DISSERTATION

FOOD AS A VISUAL CUE: AN ANALYSIS OF PERCEPTION, BEHAVIOR AND NEURAL ACTIVITY

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Fall 2009

COLORADO STATE UNIVERSITY

November 2, 2009

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY KYLE BURGER ENTITLED FOOD AS A VISUAL CUE: AN ANALYSIS OF PERCEPTION, BEHAVIOR AND NEURAL ACTIVITYBE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

FOOD AS A VISUAL CUE: AN ANALYSIS OF PERCEPTION, BEHAVIOR AND NEURAL ACTIVITY

Intake regulation is a complex process impacted by a number of factors such as homeostatic, environmental and hedonic influences. Previous models of intake regulation tend to not take into account the large influence that the environment (e.g., visual cues) has on eating behavior. Little work has been completed that evaluates the interrelationship of environment, psychology and physiology relations' to eating behavior. A new model of intake regulation, including aspects of environment, psychology and physiology serves as the basis for this investigation. A series of three studies were completed. The first study evaluated the effect of visual cues i.e., portion size and blindfolding on energy intake. The second study used a computer program to assess individuals' subjective hedonic ratings (i.e., liking and wanting) of food images. The third study used neuroimaging to evaluate individuals' brain activity in response to food images. The first study demonstrated that energy intake increased 26% and bite size increased 2.3g/bite in response to presentation to a large portion. This was driven by overweight individuals. No portion by blindfolding interaction was found, indicating that blindfolding did not attenuate the portion size effect. It was observed in the second study that ratings for wanting were consistently higher that ratings for liking and fruits were the highest rated foods. In addition, in a fed state, overweight individuals rated large portions of food higher smaller portions of food for wanting, but not liking. Ratings for liking were related to activation of the posterior cingulate (decision making). It was also

observed that dietary restraint was related to suppression of activity in the anterior cingulate (food reward). An increase in portion size appears to impact overweight individuals' energy intake (which occurs via changes in bite size) and ratings for wanting. A positive energy state could affect ratings for wanting but not liking. This decrease in wanting could be interpreted as dietary restraint which might function by decreasing brain activity in food reward related regions. Studying a comprehensive model including of intake environment, perception, behavior and physiology provides valuable insight to the interrelationship of all of eating behavior.

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ACKNOWLEDGEMENTS

There are many people that I want to thank throughout this process; it has truly been a group effort. My first thanks go to my mother and father, Don and Peggy, as well as my brother and sister, Ryan and Nikki. Your omnipresent love and support in the past five years has played a critical role in my success. Without each of you supporting my education over the years I wouldn't be able to do things like use words like omnipresent and actually know what it means. I always knew each of you would do anything to help me whether it was trying to understand brain physiology, listening to me vent daily driving to and from Fort Collins or overnighting me your laptop.

A special thank you goes to Susan, my mentor, who has provided me with ample opportunity, assistance and education in the past four years. I seen the lab grow from just the two of us sitting in the basement of JFK writing a fellowship application on a late on Friday night evolve into journal clubs in our eating observation lab with more people than chairs. You took so much time listening and fostering my ideas. I hope my career is successful simply so you are consistently reminded about how far you have taken me.

My friends of course were, on a day to day basis, made this time in my life unforgettable. Stacy, knowing you has changed my life (for the better, of course). You'll never know how much your friendship means to me. Amy, Alena, Pfaff, Laura et al., you've all have help me through some pretty low times and provided me with some of the best times in my life.

I would like to thank the members of the Children's Eating Lab, Adrienn, Richard, Erin and the interns that have passed through the lab. I also like to thank my committee members Marc-Andre Cornier, Mike Pagliassotti and Deana Davalos for their assistance and feedback throughout my time here.

- Go team.

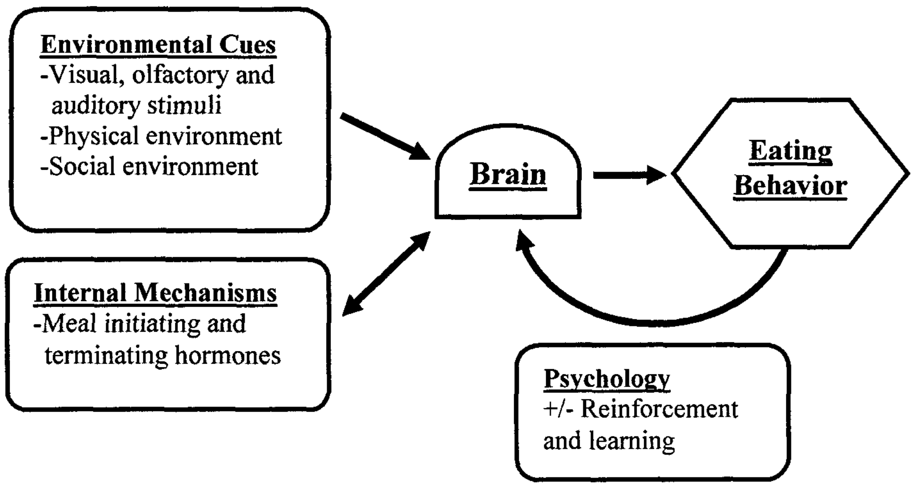
CHAPTER 1

INTRODUCTION

Superficially, eating is a relativity simple decision: a person chooses when to eat and when to stop eating. Yet, the prevalence of obesity and related metabolic disorders, such as diabetes and cardiovascular disease, continue to increase (1), indicating a dysregulation of food intake. The increase in prevalence and incidence of weight-related diseases amplifies the need to study a variety of factors and processes associated with eating behavior. These factors and processes are extraordinarily diverse and complex, involving physiological, psychological and environmental influences. Internal mechanisms, e.g., hormones, act to keep the body in nutrient homeostasis, in part by regulating feelings of hunger and fullness (2). Dietary attitudes, social norms and mood all influence eating behavior (3-7). Visual, olfactory and auditory stimuli from the surrounding environment can cue anticipation of consumption, and food intake itself, by evoking memories of positive and negative reinforcement from food (8, 9).

These cues also identify availability and hedonic value of foods, thus influencing eating behavior (10, 11). The current physical eating environment presents large portions of a wide variety of easily accessible, energy dense foods (12). Independent of the origin of input that influences food intake, ultimately all food-related processes, including intake, are funneled through regions of the brain (**Figure 1.1**). Therefore, studying brain activity in response to food-related stimuli is at the forefront of research focusing on eating behavior.

Figure 1.1 Inputs influencing Eating Behavior



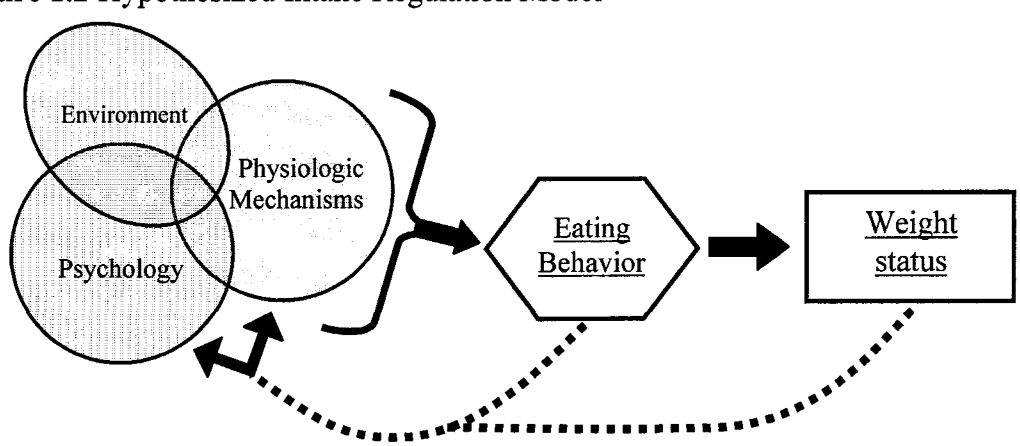
The impact of psychological and environmental factors that influence eating behavior has been well studied since the late 1960s (13-15), whereas the technology to study brain activation has only been available in the past 20 years. The rate at which functional magnetic resonance imaging (fMRI) is being used in research is expanding at an exponential rate. Zero research articles using fMRI were published in 1992 compared to 2,600 publications in 2006 (16). It has only been in the last 10 years that the relationship between brain activation, food stimuli and weight regulation has been investigated. It has been suggested that: neuroimaging reliably detects neural correlates of the pleasantness of foods (2); offers vast potential to further relate behaviors to physiology (17); and provides noninvasive means to study *in vivo* brain activation. This allows researchers to examine how variants in physiology, psychology and the environment influence the brain's response to food stimuli. Since neuroimaging has been utilized in this context, it has been proposed to categorize diseases associated with eating (e.g., anorexia nervosa, obesity, binge eating disorder and hyperphagia) as neurological diseases (17).

Currently, there is a gap in the nutrition literature regarding the interaction of individuals' perceptions of food characteristics, brain activation and the impact of the eating environment on eating behavior. To study this, a theoretical model of eating behavior was constructed and we completed three studies to specifically address key aspects of the interrelationship of physiology, food-related psychology and the eating environment.

