	764,650	107,572.0	0.803	0.410	0.232	0.359
2,3-Octanedione	35	1,140,618	1,147,806	1,141,129	1,164,802	20,123.0	0.376	0.120	0.402	0.258
2-Nonanone	18	312,771	328,802	311,506	317,569	15,044.0	0.482	0.188	0.542	0.272
2,3-Butanedione	41	1,686,434	1,657,137	1,612,262	1,691,769	57,336.0	0.668	0.587	0.243	0.449
2-Pentanone	29	5,200	6,133	5,502	6,536	3,729.5	0.757	0.381	0.964	0.245
Polymer										
Styrene	32	2,745,555	2,722,147	2,738,917	2,761,342	21,121.0	0.387	0.979	0.226	——
Pyrazines										
3-Ethyl-2,5-dimethylpyrazine	14	85,847	105,637	126,383	144,715	26,962.0	0.089	0.385	0.972	0.326
Tetradecanal	14	202,743	178,367	193,161	189,155	13,973.0	0.946	0.122	0.259	0.278
Tridecanal	14	3,795,318	3,800,502	3,799,510	3,802,475	6,037.5	0.350	0.225	0.743	0.295
2-Acetyl-2-thiazoline	20	60,445	73,068	79,695	76,171	9,456.2	0.027	0.336	0.098	0.257

After evaluating each variable's contribution to the model, final variables were reported in Table 29 along with their VIP values. Bloody/serumy and sour aromatics reported VIP scores >1 for t1 and t2, indicating their importance in their contribution in predicting consumer overall liking. All remaining variables were at least 0.85 or greater. The final model was reported in Table 30. Bloody/serumy, fat-like, and sour positively contributed to consumer overall liking as their coefficients were 0.152, 0.229, and 0.122, respectively. Warmed over flavor and sour aromatics negatively impacted consumer overall liking as their coefficients were -0.503 and -1.167, respectively. Although the volatile, aromatic compounds qualified to be part of the final regression analysis, their coefficients are too small in size to interpret for their effect on consumer overall liking. Therefore, the benefit of visualizing their special relationship to consumer overall liking was beneficial by displaying them in biplot form.

Table 29. Variable Importance in the Projection (VIP) for the partial least squares regression for Analysis 3; open flat or CS grilled top sirloin steaks cooked to either 58 or 80°C using trained, descriptive panel attributes, chemical components, and volatile, aromatic compounds.

Variable	VIP for t1	SD	Lower bound (95%)	Upper bound (95%)	VIP for t2	SD	Lower bound (95%)	Upper bound (95%)
Bloody/serumy	1.40	0.316	0.777	2.017	1.31	0.282	0.751	1.858
2-Heptenal	0.87	0.524	-0.161	1.893	0.96	0.427	0.124	1.798
Sour aromatics	1.25	0.353	0.554	1.938	1.18	0.344	0.500	1.849
1-Octanol	0.94	0.412	0.130	1.746	1.02	0.422	0.192	1.846
Sour	0.99	0.346	0.315	1.672	0.99	0.258	0.483	1.496
2-Acetyl-2-thiazoline	0.79	0.700	-0.577	2.166	0.95	0.606	-0.236	2.138
Phenylacetaldehyde	0.69	0.995	-1.260	2.640	0.81	1.049	-1.244	2.866
Fat-like	0.99	0.315	0.372	1.605	0.93	0.265	0.409	1.447
1-Heptanol	0.98	0.440	0.120	1.845	0.91	0.399	0.133	1.695
Warmed over flavor	0.91	0.229	0.462	1.358	0.85	0.210	0.437	1.259

SD = standard deviation.

Table 30. Prediction equation for the partial least squares regression for treatments for Analysis 3; open flat or CS grilled top sirloin steaks cooked to either 58 or 80°C using consumer, trained descriptive flavor attributes, and chemical components to predict consumer overall liking.

Variable	Consumer overall liking
Intercept	4.398
Bloody/serumy	0.152
Fat-like	0.229
Sour	0.122
Sour aromatics	-1.167
Warmed over flavor	-0.503
1-Heptanol	0.000
1-Octanol	0.000
2-Heptenal	0.000
Phenylacetaldehyde	0.000
2-Acetyl-2-thiazoline	0.000

CS = clam-shell style grill; Grill = open flat grill.

The biplot representing Analysis 3 was presented in Figure 6. The R^2 X cumulative value for the first two components was 43.6% while the cumulative R^2 Y value was 35.8%. Observing the variation explained along the X axis, 2-acetyl-2-thiazoline, 1-octanol, 1-heptanol, fat-like, bloody/serumy, sour, and 2-heptanal were closely associated with consumer overall liking. 2-Acetyl-2thiazoline has been documented as a volatile compound related to toasty, burnt, earthy, caramel-like, meaty, and popcorn odorants of roasted beef (Cerny and Grosch, 1992) and oven roasted beef (Rochat et al., 2007). 1-Octanol has been described as a penetrating aromatic odor, fatty, waxy, citrus, oily, walnut, moss, chemical, metal, and burnt characteristics (Calkins and Hodgen, 2007). 1-Heptanol was referred to as an odor or aroma that was fragrant, woody, oily, green, fatty, winey, sap, and herb while 2-heptenal was described as soapy, fatty, almond, fishy, and unpleasant (Calkins and Hodgen, 2007). Not surprisingly, as most of these compounds were associated with a fatty characteristic odor or flavor, they were clustered near the fat-like attribute along the X axis. Additionally, the sour and bloody/serumy trained panel attributes were placed near these compounds and near consumer overall liking. Evaluating the variation along the X axis, warmed over flavor, sour aromatics, and phenylacetaldehyde were placed furthest from consumer overall liking, indicating a lack of associated with the dependent variable. Phenylacetaldehyde was derived from the phenylalanine amino acid and has been described as honey, floral rose, and sweet in beef references (Guth and Grosch, 1994; Rochat et al., 2007; Vasta et al., 2011).

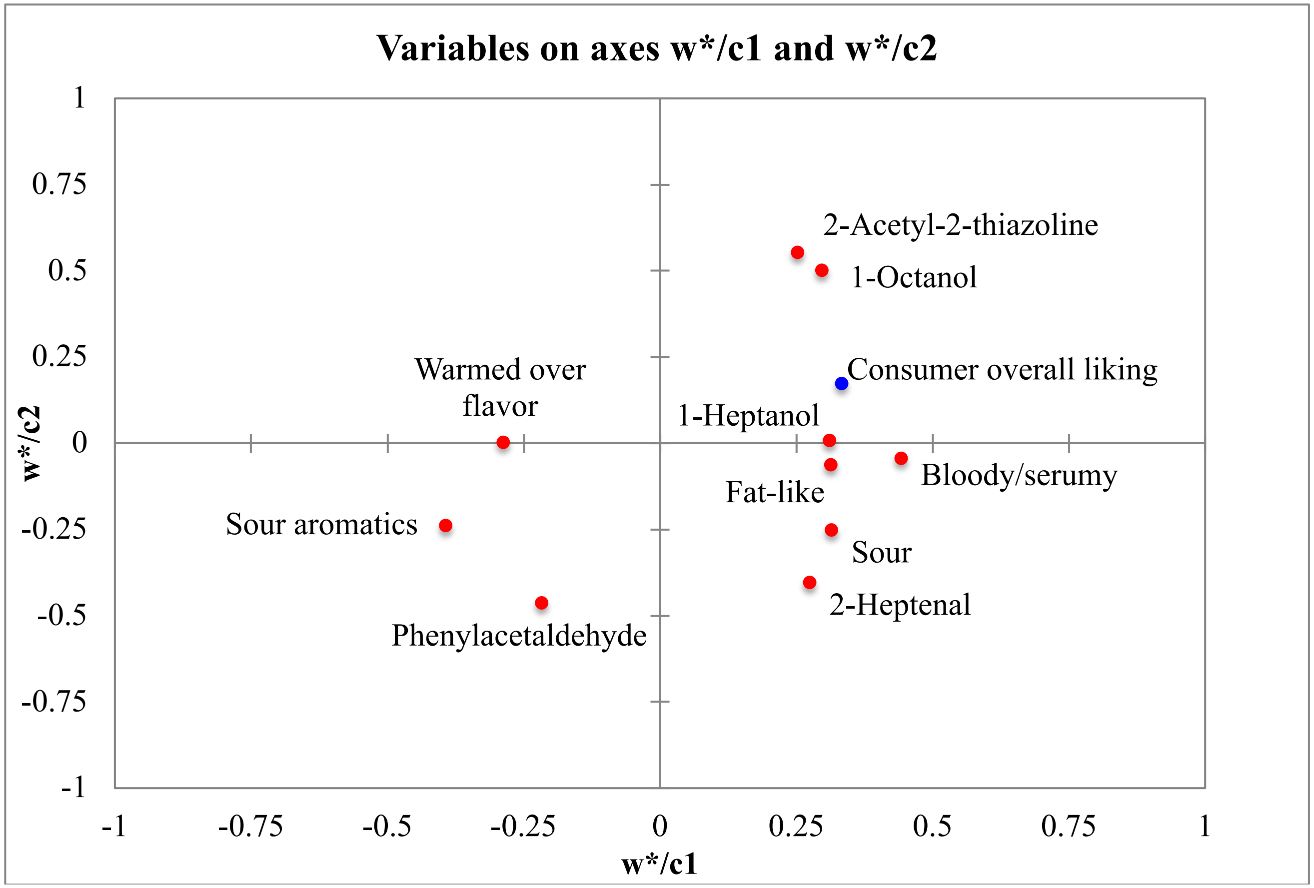


Figure 6. Partial least squares regression biplot for Analysis 3; top sirloin steaks cooked with either and open flat or clam-shell style grill to 58 or 80°C. Volatile, aromatic compounds, trained descriptive flavor attributes, and chemical components were defined as independent variables and consumer overall liking was the dependent variable. Component 1 R^2 Y and R^2 X values were 30.9 and 26.4%, respectively. Component 2 R^2 Y and R^2 X values were 4.9 and 17.2%, respectively.

Analysis 4

Analysis 4 included USDA Choice top loin steaks from Study 1, 2, and 3. The effect of cooking method styles of either open flat or CS style grilled and differing end point temperatures of 58 or 80°C on trained descriptive flavor attributes are reported in Table 31. Trained panel session and order random effects reported no significant impacts ($P > 0.05$) on the model, verifying the statistical strength of combining the multiple studies. Brown/roasted flavors were higher for steaks cooked on an open flat grill ($P < 0.05$). Temperature end point affected numerous trained descriptive flavor attributes ($P < 0.05$). Lower temperature endpoints of 58°C had higher levels of bloody/serumy and metallic and lower levels of umami. Chemical means for fatty acid analysis, myoglobin content, non-heme iron, moisture percentage, and lipid percentage are reported in Table 32.

Table 31. Least squares means and SEM values for trained descriptive flavor attributes for Analysis 4; USDA Choice top loin strip steaks either open flat or clam-shell style grilled (n = 80).

	Grilled		CS			*P*-value			Random effects	
Attribute	58°C	80°C	58°C	80°C	SEM	Trt	Temp	Trt x Temp	Session	Order
Major										
Beef identity	8.4	9.2	7.8	8.3	0.57	0.180	0.240	0.806	0.435	0.460
Brown/roasted	1.7	2.4	0.8	1.1	0.14	< 0.001	< 0.001	0.111	——	0.453
Bloody/serumy	2.4	1.5	2.5	1.2	0.13	0.442	< 0.001	0.116	——	——
Umami	0.8	1.1	0.6	1.0	0.09	0.096	< 0.001	0.683	0.176	0.495
Liver-like	0.1	0.1	0.2	0.3	0.07	0.043	0.366	0.447	——	——
Cardboard	0.1[b]	0.0[b]	0.1[b]	0.3[a]	0.05	0.054	0.169	0.012	——	——
Minor										
Fat-like	1.6	1.5	1.5	1.3	0.11	0.121	0.131	0.742	——	0.129
Metallic	2.2	1.9	2.4	1.7	0.10	0.851	< 0.001	0.095	0.218	——
Overall sweet	0.7	0.8	0.5	0.6	0.07	0.030	0.237	0.728	0.154	——
Sweet	0.4	0.6	0.4	0.4	0.07	0.176	0.299	0.141	0.254	0.314
Sour	2.0	1.6	2.1	1.8	0.09	0.044	< 0.001	0.660	——	0.397
Salty	1.4	1.5	1.3	1.3	0.05	0.014	0.781	0.300	0.465	0.438
Bitter	1.2	1.5	1.4	1.3	0.08	0.978	0.195	0.072	0.127	——
Sour aromatics	0.0	0.0	0.0	0.1	0.03	0.290	0.012	0.084	0.368	0.373
Soapy	0.0	0.0	0.0	0.0	0.00	0.322	0.322	0.322	——	——
Warmed over flavor	0.0	0.0	0.0	0.1	0.02	0.047	0.047	0.114	——	——

[1]Trained descriptive flavor attributes were evaluated where 0 = none and 15 = extremely intense.

[a-c]Means with different superscripts are significantly different ($P < 0.05$).

SEM = standard error mean; Trt = treatment; Temp = temperature.

Table 32. Least squares means and SEM values for chemical components for Analysis 4; USDA top loin steaks.

Chemical component	Top loin steaks	*n*	SD	Min	Max
14:0	0.22	51	0.128	0.022	0.831
16:0	1.67	51	0.599	0.44	3.19
16:1	0.20	51	0.100	0.06	0.60
18:1	2.34	51	0.850	0.58	4.64
18:2	0.28	51	0.031	0.00	0.726
20:4	0.04	51	0.031	0.00	0.154
20:5	0.00	38	0.011	0.00	0.052
Moisture (%)	69.82	51	2.169	64.85	75.08
Lipid (%)	7.00	51	2.504	1.85	14.41
Non-heme	3.30	49	1.479	1.60	10.67
Myoglobin	2.64	51	1.476	0.97	10.13

[1]Fatty acids are measured as a g per 100 g meat/
n = number of observations; SEM = standard error mean.

Least squares means comparisons of volatile, aromatic amount in USDA Choice top loin steaks differing in cook method and endpoint temperature were reported in Table 33. Higher temperature endpoints were lower in levels of 1-octanol ($P = 0.028$), 1-hexanol ($P = 0.003$), and 3-hydroxy-2-butanone ($P = 0.001$). Clam-shell style grilled top loin steaks were higher in their levels of 2-heptenal ($P = 0.034$). Interactions of cooking method and endpoint temperature were reported for 2-pentylfuran ($P = 0.023$) and 2,3-octanedione ($P = 0.042$).

Table 33. Transformed volatile, aromatic least squares means and SEM values for Analysis 4; USDA Choice top loin steaks either open flat or clam-shell style grilled.

		Clam-shell style grill		Open flat grill			*P* - value			Random effect
Compound	*n*	58°C	80°C	58°C	80°C	SEM	CM	Temp	CM x Temp	Study
Acids										
Acetic acid	56	71,973	49,254	70,984	66,992	26,201	0.238	0.051	0.163	0.166
Hexanoic acid	37	81,531	88,236	91,109	71,121	28,789	0.785	0.615	0.317	0.20
Octanoic acid	17	115,075	111,531	114,199	112,499	5,338	0.988	0.413	0.770	0.373
Heptanoic acid	11	3,458,095	3,446,427	3,456,746	3,458,996	8,284	0.523	0.590	0.433	——
Alcohols										
1-Heptanol	42	492,981	459,203	470,896	467,965	32,200	0.527	0.084	0.140	0.182
1-Octen-3-ol	50	103,433	83,694	86,142	75,319	30,114	0.170	0.103	0.627	0.169
1-Pentanol	21	237,435	224,894	228,519	245,447	47,913	0.691	0.843	0.197	0.244
1-Octanol	48	144,330	125,014	143,131	131,380	26,824	0.706	0.028	0.582	0.207
1-Hexanol	45	110,126	77,140	96,145	78,857	22,033	0.482	0.003	0.345	0.186
1-Butanol	26	138,156	174,538	176,313	131,189	59,928	0.915	0.858	0.106	0.231
Aldehydes										
Pentanal	43	175,828	173,278	168,607	175,562	36,773	0.859	0.867	0.720	0.176
2-Decenal	21	41,726	26,745	30,049	29,145	12,781	0.426	0.153	0.203	0.176
Benzaldehyde	49	1,369,580	1,217,458	1,420,303	1,259,509	360,066	0.687	0.179	0.969	0.208
Hexanal	75	951,774	1,223,143	1,149,351	1,301,301	394,710	0.235	0.065	0.599	0.172
Nonanal	67	877,371	877,371	890,716	921,745	303,261	0.263	0.551	0.331	0.195
Nonenal	55	559,696	550,029	558,581	558,724	11,019	0.520	0.427	0.409	0.242
Octanal	69	453,469	427,625	394,987	501,444	108,436	0.859	0.354	0.131	0.212
2-Heptenal	24	38,996	39,705	31,540	30,546	6,471	0.034	0.965	0.798	0.203
Phenylacetaldehyde	15	27,956	15,931	23,146	19,549	10,033	0.900	0.139	0.373	0.193
Heptanal	33	111,988	100,627	121,180	106,074	8,353	0.326	0.081	0.800	——
Alkanes										
Thiobis-methane	30	6,618	5,972	6,065	6,146	1,338,622	0.625	0.432	0.301	< 0.001
Hentriacontane	16	16,290	15,650	13,552	6,657	4,143	0.085	0.232	0.313	0.362
Dodecane	18	171,583	171,947	151,916	170,278	46,291	0.695	0.737	0.750	0.278

Table 33 Continued.

Compound	*n*	Clam-shell style grill 58°C	Clam-shell style grill 80°C	Open flat grill 58°C	Open flat grill 80°C	SEM	*P* - value CM	*P* - value Temp	*P* - value CM x Temp	Random effect Study
Alkenes										
1,3-Octadiene	8	223,067	217,098	199,114	199,996	37,167	0.541	0.938	0.916	——
Furans										
2-Pentylfuran	38	128,678[a]	100,706[b]	93,479[b]	105,640[ab]	23,953	0.088	0.355	0.023	0.198
Hydrocarbon										
DL-Limonene	8	13,301,613	13,303,444	1,3216,882	13,290,506	95,967	0.552	0.642	0.657	——
Ketones										
3-Hydroxy-2-butanone	51	357,175	288,726	329,663	220,976	106,000	0.097	0.001	0.430	0.165
2,3-Octanedione	29	230,194[ab]	210,773[ab]	195,425[a]	250,394[b]	34,793	0.892	0.315	0.042	0.295
2,3-Butanedione	27	151,540	140,186	136,613	100,751	58,206	0.314	0.343	0.623	0.188
2-Pentanone	21	2,077	2,081	2,024	2,213	201,065	0.725	0.368	0.436	0.001
Polymers										
Styrene	30	478,855	400,398	403,925	414,453	100,970	0.210	0.163	0.071	0.265
Pyrazines										
3-Ethyl-2,5-dimethylpyrazine	20	79,811	106,558	98,561	100,887	17,650	0.491	0.118	0.219	0.176
Tetradecanal	9	30,605	38,630	5,202	45,330	16,938	0.432	0.088	0.207	0.247
Sulfur-containing										
2-Acetyl-2-thiazoline	12	113,242	108,215	100,018	110,093	24,006	0.648	0.837	0.551	0.209

Final variables included in the PLSR analysis were reported in Table 34 with their respective VIP values. Variables that reported VIP > 1 scores for both, t1 and t2, were 2-heptenal, salty, and fatty acid 20:5. This indicated that of the variables selected to be included in the final model, these were most relevant to predicting consumer overall liking.

Table 34. Variable Importance in the Projection (VIP) for the partial least squares regression for Analysis 4; USDA Choice top loin steaks either open flat or clam-shell style grilled using trained descriptive flavor attributes, chemical components, and volatile, aromatic flavor compounds to predict consumer overall liking.

Variable	VIP for t1	SD	Lower bound (95%)	Upper bound (95%)	VIP for t2	SD	Lower bound (95%)	Upper bound (95%)
2-Heptenal	1.285	0.552	0.202	2.367	1.254	0.601	0.077	2.431
Salty	1.280	0.448	0.401	2.158	1.194	0.413	0.385	2.003
20:5	1.224	0.387	0.466	1.981	1.143	0.320	0.515	1.770
Brown/roasted	0.945	0.551	-0.136	2.026	0.914	0.420	0.091	1.738
Liver-like	0.954	0.479	0.015	1.893	0.891	0.438	0.032	1.749
Metallic	0.672	0.742	-0.782	2.126	0.854	0.494	-0.115	1.823
1-Hexanol	0.535	0.500	-0.446	1.515	0.822	0.235	0.361	1.283
2-Pentylfuran	0.821	0.496	-0.152	1.793	0.814	0.381	0.068	1.560

SD = standard deviation.

The final model was reported in Table 35. The variable that was most influential to predicting consumer overall liking scores was 20:5. 20:5 was classified as a polyunsaturated fatty acid of the omega-3 family. Polyunsaturated fatty acids were found to influence color, odor, and texture of beef due to their oxidation levels in fresh beef (Kanner, 1994). This was due to the ease of which polyunsaturated fatty acids underwent oxidation under aerobic conditions. This, in turn, influenced the development of meat flavor as phospholipids higher in polyunsaturated content have been shown to induce "fishy" notes in the presence of cysteine and ribose in the development of odor in cooked meat (Campo et al., 2003). Therefore, the large, negative coefficient for 20:5 in the model predicting consumer overall liking was understandable as a large driver against consumer acceptability.

Liver-like also negatively impacted consumer overall liking based on its negative coefficient in Table 36. Salty and metallic attributes had positive coefficients of 0.457 and 0.244, respectively. These attributes were understood to contribute to consumer overall liking, but it was understood these attributes may negatively impact liking if they were too high in intensity. Metallic was also shown to be highly correlated with bloody/serumy (Table 14) and was often associated with lower endpoint temperatures.

Table 35. Prediction equation for the partial least squares regression for Analysis 4; USDA Choice top loin steaks either open flat or clam-shell style grilled using trained descriptive flavor attributes, chemical components, and volatile, aromatic flavor compounds to predict consumer overall liking.

Variable	Consumer overall liking
Intercept	6.087
Brown/roasted	0.076
Metallic	0.244
Liver-like	-0.290
Salty	0.457
20:5	-5.769
2-Pentylfuran	0.000
2-Heptenal	0.000
1-Hexanol	0.000

CS = clam-shell style grill; Grill = open flat grill.

The partial least squares regression biplot for Analysis 4 was shown in Figure 7. The cumulative R^2 X value was 58.9% and the R^2 Y value was 22.3%, indicating a majority of the variation was explained along the X axis of the biplot. Trained descriptive panel attributes for metallic, salty, and brown/roasted were closest in association with consumer overall liking. Brown roasted flavor may have been contributed from those steaks cooked with an open flat grill verses the clam-shell style grill. The open flat grill cook method was representative of a dry form of heat cookery compared to the intermediate form of the clam-shell style. Furthest was the 2-heptenal, 2-pentylfuran, and 1-hexanol compounds along with the 20:5 fatty acid and liver-like attribute. Of these listed compounds, 1-hexanol was the nearest to consumer overall liking. 1-Hexanaol has reported odor/aroma characteristics of woody, cut grass, chemical-winey, fatty, fruity, and weak metallic while 2-pentylfuran has been described as green bean and butter (Calkins and Hodgen, 2007). As reported within Analysis 3, 2-heptenal was described as soapy, fatty, almond, fishy, and unpleasant (Calkins and Hodgen, 2007).

Interpretation of the variable placement along the Y axis placed 2-pentylfuran and salty nearest to consumer overall liking. 20:5, liver-like, and brown/roasted were clustered with one another as well as 1-hexanol with metallic. 2-Heptanal remained furthest from consumer overall liking.

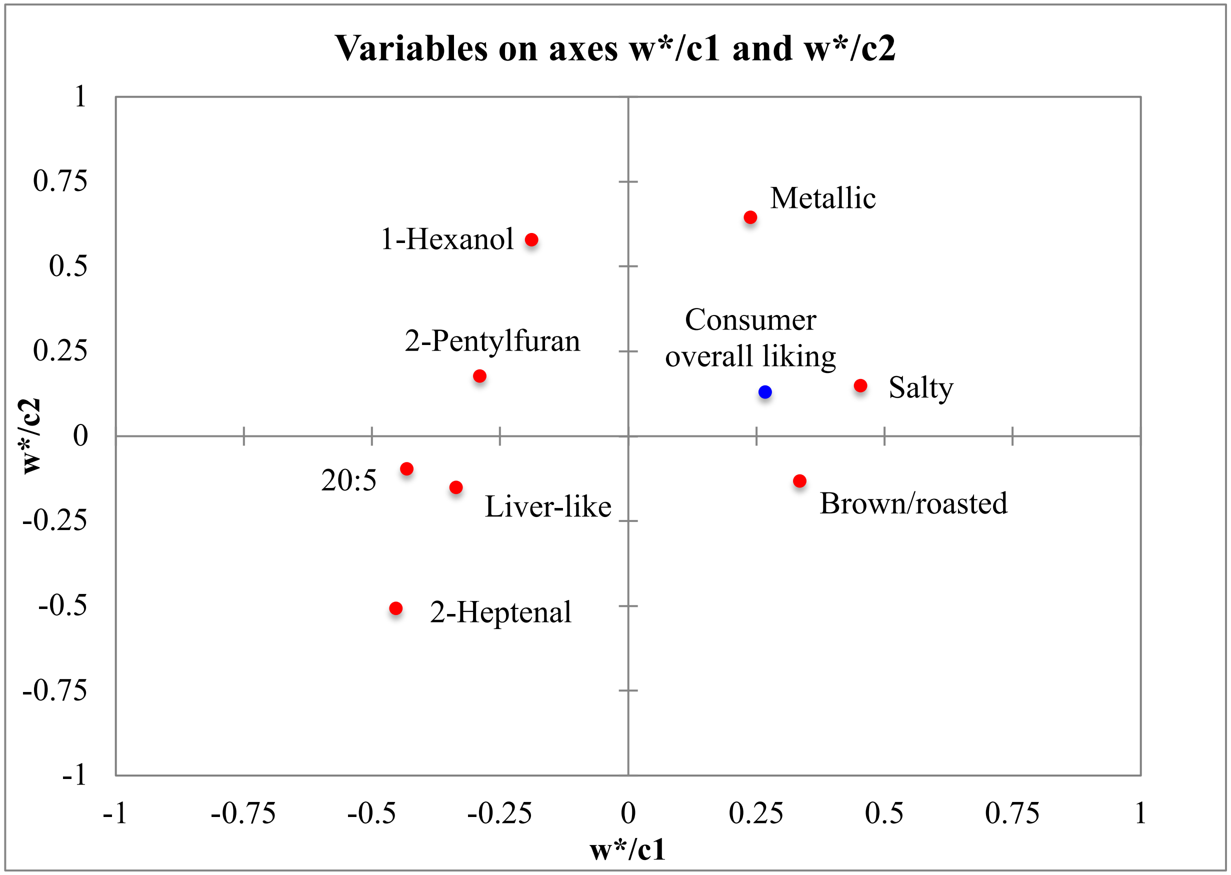


Figure 7. Partial least squares regression biplot for Analysis 4: USDA Choice top loin steaks either open flat or clam-shell style grilled cooked to either 58 or 80 °C. Volatile, aromatic compounds, trained descriptive sensory panel flavor attributes, and chemical components were defined as independent variables and consumer overall liking was the dependent variable. Component 1 R^2 Y and R^2 X cumulative values were 19.4 and 44.0%, respectively. Component 2 R^2 Y and R^2 X cumulative values were 2.9 and 14.9%, respectively.

Overall, Analysis 4 represented similar cuts and USDA quality grades that differed in their cook method of either a dry or intermediate form of cookery. This was also seen for Analysis 3. The difference between these two groups was that Analysis 3 included top sirloin steak representative of USDA Choice while the current Analysis 4 included USDA Choice top loin steaks. Therefore, the accounted for differences between these two analysis groups was the cut. The primary muscle in the top loin steak was the *M. longissimus lumborum* (LL) while the primary steak in the top sirloin was the *M. gluteus medius* (GM). Therefore, it was possible that the variables included in the final model respective to each these muscles may have been specific to the inherent differences in these muscles. Legako et al. (2015) studied the difference in volatile, aromatic compound presence between 4 different subprimal cuts. While phenylacetaldehyde was included in the assessment for top sirloin steaks in Analysis 3, it was not important for top loin steaks in Analysis 4. Legako et al. (2015) reported similar levels of phenylacetaldehyde for each of these cuts. Additionally, the 2-pentylfuran volatile was reported in similar in level between these two cuts while our results indicated its presence was important for top loin steaks and not top sirloin steaks. As Legako et al. (2015) mentioned, a lack of work has been done to understand volatile, aromatic compound differences in subprimal cuts and USDA quality grades. Previous studies have compared the sensory characteristics of top loin and top sirloin steaks. In terms of flavor desirability, the top loin steak has been preferred to top sirloin steaks by consumers (Keith et al., 1985). Flavor intensity ratings from trained, descriptive panel ratings also reported greater intensity for top sirloin steaks (Lorenzen et al., 2003).

Analysis 5

Trained descriptive flavor attributes for Analysis 5 were reported in Table 36. USDA Select bottom round roasts from Study 1, 2, and 3 were analyzed for trained descriptive panel attribute differences between roasts cooked to 58 or 80°C in crock pots. Trained panel random effects for session and order reported no significant impact on least square means ($P > 0.05$) with the exception of warmed-over flavor (session $P = 0.018$). Temperature differences were found to effect trained descriptive panel attributes ($P < 0.05$). Bottom round roasts cooked to end point temperatures of 58°C were lower in brown/roasted and umami, and higher in bloody/serumy, metallic, and sour. Chemical components for Analysis 5 were reported in Table 37. Due to no treatment present for the raw sample analysis, means, SD, minimum, and maximum values were presented.

