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Beef assessments using functional magnetic resonance imaging and sensory evaluation

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ABSTRACT

Functional magnetic resonance imaging (fMRI) has been used to unveil how some foods and basic rewards are processed in the human brain. This study evaluated how resting state functional connectivity in regions of the human brain changed after differing qualities of beef steaks were consumed. Functional images of participants ($n = 8$) were collected after eating high or low quality beef steaks on separate days, after consumption a sensory ballot was administered to evaluate consumers' perceptions of tenderness, juiciness, flavor, and overall liking. Imaging data showed that high quality steak samples resulted in greater functional connectivity to the striatum, medial orbitofrontal cortex, and insular cortex at various stages after consumption ($P \leq 0.05$). Furthermore, high quality steaks elicited higher sensory ballot scores for each palatability trait ($P \leq 0.01$). Together, these results suggest that resting state fMRI may be a useful tool for evaluating the neural process that follows positive sensory experiences such as the enjoyment of high quality beef steaks.

1. Introduction

Sensory evaluation of meat products allows researchers to evaluate how consumers perceive associated palatability. Advances in sensory evaluation have led to new areas of research affecting the development and marketing of many products due to the perception and the recognition of stimuli (Meilgaard, Civille, & Carr, 2007). Many methods are used in sensory analysis to evaluate somatosensory or organoleptic characteristics of a product (Aberle, Forrest, Gerrard, & Mills, 2001). Sensory responses of meat consumers can influence how a meat product is produced and marketed. A novel method that may complement traditional sensory evaluation is neuroimaging; this process enables images of the brain to be taken without surgery, incisions, or any other direct contact with the skin. This non-invasive technique has allowed for further evaluation of the brain and how it works and adapts when stimulated to respond in various situations (Stanford University, 2012; Qin et al., 2008; O'Doherty, Deichmann, Critchley, & Dolan, 2002). We believe that neuroimaging techniques can be adapted to better understand how solid foods, such as steaks of different qualities, are processed and evaluated in the brain. Neuroimaging shows potential to complement traditional sensory studies, by showing neural connections that cannot be observed through traditional sensory analysis.

In recent years flavor scientists have made major advancements in the evaluation of food properties using neuroimaging (Marciani, Eldeghaidy, Spiller, Gowland, & Francis, 2010). This research investigates the neural topography of the underlying taste perception (Marciani et al., 2006; Marciani et al., 2010), and how taste perception modulates the reward system and relates to other means of reinforcement (O'Doherty et al., 2002). Functional Magnetic Resonance Imaging (fMRI) has been used to show hedonic valuation of some foods. It requires a subject to lie down inside of a very strong magnet. The magnet detects small changes in the concentration of oxygen in hemoglobin, due to neural processing of the stimulus, within voxels of the brain. These voxels contain thousands of neurons, and when the neurons are stimulated researchers can observe this stimulation through hemodynamic changes that are imaged. Nevertheless, it has been a challenge for researchers to design fMRI studies to evaluate how people are satisfied with solid foods, because of head motion caused by chewing and potential choking hazards from eating these foods while lying in a supine position in the fMRI. For these reasons most fMRI studies on taste rely on liquid delivery, odors, or visual stimuli to evaluate somatosensory attributes. These studies have successfully been used to investigate flavor and taste preferences (Marciani et al., 2010). Liquid delivery works well for studying the basic perceptual dimensions of taste or the general effect of hedonic valence of many foods and beverages, but many products, such as meats, cannot be liquefied and retain their natural gustatory characteristics.

A novel method for studying the neurophysiological basis of the perceptual/hedonic experience associated with eating different quality meats is evaluation of resting state networks (RSN's). These scans will not replace traditional sensory testing, but may complement testing

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by giving information as to what neural structures are connected to the consumers' brains that causes their valuation. A resting state scan evaluates downstream effects of activation by measuring changes in functional connectivity observed through hemodynamic change, this is shown by correlations of Blood Oxygen Level Dependent (BOLD) contrasts between a region of interest (ROI) known as seed region in the brain (De Luca, Beckmann, De Stefano, Matthews, & Smith, 2006; Qin et al., 2008). Seed regions are known to have a particular effect due to a stimulus; correlations to seed regions show further connections due to the same stimulus. An example of a seed region that could be used is the anterior insula; this region responds to both taste and olfactory stimuli (De Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003). When a person is in a state of rest in the scanner, a consistent set of correlated brain regions become more active (Damoiseaux et al., 2006), which may indicate an inward focus of attention or introspection. Correlations to seed regions are the RSN's, and by evaluating these RSN's it is possible to examine the downstream effects of a hedonic experience. While this methodology has not been used to evaluate the hedonic experience of eating beef, changes in functional connectivity have been used to diagnose a number of disorders including Alzheimer's disease (Wang et al., 2006) and autism (Just, Cherkassaky, Kellar, Kana, & Minshew, 2007). Furthermore, changes in resting state networks have not only been found to track persistent differences in neural processing, but can also arise from brief experiences such as exposure to cocaine (Li et al., 2000) or acupuncture (Qin et al., 2008).