HYPOTHESIZED INTAKE REGULATION MODEL

Our model is comprised of three main constructs that influence eating regulation: environment, physiologic mechanisms, and psychology (**Figure 1.2**). The constructs of physiologic mechanisms and psychology occur within the person and thus vary on an individual basis. In contrast, the general population is exposed to a similar overall eating environment. These constructs can independently influence eating behavior, but investigating the interaction among them can provide an in-depth picture of intake regulation.

Figure 1.2 Hypothesized Intake Regulation Model



Environmental influence on intake and portion size

The environment in which society eats has contributed to the obesity epidemic, and has received an increasing amount of attention (10). The environment largely influences eating behavior on two levels, the social environment and physical environment. For example, it has been reported that eating in a social situation with family or friends can increase intake as much as 70% (18-20). A simple distraction such as television can increase acute intake of food by 14% (7, 21). Indeed, television watching and advertisements have been associated with excess intake and obesity in children (22, 23).

The most studied area of the physical eating environment is how varying portion sizes of readily available, energy dense foods affect intake behavior (10, 24). Portion sizes have increased considerably over the past three decades (25), and mounting evidence suggests that this increase in portion size is a contributing factor to the obesity epidemic within the United States (26-32). Marketplace food portions are consistently larger than portions were in the past (33, 34), as well as considerably larger than federal standard portion sizes (31).

It has been reported that increases in portion size increases intake. Barbara Rolls and colleagues performed a number of studies that demonstrate a "portion size effect." For example, they have reported that doubling the portion size of macaroni and cheese increased intake by 30%, independent of participants' hunger and fullness levels (27). Increasing a sandwich portion by 100% (from 6-inch to 12-inch) resulted in 31 - 56% more energy consumed (30). These findings are not specific to adults, as preschool-aged children's energy intake was found to be 25% larger when they were served larger portions (35). It is unclear why this portion size effect occurs. It has been suggested that this effect is a function of increased preference (36), or a naïve visual cue given by the amount of food visible during the meal (35), although neither of these hypotheses has been tested.

Physiologic mechanisms, eating psychology and hedonic regulation of food intake

The construct of physiologic mechanisms of food intake regulation includes homeostatic processes that act to keep the body in energy balance. The foremost component of this regulatory process consists of the hormones that react to a need state of the body. More specifically, when in a negative energy balance, hormones associated with meal initiation (e.g., ghrelin, and neuropeptide Y) are released in the brain to promote food intake (2). Once the body determines that it has enough energy, levels of meal terminating hormones rise (e.g., cholecystokinin from the gut, leptin from the adipose) (2). Yet, in order to have a positive energy balance, and thus gain weight, eating must occur outside of a need state. Given the current obesity epidemic, it is reasonable to conclude that food intake is influenced by factors beyond homeostatic control.

Food intake is also influenced by the psychological construct related to the hedonic properties of food (37). A positive hedonic value of food describes the palatability or the pleasantness of food, which are associated with the concept of 'liking' the food (37, 38). Another aspect of the hedonic value of food is the reinforcing value a food provides. This is associated with the concept of 'wanting' or desire for the food (37, 39, 40). Food is considered one of the most common and natural sources of pleasure in everyday life (41), and there is growing evidence that intake based on food's positive hedonic value overrides homeostatic regulation of food intake (42). Hedonic regulation is thought to be a learned process primarily occurring through reinforcement of the rewarding properties of food (9). For example, an individual eats a novel food item and finds it to be very palatable; the rewarding feeling received acts as a positive reinforcement to consume more of that food item. As this process repeats itself, individuals are conditioned to associate positive hedonic feelings with anticipation and attainment of the food. This conditioning pattern also occurs when the reinforcement from the food is negative (punishing). That is, when a food is extremely unpleasant, the negative reinforcement (punishment) acts as a discouragement for further consumption. The influences of both the physiological and hedonic regulatory systems may explain a great deal of intake behavior.

As discordant as the physiologic and psychological constructs seem, there is a growing amount of evidence demonstrating how they interact to alter food intake. To bring the body into equilibrium, a physiologic need state can alter an individual's hedonic value of a food in order to influence intake (42). For example, when the body is in need of calories, perceived palatability of energy dense foods increases (43). Increasing perceived palatability is a possible means by which the body attempts to increase intake to return to homeostasis. Currently, the interaction between physiologic mechanisms and hedonic regulation of food intake is being studied, specifically in overeating and development of obesity (17). A popular method that is being used to study the interaction between physiologic mechanisms and hedonic regulation of food intake is the use of functional neuroimaging.

Neuroimaging

A rapidly growing area of nutrition research examines the relationship between reward-related neural pathways and the hedonic value of food. The studies of food reward pathways are often modeled after studies that examine the effects of drug reward in the brain. It has been reported that the reinforcing effects of reward are what drive addictive behaviors (44), and that rewards from positive hedonic foods have similar neural circuits (e.g., dopamine opioid and serotonin pathways) to the rewards associated with illicit drug use (45). DelParigi and colleagues reported that people can become "addicted to food" (41). Food reward (positive hedonic value of food) is arguably the most powerful determinant of eating behavior (46), and the degree of overweight has been linked to sensitivity to reward (47). This suggests that the rewarding properties of food contribute to obesity.

In fMRI analysis the brain is divided into small cubes (e.g., 3mm x 3mm x 3mm) termed voxels. The fMRI indirectly measures cerebral blood flow[(a marker for neural activation (48)] on a voxel by voxel basis. This is done by assessing levels of deoxyhemoglobin, a paramagnetic agent. Because deoxyhemoglobin is a paramagnetic agent, it distorts the magnetic field produced by the fMRI. The distortion of the magnetic field in the activated voxels is detected by the fMRI as a blood oxygen level dependent (BOLD) signal. Thus a BOLD signal indirectly reflects neural activation in the affected voxels.

To study the concept of food reward effects on the brain, researchers are using this fMRI technology while presenting their participants with visual, taste and olfactory cues of foods. It has been suggested that patterns of brain response to food images are an indicator of vulnerability to obesity (49). Previously, it was reported that food images activate regions of the brain related to reward anticipation and habit learning in obese individuals (50). Rothemund and colleagues also noted that images of energy dense foods were associated with body mass index (BMI) related activity in information processing, motivation, emotion, and taste associated regions (50). A similar finding was reported by Stoekel et al. when, compared to normal-weight controls, obese women exhibited greater activation in response to pictures of high-calorie foods in areas that mediate motivation (51).

OVERVIEW OF STUDIES

There is considerable opportunity to contribute to the food intake regulation literature by exploring aspects of a comprehensive model of eating behavior. To explore this intake regulation model, we completed three studies, each using the visual of cues of food: 1) the effect of individual characteristics and altering the eating environment (portion size and visibility) on food intake; 2) individuals' subjective ratings of the hedonic value of food images, varied by food category, portion size and energy density; and 3) relations between brain activity in response to food images and subjective hedonic ratings of food images.

Study 1: Mechanisms underlying the portion size effect

Increases in portion size lead to increases in intake and can contribute to obesity, yet, the mechanisms behind this 'portion size effect' are unclear. Currently, visual cues related to portion size have been suggested to promote increased intake (35), but have not been investigated. The primary aim of this study was to investigate the effects of visibility and portion size on energy intake. Also, it has been reported that changes in portion size affect bite size in children (35). The secondary aim of the study is to assess the effects of portion size on bite size in adults.

A 2x2, repeated measures, within-subject design was used to test the effects of portion size (410g vs. 820g of a pasta dish) and visual cues (blindfolded vs. visible) on energy intake at a meal. Participants (M=12, F=15) ate lunch individually in a lab setting on four different occasions, separated by greater than four days. The menu consisted of a pasta entrée and fixed portions of two side dishes and water. At each meal, participants were exposed to one of four experimental conditions (small portion/visible; small portion/blindfold; large portion/visible; large portion/blindfold) and were instructed to eat *ad libitum*. The order of the experimental conditions was randomized. In the blindfolded conditions, participants saw the foods prior to eating, and then were blindfolded for the duration of their meals. This allowed for the initial visual cue of the portion size prior to ingestion, but denied the ability to see the amount of food remaining during consumption. Demographics, reported eating behaviors, height, weight, number of bites, palatability measures, hunger and fullness were assessed. Mixed model analyses including hypothesized interactions were performed.

Study 1- Primary hypotheses

1) Individuals will consume more when offered a large portion of food compared to when offered a smaller portion.
2) The removal of the visual cue of food by blindfolding will attenuate the effect of the portion size on energy intake.
3) Individuals' mean bite size (grams consumed/number of bites) will significantly increase when given the large portion.