Table 36. Least squares means and SEM values for trained descriptive flavor attributes for Analysis 5; crock pot cooked USDA Select bottom round roasts.

	Grilled			*P* - value	Random Effects	
Attribute[1]	58°C	80°C	SEM	Temp	Session	Order
Major						
Beef identity	5.4	6.1	0.56	0.298	0.103	——
Brown/roasted	0.3	0.5	0.09	0.024	0.085	0.262
Bloody/serumy	1.6	0.6	0.12	< 0.001	——	——
Umami	0.4	0.7	0.08	0.021	0.327	0.431
Liver-like	0.4	0.4	0.08	0.707	0.129	——
Cardboard	0.4	0.3	0.06	0.783	0.341	0.406
Minor						
Fat-like	0.6	0.6	0.06	0.988	0.243	——
Metallic	2.2	1.8	0.08	0.004	——	0.377
Overall sweet	0.2	0.5	0.07	< 0.001	——	0.054
Sweet	0.3	0.5	0.06	0.047	——	0.174
Sour	2.3	1.6	0.11	< 0.001	0.131	0.142
Salty	1.3	1.2	0.07	0.442	0.271	0.230
Bitter	1.6	1.6	0.08	0.519	0.096	——
Sour aromatics	0.1	0.1	0.04	0.801	——	0.087
Soapy	0.0	0.0	0.01	0.339	0.398	0.487
Warmed over flavor	0.1	0.1	0.04	0.046	0.018	——

[1]Trained descriptive panel attributes were evaluated where 0=none and 15=extremely intense.
SEM = standard error mean.

Table 37. Least squares means and SD values for chemical components for Analysis 5; USDA Select bottom round roasts.

Chemical component	Bottom round roasts	*n*	SD	Min	Max
14:0	0.05	39	0.032	0.02	0.16
16:0	0.46	39	0.207	0.18	1.04
16:1	0.06	39	0.035	0.02	0.20
18:1	0.72	39	0.395	0.25	2.15
18:2	0.13	39	0.058	0.05	0.26
20:4	0.03	39	0.018	0.00	0.09
20:5	0.00	34	0.002	0.00	0.01
Moisture (%)	74.34	39	2.059	70.42	79.18
Lipid (%)	2.09	39	0.957	0.84	5.15
Non-heme	3.38	37	0.717	2.35	6.04
Myoglobin	2.22	39	0.832	0.84	3.64

[1]Fatty acids are measured as a g per 100g meat.

n = number of observations; SD = standard deviation.

Least squares means of flavor volatile aromatic compounds for Analysis 5 were reported in Table 38. Acetic acid, 1-butanol, pentanal, 2-heptanone, 2,3-butanedione, and methanethiol reported differences ($P < 0.05$) between temperature endpoints for USDA Select bottom round roasts. For each of these compounds, higher levels were reported for the higher temperature endpoint of 80°C. These volatiles were used for further understanding of the relationship between cut, temperature endpoint, and consumer overall liking.

Table 38. **Transformed volatile, aromatic least squares means and SEM values for Analysis 5; USDA Select bottom round roasts cooked to 58 or 80°C.**

Compounds	*n*	58°C	80°C	SEM	Temp	Study
Acids						
Acetic acid	36	38,634	46,150	11,861.0	0.034	0.163
Butanoic acid	5	29,630	26,837	4,055.7	0.134	0.246
Hexanoic acid	23	46,079	52,617	12,323.0	0.184	0.174
Octanoic acid	8	22,337	23,418	1,893.6	0.638	——
Heptanoic acid	4	18,847	22,615	16,328.0	0.564	0.245
Alcohols						
1-Heptanol	26	58,712	68,935	11,363.0	0.090	0.175
1-Octen-3-ol	34	65,819	62,116	17,960.0	0.489	0.163
1-Pentanol	13	25,536	27,408	3,377.2	0.157	0.247
1-Octanol	23	113,738	112,217	19,168.0	0.816	0.170
1-Hexanol	19	40,241	49,475	9,914.2	0.091	0.180
1-Butanol	13	125,289	163,565	43,018.0	0.046	0.268
Aldehydes						
Tetradecanal	14	84,610	83,751	32,013.0	0.966	0.247
Pentanal	36	74,781	84,912	15,856.0	0.032	0.166
2-Decenal	12	68,312	74,869	20,751.0	0.416	0.166
Benzaldehyde	35	786,741	922,890	314,834.0	0.177	0.168
Heptanal	21	98,377	105,714	3,451.9	0.141	——
Hexanal	46	2,325,981	2,465,550	588,679.0	0.518	0.171
Nonanal	41	1,239,571	1,235,052	374,417.0	0.967	0.167
Nonenal	30	59,846	67,639	1,3481.0	0.235	0.180
Octanal	43	603,483	534,736	168,732.0	0.268	0.174
2-Heptenal	18	26,551	26,851	2,773.1	0.839	0.186
Dodecanal	13	35,274	36,339	6,467.7	0.595	0.171
Phenylacetaldehyde	11	9,361	11,082	3,388.0	0.076	0.161
Tridecanal	5	146,494	139,292	18,841.0	0.262	——

Table 38 Continued.

Compounds	*n*	58°C	80°C	SEM	Temp	Study
Alkanes						
Thiobis-methane	35	17,538	17,996	4,245	0.618	0.161
Octacosane	9	4,824	5,282	4,250	0.770	0.256
Dodecane	8	956,630	858,034	41,797	0.156	——
Alkenes						
1,3-Octadiene	5	551,333	541,712	35,282	0.823	——
Furans						
2-Pentylfuran	28	660,57	71,397	20,345	0.473	0.170
Hydrocarbons						
DL-Limonene	4	111,364	205,191	76,108	0.475	——
Ketones						
3-Hydroxy-2-butanone	38	194,517	188,641	52,229	0.591	0.162
2-Heptanone	5	11,065	13,673	1,346	0.035	0.252
2,3-Octanedione	17	119,286	153,592	34,697	0.066	0.192
2-Nonanone	4	26,841	28,006	4,953	0.249	0.240
2,3-Butanedione	20	184,623	280,154	22,060	0.004	——
2-Pentanone	15	287	286	1,266	0.881	0.005
Polymers						
Styrene	21	93,641	90,976	38,600	0.777	0.244
Sulfur-containing						
Methanethiol	22	10,093	13,811	2,682	0.011	0.170
Sulfur dioxide	7	30,428	39,330	8,459	0.410	0.335

Variable importance in the projection values were reported in Table 39. The analysis identified four variables based in VIP scores. This may be due to the similar treatment within the data set as all samples were USDA Select bottom round roasts. The myoglobin concentration variable reported the highest VIP value.

Table 39. Variable Importance in the Projection (VIP) for the partial least squares regression for Analysis 5; USDA Select bottom round roasts cooked to 58 or 80°C using trained descriptive flavor attributes, chemical components, and volatile, aromatic flavor compounds to predict consumer overall liking.

Variable	VIP for t1	SD	Lower bound (95%)	Upper bound (95%)
Myoglobin	1.21	0.874	-0.506	2.919
2,3-Butanedione	1.03	3.307	-5.453	7.512
Acetic acid	0.88	0.542	-0.184	1.942
Methanethiol	0.84	0.736	-0.598	2.286

SD = standard deviation.

The final PLSR regression model was presented in Table 40. Although not presented, the R^2 Y and R^2 X values were 26.6% and 81.8%, respectively, for the first and only component in the final model. The myoglobin concentration negatively contributed to consumer overall liking according to the coefficient of the variable. Myoglobin's physiological role is to bind oxygen and deliver it to the mitochondria in muscle cells. Oxidative fibers, rich in mitochondria, contain more myoglobin content and therefore appear darker in color. Myoglobin concentrations have been shown to vary on muscle type, species, animal age, diet, and environmental challenges (Faustman and Suman, 2017). It is understood that meat discoloration diminished the product appearance as oxymyoglobin converts to metmyoglobin. This change in the chemical structure of heme iron lead to the decrease in the heme redox stability of the structure (Faustman et al., 2010). Research has shown that biochemical reactions of myoglobin oxidation generated products for lipid oxidation and vice versa. Greater concentrations of myoglobin were associated with greater rates of lipid oxidation (Faustman et al., 2010). Therefore, the oxidative interaction of these two processes negatively contribute to the off flavors of meat products. This explained the negative coefficient of the myoglobin concentration variable in relation to consumer overall liking and the large VIP score. As the treatment of Analysis 5 contained all USDA Select beef bottom round roasts, it was inferred that myoglobin concentration was a variable that was able to be differentiated in consumer overall liking due to the variation in the concentration levels.

Table 40. Prediction equations for partial least squares regression for Analysis 5; USDA Select bottom round roasts cooked to 58 or 80°C using trained descriptive flavor attributes, chemical components, and volatile, aromatic flavor compounds to predict consumer overall liking.

Variable	58°C
Intercept	6.173
Myoglobin	-0.172
Methanethiol	0.000
Acetic acid	0.000
2,3-Butanedione	0.000

The remaining aromatic, volatile compounds identified in the final model were difficult to evaluate as their units (total ionization counts) were reported in large quantities. This leads to an extremely small coefficient. As the scope of this study was to observe the relationship of these variables to consumer overall liking and not focused on the predictability of the model, this still allowed for sufficient evaluation of the impact of the compounds. The methanethiol compound may have been created from the degradation of the sulfur compound, methionine. Its odor contribution to meat has been reported as the characteristic flavor of stewed beef (Guth and Grosch, 1994). Acetic acid may have positively contributed to beef flavor as previous literature described its odor as stewed beef juice, which also aligned with the moist heat form or cookery used for Analysis 5 (Guth and Grosch, 1994). 2,3-butanedione was associated with buttery notes (Flores, 2017). When similar subprimal cuts, specifically the bottom round cut, are evaluated for expected consumer overall liking, volatiles may contribute an understanding of how consumers may perceive and evaluate the product. Identifying differences in the myoglobin concentration of cuts high in oxidative fibers may determine the level of consumer overall liking due to myoglobin's interdependent relationship with lipid oxidation.

Conclusion

Each analysis group was developed specific to the availability of the data across the merger of three studies. Within each analysis group, defined treatments enabled us to identify whether trained, descriptive panel attributes, chemical component data, and/or volatile, aromatic flavor compounds were able to contribute to predicting consumer overall liking. Although the scope of this study was not to develop and validate the final partial least squares regression, these models were used to assess the overall important variables for each analysis for subsequent prediction modeling outside of this study. This was necessary due to the large number and broadness of the variables used.

Across the five analysis groups, subprimal cut, USDA quality grade, and cook method were either consistent or varied. All groups contained endpoint temperatures of 58 and 80°C. The trained, descriptive panel attributes of bloody/serumy and metallic (established as strongly correlated with one another) were robust as four of the five analysis group final models identified this variable. While it was tempting to conclude this was due to the commonality of the endpoint temperature difference of the treatments across all analysis groups, the sole analysis group that these variables were not included in only varied in endpoint temperature. Therefore, bloody/serumy and metallic intensity differences were impacted by the treatment differences within each analysis groups. The liver-like attribute contributed to overall liking in the two models that included the top loin steak. Fat-like was important when subprimal cuts were either bottom round roasts or top loin steaks. Additionally, fat-like contributed to differentiating top loin steaks of similar quality grade, but different cook methods. Differences in fatty acid content contributed to models where treatments bottom round roasts compared for difference in quality grade or compared top loin steaks.

Few commonalities were found for specific volatile, chemical data across each analysis group, indicating targeting volatiles may be specific for factors across treatment groups (USDA quality grade, subprimal cut, cook method and combinations of each). Interestingly, in analysis groups where bottom round roasts were cooked in crock pots, compounds that were commonly classified as Maillard reaction compounds were included in the final model parameters although the temperatures and cook methods needed to achieve the Maillard reaction are not thought to be achieved through the crock pot method. Perhaps the minimal amount of Maillard reaction compounds that were created was enough to provide significant importance to the models. As expected, in models where dry (open flat grill) and intermediate (clam-shell grill) were used, compounds commonly classified as both lipid oxidation and Maillard reaction compounds were of high importance.

Overall, the relationship between consumer overall liking and variables indicative of the flavor profile of beef products were complex. Consumer overall liking itself, was variable. Therefore, it was difficult using consumer overall liking as a criterion for determining important variables. By dividing a large, diverse set of data into common analysis groups, we were better able to identify the contributing variables within differing situations. By utilizing additional modeling parameters, we will continue to clarify the flavor variables contributing to consumer overall liking.

CHAPTER IV

EFFECT OF INFOGRAPHICS ON CONSUMER EMOTIONAL RESPONSE

Introduction

Human biometric data has been utilized across many disciplines extending the fields of psychology, engineering, and marketing (Duchowski, 2002). Eye tracking data aids companies and researchers in identifying what captures an individual's visual attention. This method may not be able to define all cognitive processes such as why a person is visually drawn to specific areas, but it can identify what captures the consumer's attention the most and the path of their gaze visualization. This information can reveal the brain's underlying processing decisions. Its usage has increased within recent years due to growth in technological innovation causing a decrease in the time commitment and costs that were originally required to use this technology.

Information graphic, commonly referred to as infographics, are used to compress and simplify information in order to increase communication efforts with consumers. Cairo (2012) describes infographics as an emerging discipline comprised of a combination of concepts, methods, and procedures from numerous fields including cartography, statistics, graphic design, and journalism. Along with the merger of these fields comes opposing theories and approaches. Cairo (2012) summarizes the differences in preferred visualization strategies into two categories based on professional training; those who come from technical backgrounds, such as statistics and engineering, and those who are graphic design based.

A simple processing model of human visual perception divides the intake of information into three stages (Ware, 2012). Stage 1 is described as parallel processing that occurs subconsciously. Billions of neurons work in parallel to extract low-level properties of the visual field simultaneously. These low levels are extractions of features, orientation, color, texture, and movement patterns. Therefore, if information is needed to be understood quickly, it should be presented in conjunction with the method of processing that occurs in the brain. Stage 2 of visual processing identifies patterns in the large mass of data being processed in order to organize the information into groupings. Patterns may be identified through similar contours, color, and textures. This stage occurs rapidly, but is slower in terms of processing because the visual system identifies and "binds" up to three patterns that will capture one's attention for a few seconds. The low-level system (Stage 1) is constantly seeking a stimulus to provide a focus for the eye. This is how a person may view perceive a shape of an object, but not consciously identify it. If the person has an inherent interest in the object, the data interpreted by the visual system in Stage 1 may be further synthesized in a manner where the shape of the object will advance to the attention of the conscious mind. If the object is not further recognized, the data captured during Stage 1 of processes will dissipate (Malamed, 2009). Stage 1 and 2 are driven by bottom-up processing where visual perception is motivated by external stimuli. Stage 3, the highest level of perception, is classified as top-down processing. This stage is reached through the need of active visual attention where stimuli are held in visual working memory. Long-term memory related to a task is used in this stage to undergo visual search strategies. This final stage is characterized by its influence of prior knowledge, goals, and expectations. Bottom-up flow of processing that is inherent to our processes of visualizing interacts and influences our top-down method of visual processing. When introduced to a new image or scene is introduced to someone, information can only flow in sequential order of the stages. The system is quickly able to adapt to a conservative strategy where we utilize the stage that is most beneficial to us and our expectations. The level of attention increases with the increasing stage that is being utilized. The pre-attentive processes may be arranged and manipulated to increase the likelihood of successful comprehension. If they are not considered, the audiences' perception, interpretation, and acceptance of the visual may fail the intended goal of the presenter.

The level of complexity of advertisements has been debated in the literature. Some hold the idea that advertisements should be clutter-free with a simple design while others promote the idea that higher levels of complexity cause people to stop and pay more attention to its message. The terms *complexity* and *comprehensibility* describe different attributes of advertising, but are often misunderstood (Pieters et al., 2010). Complexity refers to the visual characteristics of an ad image while comprehensibility refers to how well the message is understood. Pieters et al. (2010) segregated complexity into two definitions of feature and design complexity. Feature complexity was described as the level of detail and variation in an advertisement's basic visual features such as its color, luminance, and edges. Design complexity was referred to as the structure of shapes, objects, and their arrangements in an advertisement. The authors concluded that feature complexity can have a detrimental effect towards consumer attitude of an ad while design complexity aided in the attention to the advertisement, comprehensibility, and attitude toward the ad.

The topics of antibiotics, genetically modified organisms, hormones, sustainability, vaccines, and animal welfare are currently used by companies within and outside of the meat industry in order to differentiate their products from competitors. Companies place this information on labels to influence consumer perception. The structure of the meat industry does not allow consumers the opportunity to taste product before purchasing due to the high cost of sampling product. This instead leads consumers to evaluate the products based on attribute descriptions. Palma et al. (2019) measured consumers' evaluation of beef products where the attributes were described compared to when they were experienced through taste evaluation. Findings revealed that in the setting where only attribute descriptions were presented a greater amount of attention was given to nonphysical attributes compared to physical attributes and price. In the taste experience scenario, participants where influenced more by the physical and sensory attributes of the beef product. Therefore, consumer valuation of beef products can be influenced by which market environment the product is evaluated in, as the environment determines which attributes consumers pay more attention to.

Human biometric data enables researchers to gain further insight into understanding consumer behavior that is not obtainable through traditional survey methods. The usage of eye tracking as a standalone measure to predict and explain choices made by consumers has been reported by Chavez et al. (2018) where increased visual attention increased the probability of selection. Furthermore, research by

Huseynov et al. (2019) indicated additional insight was gained through the usage of biometric tools including eye tracking, facial expressions (to assess emotions), and brain activity to predict consumer purchasing decisions.

The objective of this study was to quantify consumer responses to 6 topics relative to the agriculture industry by presenting scientific information through infographic formatting. In addition to traditional Likert scale responses, our evaluations included biometric tools in order to capture a holistic view of consumer perception of the infographics. By capturing this additional form of data, further insight may be obtained to understand how to more effectively communicate complex scientific information to consumers in a positive manner.

Materials and Methods

A total of 180 participants were recruited from the general population of the Bryan/College Station through an email list serve constructed from local newspaper ads. Participants received $30 compensation for completing the experiment. The study was two-fold in its purpose as participants were recruited to measure their reaction to six infographic materials relating to agricultural topics in addition to their reaction to steak images of differing degrees of marbling and color. The discussion in this report is limited to the infographic portion of the data analyses.

Prior to the start of the experiment, each participant was calibrated for the eye tracking portion of the study. Instruction slides were presented to inform participants of the procedures. In between each infographic image slide and its corresponding question slide, a bull's eye image slide was presented for 3 s. The location of the bull's eye was randomly placed in four possible positions of the upper-left corner, lower-left corner, upper-right corner, or the lower-right corner. Participant's initial instructions informed them to stare at the bull's eye when it appeared on the screen. The purpose of this task was to randomize the position where the participants begin viewing the upcoming stimuli for measuring the areas of interest (AOI) purposes.

Each infographic was presented in a 30 S interval. During this time frame, participants were asked to view and read the information. The screen would then automatically advance to another screen that displayed a smaller image of the infographic beside three questions regarding their overall, graphic, and information liking of the infographic. A 9-point hedonic scale structure was used where 1= dislike extremely, 5= neither like nor dislike, and 9= like extremely. Each participant viewed all six infographics in a randomized order in order to reduce any ordering effects. Before beginning the viewing of the infographics, all participants completed a pre-survey questionnaire regarding their level of agreeableness towards 18 statements focused on information related to the infographics presented in a randomized order (3 statements per infographic topic). The 7-point agreeableness scale used was anchored as: 1: strongly agree; 2: agree; 3: somewhat agree; 4: neither agree nor disagree; 5: somewhat disagree; 6: disagree; 7: strongly disagree. After participants completed viewing all infographics and hedonic scale questions, they were presented with a post-survey questionnaire that contained the same questions as the pre-survey questionnaire, presented in a randomized order. Although not discussed in detail in this report, the presentation order of the study slides was blocked by either infographic or steak images. Therefore, the computer randomly determined if a participant would view slides regarding the infographics or the steak images first.

Each of the six infographics developed by Merck discussed a topic relevant to the agriculture industry. Topics included antibiotics, GMO (genetically modified organisms), hormones, sustainability, vaccines, and animal welfare. The infographics were designed to incorporate the scientific aspect relating to each of these topics in such a manner understandable and relatable to the general population.

Statistical analysis was conducted through RStudio (V 1.1.463, RStudio, Inc., Boston, MA). AOI measurements and emotional responses were computed through the iMotions (V 7.1, Boston, MA) software and exported for further analysis while the final images of the heat maps were generated through the software and exported. Differences in pre- and post-survey responses were analyzed as a paired t-test. Area of interests were defined be the research for each infographic based on the overall layout of text information and the placement of graphics. The infographics were divided into several sections, which were then divided into subsections. Least squares means were compared by section and subsection within each infographic. A predetermined alpha of 0.05 was used. Principal component analyses were used for analyzing emotional responses by infographic subject.

Results and Discussion

The topics of the infographics included in this study are representative of topics of delicate discussion between the government, scientific community, food industry, and consumers. Understanding consumer knowledge of these topics is critical in developing an approach to delivering scientific information in a positive and approachable manner. Consumer behavior interprets two components of knowledge to understand consumer unease towards products known to elicit public unease. Subjective knowledge refers to a person's perception of the information they recall for a product that is stored in their memory while objective knowledge represents the actual amount of accurate information stored in their memory (Park et al., 1994). These different classes of knowledge have different effects on information processing, and ultimately, consumer behavior (Cole et al., 1992; Flynn and Goldsmith, 1999).

The stimuli presented to participants are included in the appendix of this final report. Table 1 reports the demographic information collected from the recruited participants. Data were collected for 168 participants (62 male, 106 females). The median response for age, income, number of children, and beef consumption were reported as 26-35, 50,000-$74,999, none, and 3-4 times per week, respectively. For AOI evaluation for each infographic, the stimuli were separated into regions of where the content most naturally divided based on pre-attentive features (Cairo, 2012). These regions are referred to as Sections of the infographics. Each Section was further analyzed as AOI were defined within each, as necessary. Four measurements were evaluated for each defined AOI. The time to first fixation (TTFF) indicated the amount of time, reported in seconds, it took the participate to look at the defined AOI. Time spent is a quantitative measure of the amount of time, reported in seconds, the participants spent looking at the AOI. A revisit is defined as the number of times a participant returned their attention to the defined AOI. Fixation count is the number of times a participant's gaze is focused in an area. Eye tracking data includes metrics for both, the participants' gaze and fixation. A gaze point is the most basic unit of measurement in eye tracking and corresponds to one raw data point. The frequency of the measurement of the eye tracker determines how many gaze points are measured per second. When a series of gaze points occur in a close amount of time and distance, the cluster of gazes are determined to be a fixation. A fixation is a period of time our eyes are "fixated" on a specific area. Research indicates fixations relate to an individual's cognitive ability to receive and interpret information (Goldberg and Kotval, 1999). Therefore, the time spent and revisit counts data were reported based on the participants' fixation points rather than their gaze points

Table 41. Summary of consumer demographics.

Variable	Description of variables	*n*	Percentage (%)
Gender	Gender of participants		
	Male	62	36.9
	Female	106	63.1
Age	Age (in years) of participants		
	20 or less	2	1.2
	21 to 25	44	26.2
	26 to 35	46	27.4
	36 to 45	21	12.5
	46 to 55	23	13.7
	56 to 65	20	11.9
	66 or more	12	7.1
Income	Household income of participants ($)		
	Below 25K	24	14.4
	25,001-49,999	43	25.7
	50,000–74,999	27	16.2
	75,000-99,999	25	15.0
	100,000-149,999	36	21.6
	150,000 or more	12	7.2
Household size	The number of people currently living in participant's household (including themselves)		
	1	34	20.2
	2	61	36.3
	3	30	17.9
	4	31	18.5
	5	11	6.5
	6 or more	1	0.6
Children	Of the household size, the number of children		
	N/A	97	57.7
	1	18	10.7
	2	34	20.2
	3	15	8.9
	4	3	1.8
	5 or more	1	0.6

Table 41 Continued.

Variable	Description of variables	*n*	Percentage (%)
Employment	Status of participants' employment		
	Not employed	30	17.9
	Part-time	42	25.0
	Full-time	96	57.1
Beef purchase	Most often type of beef purchased		
	Antibiotic free	6	3.6
	Dry aged	1	0.6
	Free range	2	1.2
	Grass fed	6	3.6
	Hormone free	4	2.4
	Natural	12	7.1
	Organic	6	3.6
	Traditional	131	78.0
Beef consumption	Total days per week beef is consumed		
	0	1	0.6
	1-2	75	44.6
	3-4	73	43.4
	5-6	15	8.9
	7 or more	4	2.4

Antibiotic Infographic

Figure 8 shows the Antibiotic infographic segmented into three Sections. Because the brain processes information that appears in groups, the Sections were defined based on the closure created by the light lines that segregated the information into three defined groups. Table 2 corresponds to these defined AOI. Participants viewed Section A first, followed by Section B, then finally Section C. This corresponds to the natural scanning pattern of top to bottom and left to right. As participants progressed in their viewing, the time spent in each section decreased as well as the number of revisits and fixation counts. Time spent is often used as a measure of the relative importance of a particular object (Cullipher and VandenPlas, 2018). A longer measurement of time spent on a certain AOI may indicate that the area was attractive to the participant, the participant was confused by the AOI, or the information was difficult to process (Cullipher and VandenPlas, 2018). As a limitation of eye tracking data, the reason for an individual's drawn attention and their emotional response to the stimuli is not discernable when interpreted as the sole measurement of attention.

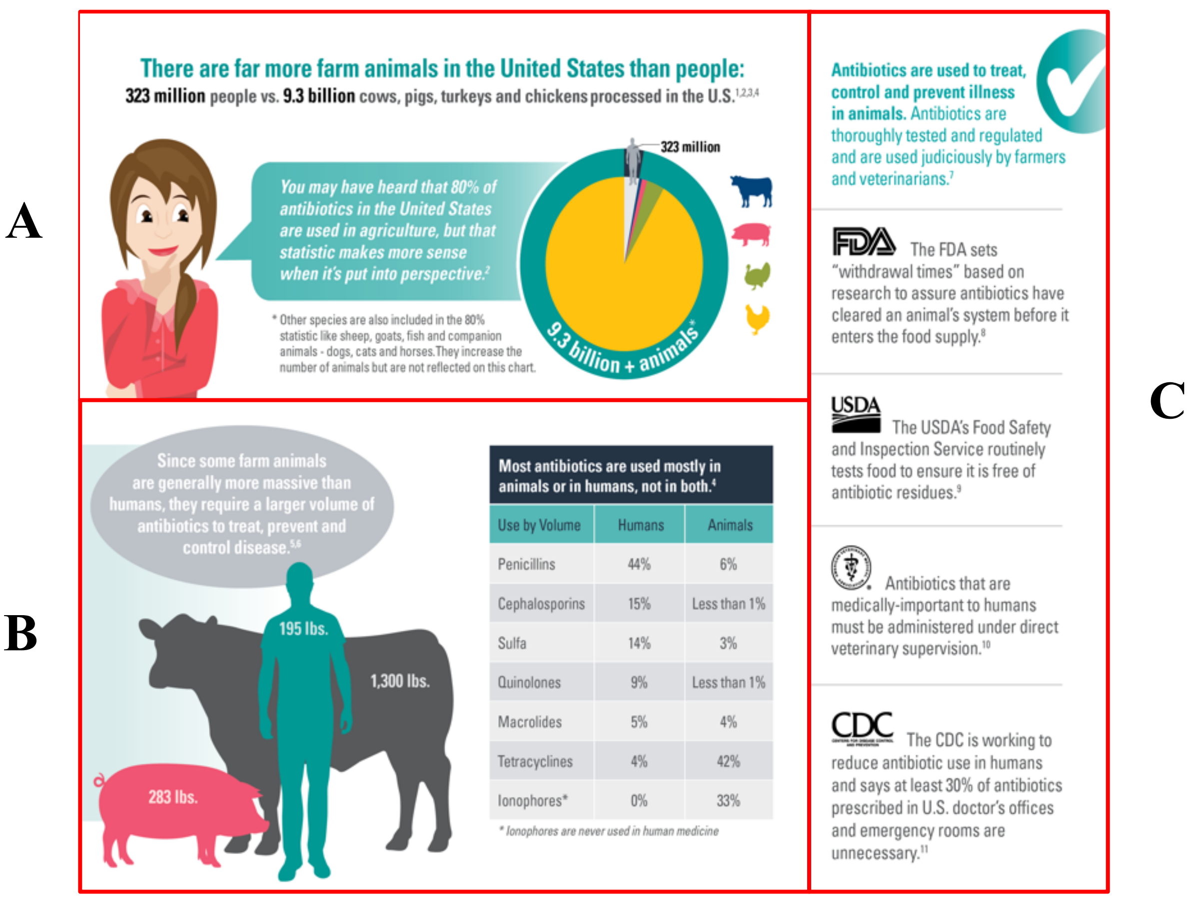


Figure 8. Areas of interests defined by sections in the Antibiotic infographic.

Table 42. Least squares means for Time to First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Antibiotic Infographic segmented by sections.