Given these demonstrated differences in resting state connectivity to positively valenced and rewarding stimuli, we expect the hedonic experience of eating beef may induce similar changes in resting state connectivity that vary with respect to the predetermined quality. The sensory experience of food is a primary reinforcer of eating, and other food stimuli have shown activation of neural networks to differ after consuming food. In a study examining brain activity after prolonged fasting, researchers found differences in activation in the ventromedial prefrontal cortex, dorsolateral prefrontal cortex, and inferior parietal lobule between subjects of differing diets (Tataranni et al., 1999). Other literature has shown that the insula, striatum, and orbitofrontal cortex can become activated by food and other reward stimuli (Tataranni et al., 1999; de Araujo et al., 2003; Kringelbach, 2006). We expect that quality differences between steaks would produce differences in resting state connectivity between these areas.

The objective of this study is to analyze which areas of the human brain show functional connectivity in a resting state fMRI scan after differing qualities of beef are consumed. These findings will be related to a sensory ballot used to evaluate consumers' perceptions of tenderness, juiciness, flavor, and overall liking. This relationship will allow us to investigate how resting state connectivity changes in regions associated with processing information as a function of the predetermined quality of a steak. Furthermore, we hypothesize that different qualities will bring about different amounts of value as well as functional connectivity.

2. Materials and methods

2.1. Experimental Design

This study was approved by the Human Research Protection Program at Texas Tech University, and was conducted at the Texas Tech Neuroimaging Institute. Each session consisted of four participants that were fed high and low quality steak samples on two separate days, the high verse low quality samples were counterbalanced and fed to the participants on different days of each session. Each day consisted of five main divisions: 1) initial resting state scan, 2) delivery of beef and filling out a sensory ballot, 3) primary resting state scan after receiving the beef stimuli, 4) palate cleanse, and 5) final/prolonged resting state scan after palate cleanse. Each step is described in greater detail throughout the Materials and methods Section.

2.2. Participants

A total of eight research assistants in the Department of Animal and Food Sciences at Texas Tech University were recruited as participants for this project. This number of participants would allow us to see significant differences, and was an accepted number of participants for this initial study. Untrained fMRI studies may require a greater number of participants, but trained fMRI studies do not require as many participants due to the fact they are trained to evaluate certain palatability factors without interference. The participants' ages ranged from 22 to 25. Each participant ($n = 4$ females, $n = 4$ males) was a regular meat eater. They were selected from a pool of graduate students in the Animal and Food Sciences Department. There was no specific training for this project, but each of the participants had served as trained taste panelists within the last year. This criterion was used in efforts to reduce bias in subjective scores, and to have participants that would think about each of the palatability attributes that were on the ballot. Furthermore, participants were instructed not to consume any foods at least four hours before scanning to reduce possible neural connectivity brought about by other stimuli. This time period was chosen to reduce connectivity from food stimuli that we were not evaluating; we also chose this time, because we did not want to select a time that might cause strong hunger and create stress or anxiety which might result in misleading information in hedonic centers of the brain.

2.3. Steak procurement

Two qualities of beef strip loins were used to evaluate sensory differences. High quality strip loins were procured through a commercial meat processor, this treatment of strips was prime grade and aged for 35 d. The low quality product was an un-aged strip loin from a grain fed animal, which rated lowest in valuation of flavor and overall liking in a consumer study (Bueso, 2015).

2.4. Steak preparation

All steaks were cooked to a medium degree of doneness, which the USDA defines as a steak having an internal temperature of 63 °C. Cooking was carried out using an electric clamshell grill (George Foreman Grill-GRP 99; Westmont, NJ). Then the steaks were cut into approximate 38 mm^3 samples. Using a warming/serving tray, the samples were transported to an empty room that was part of the neuroimaging institute where there was not a possibility of magnetic pull.

2.5. Scanning parameters

The same methodology was used for initial resting state scanning, resting state scanning after receiving the beef stimuli, and final/prolonged resting state scanning after the palate cleanse (Divisions 1, 3, and 5, mentioned in the Experimental design Section). During scanning, participants were asked to keep their eyes open while looking at a fixation cross (i.e., a + presented at the center of a screen). All fMRI scans collected data using a Siemans 3 Tesla Skyra MRI machine (Siemans, Germany), that used a multislice gradient-echo planar imaging (EPI) sequence with the following parameters: Repetition time (TR) = 2000 ms, echo time (TE) = 25 ms, flip angle = 70°, matrix = 64×64, field of view (FOV) = 192. Thirty-nine 2.5 mm (0.5 mm gap) axial slices were collected in an ascending order and oriented 30° off of the anterior/posterior commissure (AC/PC) line to reduce orbitofrontal dropout. The full timeseries for each functional run was 6:02 (181 volumes). Additionally a T_1 anatomical image was taken using MPRAGE with a slice thickness of 1 mm, TR 1900, TE 2.44, acquisition matrix 256*256, flip angle 9°, FOV 250.