Study 2: The effects of portion size and energy density on the hedonic value of food images

In functional neuroimaging studies there is a need for food images that have been reliably rated for subjective hedonic value. Our primary aim was to develop a set of food images for use in functional neuroimaging research that are reliably rated for hedonic value across a variety of individuals. In addition, visual presentation of food provides considerable information, such as a food's palatability and its availability; both of these attributes can greatly influence eating behavior. The secondary aim of this study was to investigate relations between hedonic ratings of food images and food characteristics, specifically, food groups, portion size and energy density, as well as, hedonic ratings and participant characteristics (i.e. sex and weight status).

We investigated the subjective hedonic ratings (liking and wanting) of food images in a fed sample (n=129) using the computer paradigm ImageRate. Images chosen to be in the set were standardized for quality and size. They also varied by food category and 23 foods presented were in a large and small portion. ImageRate is designed to assess hedonic ratings using a scale of 0-100. Specifically, hedonic value was measured via two questions: 1) assessing liking for the food and, 2) assessing how much the participant wanted to eat that food. Images were collapsed into food categories based on the Dietary Guidelines for Americans (52), and mean scores were computed in each category for liking and wanting. The effects of food category, portion size, energy density were analyzed for the respective effects on liking and wanting.

Study 2 - Primary hypotheses

1) The discretionary foods category (highly palatable foods) will have the highest ratings for hedonic value among the food categories.
2) Overweight individuals will rate large food portions higher for hedonic value.
3) The measures of hedonic values, liking and wanting, will be positively correlated.

<u>Study 3</u>: Hedonic ratings and reported eating behaviors relations' with brain activation

Frequently functional neuroimaging studies present food images assumed to be highly palatable (foods with a positive hedonic value). Yet food preference is highly variable across individuals and personality-linked differences in neural responses to food images have been reported (53). The primary aim of this study was to investigate brain activation in response to food images (as measured by fMRI) and its relation to subjective hedonic ratings of the same food images (as measured by ImageRate). In addition, little is known about associations between brain activation in response to food stimuli and reported eating behaviors. Therefore a secondary aim of this study was to assess the relations between brain activation and dietary restraint, and dietary disinhibition in both a fasted and fed state.

A within-subject, repeated measures design was used to evaluate brain activation in response to food images and subjective hedonic assessments of food images in the fed and fasted state. A total of 18 participants (13 women, 5 men) were studied. Prior to the study day participants underwent three days of eucaloric feeding. At the study site, participants performed the ImageRate computer paradigm and underwent an fMRI in a fasted state, then were fed and completed the same measures in a fed state. During the fMRI, participants were presented with blocks of images of positive hedonic foods, neutral foods and non-food objects. Hunger and fullness in the fed and fasted state, as well as height and weight were assessed. Whole brain analyses were used to evaluate the main effects of presentation of food images and region of interest analyses (ROI) were used to evaluate responses in less-powered comparisons.

Study 3 - Primary hypotheses

1) Subjective hedonic ratings will be positively correlated with food image cued activation in visual attention (inferior visual cortex), memory of the rewarding effects of food and taste (insula) and the interface between emotion and memory, as well as evaluating reward/decision making and risk evaluation (cingulate gyrus).
2) We propose that the dorsal prefrontal cortex (DPFC), hippocampus and parahippocampus will be positively associated with restraint level, and the prefrontal cortex (PFC) and orbitofrontal cortex (OFC) with be negatively associated with restraint. Disinhibition and the inferior visual cortex, insula, dorsal striatum and parahippocampus gyrus.
3) Feeding will result in attenuate neural activation of in the inferior visual cortex, insula, as well as the cingulate gyrus in response to food images.

CHAPTER 2

MECHANISMS UNDERLYING THE PORTION SIZE EFFECT

INTRODUCTION

Environmental factors linked to the obesity pandemic have received an increasing amount of attention (10). One of the most studied areas of the eating environment is the effect of varying portion size on intake behavior. Portions sizes have increased considerably over the past three decades (31) and numerous studies have demonstrated that an increased portion size leads to increased intake, otherwise known as 'the portion size effect' (30, 32, 35, 54). The portion size effect has been reported to occur without the individual's knowledge that the portion has changed and without any differences in reported pre-meal hunger, palatability, or post-meal fullness (24). These data suggest that larger portions result in increased energy intake and contribute to the current obesity pandemic (24). Despite the consistency in the literature about the effects of portion size on intake, little research examines how or why this phenomenon occurs. An untested theory of why the portion size effect occurs is related to the visibly detectable amount of empty plate, (i.e., 'plate space') or food remaining on the plate, (i.e., 'residual food') during an eating occasion (55, 56). This theory suggests that individuals eat until there is a specific amount of plate space (or residual food) that then cues meal termination; indirectly providing the eater with information about how much has been consumed. The plate space theory is thought to occur independently of the amount presented. Thus, when a large amount of food is offered, more would have to be consumed before the specific amount of plate space/residual food is reached and signals meal termination.

Marketplace food portions are consistently larger than in the past and considerably larger than federal standard portion sizes (31). For example, it has been reported that portion sizes have increased from the late 1970's to 1998 (33) and from 1989-1996 (25). While the food industry has responded to research implicating increases in portion size and development of obesity (e.g., 100 calorie pack), large portions of food remain readily available to consumers, often at a less expensive price per serving.

The literature has consistently reported that an increased portion size of food leads to an increase in intake (28, 30, 32, 54, 57, 58). These effects have been noted in both acute and longer term studies with increases in food intake extending over a week (29) to a month (59). In adults, doubling the portion size of macaroni and cheese increased intake by 30% (27) and preschool-aged children's energy intake was found to be 25% larger when large portions were served (60). In children the portion size effect related to increased bite size, rather than an increase in the number of bites (35). This suggests that children select bite size in proportion to the amount offered. The mechanism has not been studied in adults.

Visual presentation of food is highly influential to meal initiation, amount consumed and meal termination. The presentation of food serves as a cue providing information about the food such as the accessibility, palatability and the amount available (61). When keeping the visual cue of food constant throughout a meal by having participants eat from covert self refilling soup bowls, individuals unknowingly consumed 73% more (62). But when removing the visual cue of food all together via blindfolding, Rooth and colleagues reported that consumption decreased 22% in lean and 24% in obese individuals without a change in eating rate or satiety (63, 64). By limiting the visibility of the food or by keeping a constant amount of food present, these researchers controlled the visual cue of how much was eaten with very different results. Therefore it is possible that individuals determine the amount of food to consume based, at least in part, on visual cues, not solely on hedonic value of food or homeostatic regulators of intake. The influence of portion size on food intake is well described, but a gap in the literature exists regarding the mechanisms underlying this effect. Our study addresses this gap by: 1) examining how removal of the visual cue of residual food impacts intake and the portion size effect; and 2) determining whether adults' bite size relates to the amount of food presented. We hypothesize that: individuals will consume more when offered a large portion of food compared to when offered a smaller portion, the removal of the visual cue of food by blindfolding will attenuate the effect of the portion size on energy intake, and individuals' bite sizes will significantly increase when given the large portion.

METHODS

Design and participants

A 2x2 repeated measures, within-subject design was used to test the interaction between portion size (small portion; SP vs. large portion; LP) and visual cues (visible; SEE vs. blindfolded; BLD) on energy intake at a meal. Each participant was exposed to four experimental conditions (**Table 2.1**). The order of experimental conditions was randomized across the sample. Demographics, reported eating behaviors, height, weight, food intake, number of bites, meal duration, palatability measures and hunger and fullness were assessed.

Table 2.1. Experimental Meal Conditions

	Condition A	Condition B	Condition C	Condition D
Portion Size	Small	Large	Small	Large
Visibility	Visible	Visible	Blindfold	Blindfold

Participants were recruited via phone or e-mail from a previously completed study. Inclusion criteria included being: between the ages of 18-60y; a willingness to eat the foods offered in the study, and the ability to read and understand the English language at a 6th grade level. Exclusion criteria included: pregnancy; restrictive dietary practices (e.g. vegetarianism or food allergies), taste or visual impairment that could interfere with data collection.

The participants were not told the purpose of the study, but were told that the aim was to investigate the effects of visibility on sensory aspects of food intake (i.e., taste and mouth feel). Participants were compensated for their time and debriefed after the study. All methods and procedures were approved by the Colorado Multiple Institutional Review Board.

Measures and procedures

Pilot testing and experimental menu

Two sessions of pilot testing, in separate samples, were completed to determine the flavor of pasta dish and the portion sizes to be offered. Four different flavors of Macaroni and Cheese (Kraft Inc, Glenview, IL) were tested, including Three Bistro Deluxe flavors (Creamy Portobello Mushroom, Sundried Tomato Parmesan, Three Cheese Italiano) and Macaroni and Cheese Dinner – Deluxe Four Cheese Sauce. A total of 15 individuals (M=8, F=6) tasted a small amount of each test food and rinsed with water between each taste. Preference was rated (Likert scale, 1-5) anchored by 1 = "this food is not pleasant at all" to 5 = "this food is extremely pleasant" and then the participant ranked the four test foods. The Three Cheese Italiano (energy density 3.1 kcal/g) had the highest preference rating (mean 3.4; range 2-5), was ranked in the top two more frequently than the other flavors (8 of 15), and was chosen as the main dish.