	Section				
Measurement	A	B	C	SEM	*P*-value
TTFF (S)	4.4[a]	17.8[b]	23.0[c]	0.83	< 0.001
Time spent (S)	8.0[a]	3.2[b]	0.9[c]	0.38	< 0.001
Revisits	12.3[a]	4.4[b]	1.5[c]	0.52	< 0.001
Fixation counts	41.8[a]	16.0[b]	4.8[c]	1.78	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Within Section A as shown in Figure 9, participants were drawn to the textual information faster than the graphics (Table 43). There was not significant evidence to suggest that participants viewed either Text 1 or Text 2 before the other. This may or may not be a crucial finding depending on the context of the information. Text 1 contains the information that explains the remaining figures and graphs in Section A. The number of revisits were greatest for Text 2, followed by Text 1. This indicted that participants were constantly returning to these areas, possibly due to issues comprehensibility. The time spent and fixation counts were greatest for Text 2, followed by Text 1, the Graph, then the image. This was to be expected as the design complexity of the subsection contains two text blocks and two visuals. More time and attention were required to comprehend the text blocks compared to the visuals.

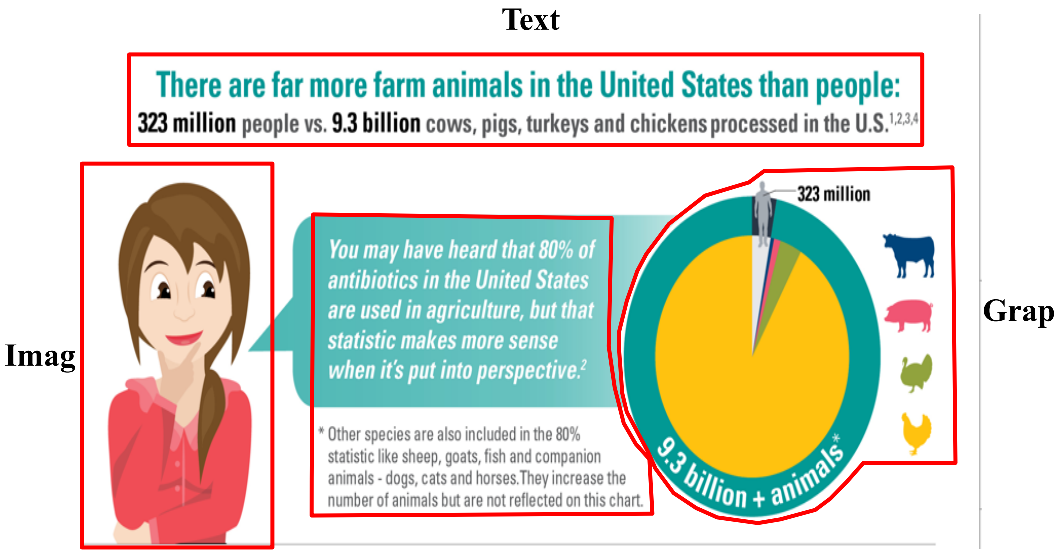


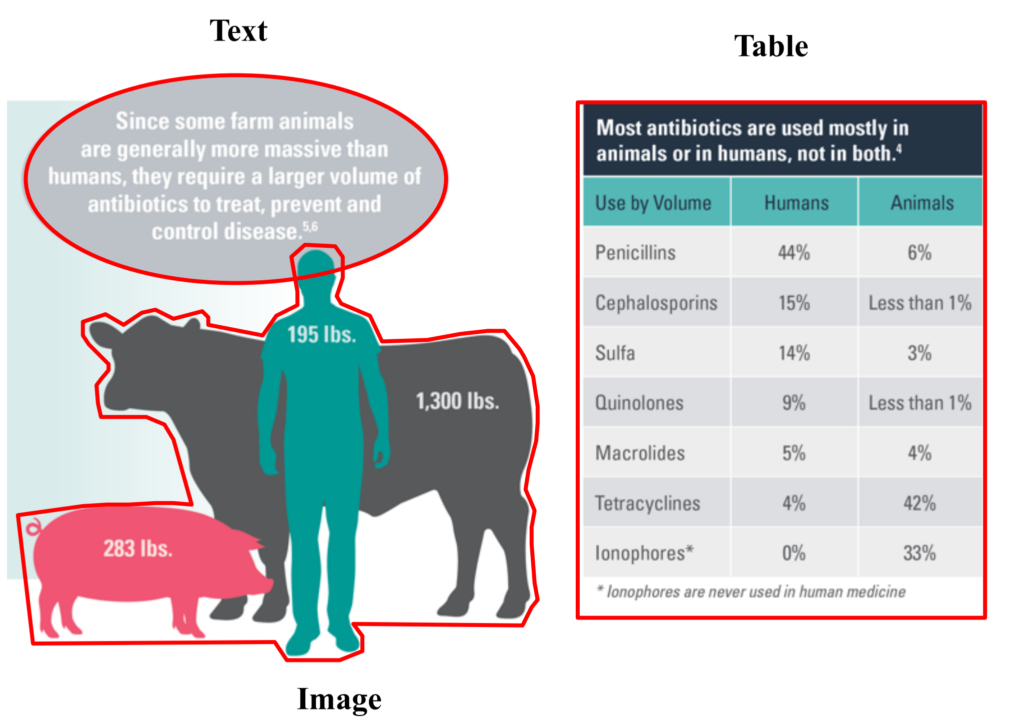
Figure 9. Areas of interest within Section A of the Antibiotic Infographic.

Table 43. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Antibiotic infographic within Section A.

	Section					
Measurement	Text 1	Image	Text 2	Graph	SEM	*P*-value
TTFF (S)	7.5^{b}	17.9^{a}	10.0^{b}	15.7^{a}	0.97	< 0.001
Time spent (S)	1.8^{b}	0.3^{d}	3.9^{a}	1.0^{c}	0.18	< 0.001
Revisits	3.8^{b}	0.7^{d}	6.3^{a}	2.3^{c}	0.31	< 0.001
Fixation counts	9.7^{b}	1.3^{d}	19.9^{a}	5.2^{c}	0.89	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

The areas of interest for Section B are displayed in Figure 10 and the eye tracking metrics are reported in Table 44. The Text and the Table were viewed before the Image in Section B. Additionally, the Text and the Table attracted participants for a greater span of time, number of revisits, and fixations compared to the image. This may be due to the lack of complexity of the image, and the greater amount of cognitive ability required to comprehend the information presented in the Text and Table. This trend of participants viewing graphics for a shorter time duration compared to textual information is justified through how we process simple visual objects in time increments as short as 0.04 – 0.05s (Treisman and Gormican, 1988). The average time spent on the graphic was 0.7s, therefore surpassing the processing threshold.



Use by Volume	Humans	Animals
Penicillins	44%	6%
Cephalosporins	15%	Less than 1%
Sulfa	14%	3%
Quinolones	9%	Less than 1%
Macrolides	5%	4%
Tetracyclines	4%	42%
Ionophores*	0%	33%

** Ionophores are never used in human medicine*

Figure 10. Areas of interests within Section B of the Antibiotic Infographic.

Table 44. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Antibiotic infographic within Section B.

	Section				
Measurement	Text	Image	Table	SEM	*P*-value
TTFF (S)	22.6^{b}	27.1^{a}	23.0^{b}	0.66	< 0.001
Time spent (S)	1.4^{a}	0.3^{b}	1.3^{a}	0.14	< 0.001
Revisits	2.2^{a}	0.5^{b}	1.8^{a}	0.19	< 0.001
Fixation counts	6.9^{a}	1.2^{b}	6.4^{a}	0.63	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-b]Least squares means within the same row without common superscript letters differ (P <0.05).

As reported in Table 42, participants spent on average less than 1.0 S within Section C AOI. This is emphasized by the comparison of AOIs within the section (Figure 11) reported in Table 45. Participants fixated on Text 1 and Text 2 before all other information. The most time was spent on Text 1, with an average of 0.5 S. All successive text received significantly less attention in terms of time spent, revisits, and fixation counts. Although not measurable by eye tracking equipment, an explanation for these differences may be due to the large amount of text present in Section C, which may have deterred the participants from fixating on the information. Additionally, this section was last to receive attention, causing the participants to near the 30 second time limit as they began to view the information. The average person is able to comprehend 17-19 characters per fixation. This number may fluctuate depending on the person's reading capability. Therefore, as Text 1 received the highest number of fixation counts (2.4) it can be estimated that if a person started at the beginning of the sentence they would have finished less than 2 of the 6 lines of the paragraph.

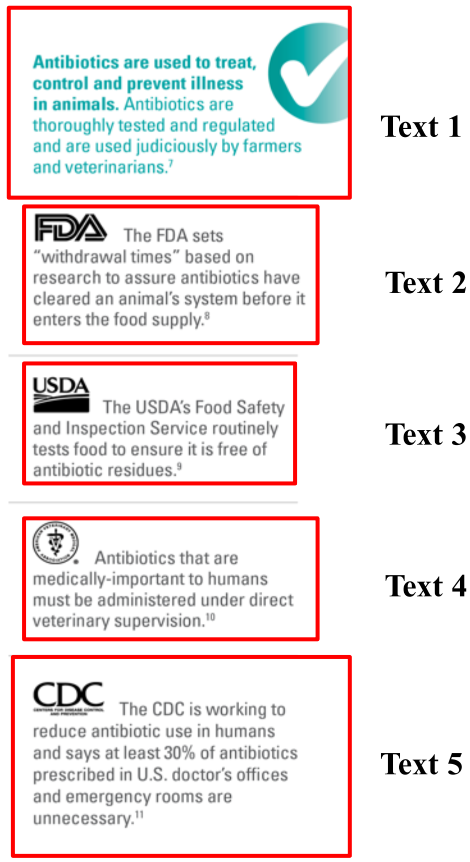


Figure 11. Areas of interest within Section C of the Antibiotic Infographic.

Table 45. Least squares means for Time To First Fixation, Time Spent, Revisits, and Fixation Counts for the Antibiotic infographic within Section C.

	Section						
Measurement	Text 1	Text 2	Text 3	Text 4	Text 5	SEM	*P*-value
TTFF (S)	25.6[b]	26.4[b]	29.1[a]	29.0[a]	29.3[a]	0.49	< 0.001
Time spent (S)	0.5[a]	0.2[b]	0.1[b]	0.1[b]	0.1[b]	0.05	< 0.001
Revisits	0.7[a]	0.4[ab]	0.1[c]	0.1[bc]	0.2[bc]	0.08	< 0.001
Fixation counts	2.4[a]	1.0[b]	0.4[b]	0.4[b]	0.5[b]	0.25	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

[a-c]Least squares means within the same row without common superscript letters differ ($P < 0.05$).

Previous research quantified the design quality of health advertisements by evaluating the design complexity of the ads. This acknowledged details such as the quantity of objects, irregularity of objects, dissimilarity of objects, details of objects, asymmetry of object arrangement, and irregularity of object arrangement in order to develop a score to indicate a value of design quality. Champlin et al. (2014) concluded messages with high levels of design were observed for longer amounts of time, indicating more allotted time and attention. The current study design established a limitation of 30s, inhibiting participants from viewing the infographic in its entirety based on the broad assumption that if more time was allotted that they would continue to observe the infographic. It must be considered that outside of a controlled research setting, the time an individual devotes to observing a message is influenced by many factors outside the control of its designer, but the design of the message can either deter or entice the observer. For example, in the field of website design, first impressions are crucial as Lindgaard et al. (2006) reported the visual appeal of a website's design is assessed by viewers within 50 milliseconds. In this amount of time, a viewer can decide whether or not to pursue the stimuli further.

GMO Infographic

The GMO infographic segmented by sections is shown in Figure 12. The concepts of closure and similarity segregate the infographics into three primary sections (Moore and Fitz, 1993). Section A is separated from Section B due to the closure defined by the line separating the text and the differences in color usage of the green and orange. The similarity of the shapes of the images and the background color shading in Section

C orient the information as a grouping. Participants viewed the GMO infographic from top to bottom as reported by the TTFF in Table 46. The time spent and the number of fixations were highest for Section A, followed by Section C, then Section B. Although this appears contrary to the TTFF pattern, this may be due to the amount of information complexity in each respective section. Higher levels of concentration are required for Section C compared to Section B due to the amount of information present. Viewers also revisited Section A a greater number of times compared to Section B and C, which were similar to one another. Additionally, these findings indicate participants overlooked the information presented in Section B. Section B describes the extent GMOs have been researched by multiple government agencies. If the intent of this message was to establish credibility and trust for the scientific soundness of GMOs, then altering the typography and position of this message may draw more attention from consumers. The holistic interpretation of the design complexity of the infographic can be interpreted by the quantity, irregularity, dissimilarity, and details of the objects as well as the asymmetry and irregularity of the object arrangement (Pieters et al., 2010). By observing the shapes of the AOI identified in Figure 6, the irregularity of the outline shape of the plate images in Section A differ from the remaining AOIs throughout the infographic. This feature does not necessarily classify the image as “good” or “bad”, but understanding how its format contributes to the complexity of the infographic could be important to understanding the consumer perception of the message.

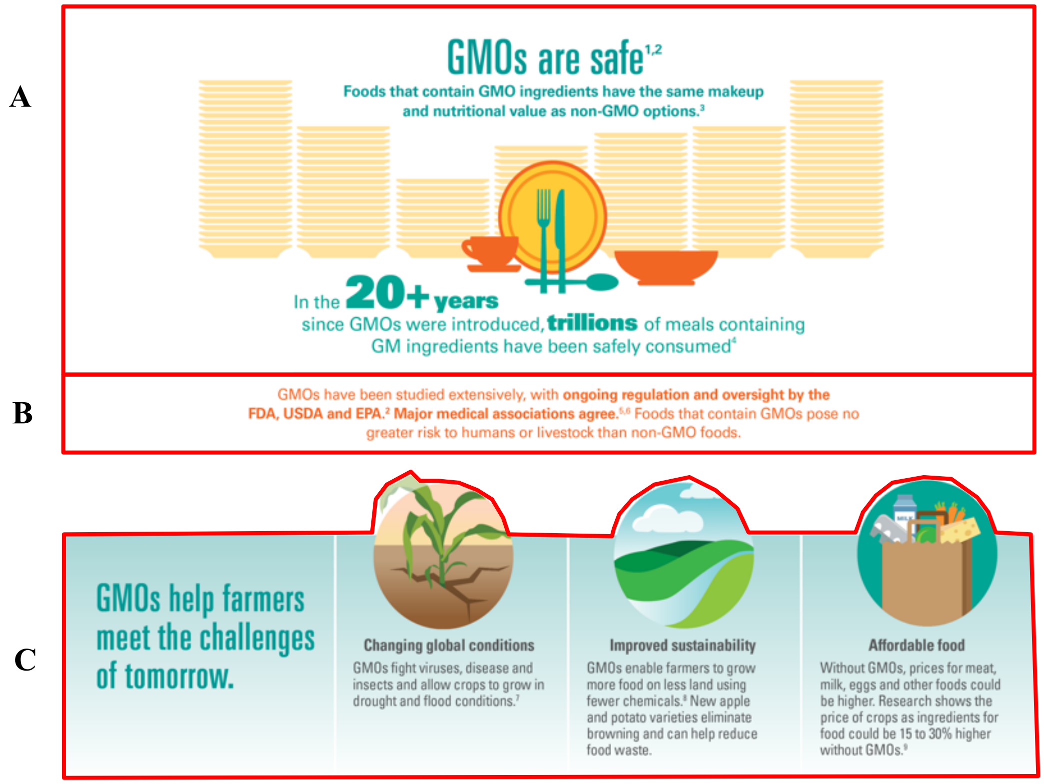


Figure 12. Areas of interest defined by sections in the GMO Infographic.

Table 46. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the GMO infographic segmented by sections.

	Section				
Measurement	A	B	C	SEM	*P*-value
TTFF (S)	4.4[c]	14.1[b]	19.2[a]	0.80	< 0.001
Time spent (S)	5.0[a]	2.6[c]	3.8[b]	0.34	< 0.001
Revisits	8.0[a]	4.6[b]	5.0[b]	0.44	< 0.001
Fixation counts	26.1[a]	13.3[c]	18.7[b]	1.57	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

A further look into the stimuli within Section A (Figure 13) shows that participants did not fixate on Text 1, Image, or Text 2 at significantly different timestamps of seconds, meaning participants differed where they began viewing and processing this portion of the infographic (Table 47). Text 1 and Text 2 are presented in the same color, but differ typography. Text 1 states the opening message of “GMOs are safe” followed by a sub statement underneath in smaller font of “Foods that contain GMO ingredients have the same makeup and nutritional value as non-GMO options.” Text 1 and Text 2 are physically separated by the graphic. Text 2 states in slightly larger font and powerful statement of “In the 20+ years since GMOs were introduced, trillions of meals containing GM ingredients have been safely consumed.” Within this string of text, “20+ years” and “trillions” are in bold typeface. The bold typeface creates a difference in saliency between the two texts. The human perception process allows viewers to use the changes in typography to influence where their attention is assigned (Moore and Fitz, 1993). Some participants may have been drawn to the message in Text 2 prior to Text 1 due to these differences in typography.

Figure 14 shows the subsections within Section C and corresponds with Table 48. The sequence of fixation from viewers suggest that the textual information was most appealing. The Subtitle was among the first to be viewed. This is important because the Subtitle gives understanding to the purpose of the remaining texts in the section. The differentiation of the subtitle through font size and color in addition to its positioning guide the viewer in their sequence of interpreting the information.

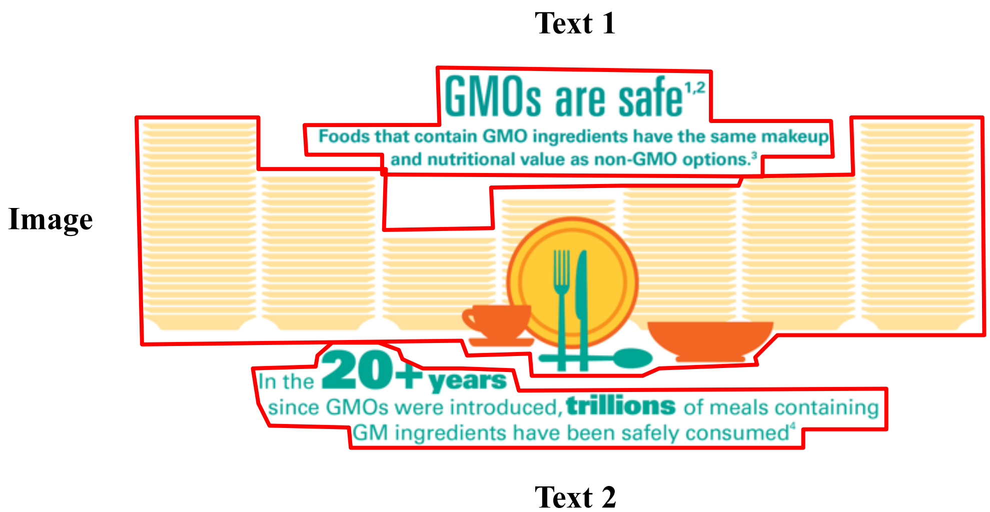


Figure 13. Areas of interest within Section A of the GMO Infographic.

Table 47. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the GMO infographic within Section A.

	Section				
Measurement	Text 1	Image	Text 2	SEM	*P*-value
TTFF (S)	8.4	11.6	10.5	1.00	0.078
Time spent (S)	1.3[a]	0.7[b]	1.6[a]	0.12	< 0.001
Revisits	2.9[a]	2.0[b]	3.4[a]	0.23	< 0.001
Fixation counts	6.6[a]	3.7[b]	8.2[a]	0.58	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

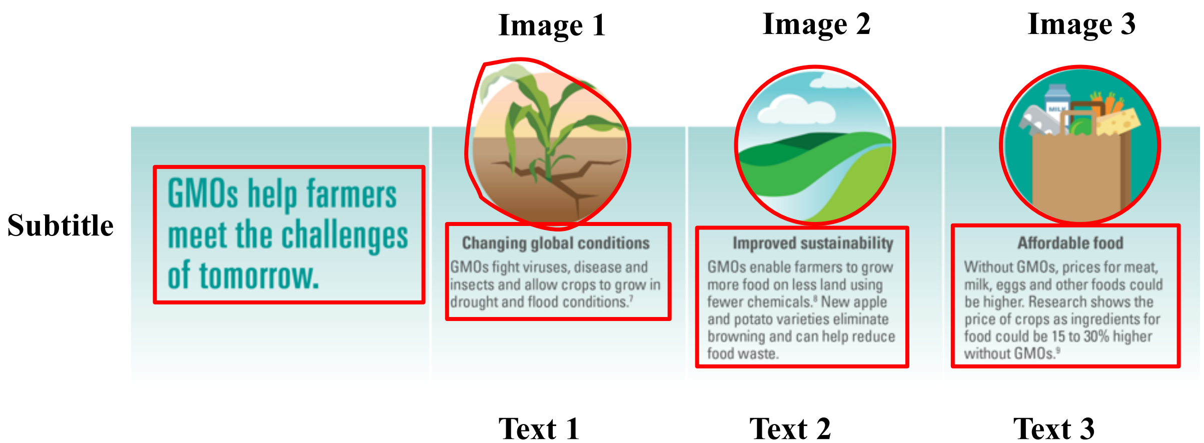


Figure 14. Areas of interest within Section C of the GMO infographic.

Table 48. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the GMO infographic within Section C.

	Section								
Measurement	Subtitle	Image 1	Text 1	Image 2	Text 2	Image 3	Text 3	SEM	*P*-value
TTFF (S)	23.0^{d}	24.4^{bcd}	23.7^{cd}	27.1^{ab}	24.7^{bcd}	28.2^{a}	26.2^{abc}	0.60	< 0.001
Time spent (S)	0.4^{bc}	0.2^{cd}	0.7^{bc}	0.1^{d}	1.1^{a}	0.1^{c}	0.8^{ab}	0.08	< 0.001
Revisits	0.9^{bc}	0.6^{cd}	1.2^{ab}	0.3^{d}	1.6^{a}	0.3^{d}	1.1^{abc}	0.13	< 0.001
Fixation counts	2.4^{bc}	1.0^{cd}	3.5^{ab}	0.5^{d}	5.1^{a}	0.5^{d}	4.0^{ab}	0.38	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

[a-c]Least squares means within the same row without common superscript letters differ (*P* <0.05).

Hormone Infographic

The Hormones infographic is divided into sections defined in Figure 15 and Table 49. The brain is able to determine subconsciously the differences in the background colors and the patterns of the similar, bold subtitles in each natural grouping of information to easily segregate the information into sections. The layout is designed for the viewer of the message to read the information in 3 rows. This, in combination with the brain's inherent scan path of reading top to bottom, defends the TTFF results that indicated participants viewed Section A, followed by Section B, and lastly Section C. Participants' time spent, number of revisits, and fixation counts decreased as progressed in their viewing of each section. It is noted that throughout the infographic, several type size and typestyles are used. Readers naturally attempt to link changes typography with patterns of change in the content of the text, as this is applicable to the Gestalt principle of similarity (Moore and Fitz, 1993).

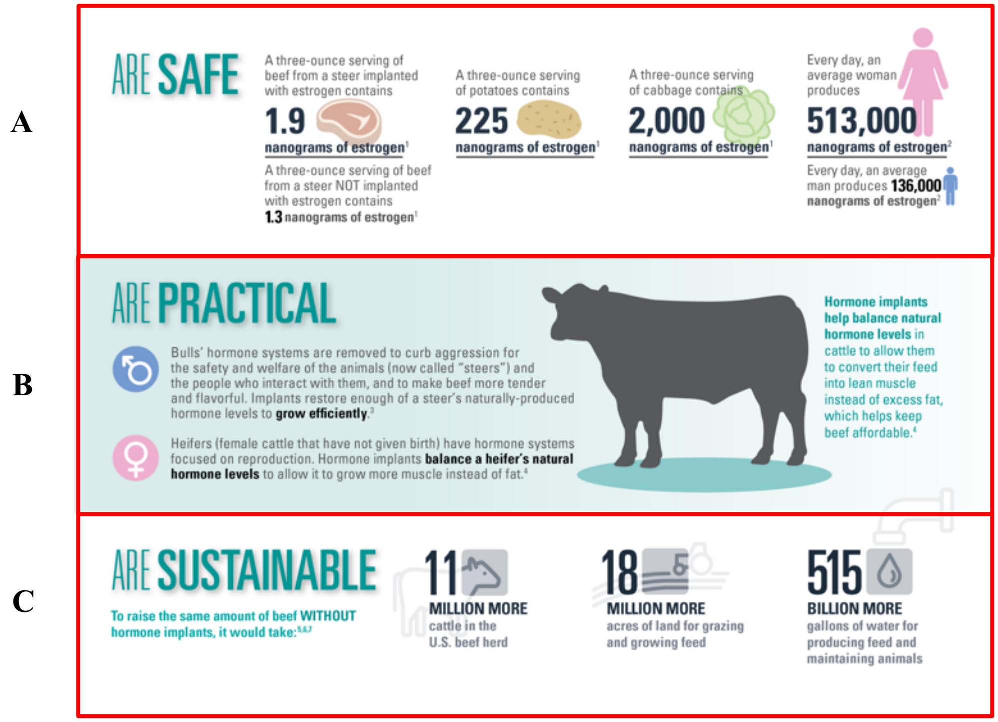


Figure 15. Areas of interest defined by sections in the Hormone Infographic.

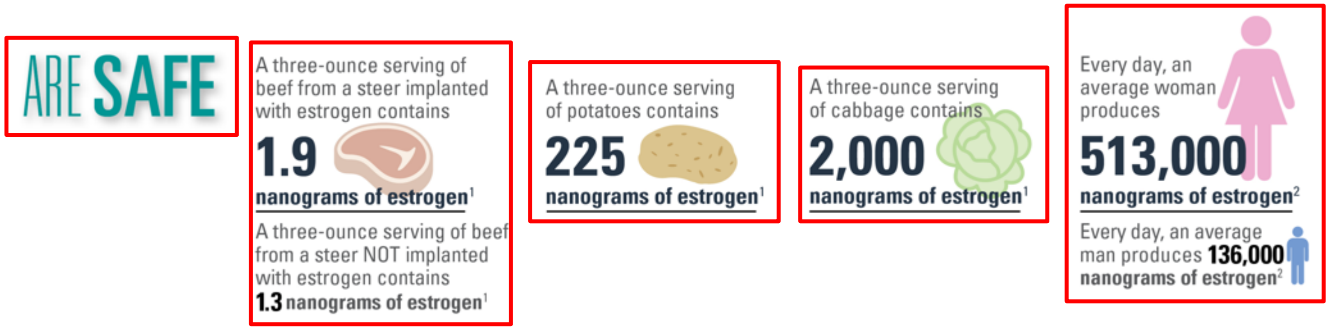
Table 49. Least squares means for Time Ro First Fixation, Time Spent, Revisits, and Fixation Counts for the Hormone infographic segmented by sections.

	Section				
Measurement	A	B	C	SEM	*P*-value
TTFF (S)	3.8^{c}	14.5^{b}	26.9^{a}	0.81	< 0.001
Time spent (S)	8.8^{a}	2.9^{b}	0.4^{c}	0.46	< 0.001
Revisits	13.2^{a}	4.4^{b}	0.6^{c}	0.53	< 0.001
Fixation counts	44.1^{a}	14.6^{b}	1.9^{c}	1.86	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Subsections within Section A are defined in Figure 16 with corresponding AOI metrics presented in Table 50. Participants fixated on Text 1 first, followed by either the Subtitle or Text 2. This scan path may be due to the participants attempting to understand the subject of the infographic. The subtitle, "are safe" does not define what it is that is considered safe. Text 3 and Text 4 were among the last areas to be viewed. The text within Section A may be comprehendible without the need to read the Subtitle initially. Viewers may be drawn to Text 1 quicker than the Subtitle due to the steak image in the background and the bolded words within the text as it took participants 6.7 S to view Text 1 compared to 15.6 S to then revert to the Subtitle. The number of revisits to Text 1 was greater than all other subsections, which may or may not be an indicator of a need of clarification of the participants.

Approximately 22 S was required for participants to fixated within Section B as indicated in Figure 17 and Table 51. Participants looked at either the Subtitle or Text 1 initially, followed by either Text 2, Image, or Text 3. Generally, as viewers progressed in their observations, their time spent, revisits, and fixation counts decreased. Sufficient time may not have been remaining for participants to view this section of the Hormone infographic. This is also apparent for Section C as the only metric that significantly differed was the TTFF for the subsections in Figure 18. Participants appeared to not have enough time to observe the information, as indicated by the AOI metrics in Table 52.



Subtitle **Text 1** **Text 2** **Text 3** **Text 4**

Figure 16. Areas of interest within Section A of the Hormone Infographic.

Table 50. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Hormone infographic within Section A.

	Section						
Measurement	Subtitle	Text 1	Text 2	Text 3	Text 4	SEM	*P*-value
TTFF (S)	15.6^{b}	6.7^{c}	15.8^{b}	21.3^{a}	20.8^{a}	0.86	< 0.001
Time spent (S)	0.3^{c}	4.0^{a}	1.2^{b}	0.7^{bc}	1.3^{b}	0.16	< 0.001
Revisits	0.9^{d}	6.9^{a}	2.6^{b}	1.6^{cd}	2.2^{bc}	0.24	< 0.001
Fixation counts	1.5^{d}	19.2^{a}	6.0^{b}	3.9^{cd}	6.4^{b}	0.73	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

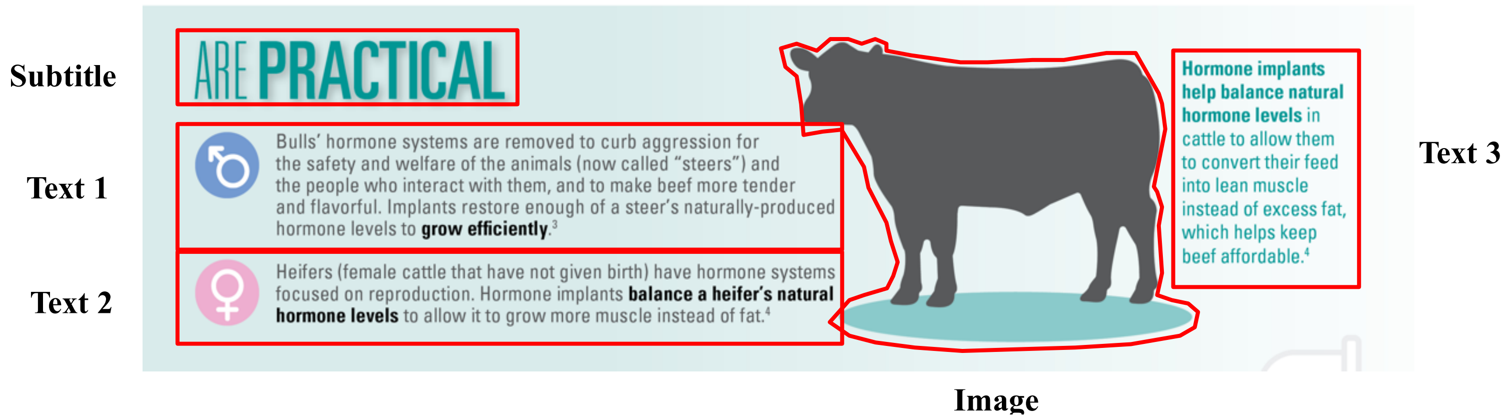


Figure 17. Areas of interest within Section B of the Hormone Infographic.

Table 51. Least squares meant for Time To First Fixation, Time Spent, Revisits, and Fixation Counts for the Hormone infographic within Section B.

	Section						
Measurement	Subtitle	Text 1	Text 2	Image	Text 3	SEM	*P*-value
TTFF (S)	22.1^{b}	22.5^{b}	27.9^{a}	27.3^{a}	28.5^{a}	0.66	< 0.001
Time spent (S)	0.3^{b}	1.5^{a}	0.4^{b}	0.1^{b}	0.3^{b}	0.11	< 0.001
Revisits	0.7^{b}	2.3^{a}	0.6^{bc}	0.1^{d}	0.5^{bc}	0.16	< 0.001
Fixation counts	1.7^{b}	7.5^{a}	2.0^{b}	0.3^{b}	1.3^{b}	0.53	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Figure 18. Areas of interest within Section C of the Hormone Infographic.

Table 52. Least squares means for Time To First Fixation, Time Spent, Revisits, and Fixation Counts for the Hormone infographic within Section C.

	Section						
Measurement	Subtitle	Text 1	Text 2	Text 3	Text 4	SEM	*P*-value
TTFF (S)	28.4^{b}	29.9^{a}	29.3^{ab}	29.7^{ab}	29.5^{ab}	0.35	0.022
Time spent (S)	0.1	0.1	0.1	0.1	0.0	0.02	0.673
Revisits	0.1	0.1	0.2	0.1	0.1	0.06	0.686
Fixation counts	0.4	0.4	0.4	0.3	0.3	0.12	0.811

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (*P* <0.05).

Sustainability Infographic

The sustainability infographic segmented by sections is presented in Figure 19 with related AOI metrics presented in Table 53. Based in TTFF, participants viewed the sections starting with Section A at the top left, followed by Section B in the top right, and finished at Section C located across the bottom of the infographic. Time spent, number of revisits, and fixation counts were greatest for Section A, while Section B and C were similar to one another. Viewers may have decreased in their attention as they looked at each section. It is also important to consider the type of information presented in each section. Section A begins with the definition of sustainability (Text 1), followed with a statement persuading the viewer how they are a part of the concept of sustainability (Text 2), and finishes with a statement of the needed increase of the food supply to support a growing population (Text 3). Section B is organized through graphics and summarizes how the agricultural industry is achieving its goal of a sustainable food supply through short statements. Section C presents a beginning sentence that guides the viewer in what they are to expect for the text that follows. There are four text statements supporting the idea of the subtitle information. Each of the four-text statement consists of statistical information cited from various sources. The AOI metrics show that viewers spent the same amount of time and stimulated the same amount of fixation counts viewing Section B and C, although the depth of information presented in each were different. Section C measurements may be lower than expected due to the time limitation. From another perspective, the saliency of the graphic in Section B may have attracted participants' attention. Regardless, it may be practicable to conclude participants did not derive as much information from Section C compared to other sections in the infographic due to the time that would be required to interpret the text.

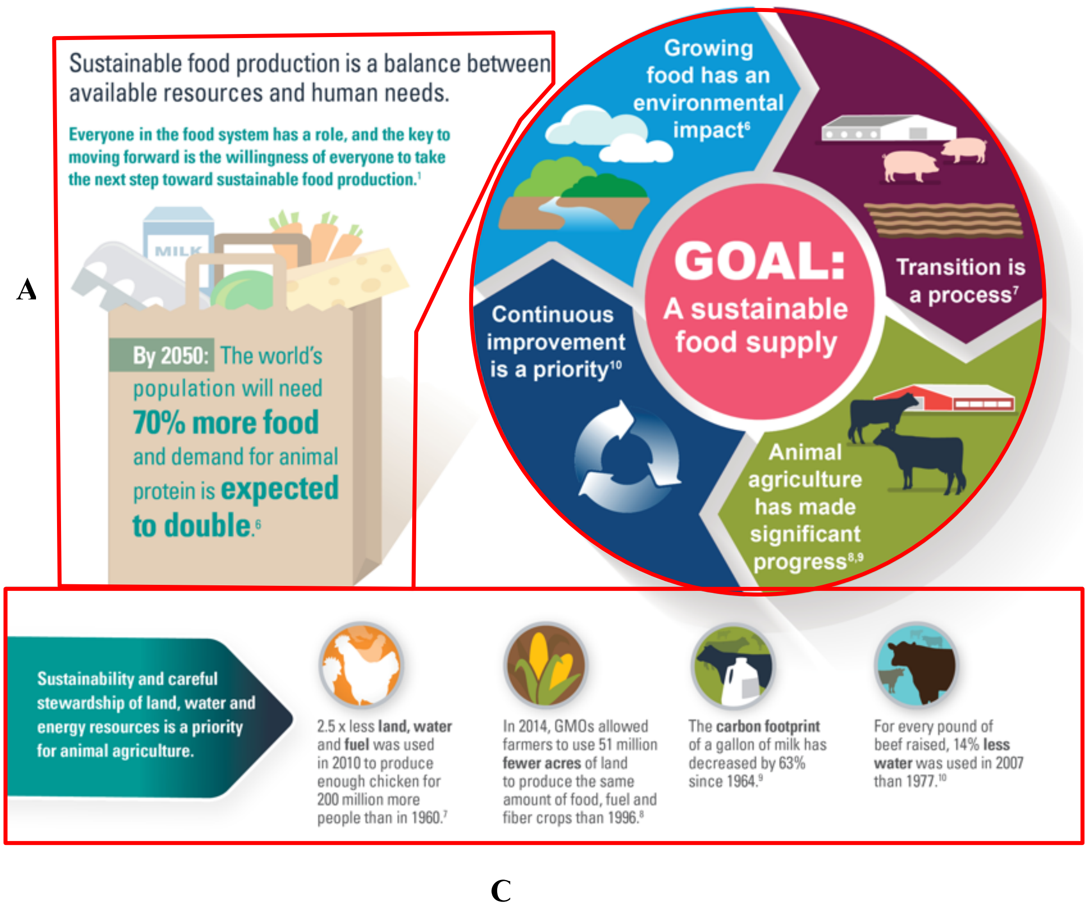


Figure 19. Areas of interest defined by sections in the Sustainability Infographic.

Table 53. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Sustainability infographic segmented by sections.

	Section				
Measurement	A	B	C	SEM	*P*-value
TTFF (S)	4.2^{c}	9.6^{b}	19.8^{a}	0.82	< 0.001
Time spent (S)	4.9^{a}	3.0^{b}	3.3^{b}	0.34	< 0.001
Revisits	8.3^{a}	5.1^{b}	4.2^{b}	0.43	< 0.001
Fixation counts	25.7^{a}	15.1^{b}	16.0^{b}	1.50	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Subsections of Section A presented in Figure 20 divide the information into 3 text components (Table 54). The image of the grocery bag laying behind Text 3 was not accounted for due to the overlapping of information. As discussed formerly, Text 1 provides the definition of sustainability and sets the foundational understanding of the remaining information for the viewer. The TTFF reveals that participants took the same amount of time to fixate on both, Text 1 and Text 2. There is concern for if a participant viewed Text 2 before Text 1, as they may not have been able to comprehend the meaning of the information without knowing the subject of the infographic, as it is not clear in Text 2, solely. Participants reported more time spent, more revisits, and higher fixation counts for viewing Text 2 and Text 3 compared to Text 1. Due to the degree of complexity of the statements, these results are expected. Additionally, the increased saliency of the background image of the grocery bag may have attracted consumer attention, explaining the higher fixation counts.

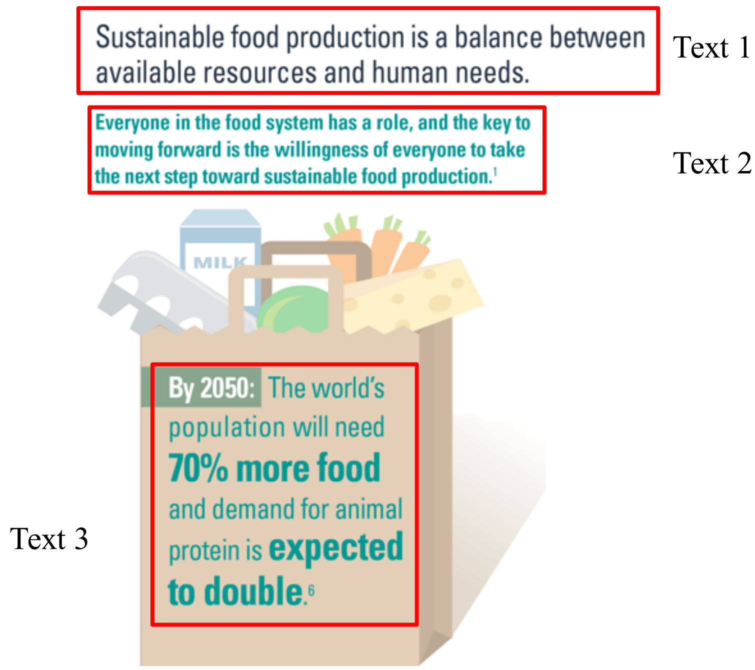


Figure 20. Areas of interest within Section A of the Sustainability Infographic.

Table 54. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Sustainability infographic within Section A.

	Section				
Measurement	Text 1	Text 2	Text 3	SEM	*P*-value
TTFF (S)	10.1^{b}	10.4^{b}	14.6^{a}	0.95	0.001
Time spent (S)	0.9^{b}	1.6^{a}	1.7^{a}	0.14	0.000
Revisits	2.2^{b}	3.2^{a}	2.7^{ab}	0.24	0.007
Fixation counts	4.9^{b}	8.2^{a}	8.5^{a}	0.66	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-d]Least squares means within the same row without common superscript letters differ (*P* <0.05).

The layout of Section B presented in Figure 21 reported interesting AOI metrics in Table 55. All text information is presented in a brief, summarized form. The circular figure highlights the overall message of the figure in the center with four supportive details surrounding it. The details are separated through different colors inside of shapes representing a continuous arrow that create a flow of information. Ideally, a viewer would first interpret the overall message, then read each supportive statement surrounding it with no desired particular order. Time to first fixation data reported participants either fixating on Text 1 or Text 5 information prior to other text. The eludes to the possibility that viewers may being reading the supportive information prior to understanding the main idea of the information. Additionally, viewers reported the highest fixation count for Text 5 and revisited Text 1 and Text 5 greater than the other text information. A possible explanation for the greater number of revisits may be due to the viewer attempting to understand the layout of the information. When a visual guides a viewer in a direction or is designed to create a preconceived path for the viewer there is an increase in the speed of processing, an improvement in the processing of relevant information, and an increase in comprehension of the visual (Malamed, 2009).

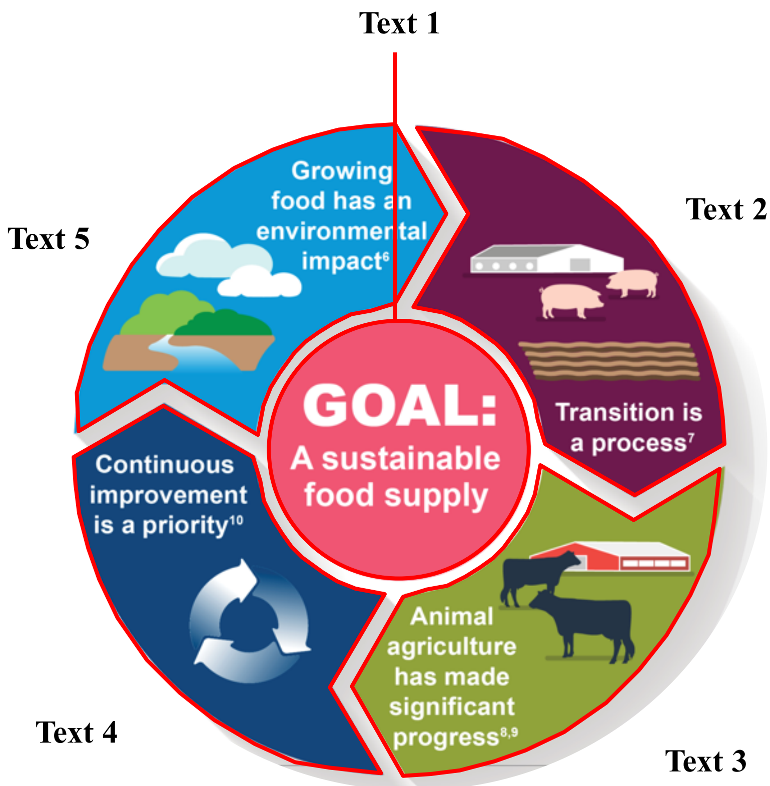


Figure 21. Areas of interest within Section B of the Sustainability Infographic.

Table 55. Least squares meant for Time to First Fixation, Time Spent, Revisits, and Fixation Counts for the Sustainability infographic within Section B.

	Section						
Measurement	Text 1	Text 2	Text 3	Text 4	Text 5	SEM	*P*-value
TTFF (S)	17.4^{bc}	20.2^{ab}	21.9^{a}	20.1^{ab}	15.2^{c}	0.87	< 0.001
Time spent (S)	0.5^{b}	0.5^{ab}	0.6^{ab}	0.5^{ab}	0.7^{a}	0.06	0.035
Revisits	1.2^{ab}	0.9^{b}	0.9^{b}	1.1^{b}	1.7^{a}	0.13	0.000
Fixation counts	2.6^{b}	2.6^{b}	2.7^{b}	2.6^{b}	3.8^{a}	0.27	0.003

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Figure 22 shows the sections described for the AOI metrics in Table 56. In general, it appears that viewers divided the stimuli into two groups. Text 1, Text 2, Text 3, and Image 1 were generally lower in TTFF and higher in the remaining metrics. The latter stimuli, Image 2, Text 4, Image 3, Text 5, and Image 4 were greater in their TTFF, were viewed for less time, revisited less, and accounted for less fixations. This may be due to the layout of the section as there are several long statements next to each other and may have caused participants to decrease in their interest as the read the information. Also, the viewing of Section C occurred near the time limit of viewing the infographic as the TTFF within this section occurred at 23.6 s.

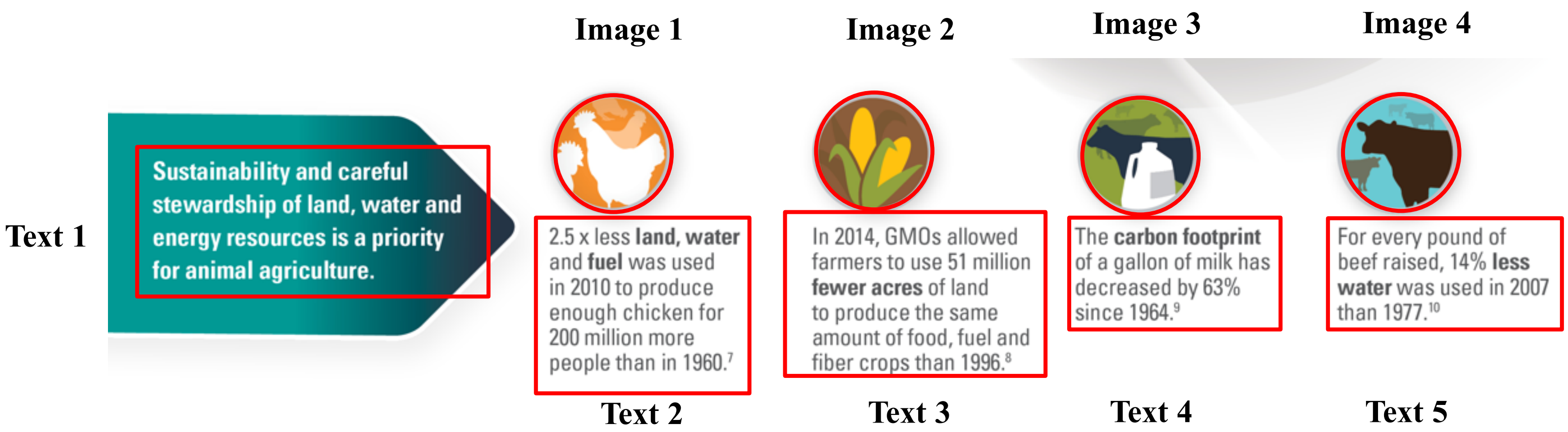


Figure 22. Areas of interest within Section C of the Sustainability Infographic.

Table 56. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Sustainability infographic within Section C.

	Section										
Measurement	Text 1	Image 1	Text 2	Image 2	Text 3	Image 3	Text 4	Image 4	Text 5	SEM	*P*-value
TTFF (S)	23.6^{e}	27.3^{bcd}	25.5^{de}	28.3^{abc}	26.4^{cd}	29.2^{ab}	28.5^{ab}	29.5^{a}	29.0^{ab}	0.47	< 0.001
Time spent (S)	0.7^{ab}	0.2^{cd}	0.8^{a}	0.1^{d}	0.5^{bc}	0.1^{d}	0.3^{cd}	0.0^{d}	0.2^{d}	0.06	< 0.001
Revisits	1.0^{a}	0.5^{bc}	1.2^{a}	0.1^{c}	0.9^{ab}	0.1^{c}	0.4^{c}	0.1^{c}	0.3^{c}	0.10	< 0.001
Fixation counts	3.3^{ab}	1.0^{d}	3.8^{a}	0.9^{d}	2.4^{bc}	0.3^{d}	1.3^{cd}	0.2^{d}	0.9^{d}	0.28	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-e]Least squares means within the same row without common superscript letters differ (*P* <0.05).

Vaccines Infographic

The Vaccines infographic is formatted in a vertical manner with Sections A, B, and C stacked upon one another (Figure 23). This layout was similar to the layout of the Hormone Infographic. The AOI metrics given in Table 57 support the idea that participants followed the layout of the infographic as the TTFF showed sequential viewing of the sections. Participants devoted similar amounts of time, revisits, and fixation counts to Section A and Section B while Section C received less of each of these measurements. As seen with the previous infographics, this pattern may have occurred due to the time constraint.

Figure 24 displays the subsections of Section A and corresponds to the AOI metrics reported in Table 58. Generally, participants initially viewed Text 1 followed by Text 2 before they returned to read the Subtitle information regarding the topic of the infographic section. A similar scan path was noted in the Hormone graphic as well. Each of these infographics do not clearly define the subject that the subtitles are referring to. For example, the subtitle in Section A states, "benefit animals." This may cause the viewer to review text sections to clarify what it is that benefits animals. Text 3 and the Image were the last of the subsections to be viewed. Text 1, Text 2, and Text 3 were viewed for more time and received more revisits and fixation counts than the Subtitle and the Image. This aligns with the idea that participants concentrated on the larger text information in order to comprehend the information

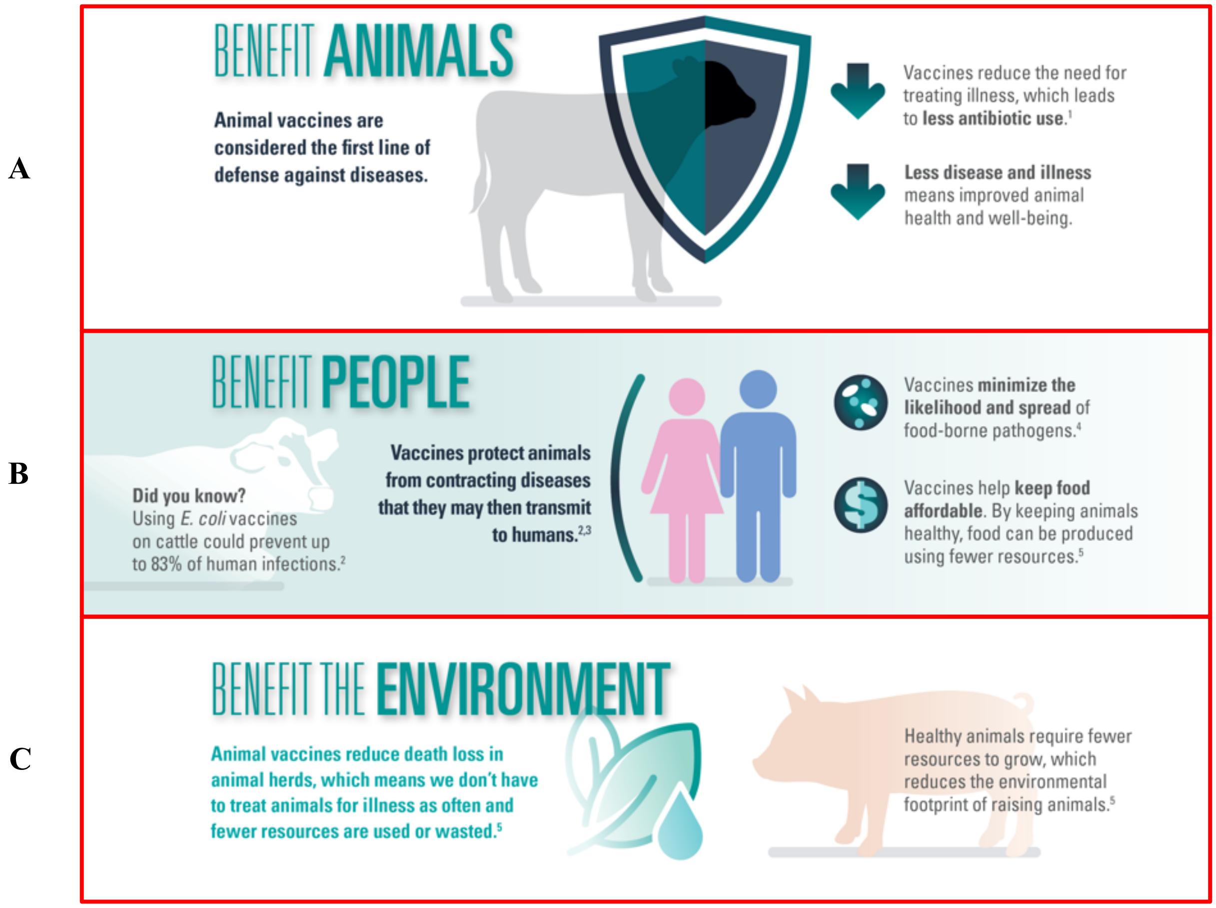


Figure 23. Areas of interest defined by sections in the Vaccines infographic.

Table 57. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Vaccines infographic segmented by sections.

	Section				
Measurement	A	B	C	SEM	*P*-value
TTFF (S)	4.1[c]	11.5[b]	21.0[a]	0.80	< 0.0001
Time spent (S)	4.3[a]	4.8[a]	2.0[b]	0.31	< 0.0001
Revisits	7.6[a]	7.4[a]	2.7[b]	0.40	< 0.0001
Fixation counts	22.3[a]	24.3[a]	9.9[b]	1.43	< 0.0001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

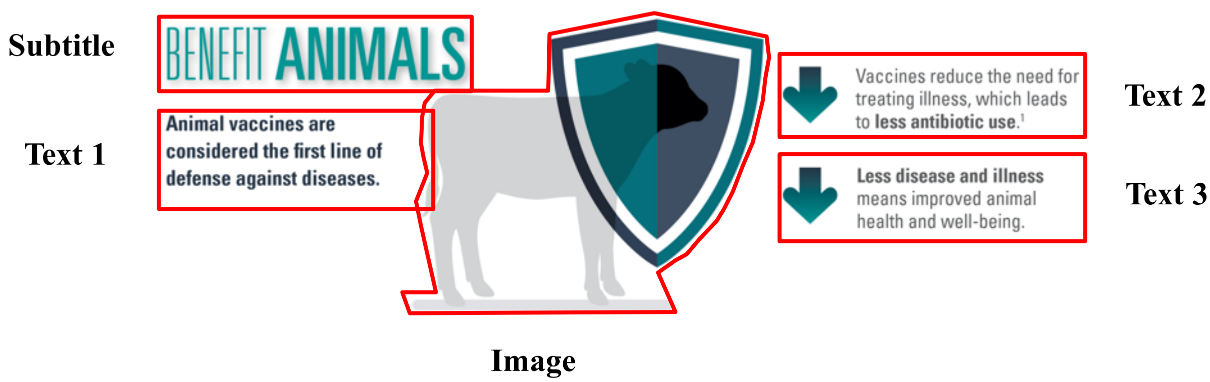


Figure 24. Areas of interest within Section A of the Vaccines Infographic.

Table 58. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Vaccines infographic within Section A.

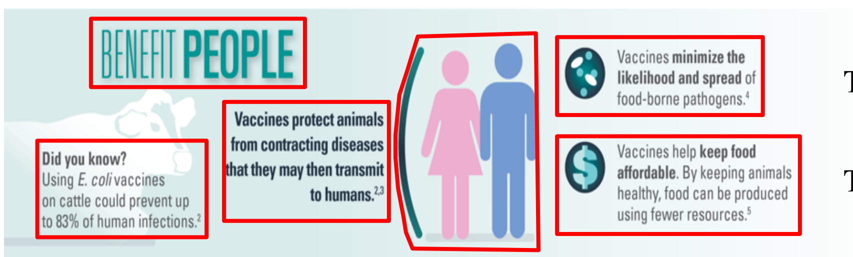
	Section						
Measurement	Subtitle	Text 1	Text 2	Text 3	Image	SEM	*P*-value
TTFF (S)	13.1^{abc}	10.5^{d}	11.5^{cd}	15.5^{a}	15.5^{ab}	1.03	0.000
Time spent (S)	0.3^{c}	1.0^{a}	1.1^{a}	0.8^{a}	0.2^{c}	0.08	< 0.0001
Revisits	0.9^{c}	2.3^{a}	2.2^{ab}	1.6^{b}	0.8^{c}	0.16	< 0.0001
Fixation counts	1.9^{c}	5.5^{a}	5.5^{a}	4.1^{b}	1.3^{c}	0.36	< 0.0001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-d]Least squares means within the same row without common superscript letters differ (P <0.05).

Participants viewed the Image and last text, Text 4, in Section B after viewing the Subtitle, Text 1, Text 2, and Test 3 portion (Figure 25 and Table 59). This is similar to their viewing pattern of Section A, with the exception that first viewed subsections of Section B were all similar, meaning that the average timestamp in which the participants looked at each of these stimuli were not different from one another. In other words, there was not a definable sequence for which the Subtitle, Text 1, Text 2, and Text 3 were interpreted. This eludes to the idea that the layout of the info graphic may not guide the viewers in a particular scan path. The context presented determines whether this observation may be interpreted as positive or negative, as it depends if a particular order in viewing the information is critical to the understanding of the information. Additionally, it must be considered if a layout of this nature would or would not deter viewers from continuing to read the presented information outside of a controlled laboratory setting. All text information, besides the Subtitle subsection, acquired more time, revisits, and fixation counts from the participants.

Figure 26 displays Section C divided into a Subtitle, Text 1, Image, and Text 2 subsections. Area of interest metrics reported in Table 60 show that participants generally viewed the left portion of Section C, including the Subtitle and Text 1, before viewing the remaining stimuli. The text information received a greater amount of time, revisits, and fixation counts.

Subtitle



Text Text

Text Text Image 1

Figure 25. Areas of interest within Section B of the Vaccines infographic.

Table 59. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Vaccines infographic within Section B.

	Section							
Measurement	Subtitle	Text 1	Text 2	Image	Text 3	Text 4	SEM	*P*-value
TTFF (S)	18.1^{b}	18.7^{b}	18.8^{b}	25.7^{a}	20.8^{b}	24.7^{a}	0.73	< 0.001
Time spent(S)	0.3^{c}	1.2^{a}	1.0^{ab}	0.1^{c}	0.8^{b}	0.8^{b}	0.08	< 0.001
Revisits	0.5^{b}	1.8^{a}	1.8^{a}	0.3^{b}	1.3^{a}	1.3^{a}	0.15	< 0.001
Fixation counts	1.4^{c}	5.7^{a}	5.2^{ab}	0.6^{c}	4.0^{b}	3.8^{b}	0.38	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

[a-c]Least squares means within the same row without common superscript letters differ (*P* <0.05).