Offering altered portion sizes in food intake studies present the challenge of floor and ceiling effects. If the small portion is too small and an individual consumes the entire amount, the researcher cannot determine whether that individual stopped eating because he/she had reached fullness or simply because there was no more food. At the same time the large portion needs to be small enough so that it is not overwhelming large. Our aim was to present a small portion of a significant size such that the majority of individuals would not eat all of it and a large portion would not appear overwhelmingly large. We also desired to have a visually detectable difference between the two portions. Portions were initially based on the smallest (500g) and largest (1000g), amounts of a similar food presented in a study conducted by Rolls et al. (32). Through pilot testing of different portion sizes ranging from 400g to 1000g, it was determined that the majority of people would not consume all of a 410g portion. The large portion was then determined by doubling the small (small portion 410 ± 10g, 1255 kcal; large portion 820 ± 10g, 2509 kcal).

In addition to the entrée, complementary foods were offered with each meal including fixed portions of baby carrots (100 ± 5g, 35 kcal), sliced apples (130 ± 10g, 68 kcal) and water (800g). Nutritional information was obtained from the manufacturer to determine energy intake. The total energy offered in the study sessions was: 1358 kcal and 2612 kcal for the small and large portion conditions, respectively. Pre- and post-weights to the nearest 0.1g served as measure of consumption in grams.

Study session procedures

Participants were instructed to have a typical breakfast on study session days. Each participant came to the Children's Eating Lab at the University of Colorado - Denver on four different occasions separated by greater than 4 days. Participants came at the same lunch time for their study sessions. After consent was reviewed and all questions regarding the study were answered, participants filled out a series of pre-meal visual analog scales (VAS). Pre-meal VAS were used to rate the participants' hunger, thirst, fullness, amount they believed they could eat (prospective consumption), and feelings of nausea. All scales were assessed using a 0-100 mm scale, anchored by "not at all..." and "extremely."

The participants were then presented with a meal and the blindfold (on blindfolded condition days) and were instructed to eat *ad libitum*. A standardized tray was used, varied only by the portion size presented. Apples were presented in a square plastic container, carrots in round plastic container, water in a plastic cup with a lid and straw and the entrée was offered in a deep bowl with a spoon. A deep bowl was selected to make the difference between the portion sizes visually detectable and to aid in eating while blindfolded, by increasing the height of the food. It has been previously reported that individuals judge volume by height of the container (65, 66).

In the blindfolded conditions participants saw the foods prior to eating and then were blindfolded for the duration of their meal. This accomplished three things: 1) it allowed the participant to initially view the different portion sizes presented; 2) it eased any reservations the participants had about eating something they could not see and; 3) it denied the participant the ability to see the amount of food remaining during consumption. Participants were instructed to indicate finishing the meal either by pushing the tray away or removing the blindfold.

Participants then completed post-meal VAS which consisted of the same five scales completed pre-meal and four additional VAS to assess the participants' ratings for: overall pleasantness of taste of the entrée, and saltiness, sweetness and how fatty the entrée tasted (0-100mm). At the end of the first session, height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) were assessed on site with a calibrated scale and stadiometer. No data were collected near any celebration or holiday that involved food or an event that could significantly impact energy balance (e.g. running a marathon).

On a date prior to the meal sessions, the Three Factor Eating Questionnaire (67) was completed to identify any participants with highly restrictive and/or disinhibited eating patterns. We were primarily interested in dietary restraint (scale range: 0-21) and dietary disinhibition (scale range 0-16) subscales. The reliability and validity of the Three Factor Eating Questionnaire and its sub-scales have been established in wide variety of nutrition-based studies (68).

Behavioral observations and discharge

Meal duration was recorded in (minutes:seconds) from the first bite or drink to the time when the participant indicated completion of the meal. Research staff recorded number of bites of the entrée via direct observation behind a two way mirror at every session. A 'bite' was operationally defined as the point when the spoon transferred food to the mouth. Any comments made by the participant were recorded by research staff throughout the study session. An informal discharge interview was performed at the end of the last study session. Participants were queried regarding their thoughts about the purpose of the study, whether they noticed differences in the meal between study sessions and their experiences related to eating blindfolded.

Statistical analyses

BMI of each participant was calculated, and weight status was dichotomized into lean (BMI < 24.99) and overweight (OW; BMI > 25). The Harris-Benedict equation using a sedentary activity factor (1.2) was used to estimate calorie needs for both men and women (69). Bite size was calculated by total grams of the entrée consumed divided by the total number of bites. Bite frequency was calculated as the sum of the total bites recorded divided by meal duration recorded.

Statistical analyses were performed using SAS Version 9.1 (SAS Institute Inc, Cary, NC 2003). Descriptive statistics were performed on all data including means, standard deviations and standard error of the means as well as tests of normality of distribution. Exploratory and graphical methods were used to examine data for outliers or other abnormalities. Independent measure t-tests were used to compare participant characteristics (e.g., age, education, dietary disinhibition and restraint) across sex and weight status. Mixed linear model analyses (PROC MIXED, SAS Institute, Inc) were conducted to assess main effects (portion size, blindfolding, sex, and weight status) and interactions (e.g., portion size x blindfolding; portion size x sex; portion size x weight status; weight status x sex; blindfolding x portion size x sex). Hypothesized covariates and interactions were entered into the models and removed if $P>0.10$. All tests were two-sided with significance levels set at $P<0.05$.

In testing the effect of portion size on intake, consuming all of the entrée (plate cleaning) can skew data, inflating the effect of the increase in portion. Our study included three steps to account for the effect of plate cleaning: pilot testing of the portion sizes, operationally defining a 'plate cleaner' and completing an analysis to determine whether a plate cleaner x portion size interaction existed. Based on previous literature (32) a participant was defined as plate cleaner if they left ≤ 20g of the entrée in both of the small portion conditions (blindfolded and visible).

RESULTS

Participants

A total of 30 individuals (M=15, F=15) completed the study, 3 men (BMI=31.3 ± 4.4) were identified as plate cleaners. In addition to consuming all of the small portions, one of these men left ≤ 20g of the large portion entrée in the blindfolded condition. No participant left ≤ 20g of the large portion entrée in the visible condition. A plate cleaner x portion size interaction was observed ($P < 0.001$). The plate cleaners had a significantly larger response to the increase in portion size suggesting that they would have possibly continued to eat in the small portion condition if there has been more food available. Because the plate cleaners were restricted by the amount of food presented in the small portion conditions and likely were not able to eat until full, their response to portion size was inflated, thus skewing the data and they were eliminated from further analyses. All subsequent results presented are on the remaining 27 participants (1 Hispanic, 1 Asian, 25 non-Hispanic whites). Participant characteristics are presented in **Table 2.2**. A total of 13 individuals (5 Men, 8 Women) were classified as lean (BMI ≤ 24.9) and the remaining 14 individuals (7 Men, 7 Women) were classified as overweight

(BMI ≥ 25). As expected, overweight (OW) individuals had a significantly higher BMI (29.2 ± 3.7 vs. 22.4 ± 1.7; $P < 0.001$) and also higher dietary disinhibition scores (6.7 ± 2.8 vs. 3.7 ± 2.7; $P < 0.05$). Overweight individuals also had a trend toward higher dietary restraint than had lean individuals (11.4 ± 6.1 vs. 8.1 ± 2.6; $P = 0.08$).

Table 2.2. Sample Characteristics[1]

	Men (n=12)	Women (n=15)	Total (n=27)
Age (y)	37.7 ± 11.4	37.1 ± 11.3	37.4 ± 11.1
Height (cm)	182.8 ± 6.1**	162.9 ± 6.7	171.8 ± 11.9
Weight (kg)	88.3 ± 12.7**	67.4 ± 11.8	76.7 ± 15.9
BMI (kg/m^2)	26.6 ± 4.9	25.4 ± 4.2	25.9 ± 4.5
Education (y)	16.3 ± 1.4	16.0 ± 1.6	16.1 ± 1.5
Dietary Restraint[2]	7.8 ± 4.3*	11.4 ± 5.1	9.8 ± 4.9
Dietary Disinhibition[2]	4.1 ± 2.1*	6.2 ± 3.7	5.3 ± 2.4

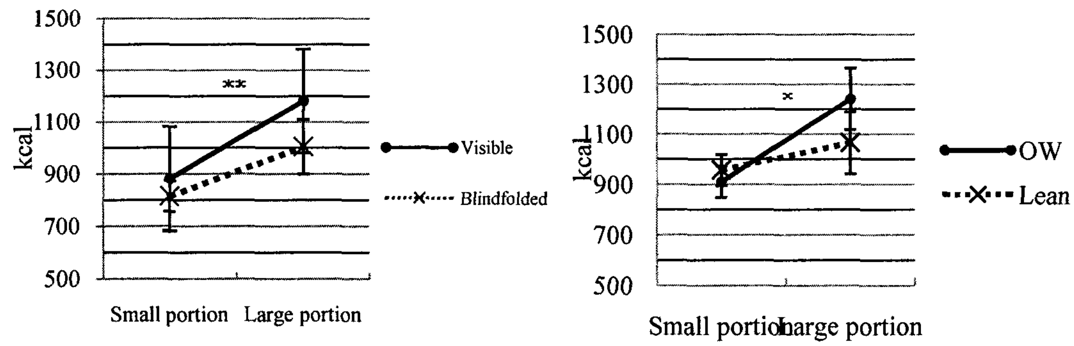
[1]Means ± SD.
[2]Three Factor Eating Questionnaire (21).
**Significant differences between men and women ($P<0.001$).
*Trending differences between men and women ($P<0.10$).

Entrée intake

A significant portion size main effect was observed (**Figure 2.1A;** $P < 0.001$), in which entrée intake increased 26% (220 kcal; 71.9g), independent of visibility condition, weight status, and sex. A weight status x portion interaction was also observed (**Figure 2.1B;** $P < 0.05$).

Figure 2.1: Entrée energy intake adjusting for visibility, weight status and sex (Mean ± SEM). **A)** Large portion resulted in significantly increased entrée energy intake **(P<.001). **B)** Significant weight status by portion interaction, indicating overweight (OW) individuals had a greater response to an increase portion *(P<.05).

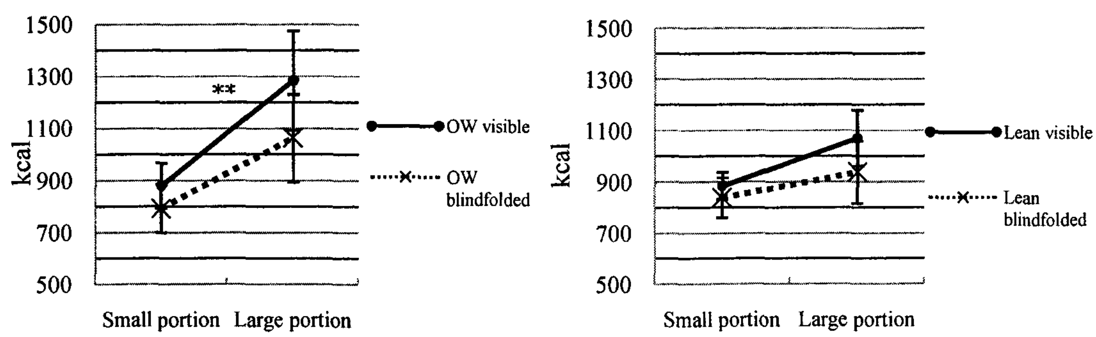
A) **B)**



Overweight individuals consumed 40% (334 kcal; 109g) more of the entrée in response to the large portion condition (**Figure 2.2A;** $P < 0.001$) while lean individuals' intakes did not differ (**Figure 2.2B;** $P = 0.56$). A 12% (122 kcal; 31.8g) decrease in entrée intake was observed in the blindfolded condition ($P < 0.01$), independent of portion size, sex and weight status. No portion by visual cue interaction was found ($P = 0.29$); indicating that blindfolding did not attenuate the portion size effect. An overall sex effect was observed in which men ate 188 kcal (61.6g) more, independent of portion size, visibility condition and weight status ($P < 0.05$).

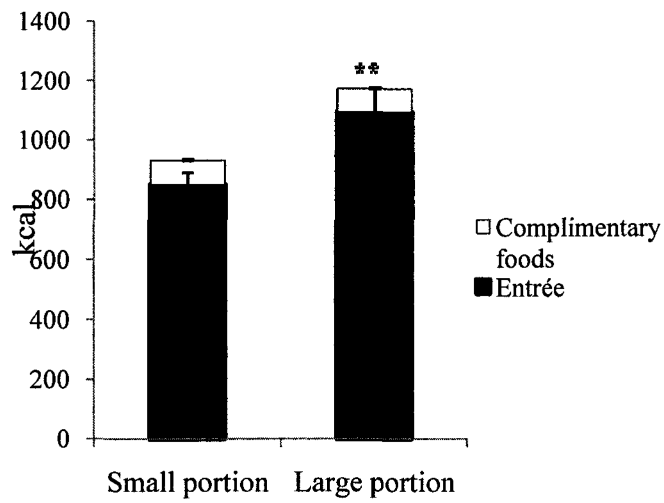
Figure 2.2: Entrée energy intake in response to an increase in portion by weight status and visibility condition. **A)** Large portion resulted in significantly increased entrée energy intake in overweight (OW) individuals' **(P <.001). **B)** Lean individuals entrée intake did not differ by portion (P =.56). No portion by visibility interaction was observed in either OW or lean individuals.

A) **B)**



Complementary foods and total intake

Figure 2.3: Mean (± SEM) entrée and complimentary energy intake during the large and small portion meals. **Significantly higher total intake ($P < 0.001$).



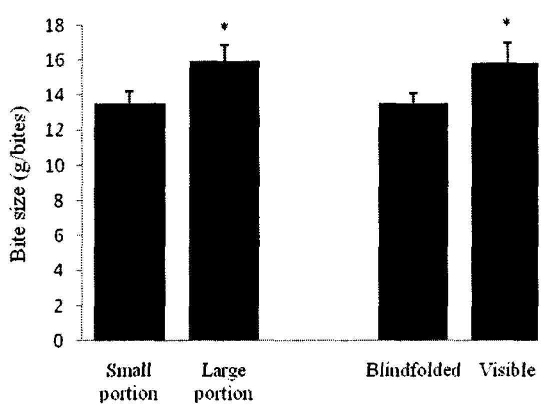
Total energy intake at the meal increased 220 kcal in response to the large portion independent of the visibility condition ($P < 0.001$; **Figure 2.3**). Blindfolding resulted in a 102 kcal decrease in total meal intake ($P < 0.01$) and men consumed significantly more at the meal than women (217 kcal; $P < 0.01$). A trend was observed for a weight status x portion interaction for total energy intake ($P = 0.059$). Energy intake of the complementary foods did not significantly differ by weight status (lean 84.0 kcal and OW 78.2 kcal; $P = 0.17$). No significant differences of intake in carrots ($P = 0.84$), apples ($P = 0.54$) and water ($P = 0.89$) were observed across the four experimental conditions. Men consumed more apples (118.2 ± 21.4g vs. 102.8 ± 37.9g; $P < 0.01$), carrots (79.7 ± 25.7g vs. 55.7 ± 34.3g; $P < 0.001$) and water (393.6 ± 161.5 vs. 291.1 ± 202.3; $P < 0.05$) than women. In addition, lean individuals consumed more apples than their overweight counterparts (115.9 ± 26.4 vs. 103.7 ± 36.6; $P < 0.05$).

Estimated daily energy needs were calculated on an individual basis (mean, M = 2321 kcal/d, F = 1717 kcal/d). Men's mean total intake for the small (1084.7 ± 221.6 kcal) and large (1392.9 ± 540.1 kcal) portion meals represented 47% and 60% of total estimated daily energy needs respectively. Similarly, women's mean total intake for the small portion meal (813.4 ± 286.8 kcal) accounted for 47% and the large portion meal (1005 ± 532.1 kcal) represented 59% of total estimated daily energy needs.

Bite size and meal duration

No differences in number of bites taken across the four experimental conditions were observed ($P = 0.89$; **Table 2.3**), by weight status ($P = 0.51$) or by sex ($P = 0.98$). Mean bite size increased 2.4 g/bite in the large portion condition ($P < 0.05$; **Figure 2.4**) and blindfolding resulted in a 2.3 g/bite decrease in size ($P < 0.05$; Figure 4). Men took significantly larger bites than women (16.6 ± 7.3 compared with 13.2 ± 7.6 g/bite; $P < 0.01$). Portion size did not significantly interact with blindfolding for either number of bites ($P = 0.78$) or bite size ($P = 0.88$). In addition, number of bites was not associated with sex ($P = 0.98$) or weight status ($P = 0.52$).

Figure 2.4: Mean (±SEM) bite size by portion and visibility conditions. *Bite size significantly increased in the large portion and visible conditions ($P<.05$).



Mean meal duration for all participants was 15:30 ± 4:06; (min:sec). No differences were observed in meal duration across any of the experimental conditions or by sex or weight status ($P = 0.28$- 0.99). Participants averaged one bite of the entrée every 0:54 ± 0:43 sec. No differences were observed in bite frequency between men and women, but a trend towards a difference was found between overweight and lean individuals.