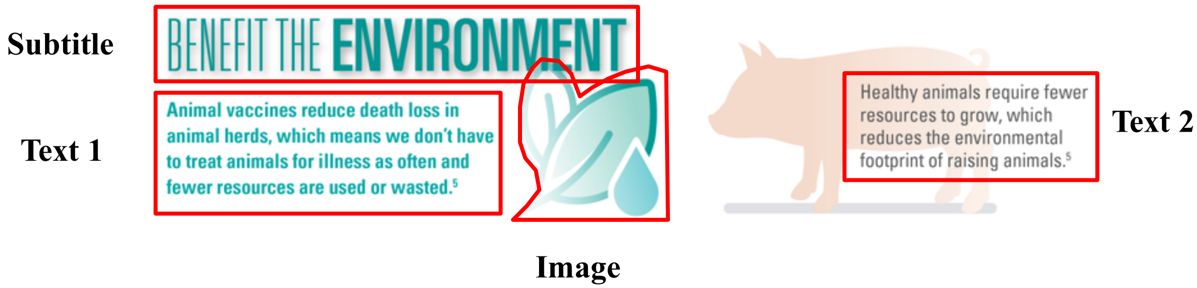


Figure 26. Areas of interest within Section C of the Vaccines Infographic.

Table 60. Lest squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation Counts[4] for the Vaccines infographic within Section C.

	Section					
Measurement	Subtitle	Text 1	Image	Text 2	SEM	*P*-value
TTFF (S)	25.5^{b}	26.1^{b}	28.5^{a}	27.0^{ab}	0.52	< 0.001
Time spent (S)	0.3^{bc}	0.8^{a}	0.0^{c}	0.5^{ab}	0.08	< 0.001
Revisits	0.5^{b}	1.2^{a}	0.0^{c}	0.8^{b}	0.11	< 0.001
Fixation counts	1.5^{b}	3.9^{a}	0.1^{c}	2.5^{b}	0.33	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.
[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.
[3]Number of returns to the area of interest.
[4]Number of fixations recorded inside the area of interest.
[a-c]Least squares means within the same row without common superscript letters differ ($P < 0.05$).

Welfare Infographic

The Welfare infographic shown in Figure 27 corresponds to the AOI metrics presented in Table 61. The infographic uses white space, colors, and shapes to partition itself into four sections. The layout of the welfare infographic differed visually from the others. It applied the principle of chunking, which decreases the cognitive load of the viewer by breaking the visual into smaller chunks to comprehend. The orientation of the information in a chunk pattern aids the viewer in following and interpreting the information with less distraction (Majooni et al., 2018). Participants viewed either Section A or Section B when initially presented the image, followed by Section C then Section D. Ideally, we would like participants' TTFF value for Section A to be significantly less than the value for Section B to indicate that viewers read the title and the summary of the information presented in the latter sections. The information in Section B is information that may be able to be understood without reading the prior section, but to gain the complete insight for the meaning behind the infographic the comprehension of Section A is most beneficial upon initial viewing. Section B also reported more time spent, revisits, and fixation counts compared to the other sections. This may be in part due to the amount of information provided, but it also raises the question of if participants may have become confused about the layout of the information, as possibly indicated by the number of revisits to this section. This question's validity is supported by the Gestalt principle of symmetry (Moore and Fitz, 1993). Visuals that are not centered on a page and use white space irregularly make readers anxious about where to start reading and processing information, ultimately leading them to question the design. Altering this scan path may be accomplished simply by a slight adjustment in text placement and/or changes in typography.

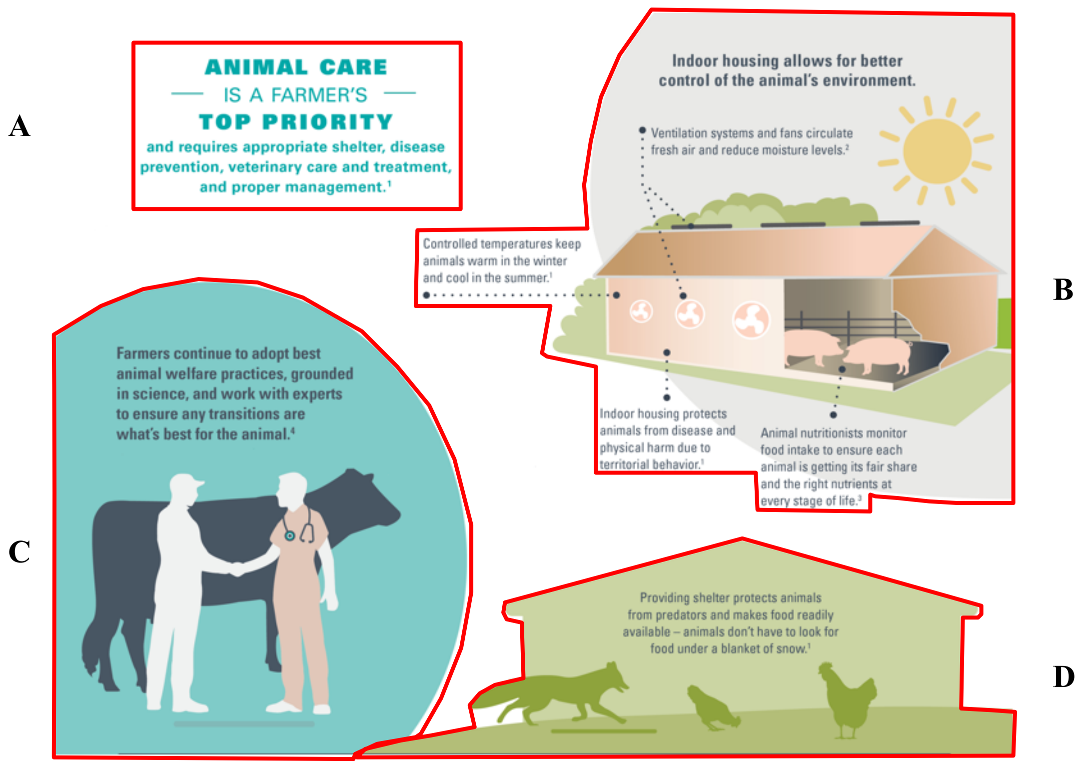


Figure 27. Areas of interest defined by sections in the Welfare Infographic.

Table 61. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation counts[4] for the Welfare infographic segmented by sections.

	Section					
Measurement	A	B	C	D	SEM	*P*-value
TTFF (S)	6.0[c]	7.9[c]	13.2[b]	22.7[a]	0.82	< 0.001
Time spent (S)	2.2[b]	5.4[a]	2.0[b]	1.5[b]	0.26	< 0.001
Revisits	4.4[b]	8.8[a]	3.2[c]	2.0[c]	0.35	< 0.001
Fixation counts	11.3[b]	27.2[a]	9.7[b]	7.3[b]	1.16	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

[a-c]Least squares means within the same row without common superscript letters differ ($P < 0.05$).

Further investigation into the subsection of Section B presented in Figure 28 and Table 62 further defend this theory as participants' TTFF indicated they either viewed Text 3, Image, or Text 1 first. Text 1 of this section lays the foundational understanding of the remaining texts. The layout of the information sounding the Image may not clearly guide some viewers of where to begin reading the information. It is noted that Text 1 was differentiated from the other texts through bolding the font, but this may not be enough to draw viewers to this subsection initially. This pattern is also supported by the remaining AOI metrics as Text 3 was among the highest in time spent, revisits, and fixation counts.

Section C was simple in its layout as shown in Figure 29 and Table 63 as it consisted of a Text and an Image. The Text portion of this section was viewed faster, acquired more viewing time, more revisits, and a greater number of fixations. As previously discussed, these results are expected as less time is required in terms of processing simple visuals. While the image was noticed by participants, it appears that it was not overly distracting from the information provided in the Text.

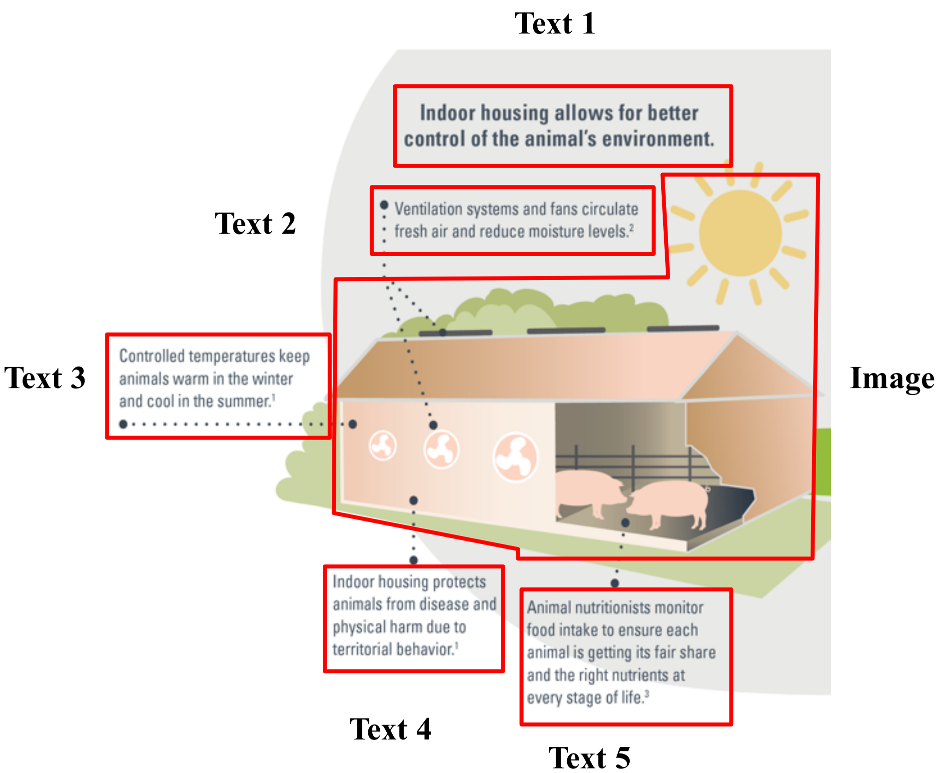


Figure 28. Areas of interest within Section B of the Welfare Infographic.

Table 62. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation counts[4] for the Welfare infographic within Section B.

	Section							
Measurement	Text 1	Text 2	Text 3	Text 4	Text 5	Image	SEM	*P*-value
TTFF (S)	17.9^{cd}	19.3^{bc}	15.0^{d}	21.8^{ab}	24.2^{a}	15.6^{d}	0.81	< 0.001
Time spent (S)	0.6^{b}	0.7^{ab}	1.0^{a}	0.8^{ab}	0.8^{ab}	0.7^{ab}	0.09	0.011
Revisits	1.4^{ab}	1.3^{ab}	2.0^{a}	1.5^{ab}	1.1^{b}	1.8^{a}	0.16	0.002
Fixation counts	3.0^{b}	3.6^{ab}	5.2^{a}	4.0^{ab}	3.6^{ab}	3.4^{b}	0.40	0.003

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

[a-d]Least squares means within the same row without common superscript letters differ (*P* <0.05).

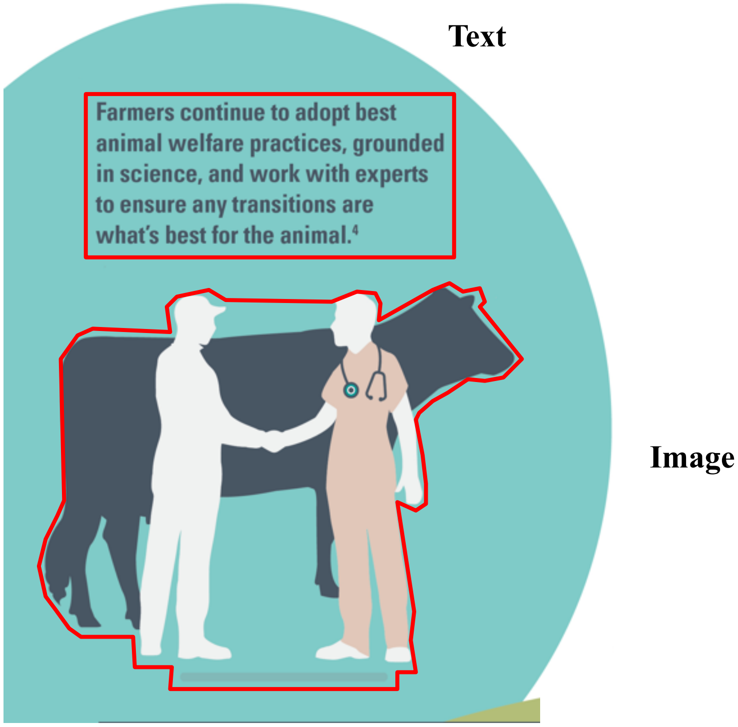


Figure 29. Areas of interest within Section C of the Welfare infographic.

Table 63. Least squares means for Time To First Fixation[1], Time Spent[2], Revisits[3], and Fixation counts[4] for the Welfare infographic within Section C.

	Section			
Measurement	Text	Image	SEM	*P*-value
TTFF (S)	17.0	22.8	0.90	< 0.001
Time spent (S)	1.5	0.2	0.10	< 0.001
Revisits	2.6	0.4	0.19	< 0.001
Fixation counts	7.3	0.9	0.48	< 0.001

[1]Time in S for the average time stamp of the first fixation inside of the area of interest.

[2]Time in S spent in the area of interest based on the total duration of all respondent's fixations.

[3]Number of returns to the area of interest.

[4]Number of fixations recorded inside the area of interest.

Heatmaps

Figures 30 through 35 represent static heatmaps of the infographic images presented to participants for predefined 30 second intervals. Heatmaps are created through a visual overlay of the aggregated fixation points over time and serve as a visualization of which elements of the stimulus drew the attention of individuals. Red areas suggest a high number of fixations, which relates to a higher level of interest from participants. Yellow and green define areas of less fixation points that suggest areas of less visual attention. Although less information is presented in heatmaps as compared to the previous discussion involving AOIs, heatmaps are beneficial in the sense that a large amount of information concerning participants' attention can be interpreted quickly and easily.

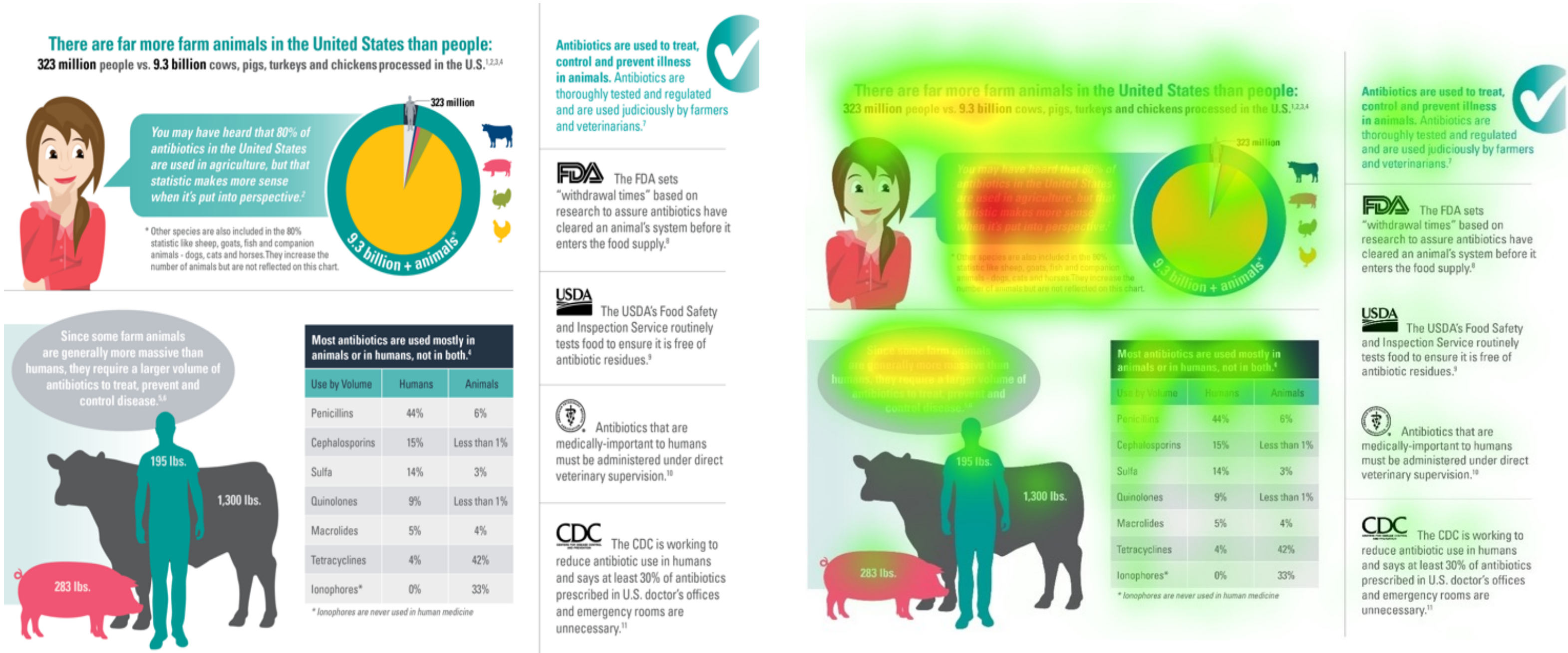


Figure 30. Heatmap of Antibiotic Infographic. Attention intensity represented by the colors red (high), yellow (intermediate), and green (low).

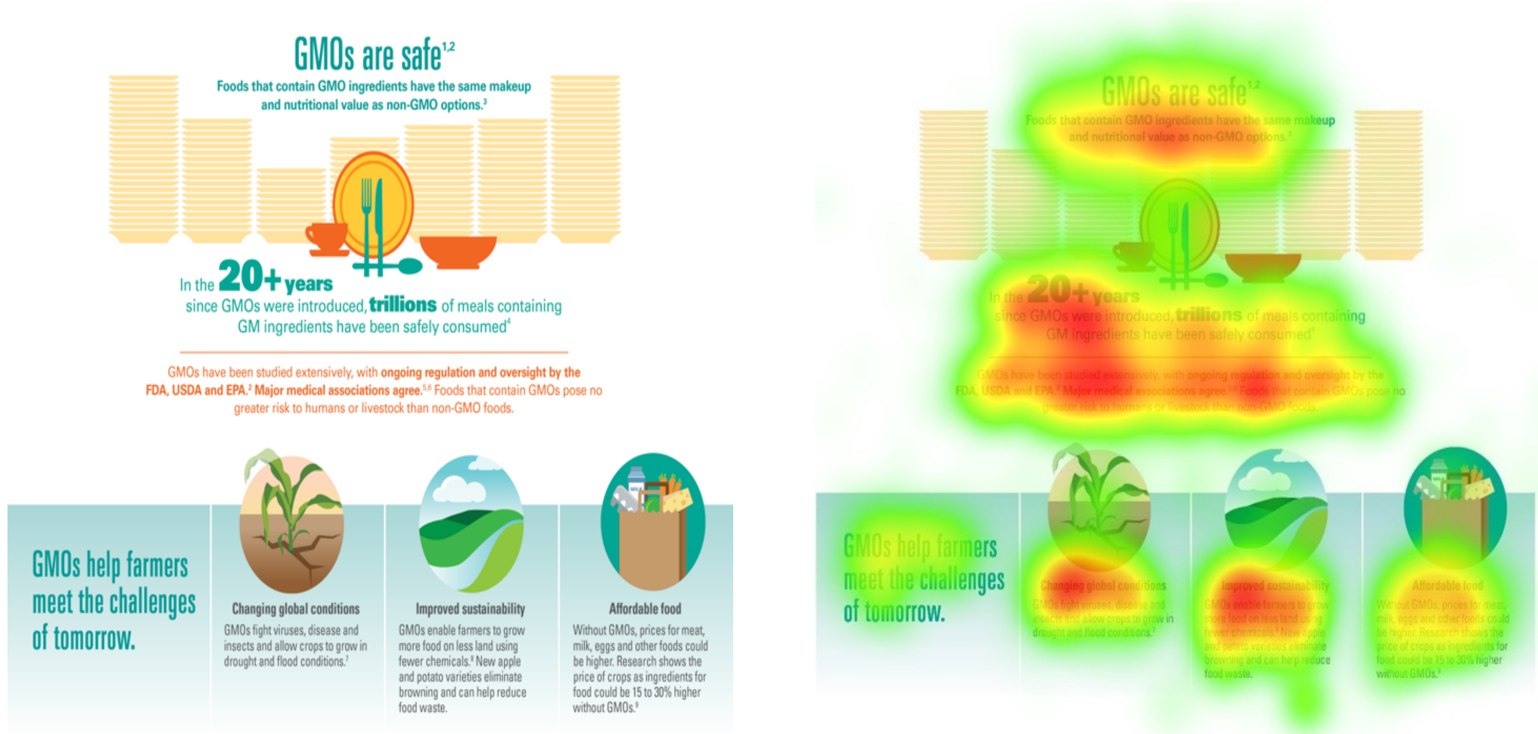


Figure 31. Heatmap of GMO infographic. Attention intensity represented by the colors red (high), yellow (intermediate), and green (low).

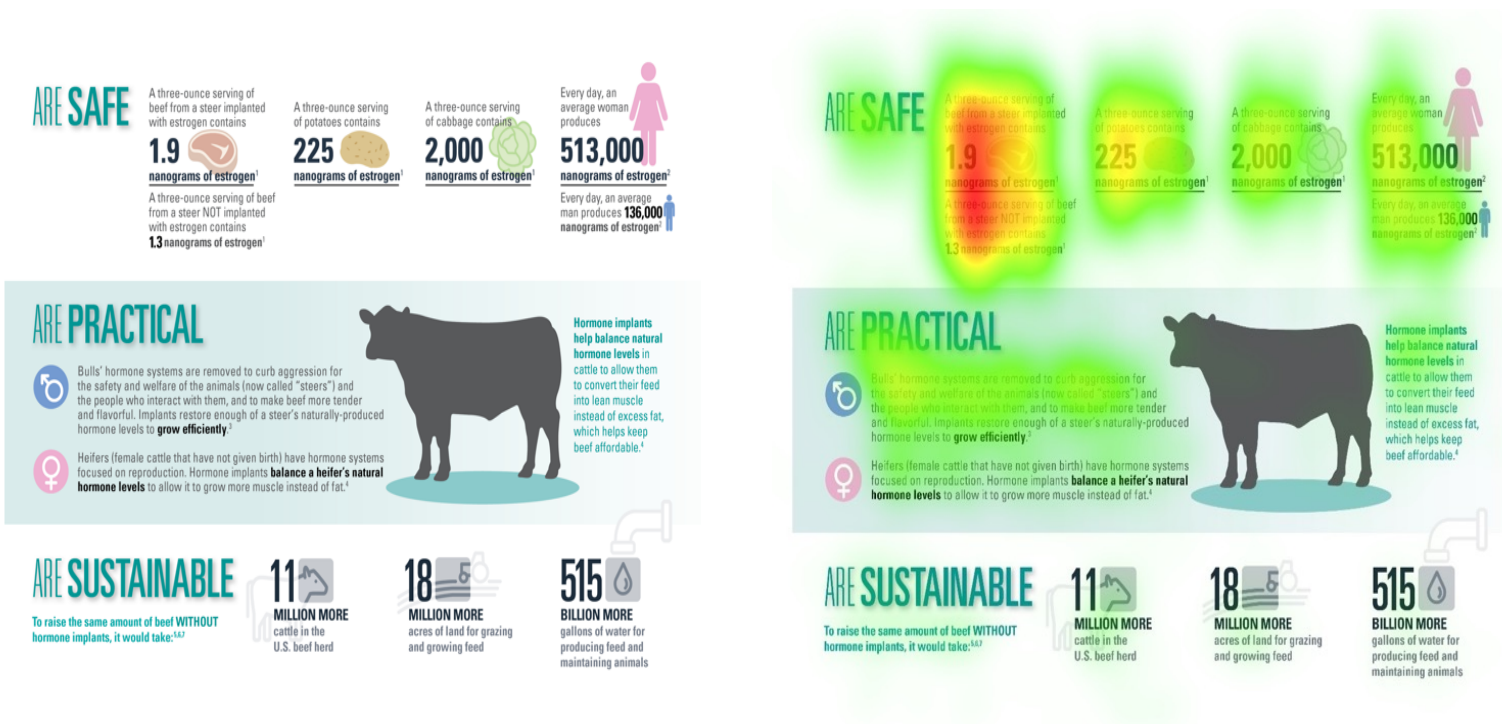


Figure 32. Heatmap of Hormone Infographic. Attention intensity represented by the colors red (high), yellow(intermediate), and green (low).

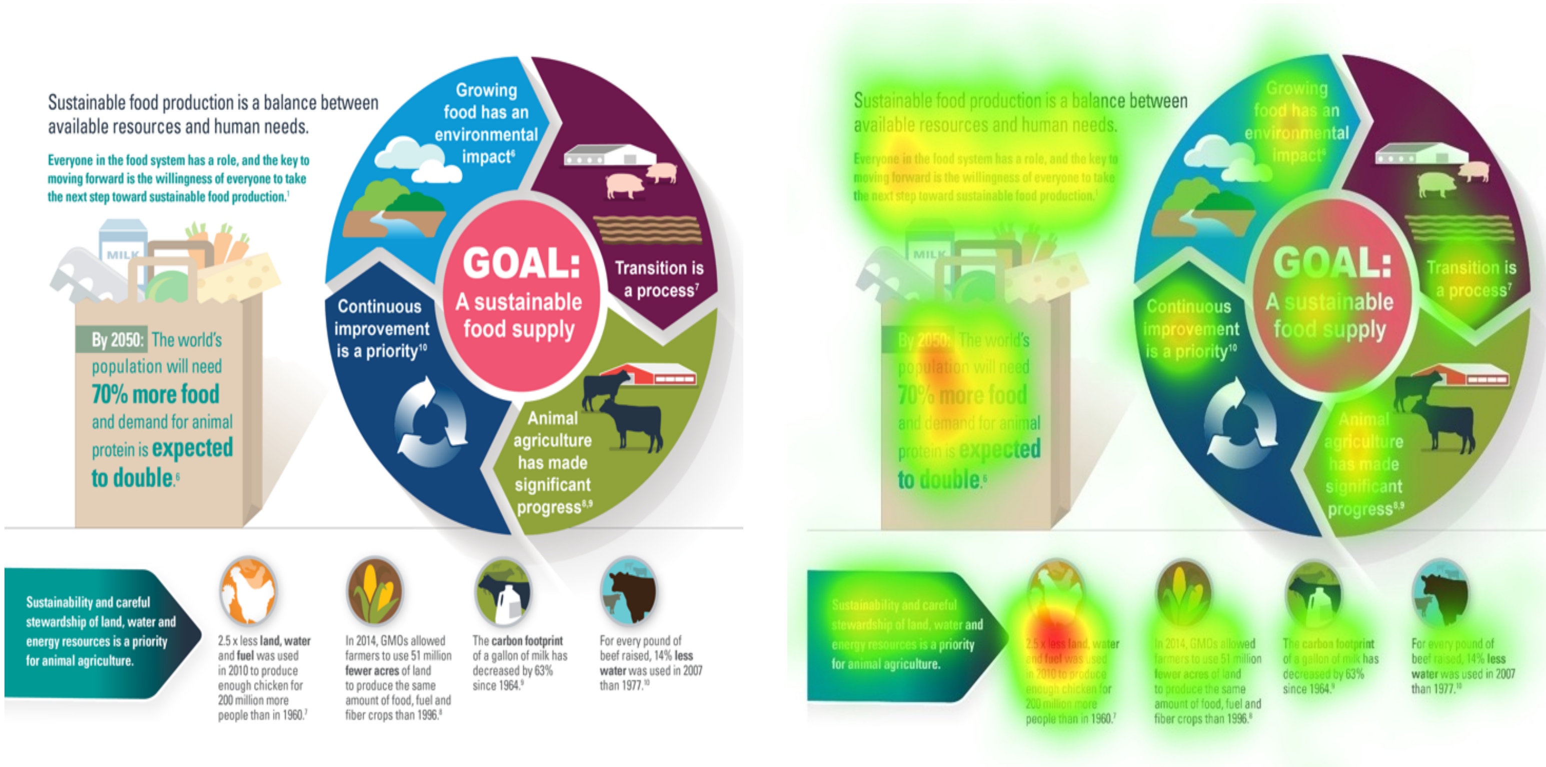


Figure 33. Heatmap of Sustainability Infographic. Attention intensity represented by the colors red (high), yellow (intermediate), and green (low).