Table 2.3. Ratings of hunger, satiety and palatability by experimental condition[1]

	SP/SEE[2]	LP/SEE	SP/BLD	LP/BLD	Mean
Number of bites	22.4 ± 11.7	24.6 ± 14.4	22.5 ± 9.0	23.4 ± 11.2	23.2 ± 11.6
Pre-meal hunger	61.3 ± 21.5	60.3 ± 22.5	68.3 ± 18.7	59.9 ± 19.8	63.4 ± 20.7
Pre-meal thirst	61.6 ± 20.2	61.2 ± 18.6	57.4 ± 19.4	60.6 ± 15.8	60.3 ± 18.4
Pre-meal prospective consumption[3]	64.1 ± 14.6	61.9 ± 17.6	64.6 ± 15.3	60.9 ± 16.7	62.9 ± 15.9
Pre-meal nausea	3.5 ± 7.6	2.9 ± 6.2	4.7 ± 7.4	4.2 ± 8.5	3.8 ± 7.4
Pre-meal fullness	22.8 ± 13.6	22.3 ±15.4	20.0 ± 17.9	23.5 ± 17.2	22.2 ± 15.9
Post-meal hunger	9.8 ± 10.6	7.1 ± 6.0	8.8 ± 8.6	8.8 ± 8.9	8.6 ± 8.6
Post-meal thirst	16.5 ± 14.4	15.6 ± 16.7	16.6 ± 16.1	16.5 ± 15.4	16.3 ± 15.4
Post-meal prospective consumption[3]	15.9 ± 16.6	11.6 ± 14.9	21.9 ± 10.0	13.7 ± 9.7	13.5 ± 13.2
Post-meal nausea	4.3 ± 7.3	3.1 ± 3.7	4.1 ± 11.2	4.3 ± 5.0	3.9 ± 7.3
Post-meal fullness	79.6 ± 12.7	81.3 ± 14.5	81.3 ± 7.8	78.8 ±11.7	80.2 ± 11.9
"How pleasant did the food taste?"	56.9 ± 20.3	57.5 ± 23.1	62.2 ± 20.6	57.3 ± 21.4	58.5 ± 21.1
"How fatty did the food taste?"	58.9 ± 14.5	59.7 ± 18.2	56.4 ±17.0	61.3 ± 15.1	59.1 ± 16.1
"How salty did the food taste?"	55.4 ± 19.3	52.0 ± 22.9	47.4 ± 21.2	48.1 ± 21.0	50.8 ± 21.1
"How sweet did the food taste?"	30.0 ± 24.0	27.9 ± 18.8	30.9 ± 26.9	28.6 ± 23.4	29.4 ± 23.1

[1]Mean ± SD. No significant differences among conditions were observed.
[2]SP=small portion, LP=large portion, SEE=visible, BLD=blindfolded
[3]Prospective consumption was asked as, "How much food do you think you could eat right now?"

VAS measures and participant comments

As presented in Table 2.3, perceived energy state and palatability measures did not vary across any of the four experimental conditions ($P = 0.42$-0.96). Observed differences between sex included men reporting higher pre-meal hunger (69.4 ± 12.0 vs. 57.1 ± 24.2; $P < 0.01$) and pre-meal prospective consumption (69.6 ± 11.8 vs. 57.7 ± 16.9; $P < 0.001$), whereas women reported higher pre-meal nausea (5.3 ± 9.2 vs. 2.0 ± 3.0; $P < 0.05$), though these levels were quite low. Overweight individuals reported being less full post-meal (77.4 ± 13.8) compared to lean individuals (83.0 ± 8.3; $P < 0.05$).

The majority of the participants noticed the difference in portion size, yet no participant was able to deduce the purpose of the study. When asked about eating blindfolded, participants reported that it felt a little unusual at first, but that they found it easier than they had anticipated; many participants reported it as being fun. No participant felt that blindfolding significantly impacted their intake, nor did any participant spill.

DISCUSSION

The primary aim of this study was to investigate the mechanisms underlying portion size effects on food intake. In concert with previous research, we demonstrated that an increase in portion size results in increased intake (30, 32, 54). Our investigation is the first to report that the removal of the visual cue of the plate space (and/or residual food) during the meal failed to attenuate the participant's response to the increase in portion size. Whether it is a case of plate space or residual food on the plate, the visual cues serve as a proxy of how much one has eaten, but this visual cue during the meal does not appear to drive the additional intake associated with larger portions of food. The retention of the portion size effect despite blindfolding does, on the other hand, suggest that the initial visual cue of the amount of food presented may be powerful enough to influence how much is eaten. Data presented in the current study suggest that there is a possible interaction between the visual cue and bite size which ultimately influences food intake.

Increases in portion size have been previously shown to increase children's bite size (35), however these effects have never been reported with respect to impacts on adults' bite size. Fisher and colleagues interpreted their data by suggested that a "naïve visual cue of the food on the plate provides a subtle reference upon which bite size is based" (35), which is similar to the plate space concept previously discussed. In contrast, the current study did not find support for the plate space theory. Further, Fisher et al.'s interpretation would suggest that as the amount of food decreased during consumption, bite size would also decrease. While this could be true, no data has been presented regarding fluctuations in bite size during a meal. The methods of determining bite size in Fisher et al. (35) and this study, do not allow determination of change in bite size over the course of the meal. Studies by Linne et al. (63) and Barkeling et al. (64) did utilize a system (VIKTOR) that can measure intake in real time, however analyzing bite size was not an aim of either of those studies.

Increases in bite size in response to increases in portion size suggest a different explanation as to why the portion size effect remained, despite being blindfolded. Our hypothesis is related to physical property of having more food available relative to the spoon. It is possible that, independent of the individual, the spoon has greater probability of capturing more food simply because of the volume of food it is scooping from is greater. It has been previously reported that when self-serving, an increase in serving spoon size leads to an increase in food taken (70), suggesting that spoon size can influence the amount scooped. Whereas our data suggest that the volume of food presented affects the amount scooped, independent of visibility and spoon size. It is also possible that individuals, when blindfolded, used the spoon to feel how much food was left and estimate how much they had eaten. However, it was observed that individuals in the blindfolded conditions generally ate from the same area of the bowl creating a one large divot in the entrée, suggesting that they did not feel around the bowl to determine the amount of residual food.

The entire sample ate considerably more than their estimated needs for one meal in all experimental conditions. However we were still able to demonstrate a portion size by weight status interaction, where overweight individuals' intakes appeared to be more responsive to an increase in portion size compared to their lean counterparts. Previous similarly designed studies have not reported a weight status by portion size interaction. The foremost possibility for this difference is that the present study recruited a sample with a nearly equal number of overweight and lean individuals, who had considerably different BMIs. The speculation that overweight individuals are more responsive to increases in portions suggests that environmental influences on eating behavior do not impact individuals equally and this could play a role in weight status. Why and how these differences exist is unclear.

While eating blindfolded can be considered "unnatural," reported fullness, meal duration and number of bites did not vary across the experimental conditions indicating that participants' intake was not impacted by the challenge of trying to eat blindfolded. Participants' also reported that eating blindfolded was easier than anticipated and they reported that they felt that it did not impact their consumption of the entrée or the total meal.

CONCLUSION

In conclusion, this study has provided evidence that overweight adults appear to be more susceptible to the effects of increases in portion size than their lean counterparts. The present investigation has provided insight regarding the mechanisms underlying the portion size effect in adults i.e., bite size. In our study, adults' increased intake when presented with a large portion is a function of unknowingly increasing bite size. Why the phenomena of increased intake and increased bite size occur is less clear. These results present evidence that: 1) the initial visual cue of the amount presented may influence intake independent of residual food or plate space, and/or 2) the physical amount of food affects how much is transferred to the spoon for a bite. Additional research is needed to study these concepts and determine how this can affect long term intake and weight regulation.

CHAPTER 3

THE EFFECTS OF PORTION SIZE AND ENERGY DENSITY ON THE HEDONIC VALUE OF FOOD IMAGES

INTRODUCTION

Food intake is influenced by a number of factors such as visual food cues in the eating environment, the hedonic value of food and an individual's energy state. The visual stimulus of the food is a key signal to the initiation of a meal. By simply seeing the food one is aware of its availability and potential palatability, both of which can act as incentive to initiate food intake (71).

Individuals are bombarded with visual food cues on a continual basis. Images of foods appear in print media, on screen and are visually present when other individuals are eating. Studies have reported that altering the visual aspects of food can increase food intake (i.e., portion size and visibility (32, 61), yet little is known about the mechanisms by which this occurs. To understand the possible physiologic basis of the effect of visual presentation of food, recent research has assessed brain activation in response to food images. These studies have reported that brain activation in reward related areas is increased when individuals are shown pictures of energy dense, highly palatable foods (72) and that activation resulting from high calorie foods is positively associated with body mass index (50, 51, 72). However little is known about individuals' preference of these food items, the relationship between perceptions of the hedonic value of food, and various other food characteristics known to influence food selection (e.g., food categories, portion size, and energy density).

Hedonic value, food liking and wanting

The term hedonic value refers to an individual's perception of the potential positive or negative reinforcement when consuming the food. Unlike food reward (direct positive reinforcement/high palatability), a positive hedonic value can occur outside of actually tasting the food item. A positive hedonic value of food and food reward are powerful determinants of eating behavior (46). Neural responses to positive hedonic food cues can occur on two levels, 'liking' and 'wanting', and have independent neural pathways (37). However there are few data regarding the ability to reliably assess differences in subjective liking and wanting (e.g., "That is my favorite food, but since I just ate I don't want it").

It has been reported that subjective preference of food images are affected by energy state (73-75) and this could play a role in unsuccessful dieting (76). Specifically, food deprivation increased craving and pleasantness of the viewed food items (73-75). These data are in concert with physiological measures. An enhanced startle reflex, increased blood pressure and brain activation in regions associated with attention (visual cortex), and taste (insula) have been reported in the fasted as compared to the fed state (73, 77-80).

Few data are available regarding the relations among weight status, food type and subjective hedonic value. However, increased consumption of preferred foods has been reported to be positively associated with BMI and is associated with obesity (81, 82). Obese individuals appear to consume a diet higher in energy density food items despite few differences in perceived sensory or hedonic attributes when compared to their lean counterparts (83).

The eating environment and portion size

The effect of large portions on food intake is well researched. The influence and change in portion sizes of the past three decades have been suggested to significantly contribute to the obesity epidemic (12). Portion sizes have increased in a near parallel rate to the rise in obesity (31) and increases in portion sizes have been shown to markedly increase food and energy intake in both children (35, 84) and adults (29, 32, 85), although few studies have reported a direct relationship between portions of food and BMI (59, 86). Currently there is a gap in the literature regarding the mechanisms by which portion size impacts intake. We hypothesize that visual presentation of a large amount of food is responsible for the portion size effect. To date no study has assessed liking and wanting of foods varied by portion size. Furthermore, few data are available regarding the individual characteristics that are associated with food liking and wanting.

Dietary restraint and disinhibition

Dietary restraint

The increase in obesity and dieting practices in the past 40 years have resulted in great interest in the effects of dietary restriction on eating behaviors and weight regulation. Dietary restraint, defined as 'a conscious effort to limit and control dietary intake, specifically to reduce or maintain weight, has been associated with altering individuals' biology and psychological attitudes surrounding food' (87). In the late 1940's Schiele and Brozek reported that dietary restraint resulted in an increase in participants' thoughts of food, participants' decision to change career paths to food-related careers, participants' stealing food items, and hanging up pictures of food instead of pin-up girls (88). Restrained eaters have an increased salivary reactivity in response to food presentation compared to non-restrained controls, suggesting cognitively restrained eaters might "desire" food more when it is presented (3). Additional studies have noted that restraint is associated with being overweight or obese status (89, 90) and fat mass and body fat percentage in women (91).

Disinhibition

Disinhibition (disinhibited eating) refers to impulsive eating or a general loss of control in relation to food consumption (87). There is consistent evidence that restrained eaters are likely to have episodes of disinhibited eating once restraint has been broken, independent of weight status (see Hawks et al. 2008 for review). These data have lead to the hypothesis that restrained eaters rely on external influences when their cognitive dietary process is challenged (92). This, in part, might be explained by changes in appetite-regulating hormones (93) and neuronal activation associated with hedonic value of food (94) as previously discussed. In a laboratory setting common ways to 'break' restraint and invoke disinhibited eating are: giving a large, calorically dense preload (e.g., a milkshake (95)), inducing a negative mood state (e.g., watching a sad movie (96)) , providing a distraction (21, 97, 98), threat of shock (5, 99) and inducing physical pain or physiological stress (4).

Study aims and hypotheses

This study aimed to develop and utilize a computer paradigm and image set to investigate individuals' perceived hedonic value of foods, that is, characteristics, similarities and differences between liking and wanting. In addition, we aimed to examine the relationships among hedonic ratings, USDA-based food categories, portion size, energy and sugar density, and participant characteristics (e.g., sex, weight status, dietary restraint). Our primary hypotheses included: liking and wanting would be positively correlated, but individuals would be able to separate the constructs; when separating food images by category, discretionary foods (desserts, energy dense foods) would be rated highest; and BMI, hunger and dietary disinhibition would be positively associated with hedonic ratings, whereas fullness and dietary restraint would have an inverse relationship with hedonic ratings. In addition, we hypothesized that overweight individuals would rate large portions of food higher for hedonic value and that energy and sugar density of food would be positively associated with hedonic ratings.

METHODS

Development of the image set

Over 600 images of food were considered for inclusion into the set including those: 1) taken by lab personnel; 2) obtained via the internet; 3) from the International Affective Picture System (100); 4) and used in previous fMRI research (74, 79). Permission was obtained to use images downloaded from the internet and from previous research. All images were matched for brightness and contrast using Microsoft Office Picture Manager® (Microsoft, Seattle WA, 2007), were sized to be at least 800x600 pixels and were converted to a JPEG file type. After the images were standardized, images were excluded if: the image quality (clarity, brightness, contrast) was poor or the food could not be easily identified; if there was an overrepresentation of a kind of food item; or if the food was presented in a manner not typical for consumption (e.g., a whole, uncut pineapple). Liquids were excluded from the image set due to the difficulty in identifying the liquid. Images were selected to represent a variety of ethnic foods and food categories as well as different portion sizes.

Food images were assigned to categories similar to food groups presented in the Health and Human Services 2005 Dietary Guidelines for Americans (52). When a mixed plate of food was shown, the category assigned represented the predominant food item in the image, as determined by five members of the research staff. If there was no predominant food, the image was placed into a "mixed dish" category. Examples of foods represented in each category and the number of images in each category can be seen in **Table 3.1**.

A total 165 food images were presented to each participant in a random order. This included 104 unique food images, 46 images of foods which varied by portion size (23 food pairs) and 15 repeated images for reliability analyses.

The 46 portion size images were all photographed by research staff. Twenty-three foods were presented in a small portion (based on one serving per manufacturer nutritional facts label or USDA guidelines) and a large portion (double the small portion). Each of the portion size images was taken with identical presentation on the same plate in the same lighting. The angle and distance from which these images were taken were based on how an average height male (5' 10") would see a food if seated at a table.

Table 3.1.
Descriptive information of the food images and their categories

	Number of Images Included	Examples of Foods in Each Category
Fruit	18	-Strawberries, ready to eat oranges and mixed fruit platters
Discretionary foods	21	-Brownies, ice cream, cakes and high calorie savory foods such as French fries, and potato chips.
Grains	16	-Breads, pastas, bagels and cereals
Dairy	5	-Different types of cheese and butter
Vegetables	15	-Broccoli, baked potatoes, peas and mixed vegetable dishes such as a salad or salsa
Mixed dishes	28	-A plate with eggs and hash browns, a basket of fish and chips and pizza with meat and vegetable toppings
Protein	24	-A steak, chicken, seafood, and eggs
Total	127	

For reliability analyses, five sets of 15 images were randomly selected from the original 150. One of the five sets was imbedded randomly into the original set of 150 images for each participant. Thus, each participant rated a total of 165 images in their session. Across the entire sample of participants, reliability data was collected on a total of 75 different images (5 sets of 15 images). Reliability was not assessed on all 150 images to minimize participant burden.

ImageRate

The computer program ImageRate was written in Microsoft Office Access® (Microsoft, Seattle WA, 2007) and presented images one at a time in a random order. Hedonic ratings were assessed for each image by visual analog scales (VAS; 0-100) measuring liking and wanting for the food presented in the image. The question measuring liking was phrased 'How appealing is this food?' anchored by 'Not appealing at all' to 'Extremely appealing.' The question to measuring wanting was phrased, 'How much do you desire to eat this food?' anchored by 'I have no desire to eat this food' to 'I have a strong desire to eat this food.' An additional VAS assessed image quality and was used as a covariate in exploratory analyses. Image quality was defined as 'the clarity and quality of the image independent of the food item presented.' The VAS were presented under the image of the food one at a time and participants progressed at their own pace.

Measures and procedures

Participants were recruited via flyer, email distribution lists and website message boards in the Denver Metro and Northern Colorado areas. Individuals were excluded if they had a visual disability that would affect the ability to differentiate colors or impair seeing in the dark or any developmental impairment that could impact data collection.

Each participant attended one session conducted either at the University of Colorado Denver or Colorado State University. Once informed consent was reviewed and obtained, participants were first asked to drink ≥ 80% of a Boost® nutritional drink (Nestlé HealthCare Nutrition, Fremont, MI 2008) to control for individuals' hunger/fullness levels across the sample. The nutritional drink contained 240 kcal, 10 grams of protein and 4 grams of fat. A gap of 15 minutes was placed between consumption of the nutritional drink and hedonic ratings to allow for the satiating effect of the supplement to occur. Participants were then asked to fill out VAS for hunger and fullness (0-100; ranging from not hungry/full at all to extremely hungry/full) prior to the ImageRate procedure.

The participant was given instructions on how to use the ImageRate program and given the opportunity to practice with the assistance of the researcher to ensure complete understanding of the procedures. All ratings were completed on the same 17 inch computer monitor in a quiet, dimly lit, private room. Once the image rating was finished, the participant then completed the Three Factor Eating Questionnaire (67). The TFEQ has been validated and has demonstrated good reliability (67). Constructs of interest for this investigation were dietary restraint (range 0-21) and dietary disinhibition (range 0-16). At the end of the session participant's height and weight were measured with a standardized scale and stadiometer. All procedures and measures were approved by the Colorado Multiple Institutional Review Board.