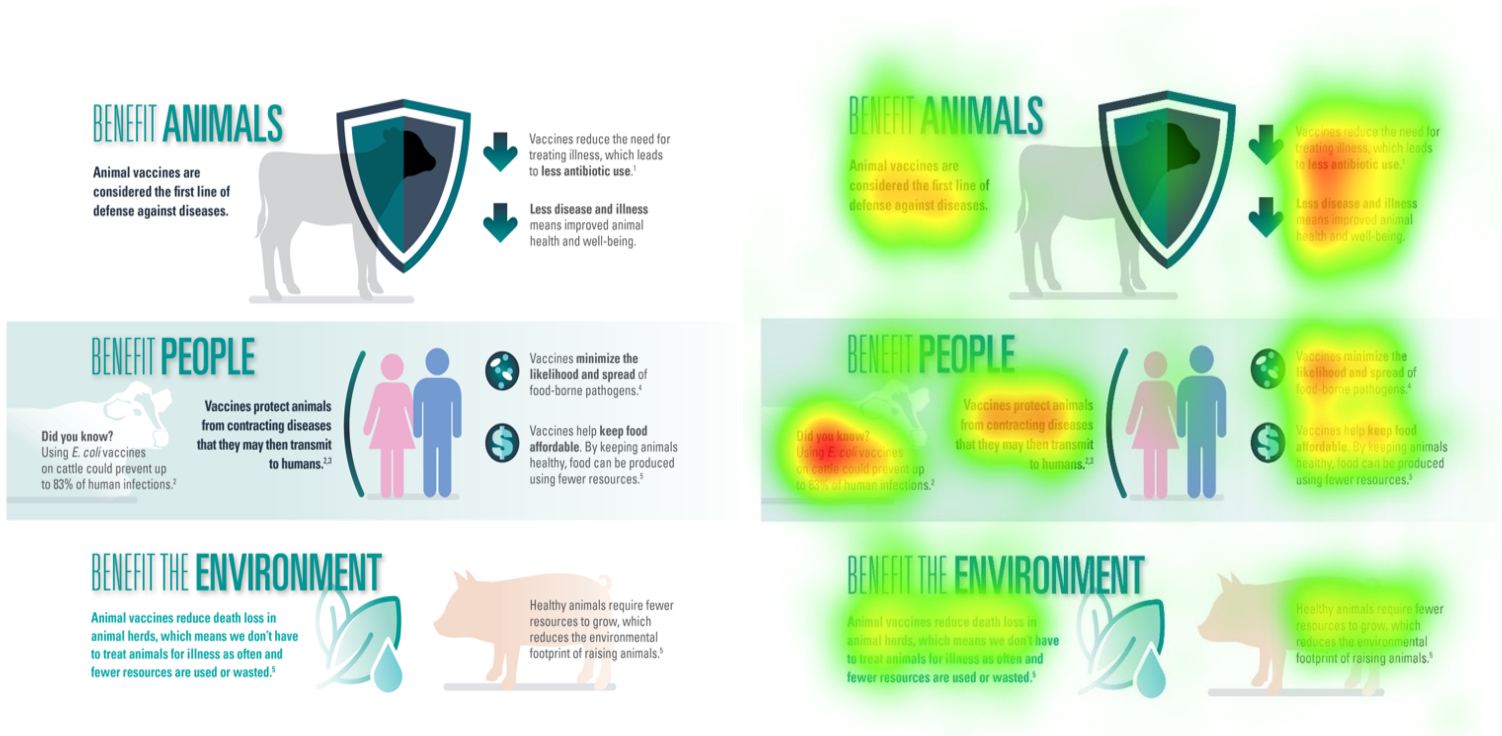


Figure 34. Heatmap of Vaccine Infographic. Attention intensity represented by the colors red (high), yellow (intermediate), and green (low).

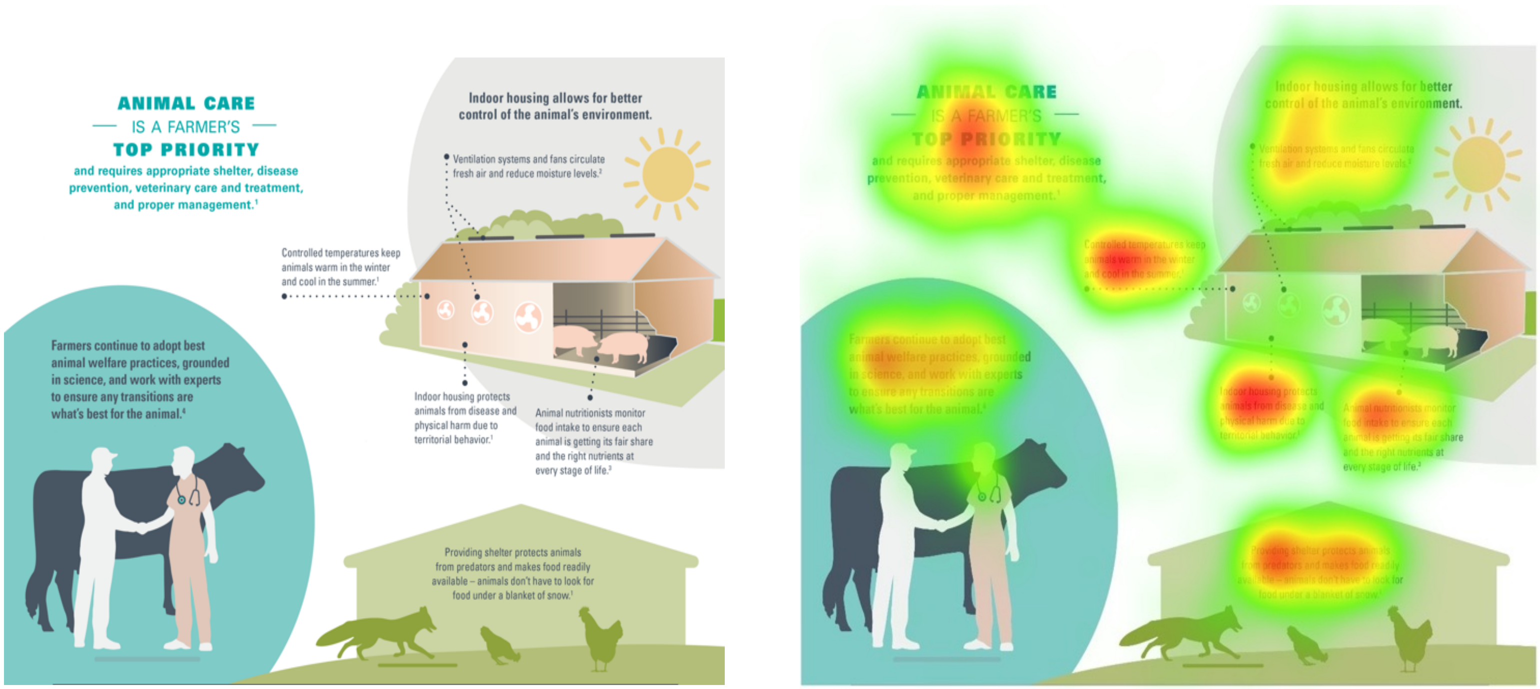


Figure 35. Heatmap of Welfare Infographic. Attention intensity represented by the colors red (high), yellow (intermediate), and green (low).

Consumer Pre- and Post-Survey Responses

Table 64 reported the pre and post-survey questionnaire responses from participants segmented by infographic topic. All questions showed a significant change ($P < 0.05$) in response with the exception of the statement of "I am concerned about the environmental impact of agriculture production" regarding the sustainability infographic ($P = 0.167$). When averaging the change in magnitude for each set of questions by topic, the hormone infographic reported an average shift of 0.9 between its three questions (data not presented in table). The statement representing the largest numerical change between the average pre- and post-response was "Using hormone implants in beef is a good idea." The pre-response average was 3.6, between slightly disagree and neutral. The post-response increased by 1.2 points to an average of 4.8, nearing the slightly agree anchor. Participants shifted from a near neutral response (4.2) to the statement "I believe all beef animals should be raised without hormone implants" to a slightly disagree (3.2) viewpoint. The animal welfare infographic also impacted consumer response, particularly for the statement "animals raised for food consumption are treated well." Participants' pre-survey response average for this statement averaged 4.2, representing a neutral standpoint. The post-response average increased to 5.1, representing a slightly agree position. The average change in the shift in responses were lowest for sustainability (where one question was not significantly different in its pre- and post-response average) and the vaccine infographic.

Table 64. Matched paired test of pre- and post-responses of consumer perception survey[1] segmented by topic.

Statement	Pre-response average	Post-response average	p-value	SEM	*n*
Genetically Modified Organisms					
Sufficient research has been conducted to ensure genetically modified organisms are safe.	4.9	5.4	<0.0001	0.10	164
I am against the production of genetically modified food.	2.8	2.6	0.0133	0.09	164
I believe genetically modified organisms are safe to consume.	5.1	5.4	0.0007	0.08	166
Antibiotic Usage					
Sufficient research has been conducted to ensure antibiotic usage in beef cattle is safe.	4.8	5.4	<0.0001	0.09	164
Antibiotic usage in animals is well regulated.	4.6	5.3	<0.0001	0.09	165
I trust that the meat I consume is antibiotic free.	4.2	4.4	0.0257	0.10	162
Vaccines					
Vaccines are necessary for the animal's health.	6.0	6.2	0.0072	0.08	163
Vaccines for animals help keep me safe.	5.7	6.1	0.0002	0.09	164
I believe vaccines are unnecessarily administered to farm animals.	2.6	2.3	0.0219	0.11	161

[1]Pre- and post-responses of consumer perception were evaluated where 1=strongly disagree and 7=strongly agree.

Table 64 Continued.

Statement	Pre-response average	Post-response average	p-value	SEM	*n*
Antibiotics					
Animals raised for food consumption are treated well.	4.2	5.1	<0.0001	0.10	162
Production animals are fed healthy diets.	4.5	5.2	<0.0001	0.09	164
An animal's well-being is a large concern for farmers.	5.5	5.8	0.0003	0.09	165
Hormones					
I believe all beef animals should be raised without hormone implants.	4.2	3.2	<0.0001	0.12	167
I am concerned with the amount of hormones in the beef I consume.	4.0	3.5	<0.0001	0.11	163
Using hormone implants in beef cattle is a good idea.	3.6	4.8	<0.0001	0.11	162
Sustainability					
I am concerned about our ability to feed the growing population.	5.2	5.5	0.0113	0.10	161
Agriculture practices are making progress towards a more sustainable production system.	5.4	5.9	<0.0001	0.09	164
I am concerned about the environmental impact of agriculture production.	4.7	4.8	0.1678	0.09	163

[1]Pre- and post-responses of consumer perception were evaluated where 1=strongly disagree and 7=strongly agree.

When comparing how each question related to the information presented in the infographic, interesting findings were noted. Section A of the GMO infographic focused on the safety of consuming GMO products. Section B supports the regulation of GMOs by several governmental agencies, while Section C pertained to how GMOs contribute positively to changing global conditions, sustainability, and food affordability. The information located within this infographic that was relative to the subjects of the corresponding pre- and post-survey statements support the positive shift in agreeableness. In other words, the informative needed to aid in changing consumer perspective, based on the statements, were viewed by consumers based on the eye tracking data. This association was also seen in the Hormone infographic. The statement "I am concerned with the amount of hormones in the beef I consume" corresponds with the information provided in Section A, where consumers spent most of their time viewing information. This was further supported by the heatmap image for this infographic as the overlay of the fixation counts show consumer attention was focused on the information pertaining to the level of hormones in a three-ounce serving of beef steak. Self-reported survey responses for the Sustainability infographic correspond to the eye tracking data. Two of the three statements related to the overall message of the Sustainability infographic, meaning shifts in agreeableness may be obtained by viewing any the A, B, or C Sections. The infographic was not able to shift the agreeableness of the statement "I am concerned about the environmental impact of agricultural production" (P = 0.167). The information that may have contributed to the shift in the response to the question may be derived from Section C, which received less attention compared to the other sections. The information that corresponds to the statements regarding the Vaccines infographic are found throughout each of the sections. Comparing the heatmap in Figure 43 to the subject of each statement, it was found that consumers viewed and interpreted the information regarding the self-reported survey response as the fixation count density was well distributed among the Sections A, B, and C. This same relationship was seen with the Welfare infographic as the heatmap in Figure 44 shows a well dispersed fixation count density regarding all of the textual information.

For the Antibiotic infographic, Section A focused on the numerical differences between the number of humans and farm animals that antibiotic usage statistics are based on. Section B emphasized how a larger volume of antibiotics are required for animals compared to humans due to the size difference of the species. Additionally, different types of antibiotics are used for humans compared to farm animals. Section C focused on the regulation of antibiotics through the Federal Department of Agriculture, United Stated Department of Agriculture's Food Safety Inspection Services, veterinarians, and the Center for Disease Control. The questions in the pre- and post-survey responses presented in Table 25 are formatted more towards the topics discussed in Section C, although the eye-tracking data support the theory that consumers did not spend as much time viewing Section C compared to Section A and B. Therefore, consumers had a positive shift in their agreeableness of this topic although they did not interpret the specific information relative to the subject of the self-report questions.

Overall, all infographics were able to achieve a shift in agreeableness that would be seen as beneficial of informing consumers of the positive nature of the agricultural industry, as supported by the significant changes in the difference in pre and post-response averages. These findings are supported by Klerck and Sweeney (2007) who concluded that when consumers are exposed to and absorb more scientific based information their subjective knowledge shifts to include not only their memory of information from the media, but also the factual, scientifically based information. The infographics that appeared to create the largest shift in viewpoint were the hormone and animal welfare topics while the sustainability and vaccine topics, although reported changes in opinion, were among the least impactful from this aspect.

Consumer Liking Ratings for Infographics by Topic

As reported in Table 65, the comparisons of participant responses of their overall liking ($P = 0.007$) and overall liking of the information ($P = 0.004$) differed by infographic topic while their liking of the graphics did not ($P = 0.118$). In regards to overall liking, the sustainability, vaccines, and welfare topics reported higher liking scores compared to the antibiotics and hormone topics. The GMO infographic liking rating was similar to all other infographic topics. The liking of information ratings differed from the overall liking scores. Participants rated the vaccines infographic higher than all other topics with the exception of the sustainability infographic, which was similar. The lowest rated infographic was the antibiotic subject (6.8), although the GMO, hormone, and welfare were statistically similar as they each reported an average value of 7.1.

Interpreting the liking rating findings with the pre- and post-survey response scores sheds interesting insight. The hormone topic elicited the largest shift in agreeableness, but was not among the highest rated in overall liking nor the liking of information. It was noted for the welfare topic reported a notable shift in agreeableness and was among the highest in overall liking and was mediocre in its liking of information ratings. The sustainability and vaccines topics reported lower changes in agreeableness, but were rated among the highest in overall liking and liking of information.

Table 65. Least squares means (± SEM) for overall liking, liking of information, and liking of graphics for infographics categorized by topic.

Infographic by topic	Overall liking	Liking of information	Liking of graphics
Antibiotics	6.8^{b} (0.12)	6.8^{c} (0.12)	6.8 (0.13)
GMO	7.0^{ab} (0.12)	7.1^{bc} (0.13)	6.9 (0.13)
Hormones	6.9^{b} (0.12)	7.1^{bc} (0.13)	6.8 (0.13)
Sustainability	7.2^{a} (0.11)	7.3^{ab} (0.12)	7.1 (0.13)
Vaccines	7.3^{a} (0.11)	7.6^{a} (0.10)	7.1 (0.11)
Welfare	7.2^{a} (0.11)	7.1^{bc} (0.12)	7.2 (0.12)
RMSE	1.50	1.57	1.62
P-value	0.0072	0.0004	0.1118

Consumer overall liking, liking of information, and liking of graphics were measured using a 9-point hedonic scale where 1=extremely dislike and 9=extremely like.
$^{a\text{-}c}$Mean values within a column followed by the same letter are not significantly different ($P \geq 0.05$).

Emotional Responses

Emotional response evaluations were separated in to two analyses of discrete emotion and dimensional models. The discrete emotion evaluation assesses the seven basic emotions (joy, anger, surprise, fear, contempt, sadness, and disgust) as mutually exclusive. Dimensional models use valence emotions (positive, negative, and neutral) to assess the quality of emotional responses.

The core emotions are estimated based on a determined threshold value that ranges from 0 (completely absent) to 100 (strongly present). Stimuli used for emotional analysis is commonly in the form of video, therefore a threshold of 50% is suitable because of how emotions are expressed during this form of media. This can be interpreted as values that occur at the value of 50 or above are recorded and all others are set to zero. The seven core emotional responses in this study were estimated at a 30%

threshold value. Due to the static form of the infographics, lowering the threshold to 30% was necessary. The quality of representation of the variables included in a PCA is defined by their square cosine or squared coordinates (cos2) value. A high cos2 value indicated that the variable is represented well on the principal components. Visually, the variable will be positioned nearer to the circumference of the plotted circle. Contrarily, variables with a low cos2 value will be positioned nearer to the origin and are not well represented on the principal components. Variables that are well represented are more important for interpretation.

The biplot of the seven core emotions and infographic topics is shown in Figure 36. The first loading explains 52.3% of the variation and places most of its weight on the sad, anger, and contempt emotions. The surprise emotion was represented by the first loading, as it was high and positive in its score although it has a lower cos2 value compared to the sad, anger, and contempt emotions. The second loading explains 27.5% of the variation and places near equal weight on the joy and disgust emotion. The placement of joy and disgust in nearly opposite directions indicates a lack of correlations between these emotions. Surprise and fear appear to be correlated due to their close placement. This is also seen for the grouping of sad, anger, and disgust, as well as contempt with joy. The hormone infographic had a large positive loading on the first component indicating its association with the surprise emotion. The GMO infographic reported high, negative first loading values and therefore was associated with the sad, anger, and contempt emotions. Hormone and GMO scored high, positive second loading values, indicating an association with the disgust emotion. The welfare infographic's low loading value on the first component and high, negative loading on the second indicate its association with joy. The sustainability and antibiotic infographics were not strongly loaded on either component. The vaccines infographic is placed near zero for both components, indicating it elicited and average response of the sad, anger, contempt, joy, and disgust.

Figure 37 shows the biplot of the principal component scores and the factor loadings of the valence emotions and the infographics by topic. The first loading reported a high, positive loading for the negative emotion and high, negative loading for a neutral response. The second loading was high and positive for positive emotions. The first and second components accounted for 97.4% of the variation. The vaccine, antibiotics, and sustainability reported a score of or near zero for the second loading, indicating these infographics reported an average response for the positive emotion**.** GMO reported a high, positive score for the first loading, showing its relation to the negative emotion. The topic of vaccines was near the origin and therefore had an average response of positive, neutral, and negative emotions. Sustainability was related to the neutral emotional response as it score high and negative on the second loading. Welfare reported a high, positive score for the second loading. This indicates consumer emotion response was positive for the animal welfare infographic. The hormone infographic scored a high, negative value and therefore was not associated with the positive emotional response of consumers.

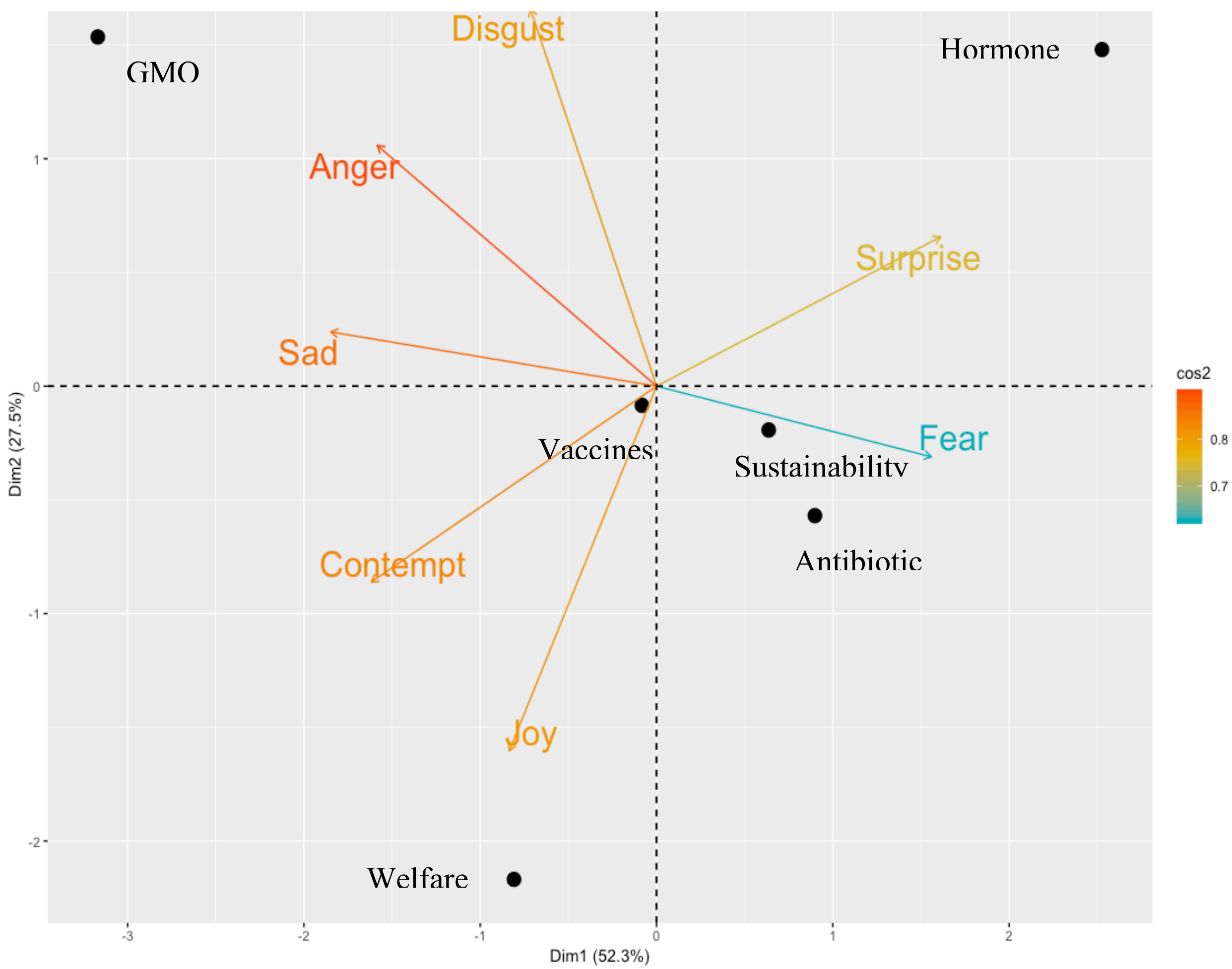


Figure 36. Biplot of consumer response for the seven core emotions and infographics by topic.

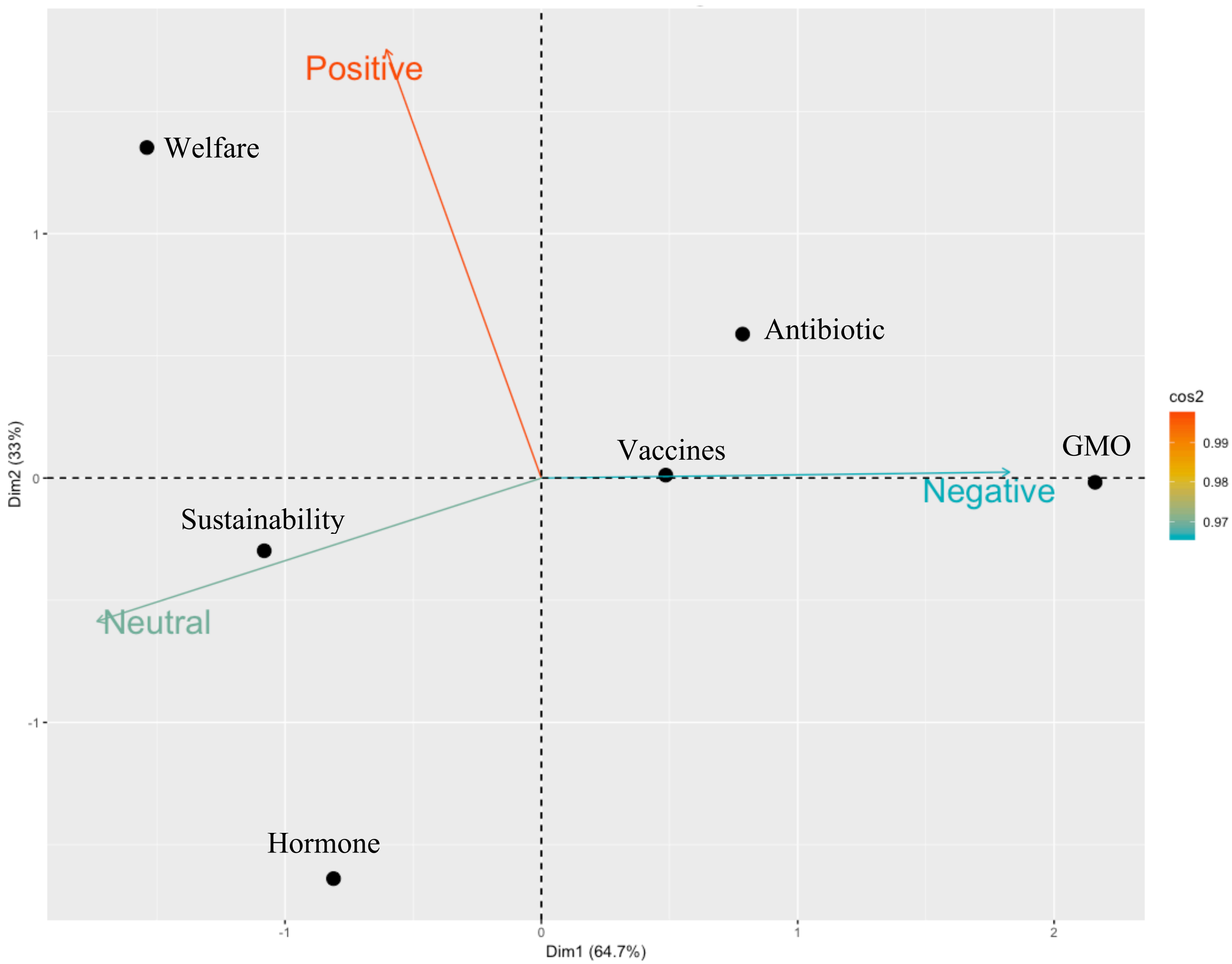


Figure 37. Biplot of consumer response for the valence emotions and infographics by topic.

Overall assessment of consumer overall liking, emotional response, valence response, changes in pre and post perception questions, and attention measurements caused the infographics to group themselves in terms of their degree of impact on consumer perception. A summary of these groupings is described:

The GMO and antibiotic infographics were among the lowest in terms of overall liking.

- The GMO infographic was associated with sad, anger, contempt, and disgust emotions, as well as a negative valence response.
- The topic of GMOs is isolated to the topic of food production. The combination of the emotional and overall liking responses may be indicative of the stigma associated with this topic.
- The antibiotic infographic did not report a strong relation to emotions or valence reactions. A modest association was seen with the fear emotion and negative response. This may be due to the crossover of antibiotic discussion in human medicine and a high level of subjective knowledge of participants, which may require a different approach to combat.

The hormone and welfare infographics showed the largest shift in consumer perception. Although some common features were notable, there are differences between the two information sources.

- The hormone infographic positioned relatable, factual statements across the top of the first section viewed. People were able to connect with the information because they compared hormone levels of items we are frequently exposed to (steaks, potatoes, and cabbage). According to the eye tracking measurements, consumers were not able to read a large portion of the information presented to them. This may explain their low response in terms of overall liking. Emotional measures associate surprise and disgust responses.

- The welfare infographic reported among the highest values for overall liking, contrary to the hormone infographic. The eye tracking data revealed consumers were able to view a majority of the information presented in the infographic. This is also interpretable through the heatmap. The joy emotion was associated with the welfare topic as well as the positive valence measure.

The vaccines and sustainability infographics were both rated among the highest in terms of overall liking from consumers. Interestingly, they represented the topics that reported the lowest shift in consumer perception.

- The sustainability infographic was associated with a neutral valence response.
- The vaccine infographic reported average responses for sad, anger, contempt, joy, and disgust emotional responses as well as average valence responses for positive, neutral, and negative.
- Possible explanations for these responses towards the vaccine and sustainability topics may be due to the demographics of the consumers. Although participants were randomly selected from the Bryan/College Station community, they are representative of a population that may differ in agricultural views of other regions.
- Additionally, these topics are broad in their relativity to many fields. For examples, vaccines are also widely discussed in human medicine and

sustainability is applicable for a large portion of industries aside from agriculture. Therefore, an average emotional and valence response towards these topics may indicate individuals' previous exposure to information regarding these topics.

Is it possible that the participants may have greater objective knowledge of the topics of sustainability and vaccines, which caused their high levels of overall liking for these infographics as it confirmed their current opinions of the topic? These topics are broad in their relativity to many fields, therefore may have been exposed to participants more compared to other topics covered in this study, thus increasing participants' objective knowledge of these topics. If participants had greater objective knowledge of these topics, this may justify why they reported lower magnitudes of change concerning pre and post-perception responses. Additionally, this would explain their neutral valence responses and average emotional expressions towards these topics.

The welfare infographic reported high overall liking and a large shift in agreeableness. The question arises of whether consumers' shift from a neutral standpoint towards the statement "animals raised for food consumption are treated well" to a slightly agree standpoint was heightened by their emotional and valence responses of joy and positive, respectively. The measured positive response may be due to the participants viewing the infographic statements as a credible source of information. Although it cannot be confirmed through these data, further research should be conducted to consider if the perspective of the information displayed in the infographic influenced consumer perception. For example, the subtitle emphasizes animal care is linked to the farmer's priorities, not a government agency or a company. Supplementary texts supported this idea by reiterating the compassion of the farmer translated to a high regard for animal welfare practices. This perspective is contrary to the messages in the GMO and Antibiotic infographics which use governmental agencies as their credibility source.

The hormone infographic reported similar shifts in agreeableness responses as the welfare infographic. Interestingly, unlike the welfare topic, the hormone infographic did not stand out in its participants' responses to their overall liking of the message. It must be considered that a participant's overall liking response encompasses their viewpoint on a conscious and subconscious level. Meaning, layout design, wording, format, and the topic of the infographic are just a few of the factors that play a role in the participants' formation of their opinion. To further emphasize, if this study limited its interpretation of the effect of the infographics solely on consumer liking ratings, then the hormone infographic would not fare well in comparisons to the others. By combining AOI measures, pre and post-perception questionnaires, and emotional and valence responses, we gain further insight into the understanding of the participants. This shifts the researchers' interpretation of the hormone infographic. Although its overall liking was reported as among the lowest, the shift in agreeableness response was the greatest. The estimated emotions evoked from participants were surprise and disgust. We are not able to discriminate at what point these emotions were expressed in participants' comprehension of the infographic, therefore limiting what portion of the stimuli induced the disgust response (for example, a statement that accounted for a portion of time spent and fixation count described the level of estrogen in potatoes and cabbage; therefore, participants may have expressed disgust for these statements). Nevertheless, this leads to the conclusion that emotional response was among the factors that influenced consumer overall liking, agreeableness, and scan paths.

Conclusions

Based on self-reported pre- and post-survey responses, shifts towards positive improvements in agreeableness regarding the general agricultural based questions support the conclusion that the infographics informed and educated consumers. In general, it was concluded that the amount of scientific information presented in each infographic should be reduced. By reducing and simplifying the information, even larger shifts in agreeableness may be achieved. Consumers were allotted 30 s to evaluate each infographic, but this length of time may not have translated into a “real world” situation where consumers would come across this information. Given the laboratory setting and compensation value, consumer reading intensities may have been greater than what would be experienced in other environment settings without compensation. Further research is needed to understand consumer interest in this type of information.

There may be benefit in formatting infographics containing scientific information to elicit emotional responses from consumers. Further research is needed to understand the effects of each of the seven core emotions on influencing consumer perception as each infographic was able to positively shift consumer agreeableness towards their topic, regardless of the emotion they were most associated with. There was support that infographics formatted in a positive manner that provoked a joyful emotional reaction created a balance of achieving high consumer overall liking and agreeableness scores.

CHAPTER V

USING EYE TRACKING TO AID IN UNDERSTANDING CONSUMER PERCEPTION OF BEEF STEAK IMAGES DIFFERING IN LEVELS OF MARBLING AND COLOR

Introduction

Sensory evaluation was designed to use a scientific method to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing (Stone et al., 2012). Quantitative affective tests were used in consumer sensory evaluation to determine preference or liking of a product's sensory characteristics. Consumer responses were surveyed and quantified through intensity, hedonic, or "just right" scales (Meilgaard et al., 2016). These self-reported consumer surveys were commonly used to measure product success as they focus on the result of consumer actions. A better approach to measuring a product's success may be to understand how the consumer is driven to make their purchases.

The decision-making process is complex. Consumers must make numerous decisions, regardless of the commodity, when selecting goods to purchase in the modern supermarket setting. Consumers are influenced by external and internal forces including market actions (e.g., product promotion, availability), competitive factors (e.g., new product introductions), and environmental factors (e.g., weather, season) (Duchowski, 2017). An issue facing the beef industry in terms of meeting consumer satisfaction for beef quality was the concept that consumers misconstrue intrinsic and extrinsic cues that lead to unsuitable quality expectations (Grunert et al., 2004). Our current understanding of consumer perception of meat products was derived from self-reported survey methods (Henchion et al., 2017).

Additionally, consumers were influenced by the position and placement of products. The starting point of where consumers begin viewing products on a computer screen became a baseline for the comparisons of the remaining alternatives as remaining options were judged relative to the first viewed product. This suggested a 'premium' could be placed on certain product position due to increased attention and visibility of the respondents (Palma et al., 2016). Furthermore, when a product was viewed greater time periods or repeatedly viewed, the likelihood of the product being purchased increased (Armel et al., 2008; Milosavljevic et al., 2012; Pärnamets et al., 2015; Gidlöf et al., 2017). Product developers and retailers have built an industry around the motive of capturing consumers' visual attention as research has shown that consumers tend to look at the center shelves more often (Atalay et al., 2012). Large manufacturers were willing to pay premiums to ensure their products were placed at what was considered prime shelf space as they related the position of their product to the consumers' willingness to purchase (Forster, 2002). Retailers use consumer behavior concepts to make decisions regarding store layout and shelf facings in order to increase sales as consumers have been shown to believe retailers organized shelf space in a specific manner as they associated the center shelf with popular, high turn-over items and the top shelf with expensive items (Wright, 2002).

It was hypothesized that meat industry may gain a better understanding of how to ensure and maintain consumer satisfaction of meat products by incorporating the use of human biometric data. Applying this concept to the beef industry, it was proposed that through measuring how a consumer disperses their visual attention towards images of combinations of beef steak images, varying in either color or marbling attributes, and located in different positions on the computer screen, insight may be gained in understanding how consumers perceive quality differences. The objective of this study was to apply eye-tracking methodology in combination with traditional self-reported measures to further understand consumer perception of beef color and marbling through their visual attention and choices.

Materials and Methods

Subject Recruitment

Consumers (n = 158) were randomly selected from the Bryan/College Station area using a consumer email data bank. Stipulations placed on consumer selection included a minimum age of 18 years and must be beef consumers. Consumers signed up for a 60-minute time-frame based on their availability. Consumer demographic information of sex, age, income, beef consumption, and food choices were completed by each consumer. This study was approved by the Institutional Review Board and the data were collected during Fall 2018.

Experimental Procedures

The official USDA Small^{50} grading card image from USDA, 2019a was edited by an experienced photographer (Adela Fernandez Photography, Adobe Photoshop CC, San Jose CA) to create different degrees of color (pale, ideal, and dark) and marbling (Slight, Small, and Modest) (Figure 38). Since these images were a modification from USDA, 2019a, they were a representation of the nationally uniform standards of quality reflective of the beef grading system facilitated by the USDA (USDA, 2019a). By editing this one image to create those three different levels of color and marbling, we were able to control the inherent variation that would occur through selecting multiple steaks to obtain these images (i.e. fat thickness, marbling texture, Slight color variations, loin eye area). Six trials were created by arranging the images in sets of three where either marbling or color was held constant among the images while the other color or marbling characteristic differed (Figure 39).

Testing was conducted by consumers individually at the Texas A&M University Human Behavior Laboratory. Upon arriving to the laboratory, consumers signed a consent form and received a unique participant code that could not be traced to their identity. Biometric data were collected with an eye tracking device. Consumers viewed the 6 trials in random order. In each trial, consumers were shown a randomly placed fixation point for 3 s, after which she/he was presented with a stimulus (set of three beef steak images) for 10 s, followed by a questionnaire pertaining to their liking of attributes of the steak images (no time restriction). Consumers were asked their overall, color, and marbling liking of each image on a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely.

Figure 38. Official USDA Small^{50} grading card from USDA, 2019a.

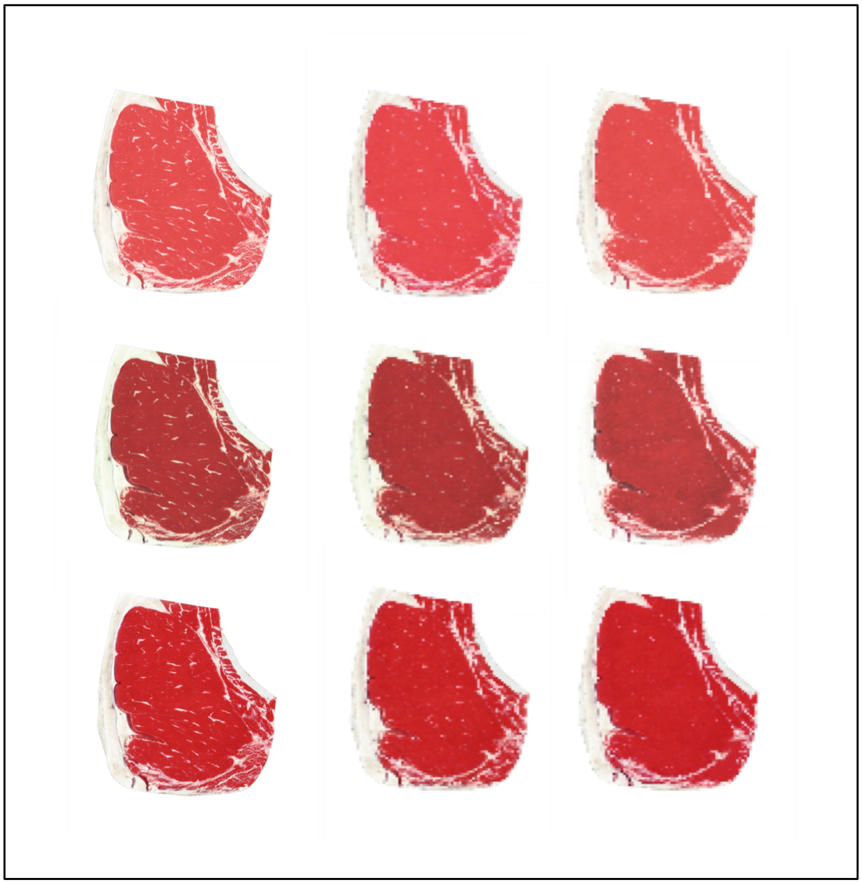


Figure 39. Edited variations of the official USDA Small[50] grading card modified from (USDA, 2019a). From top to bottom and left to right, the images represented degree of marbling x color beef steak images of Modest x Pale, Small x Pale, Slight X Pale, Modest x Dark, Small x Dark, Slight x Dark, Modest x Ideal, Small x Ideal, and Slight x Ideal.

Eye Tracking

Eye movements were tracked using a TX300 eye-tracking device. This device was located at the base of the computer screen and used near-infrared technology to track the eye movements of the consumers by identifying the reflections in the cornea (Ramsøy, 2015) Images were presented on a 1920 x 1080 pixels computer screen. iMotions software was used to collect all eye tracking data at a rate of 120 Hz. Eye tracking metrics collected included fixation counts (FC), time to first fixation (TTFF), the time spent in the area of interest (TS), and revisits. These metrics allowed for the quantification of consumers' visual attention in order to better understand their choices through capturing deeper insight of their cognitive processes.

Statistical Analysis

Statistical analyses were conducted through RStudio (V 1.1.463, RStudio, Inc., Boston, MA). Forms of analysis used were least squares means compared with Wilcox tests for paired comparisons and through the lsmeans package for ANOVA. Repeated measures correlation (rmcorr package) was used to account for common within-individual association for consumers and to avoid violating the assumption of independence of observations.

Results and Discussion

The consumer demographic data were the same as previously reported in chapter IV of this dissertation. Least squares means of consumer evaluations for overall, marbling, and color liking of steak images by trial were reported in Table 66.

In trials where color was held constant and degree of marbling differed, consumer overall liking and marbling liking was higher for Modest and Small marbling levels compared to Slight marbling levels ($P < 0.001$), regardless of color. Our findings of consumer preference for higher degree of marbling steaks contradict previous research. It has been well documented that consumer preferences for intramuscular fat levels have changed over time. At one point, consumers preferred higher marbling levels over lower marbling levels (Dunsing, 1959). Consumers then shifted to preferring lower marbling levels (Forbes et al., 1974). The National Consumer Retail Beef Study concluded consumers were segmented into two classes (Savell et al., 1989). Higher marbled steaks were either evaluated positively for their high flavor ratings or were critiqued for their level of fat while lower marbled steaks were either rated high in liking for their leanness, or criticized for their flavor or texture. Most recently, Killinger et al. (2004) reported consumers visually preferred low marbled steaks. Our results may indicate a shift towards consumer preference for higher levels of marbling for beef steaks.

Table 66. Least squares means of consumer overall liking, overall marbling liking, and overall color liking of beef steak images by trial where either marbling or color was held constant among the image while the other color or marbling characteristic differed.

Trial	Overall liking[1]	Overall marbling liking[1]	Overall color liking[1]
Color held constant			
Dark			
Modest	6.4[a]	6.5[a]	6.1[ab]
Small	6.3[a]	6.3[a]	6.4[a]
Slight	5.3[b]	4.8[b]	5.8[b]
SEM	0.17	0.17	0.15
P-value	< 0.001	< 0.001	0.039
Ideal			
Modest	6.8[a]	6.7[a]	6.9
Small	6.7[a]	6.4[a]	7.0
Slight	5.4[b]	4.9[b]	6.6
SEM	0.16	0.18	0.14
P-value	< 0.001	< 0.001	0.116
Pale			
Modest	6.4[a]	6.6[a]	5.8[b]
Small	6.4[a]	6.3[a]	6.5[a]
Slight	5.1[b]	5.0[b]	5.8[b]
SEM	0.16	0.17	0.14
P-value	< 0.001	< 0.001	< 0.001
Marbling held constant			
Modest			
Dark	5.8[b]	6.5	5.5[b]
Ideal	7.2[a]	6.6	7.4[a]
Pale	5.1[c]	6.3	4.9[c]
SEM	0.15	0.12	0.16
P-value	< 0.001	0.155	< 0.001
Small			
Dark	5.4[b]	5.9[b]	5.0[b]
Ideal	7.2[a]	6.4[a]	7.4[a]
Pale	5.3[b]	5.7[b]	5.1[b]
SEM	0.15	0.13	0.17
P-value	< 0.001	0.001	< 0.001
Slight			
Dark	5.0[b]	5.2	5.0[b]
Ideal	6.4[a]	5.4	6.8[a]
Pale	5.1[b]	5.1	4.9[b]
SEM	0.17	0.17	0.18
P-value	< 0.001	0.517	< 0.001

SEM = standard error mean.

[1]Consumer overall liking, overall marbling liking, and overall color liking were rated on a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely.

[a-c]Least squares means within the same row without common superscript letters differ (P <0.05).

Overall color liking scores were different for the trials where steak images were consistent in dark ($P = 0.039$) and pale color ($P < 0.001$). This indicated the degree of marbling may have influenced consumer color liking ratings due to color serving as the only detail that differed among the steak images. For the dark color held constant trial, consumers preferred the color of the Modest to the Slight steak image. The intermediate marbling level of Small was similar to both, the Modest and Slight steak images.

In trials where degree of marbling was held constant and color differed, consumer overall liking and color liking were highest for the ideal colored steak image compared to the dark and pale colored steak images when the degrees of marbling were Small and Slight ($P < 0.001$). Consumers did not differentiate which of the dark or pale colored steak images they preferred, as they were statistically similar. For steak images consistent in the Modest marbling degree, consumers reported preferences for each color in terms of overall liking and color liking ($P < 0.001$). Consumers preferred ideal over dark colored steak images while dark was preferred over pale colored steak images. Therefore, when marbling degree was high, consumers used color as a criterion to weigh the extent they liked the steak image compared to when marbling level was lower, color did not impact their liking to the same magnitude. These findings oppose those found by Killinger et al. (2004) where surveyed participants who preferred low-marbled steaks mentioned color as a selection criterion more than those who preferred high marbled steaks. Interestingly, within the consistent degree of marbling level of Small, consumers reported an overall marbling liking preference ($P < 0.001$) for ideal colored steak images over dark and paled colored.

The design of the study allowed for each steak image to be exposed to each participant twice, but in different comparison scenarios. For example, the image representing a Slight, pale colored steak image was grouped with the Slight, ideal colored steak image and the Slight, dark colored, steak image. Conversely, the Slight, pale colored steak image was also grouped with the Small, pale colored and Modest, pale colored steak images. This allowed us to measure whether consumer overall liking was similar or different for each steak image with respect to the scenario in which the image was viewed. Figure 40 compared the overall liking for each steak image across their two scenarios. For the steak images representing ideal color, regardless of the level of marbling, consumer overall liking was significantly greater for each of these images when they were among steaks of pale and dark color that were consistent in marbling. This may be due to the consumers easily being able to distinguish the color differences. Steak images of either pale or dark color and either Small or Modest marbling were rated higher in consumer overall liking when presented with steak images of similar color. The steak images that were Slight and either pale or dark color were statistically similar in consumer overall liking between their two presented scenarios. In other words, when the steak images were lowest in marbling and contained a color defect, it did not matter how the steak images were presented, as their overall liking was the same. Overall, consumer overall liking of a steak image was contingent on the details of the surrounding steak images. Consumers did not have a consistent level of preference for a steak of a specific color and degree of marbling. Their level of preference may have varied depending on the layout and merchandising of the beef steaks in a retail setting. If a retailer segregates beef steaks based on quality grade, steaks of ideal color will increase in overall liking from consumers and benefit from being placed by steaks of a color defect. Consequently, steaks with a color defect would have suffered in consumer perception in this situation as they would have benefited greater if they were grouped and placed by color rather than degree of marbling, especially if they were of higher degrees of marbling.

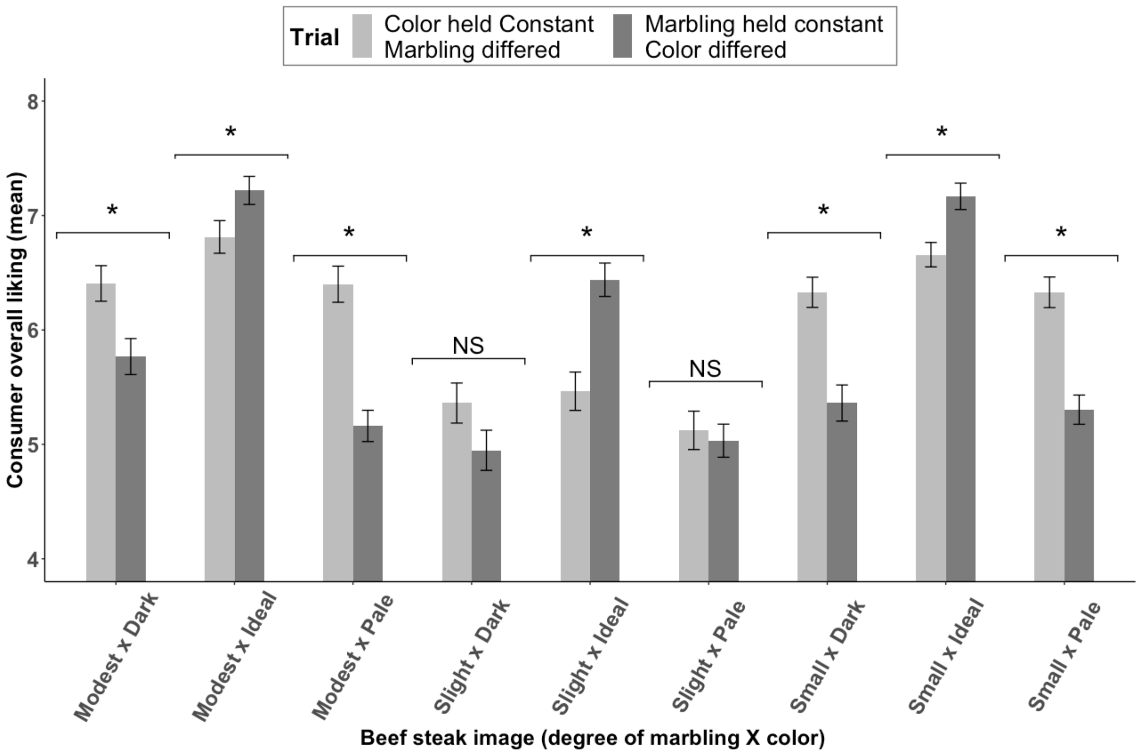


Figure 40. Comparison of steak image degree of marbling x color consumer overall liking scores where 1 = dislike extremely and 9 = like extremely. Means were compared among each steak image where the image was presented with other steaks of either similar color and similar degrees of marbling. * = *P* < 0.05; NS = not significant.

Correlation coefficients were reported by steak image trial in Table 67. For trials where dark and ideal color was held constant within steak images, consumer overall liking and FC, TS, and revisits eye tracking metrics reported positive, weak associations ($P < 0.01$). For pale colored steak images, FC (r = 0.34), TS (r = 0.36), and revisits (r = 0.30) were associated with consumer overall liking, also. In general, as consumers fixated on a steak image more, spent more time fixating on a steak image, and revisited the steak image more, their overall liking increased. For all color variations, TTTF was not associated with consumer overall liking ratings (pale, $P = 0.150$; dark, $P = 0.400$; Ideal, $P = 0.130$). This indicted that when marbling varied among steak images of similar color, the amount of time a consumer took to view a specific image did not affect what overall liking score they assigned.

For trials where marbling was constant and color was the characteristic that varied, all eye tracking metrics reported significant associations for consumer overall liking ($P < 0.05$). Specifically, Slight and Modest degree of marbling trials reported weak, positive relationships while the Small degree of marbling images reported moderate, positive relationships for FC, TS, and revisits eye tracking variables. Similar to the trials where color was held constant, as consumers fixated on a steak image more, spent more time fixating on a steak image, and revisited the steak image more, their overall liking increased. Where these sets of trials differed was with the TTFF variable. For all trials where marbling was held constant, a weak, negative relationship was reported for consumer overall liking and TTFF (Slight, $P = 0.010$; Small, $P = < 0.001$); Modest, $P = 0.010$). Therefore, when color varies among steak images of similar marbling degrees, consumer overall liking was greater when the steak image was looked at sooner. As more time passed for an image to be viewed, consumer overall liking decreased. This most likely indicated that color was a factor that consumers where able to identify quickly, and aided them in identifying the steak images they preferred.

Table 67. Correlation coefficients (95% confidence interval) for consumer overall liking and eye tracking metrics by steak image trial.

Consumer overall liking by trial	FC	TTFF	TS	Revisits
Color held constant				
Pale	0.34 (0.24, 0.44)	-0.08 (-0.19, 0.03)	0.36 (0.26, 0.45)	0.30 (0.19, 0.40)
P-value	< 0.001	0.150	< 0.001	< 0.001
Dark	0.26 (0.16, 0.36)	-0.04 (-0.16, 0.06)	0.26 (0.15, 0.36)	0.25 (0.15, 0.35)
P-value	< 0.001	0.400	< 0.001	< 0.001
Ideal	0.26 (0.16, 0.37)	-0.09 (-0.20, 0.03)	0.23 (0.12, 0.34)	0.21 (0.10, 0.32)
P-value	< 0.001	0.130	< 0.001	0.001
Marbling held constant				
Slight	0.32 (0.21, 0.41)	-0.15 (-0.25, -0.03)	0.28 (0.17, 0.38)	0.30 (0.20, 0.40)
P-value	< 0.001	0.010	< 0.001	< 0.001
Small	0.40 (0.30, 0.49)	-0.20 (-0.31, -0.10)	0.37 (0.27, 0.46)	0.47 (0.38, 0.55)
P-value	< 0.001	< 0.001	< 0.001	< 0.001
Modest	0.21 (0.10, 0.32)	-0.15 (-0.25, -0.03)	0.22 (0.11, 0.32)	0.28 (0.17, 0.38)
P-value	< 0.001	0.010	< 0.001	< 0.001

FC = fixation count; TTFF = time to first fixation; TS = time spent in area of interest; revisits = the number of returns to an area of interest.

Consumer overall liking rated on a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely.

Table 68 reports three multiple variable regressions developed to predict consumer overall liking of beef steak images. The equations progressed by adding additional explanatory variables in order to interpret the robustness of the variables. The first equation considered the position (left, middle, or right), the color (pale, ideal, or dark), and the degree of marbling (Slight, Modest, or Small) of the steak image. The interpretation of the coefficients lead to the conclusion of the importance of each of these variables. The constant to which each coefficient was compared to was the Slight x pale steak image in the right position. The constant was estimated to receive an overall liking rating of 4.927. Compared to a steak image in the right position of the screen, a consumers' overall liking was not significantly impacted by moving the image to the left position ($P > 0.05$). However, changing the image from the right position to the middle position significantly increased overall liking ($P < 0.01$) by nearly one point. Furthermore, changing the constant to a Slight x ideal colored steak in the right position increased overall liking by 0.655 points ($P < 0.01$). Changing the color from pale to dark only approached a level of significance ($P < 0.10$). When interpreting the effect of changing the degree of marbling from Slight to Small, a significant increase ($P < 0.01$) of 0.383 points was estimated. A change from Slight to Modest significantly increased ($P < 0.01$) consumer overall liking by 0.916 points. Overall, the position of the steak image was more influential on consumer overall liking than the color or degree of marbling of the steak image.

Table 68. Variable coefficients (SEM) for multiple variable regression predicting consumer overall liking of beef steak images.

	Dependent variable:		
	Overall liking		
	(1)	(2)	(3)
Constant	4.927*** (0.098)	4.677*** (0.557)	4.692*** (0.557)
Left position	0.098 (0.088)	0.108 (0.092)	0.104 (0.092)
Middle position	0.892*** (0.114)	0.800*** (0.114)	0.753*** (0.166)
Ideal color	0.655*** (0.101)	0.402** (0.156)	0.403*** (0.156)
Dark color	0.154* (0.087)	0.014 (0.146)	0.008 (0.146)
Small	0.383*** (0.101)	0.289* (0.156)	0.294* (0.156)
Modest	0.916*** (0.087)	0.657*** (0.146)	0.652*** (0.146)
Modest x dark		0.280 (0.206)	0.281 (0.206)
Modest x ideal		0.442*** (0.211)	0.450** (0.211)
Small x dark		0.043 (0.211)	0.033 (0.211)
Small x ideal		0.245 (0.211)	0.241 (0.211)
Fixation time		0.219*** (0.032)	0.163*** (0.042)
Revisits			0.042** (0.020)
Age	*No*	*Yes*	*Yes*
Income	*No*	*Yes*	*Yes*
Gender	*No*	*Yes*	*Yes*
Beef consumption	*No*	*Yes*	*Yes*
Children	*No*	*Yes*	*Yes*
Observations	2,790	2,772	2,772
R^2	12.1	16.6	16.7
Adjusted R^2	11.9	15.6	15.7
Residual standard error	1.848	1.810	1.808
Degrees of freedom	2783	2739	2738

*p < 0.1; **p < 0.05; ***p < 0.01

The second regression equation included consumer demographic information in order to assess the robustness of the explanatory variables. In other words, we sought to understand that if we reduced the amount of unknown variation by accounting for the demographic information if the significance of the explanatory variable would be impacted. In addition, interactions of color and degree of marbling were included. The constant overall liking score decreased from 4.927 to 4.677, but was still significant ($P < 0.01$). The middle position ($P < 0.01$), and ideal color ($P < 0.05$), and Modest ($P < 0.01$), variables remained important while Small decreased to a trending level of significance ($P < 0.1$). The constant interaction was considered a Slight x Pale steak image. The only interaction of significance was reported as ideal x Modest where consumer overall liking increased by 0.442 points. This regression equation also included fixation time. Its significant impact ($P < 0.01$) indicated that for every additional five seconds a consumer fixated on an image, overall liking increased by one point. The position of the steak image continued to the be most influential variable on estimated consumer overall liking ratings.

All variables of significant impact from the second regression equation remained of significance of at least $P < 0.05$ in the third regression equation, indicating the robustness of these explanatory variables. The third regression equation included an additional variable of the number of revisits. A revisit is defined as when a participant fixated on an image, shifted their viewing to another point on the screen where they fixated once more, then returned to fixate on the original image once more. This variable impacted the consumer's overall liking score as for each revisit that occurred, overall liking increased by 0.042 ($P < 0.05$).

Marginal effects measured the expected instantaneous change in the dependent variable (consumer overall liking) as a function of change in a specified independent variable while all other covariates were held constant. This measurement was used to interpret the effect of the independent variables of either fixation time or revisits on consumer overall liking. Figure 41 reports the marginal effect of the number of revisits for consumer overall liking considering steak image color. Ideal colored steak images were preferred over pale and dark colored steak images when the number of revisits were below nine. When revisits increased to nine, consumers liked dark and ideal colored steak images similarly. Considering the marginal effects of fixation time for consumer overall liking displayed in Figure 42, when consumer fixation time was less than 3 seconds, pale and dark steak images were disliked similarly and more than ideal steak images. As fixation time increased from 3 seconds, consumer overall liking was similar among all three colors. This indicated that when consumers spent more time examining a steak image, they did not differentiate images for color.

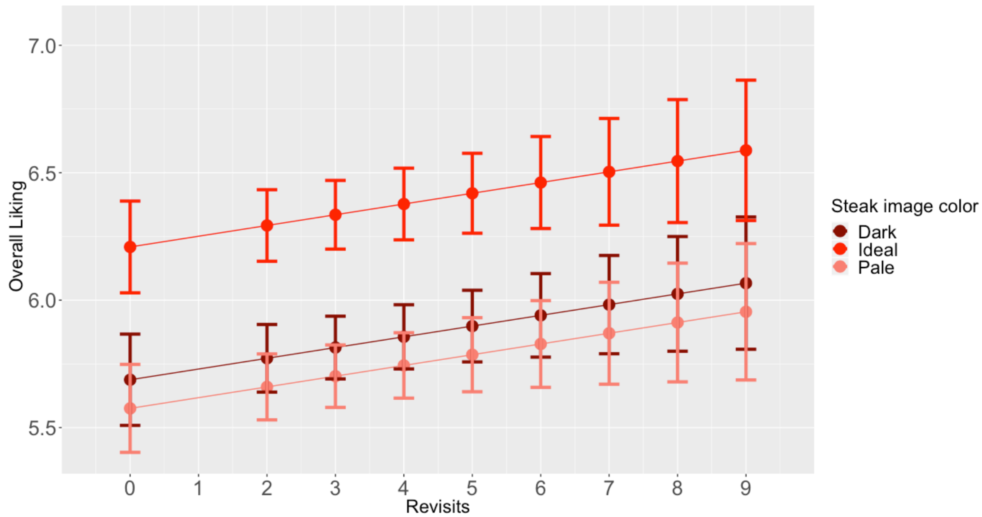


Figure 41. Marginal effects of number of revisits on consumer overall liking of beef steak images representing dark, pale, or ideal color.

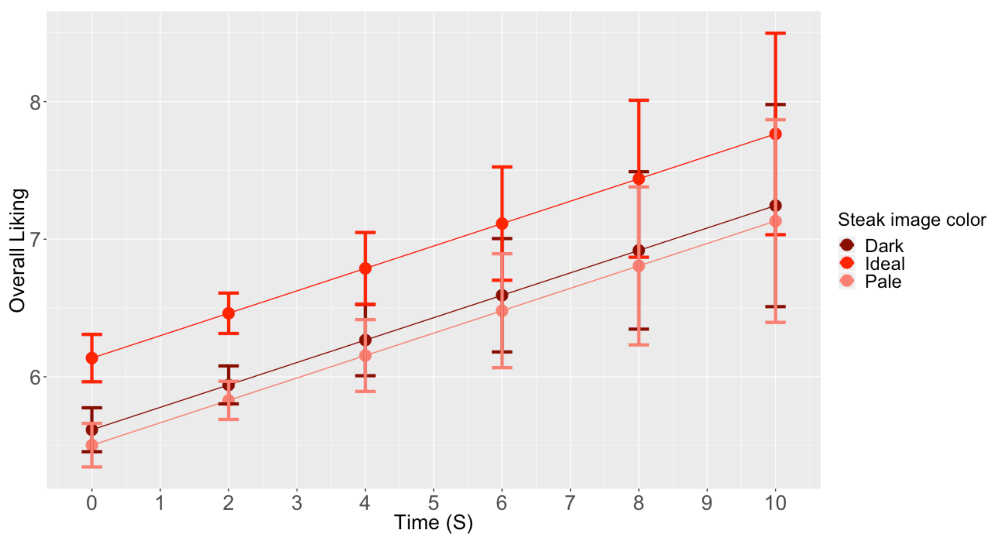


Figure 42. Marginal effects of fixation time (s) on consumer overall liking of beef steak images representing dark, pale, or ideal color.

As previously discussed, consumers liked steak images with higher degrees of marbling. Therefore, they liked images with Modest marbling compared to steak images with Small marbling. Additionally, steak images with Small marbling were preferred over steak images with Slight marbling. Figure 43 displayed the marginal effects of the degree of marbling on consumer overall liking. As long as consumers had six or less revisits to an image, overall liking for the steak images differing in degrees of marbling were consistent with our previously defined findings. When consumers had seven or more revisits, steak images with Small and Slight marbling were liked similarly and steak images with Modest marbling were liked most. Figure44 presented marginal effects of the degree of marbling and consumer overall liking. When fixation time was three seconds or less, consumer liked steak images with higher degrees of marbling. However, after eight seconds, overall liking was similar for all marbling levels in steak images. This may indicate that as consumers view fresh retail beef products for longer periods of time and compare these products, the differences of color and degree of marbling may become less crucial in their purchase decision process. Conversely, consumers who spend less time making purchase decisions, differentiated steak images for differences in marbling and color, but overall liking was lower.

The insight provided by analyzing the fixation count and number of revisits variables more in depth suggested that the manner in which consumers made their decisions (quickly verses slowly in terms of inspecting and comparing product) may be related to the information they require for making their purchase decision for beef products. Based on the consumer type, different product information may be more or less important.

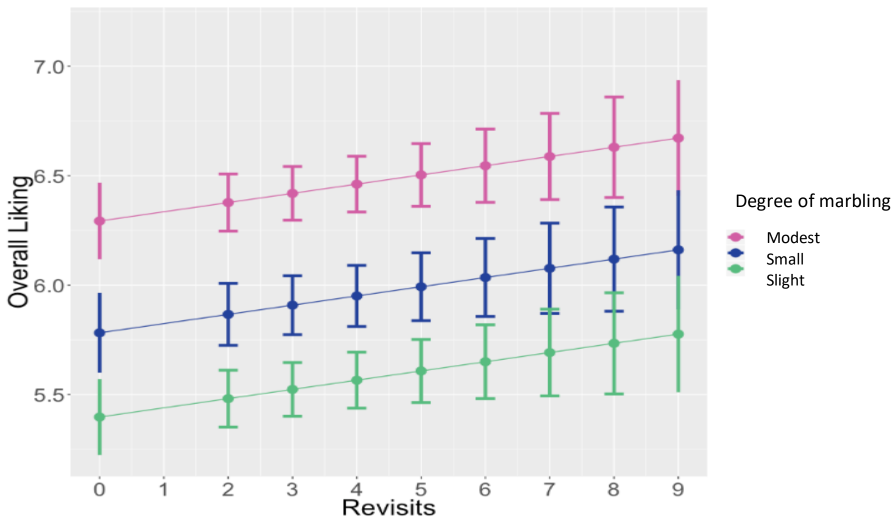


Figure 43. Marginal effects of fixation time (s) on consumer overall liking of beef steak images representing Modest, Small, or Slight degrees of marbling.

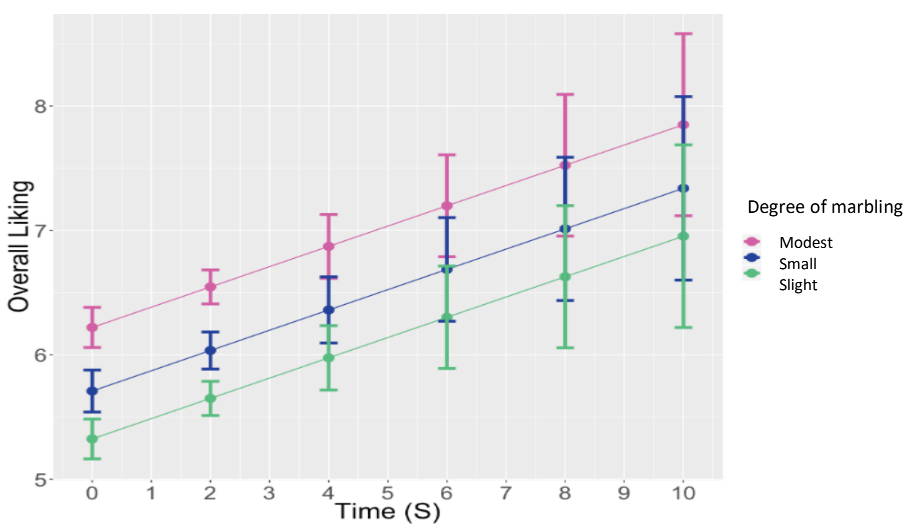


Figure 44. Marginal effects of fixation time(s) on consumer overall liking of beef steak images representing Modest, Small, or Slight degrees of marbling.

Conclusions

As consumers spent more time fixating and revisiting beef steak images, overall liking of the steak images increased, but differences in marbling and color did not resonate to the same extent. Subconscious factors most likely affect consumers' preference of beef appearance in the retail meat case by influencing the time they take to decide. If a purchasing decision is made rapidly, differences in marbling and color affect the decision to a greater extent. However, for consumers who spend more time making purchasing decisions, differences in marbling and color were not as impactful.

Of the variables used to understand the influences of a consumer's overall liking in the study, the most easily controlled would be the positioning of the product. The position of the steak image proved to be of great influence in overall liking ratings as the consumer's opinion of initially viewed steak created a baseline for any further comparison made. These findings confirm the use of eye tracking equipment's potential benefit towards providing additional insight of the factors that drive consumer beef consumption. Implementing this tool in future studies will provide information of consumers' cognitive behavior that cannot be observed through self-reported measures, solely.

CHAPTER VI

SUMMARY

Sensory scientists have developed survey systems designed to capture consumers' conscious opinions of food products. The history of consumer liking of beef has been well documented through using these methods. As the beef industry continues to progress in genetic selection and overall improvement of pre- and post-harvest factors, improvements in beef tenderness has occurred. Updating consumer tenderness thresholds created 30 years ago will ensure consumers continue to be satisfied with the work of those involved in the beef industry. Additionally, the combination of previously collected data from consumers proved to provide a more holistic perspective on the specific flavor and texture attributes, volatile aromatic compounds, and fatty acids that influenced different subrimal cuts cooked to differing internal temperatures.

Understanding the drivers of liking of consumers is complex. Subconscious factors drive consumers' actions whether they are aware or not. Although current survey method strategies from sensory scientists have been proven effective for the beef industry, advances in technologies capable of capturing deeper insights from consumers presents an opportunity for our industry to increase its understanding of what drives consumers. Consumer perception of beef color and marbling has been researched heavily. Combining this rich knowledge with eye-tracking gave further insight into what drives consumer perception of these attributes. Consumer perception can be altered by presenting beef products in different positions and combinations as an individual's opinion is contingent on what product is available to them.

Further, with advances in technology, consumers have been more informed of beef products and the agricultural system, in general. With this increase in availability of information, the need to effectively communicate the efforts of those involved in the production of food increases as well. Information sources sought by consumers often relay false and misinterpreted details regarding topics such as animal welfare, hormones, genetically modified organisms, sustainability practices, and animal vaccines. Taking advantage of innovations capable of measuring how and what consumers interpret from scientifically-based infographics provided support in increasing the effectiveness of communicating material regarding these topics that were supported by research findings. This aided consumers in shifting and developing their opinions based on factual information.

The beef industry would benefit in applying a multidisciplinary approach to understanding consumers. Just as the beef industry has progressed with time, so has technological tools and statistical methods. Accepting and implementing these advances studied in this dissertation provided further insight into understanding consumer motives.

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APPENDIX

Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]0= none; 15= extremely intense from Adhikari et al. (2011) and are adapted from AMSA (2016).

Attribute	Definition	Reference
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid (hexanoic acid) = 12.0
Asparagus	A vegetative aroma note associated with canned asparagus.	Asparagus microwaved in water = 6.5
Barnyard	The aromatic characteristic of barn or barnyard; combination of manure, urine, moldy hay, feed, livestock odors.	White pepper in water = 4.5 Tinture of civet = 6.0
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Beet	The aromatics associated with cooked beets, caramelized, sweet, and earthy.	Canned beet juice in water = 4.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/serumy	The aromatics associated with blood on cooked meat products, closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Buttery	The clean, fatty, mild flavor of fresh butter	Land O' Lakes unsalted butter = 7.0

Continued.

Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum based product such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 Clorox in water = 6.5
Cocoa	The aromatics associated with cocoa beans and powdered cocoa and chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Cumin	The aromatics associated with cumin and characterized as dry, pungent, woody, and slightly floral.	McCormick ground cumin = 7.0
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat–like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Floral	The sweet fragrant aromatic associated with flowers.	Welch's white grape juice in water = 5.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (aroma) Fresh parsley water = 9.0
Green–hay	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in medium snifter = 5.0 (aroma) Dry parsley in ~30-mL cup = 6.0
Heated–oil	The aromatic associated with fresh oil that is heated.	Wesson vegetable oil cooked 3 min.= 7.0
Leather	Musty, old leather (like old book bindings)	2,3,4-Trimethoxybenzaldehyde = 3.0 (aroma)
Liver–like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5

Continued.

		Braunschweiger liver sausage = 10.0 (must taste and swallow)
Metallic	The impression of slightly oxidized metal, such as iron, copper , and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (aroma)
Petroleum–like	The aromatic reminiscent of hydrocarbons such as gasoline or kerosene.	Vaseline petroleum jelly = 3.0 (aroma)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboardy, painty, varnish and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 5 min at high) = 9.0
Refrigerator–stale	The off flavor associated with a product that has absorbed odors from the refrigerator.	Ground beef cooked and set to cool =
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Smoky–charcoal	An aromatic associated with meat juices and fat drippings on hot coals which can be acrid, sour, burned, etc.	Wright's Natural Hickory seasoning in water = 9.0 (aroma)
Smoky–wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (aroma)
Soapy	The aromatic commonly found in unscented hand soap.	Ivory Bar Soap in water = 6.5 (aroma)
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese = 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5

Continued.

		0.050% citric acid solution = 3.5
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed–over	Perception of a product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0

You will be asked to answer a series of questions regarding your thoughts and opinions for several topics regarding agricultural production.

Press **Next ➡** to continue.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I believe genetically modified organisms are safe to consume.	☐	☐	☐	☐	☐	☐	☐
I am against the production of genetically modified food.	☐	☐	☐	☐	☐	☐	☐
I am concerned with the amount of hormones in the beef I consume.	☐	☐	☐	☐	☐	☐	☐
Using hormone implants in beef cattle is a good idea.	☐	☐	☐	☐	☐	☐	☐
I trust that the meat I consume is antibiotic free.	☐	☐	☐	☐	☐	☐	☐
Vaccines are neccesary for the animal's health.	☐	☐	☐	☐	☐	☐	☐
I am concerned about our ability to feed the growing population.	☐	☐	☐	☐	☐	☐	☐
Agriculture practices are making progress towards a more sustainable production system.	☐	☐	☐	☐	☐	☐	☐
I am concerned about the environmental impact of agriculture production.	☐	☐	☐	☐	☐	☐	☐

Next ➡

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Sufficient research has been conducted to ensure genetically modified organisms are safe.	☐	☐	☐	☐	☐	☐	☐
I believe all beef animals should be raised without hormone implants.	☐	☐	☐	☐	☐	☐	☐
Anitibiotic usage in animals is well regulated.	☐	☐	☐	☐	☐	☐	☐
Sufficient research has been conducted to ensure antibiotic usage in beef cattle is safe.	☐	☐	☐	☐	☐	☐	☐
Vaccines for animals help keep me safe.	☐	☐	☐	☐	☐	☐	☐
I believe vaccines are unnecessarily administered to farm animals.	☐	☐	☐	☐	☐	☐	☐
Animals raised for food consumption are treated well.	☐	☐	☐	☐	☐	☐	☐
Production animals are fed healthy diets.	☐	☐	☐	☐	☐	☐	☐
An animal's well-being is a large concern for farmers.	☐	☐	☐	☐	☐	☐	☐

Next ➡

You will view a series of infographics containing images and information over several different topics.

The screen will automatically advance after each image to a series of questions regarding the image you just viewed.

After you complete each set of questions **press** Next ➡ to advance to the next image.

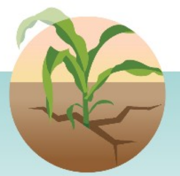
GMOs are safe[1,2]

Foods that contain GMO ingredients have the same makeup and nutritional value as non-GMO options.[3]

In the **20+ years** since GMOs were introduced, **trillions** of meals containing GM ingredients have been safely consumed[4]

GMOs have been studied extensively, with **ongoing regulation and oversight by the FDA, USDA and EPA.[2] Major medical associations agree.[5,6]** Foods that contain GMOs pose no greater risk to humans or livestock than non-GMO foods.

GMOs help farmers meet the challenges of tomorrow.



Changing global conditions

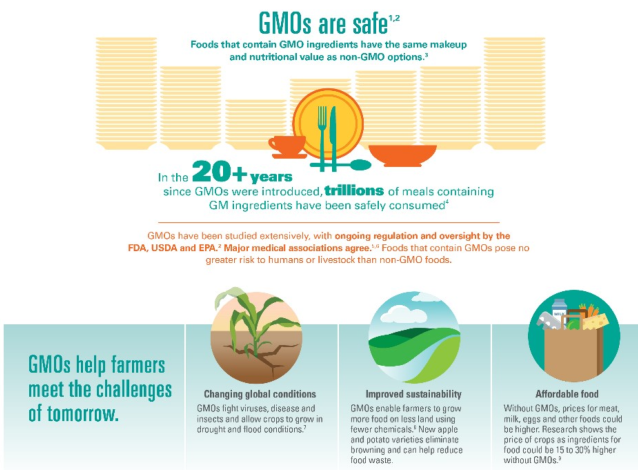
GMOs fight viruses, disease and insects and allow crops to grow in drought and flood conditions.[7]

Improved sustainability

GMOs enable farmers to grow more food on less land using fewer chemicals.[8] New apple and potato varieties eliminate browning and can help reduce food waste.

Affordable food

Without GMOs, prices for meat, milk, eggs and other foods could be higher. Research shows the price of crops as ingredients for food could be 15 to 30% higher without GMOs.[9]



How much do you like or dislike of the infographic OVERALL?

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Dislike Extremely				Neither Like or Dislike				Like Extremely

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ARE SAFE

A three-ounce serving of beef from a steer implanted with estrogen contains **1.9** **nanograms of estrogen**[1]

A three-ounce serving of beef from a steer NOT implanted with estrogen contains **1.3** **nanograms of estrogen**[1]

A three-ounce serving of potatoes contains **225** **nanograms of estrogen**[1]

A three-ounce serving of cabbage contains **2,000** **nanograms of estrogen**[1]

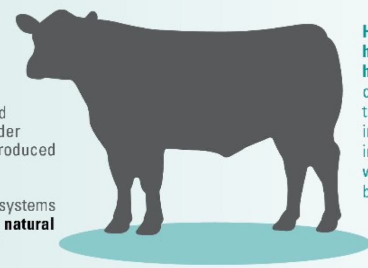
Every day, an average woman produces **513,000** **nanograms of estrogen**[2]

Every day, an average man produces **136,000** **nanograms of estrogen**[2]

ARE PRACTICAL

Bulls' hormone systems are removed to curb aggression for the safety and welfare of the animals (now called "steers") and the people who interact with them, and to make beef more tender and flavorful. Implants restore enough of a steer's naturally-produced hormone levels to **grow efficiently**.[3]

Heifers (female cattle that have not given birth) have hormone systems focused on reproduction. Hormone implants **balance a heifer's natural hormone levels** to allow it to grow more muscle instead of fat.[4]



Hormone implants help balance natural hormone levels in cattle to allow them to convert their feed into lean muscle instead of excess fat, which helps keep beef affordable.[4]

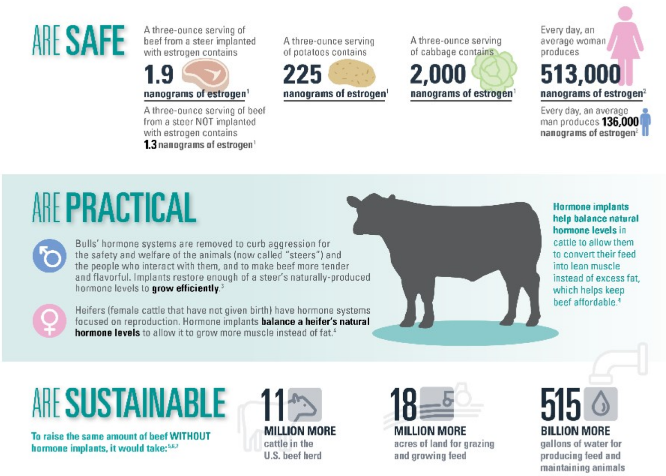
ARE SUSTAINABLE

To raise the same amount of beef WITHOUT hormone implants, it would take:[5,6,7]

11 **MILLION MORE** cattle in the U.S. beef herd

18 **MILLION MORE** acres of land for grazing and growing feed

515 **BILLION MORE** gallons of water for producing feed and maintaining animals



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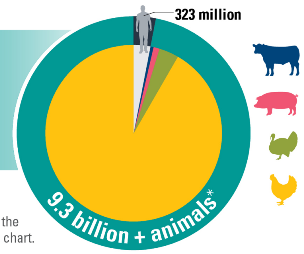
Next

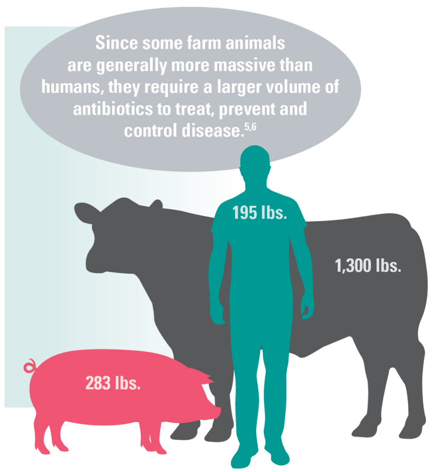
There are far more farm animals in the United States than people:

323 million people vs. **9.3 billion** cows, pigs, turkeys and chickens processed in the U.S.[1,2,3,4]

You may have heard that 80% of antibiotics in the United States are used in agriculture, but that statistic makes more sense when it's put into perspective.[2]



* Other species are also included in the 80% statistic like sheep, goats, fish and companion animals - dogs, cats and horses. They increase the number of animals but are not reflected on this chart.



Most antibiotics are used mostly in animals or in humans, not in both.[4]

Use by Volume	Humans	Animals
Penicillins	44%	6%
Cephalosporins	15%	Less than 1%
Sulfa	14%	3%
Quinolones	9%	Less than 1%
Macrolides	5%	4%
Tetracyclines	4%	42%
Ionophores*	0%	33%

** Ionophores are never used in human medicine*

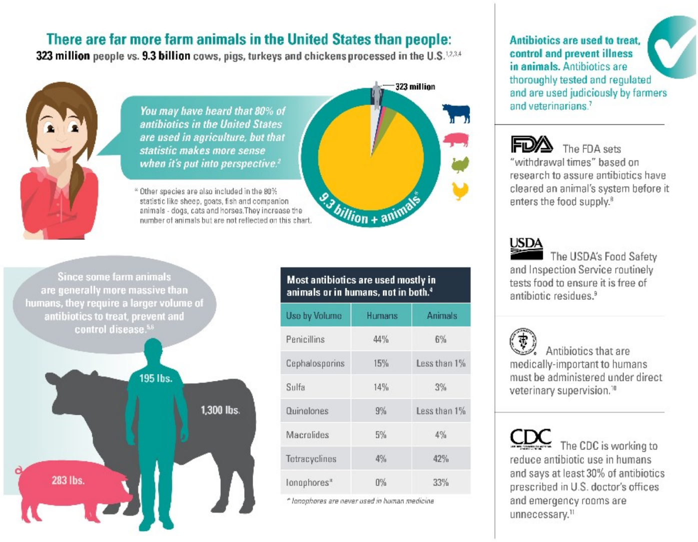
Antibiotics are used to treat, control and prevent illness in animals. Antibiotics are thoroughly tested and regulated and are used judiciously by farmers and veterinarians.[7]

The FDA sets "withdrawal times" based on research to assure antibiotics have cleared an animal's system before it enters the food supply.[8]

The USDA's Food Safety and Inspection Service routinely tests food to ensure it is free of antibiotic residues.[9]

Antibiotics that are medically-important to humans must be administered under direct veterinary supervision.[10]

The CDC is working to reduce antibiotic use in humans and says at least 30% of antibiotics prescribed in U.S. doctor's offices and emergency rooms are unnecessary.[11]



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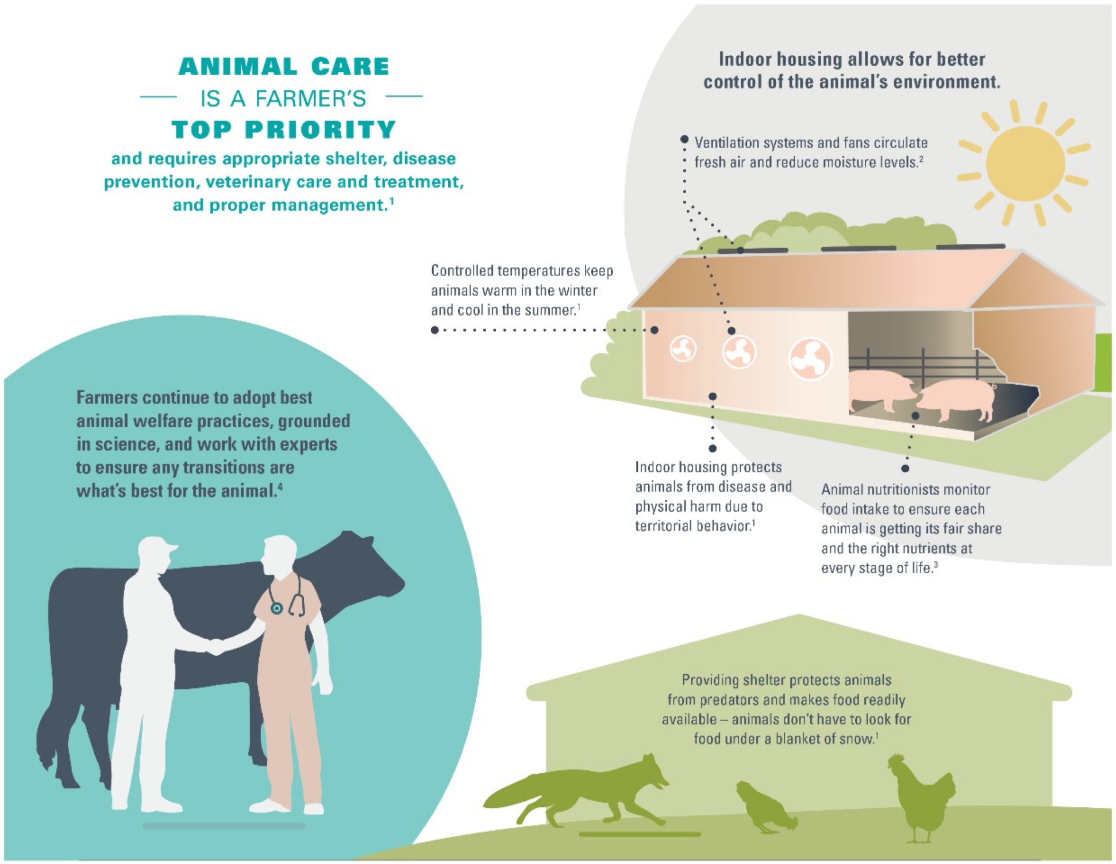
ANIMAL CARE
IS A FARMER'S
TOP PRIORITY
and requires appropriate shelter, disease prevention, veterinary care and treatment, and proper management.1
Indoor housing allows for better control of the animal's environment.
Ventilation systems and fans circulate fresh air and reduce moisture levels.2
Controlled temperatures keep animals warm in the winter and cool in the summer.1
Farmers continue to adopt best animal welfare practices, grounded in science, and work with experts to ensure any transitions are what's best for the animal.4
Indoor housing protects animals from disease and physical harm due to territorial behavior.1
Animal nutritionists monitor food intake to ensure each animal is getting its fair share and the right nutrients at every stage of life.3
Providing shelter protects animals from predators and makes food readily available – animals don't have to look for food under a blanket of snow.1

BENEFIT ANIMALS

Animal vaccines are considered the first line of defense against diseases.

Vaccines reduce the need for treating illness, which leads to **less antibiotic use.**[1]

Less disease and illness means improved animal health and well-being.

BENEFIT PEOPLE

Did you know?
Using *E. coli* vaccines on cattle could prevent up to 83% of human infections.[2]

Vaccines protect animals from contracting diseases that they may then transmit to humans.[2,3]

Vaccines **minimize the likelihood and spread** of food-borne pathogens.[4]

Vaccines help **keep food affordable**. By keeping animals healthy, food can be produced using fewer resources.[5]

BENEFIT THE ENVIRONMENT

Animal vaccines reduce death loss in animal herds, which means we don't have to treat animals for illness as often and fewer resources are used or wasted.[5]

Healthy animals require fewer resources to grow, which reduces the environmental footprint of raising animals.[5]

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I believe genetically modified organisms are safe to consume.	☐	☐	☐	☐	☐	☐	☐
I am against the production of genetically modified food.	☐	☐	☐	☐	☐	☐	☐
I am concerned with the amount of hormones in the beef I consume.	☐	☐	☐	☐	☐	☐	☐
Using hormone implants in beef cattle is a good idea.	☐	☐	☐	☐	☐	☐	☐
I trust that the meat I consume is antibiotic free.	☐	☐	☐	☐	☐	☐	☐
Vaccines are neccesary for the animal's health.	☐	☐	☐	☐	☐	☐	☐
I am concerned about our ability to feed the growing population.	☐	☐	☐	☐	☐	☐	☐
Agriculture practices are making progress towards a more sustainable production system.	☐	☐	☐	☐	☐	☐	☐
I am concerned about the environmental impact of agriculture production.	☐	☐	☐	☐	☐	☐	☐

Next ➡

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Sufficient research has been conducted to ensure genetically modified organisms are safe.	☐	☐	☐	☐	☐	☐	☐
I believe all beef animals should be raised without hormone implants.	☐	☐	☐	☐	☐	☐	☐
Anitibiotic usage in animals is well regulated.	☐	☐	☐	☐	☐	☐	☐
Sufficient research has been conducted to ensure antibiotic usage in beef cattle is safe.	☐	☐	☐	☐	☐	☐	☐
Vaccines for animals help keep me safe.	☐	☐	☐	☐	☐	☐	☐
I believe vaccines are unnecessarily administered to farm animals.	☐	☐	☐	☐	☐	☐	☐
Animals raised for food consumption are treated well.	☐	☐	☐	☐	☐	☐	☐
Production animals are fed healthy diets.	☐	☐	☐	☐	☐	☐	☐
An animal's well-being is a large concern for farmers.	☐	☐	☐	☐	☐	☐	☐

Next ➡

How many children do you have?

N/A	1	2	3	4	5+
○	○	○	○	○	○

Indicate your employment level.

Not employed	Part-time	Full-time
○	○	○

How many days a week total do you consume beef?

0	1-2	3-4	5-6	7 or more
○	○	○	○	○

When purchasing beef, what do you typically tend to buy at the retail store?

Grass Fed	Dry Aged	Organic	Hormone Free	Antibiotic Free	Natural	Free Range	Traditional
○	○	○	○	○	○	○	○

Next ➡