Statistical analyses

The goals of the statistical analyses were the following: 1) to investigate individuals' ratings of the hedonic value of foods, food categories and the reliability of those ratings; 2) to examine the data for differences between liking and wanting; 3) to determine if relations exist between hedonic ratings and participant characteristics (e.g., weight status, reported energy state, dietary restraint and disinhibition); 4) to perform higher level and exploratory analyses including covariates (weight status, sex, fullness and dietary restraint); and 5) to investigate the impact of food characteristics (e.g., energy density and portion size) on hedonic ratings. Statistical analyses were performed using SAS Version 9.1 (SAS Institute Inc, Cary, NC 2003). All tests were two-sided, with the significance level set at $P < 0.05$. Data are presented as mean ± standard deviation (SD) unless otherwise specified.

Descriptive statistics were performed on all data including means, SD, standard error of the means (SEM) and range by sex and weight status. Weight status was determined by calculating body mass index (BMI; kg/m^2) and then BMIs were dichotomized into lean (BMI < 25) and overweight (BMI ≥ 25) groups. Independent measures t-tests were used to compare participant characteristics by sex and weight status.

Liking and wanting were analyzed using independent measures t-tests and analysis of variance (ANOVA) to study differences in ratings among food categories, and liking and wanting for each food category. Correlations and Cronbach's α were calculated to assess test/retest reliability utilizing the repeated images that were imbedded into the image set. Pearson correlations were used to analyze the relationships among liking and wanting by food category and participant characteristics. Participant characteristics of interest included: BMI, hunger, fullness and dietary restraint and disinhibition. Correlations of the participants' characteristics with hedonic ratings were analyzed by sex as well as weight status.

Higher level models and exploratory analyses using mixed model techniques were used to further study liking and wanting. Full models included the covariates: image quality, weight status, sex, fullness, dietary restraint and disinhibition, as well as interactions. To reduce the models, interactions and variables were removed in a stepwise fashion if $P > 0.10$. Image quality was included in exploratory analyses to provide additional insight to liking and wanting, by controlling for the non-food aspects of the picture (e.g., clarity, color, contrast).

To study the effect of portion size on hedonic ratings, difference scores were calculated between ratings for the large and small portions. Mixed model analyses were used including weight status, sex, level of fullness and all interactions to study the effect of portion size. In the case of a significant interaction, least squared means were compared using a Tukey-Kramer adjustment for multiple comparisons.

The USDA Food Database was used for the dietary analyses of the energy (kcal/food (g)) and sugar densities (sugar (g)/food (g)) (101). In the case that the sugar density was < 0.0001, that food image was eliminated from any sugar density analyses. Correlational analyses were used to study the relationship between hedonic ratings and energy and sugar densities.

RESULTS

A total of 130 individuals (M=56, F=74) completed the study. One woman was excluded from analysis due to an outlying BMI (62.4). This exclusion was based on graphical observations, standardized residuals and measures of influence. Her BMI was four SD above the mean and a Cook's Distance greater than 1 revealed that her BMI was an overly influential data point, and thus she was eliminated from further analyses. All subsequent analyses are presented on the remaining 129 participants. Demographic information and participant characteristics are presented in **Table 3.2**. The mean age of the entire sample was in mid-thirties. They reported relatively low levels of dietary restraint (8.6 out of 21) and disinhibition (5.9 out of 16). Men reported being hungrier and less full than women.

Table 3.2.
Sample description and characteristics[1]

	Men	Women	Total
N	56	73	129
Age (y)	34.5 (11.2)	33.3 (11.3)	33.8 (11.5)
BMI	26.0 (5.5)	25.7 (7.8)	25.9 (6.8)
Education (y)	16.1 (1.2)*	15.5 (1.7)	15.7 (1.5)
Dietary Restraint[2]	8.1 (4.5)	9.0 (4.5)	8.6 (4.5)
Dietary Disinhibition[2]	5.3 (3.3)	6.4 (3.7)	5.9 (3.6)
Hunger	35.0 (23.3)*	25.2 (21.3)	29.5 (22.6
Fullness	45.6 (23.9)*	59.0 (22.1)	53.2 (23.7)

[1]Values are presented in mean (SD)
*Different letters indicate significant differences between men and women $P < 0.05$
[2] Measured via the Three Factor Eating Questionnaire (67)

No significant differences in age, BMI, dietary restraint or dietary disinhibition were found between men and women. Seventy-four participants (M=27, F=47) were classified as lean (BMI 21.6 ± 1.9) and 55 participants (M=29, F=26) were classified as overweight (BMI 31.7 ± 6.8). Overweight participants were significantly heavier ($P < 0.001$) and older (37.6y ± 11.6 vs. 30.9y ± 10.6; $P < 0.05$) than their lean counterparts. No other significant differences were found between men and women in the subsequent analyses unless noted.

Hedonic ratings, food categories and reliability

The overall mean ratings for liking and wanting are presented in **Table 3.3.** Liking was significantly higher than wanting and liking and wanting were positively correlated ($r = 0.57$, $P < 0.001$). When looking at the food categories, fruit had a mean liking rating of 71.8, which was significantly higher than all other food categories (ratings ranged from 49.3-61.7). A similar pattern was observed in wanting (Table 3.3).

Table 3.3.
Differences between food categories[1]

	Liking	Wanting
Fruit	71.8 (12.7)*#	59.7 (19.9)*
Discretionary foods	61.7 (14.1)#	45.9 (21.6)
Grains	58.1 (13.9)#	44.3 (21.0)
Dairy	49.3 (17.8)#	38.3 (21.8)
Vegetables	56.2 (13.2)#	41.5 (19.3)
Mixed dishes	55.2 (14.9)#	42.6 (21.6)
Protein	53.4 (17.8)#	40.9 (23.6)
Total	57.9 (11.6)#	44.7 (18.0)

[1]Values are presented in mean (SD).
*Fruit was rated significantly higher than all other food categories in liking and wanting ($P < 0.05$).
#Liking was rated significantly higher than wanting in each food category and overall ($P < 0.05$).

Measures of reliability for ratings of liking and wanting were high for both test-retest reliability and internal consistency: liking ($r = 0.91$, Cronbach's $\alpha = 0.95$; $P < 0.001$) and wanting ($r = 0.91$, Cronbach's $\alpha = 0.95$; $P < 0.001$).

Participant characteristics, energy state and reported eating behaviors associations with hedonic ratings

Body mass index

BMI was positively associated with ratings for wanting, but not liking (**Table 3.4**). The relationship between BMI and hedonic ratings was significant in overweight men (liking: $r = 0.39$, $P < 0.05$; wanting: $r = 0.48$, $P < 0.01$) but not in lean men or women.

When looking at the relationship between weight status and hedonic ratings by food category, BMI was the only significant correlate of liking ratings for discretionary foods (Table 4). The relationship between BMI and wanting discretionary foods was driven by overweight individuals in that BMI was correlated with wanting discretionary foods in overweight ($r = 0.38$, $P < 0.01$), but not lean, individuals. Discretionary foods, grains, vegetables, and protein all had a similar strength of positive correlation with BMI for wanting, followed closely by trending relationship with mixed dishes and dairy foods. For ratings of wanting the fruit category was the only category not significantly correlated (or trending towards significance) to BMI.

Hunger and fullness

Hunger and fullness were associated with wanting in the directions one would anticipate: i.e., as hunger increased, wanting increased and as fullness increased, wanting decreased. However, neither hunger nor fullness were associated with liking (Table 3.4). When analyzed by weight status, the relationship between hunger and liking was significant for overweight ($r = 0.27$, $P = 0.05$), but not lean individuals ($P = 0.37$), indicating that lean individuals may be able to better differentiate between feelings of hunger and how much they like a food.

Analyses of the hedonic ratings by food categories revealed that only mixed dishes and protein were associated with hunger and fullness for both liking and wanting (Table 3.4). The only categories not significantly associated with ratings for wanting and hunger and fullness were discretionary foods and fruits.

Table 3.4.
Pearson correlations among hedonic ratings by food category and participant characteristics

	BMI	Hunger	Fullness	Dietary Restraint	Dietary Disinhibition
Liking					
All foods (total)	.15	.16	-.10	-.11	-.08
Fruits	.02	-.12	.12	.02	-.12
Discretionary foods	**.29****	-.03	-.01	-.07	.03
Grains	.13	.15	-.14	-.10	-.04
Dairy	.01	.12	-.01	-.04	-.12
Vegetables	.10	.06	-.04	-.07	-.07
Mixed Dishes	.12	**.30****	**-.23***	-.14	-.01
Protein	.13	**.29****	**-.20***	-.16	-.07
Wanting					
All Foods (total)	**.20***	**.34****	**-.24****	**-.21***	.11
Fruits	.04	.06	-.01	-.11	.02
Discretionary foods	**.20***	.09	-.07	-.15	**.19***
Grains	**.19***	**.30****	**-.25****	**-.21***	.15
Dairy	.16^	**.36****	**-.24****	-.09	.08
Vegetables	**.18***	**.31****	**-.22***	**-.19***	.07
Mixed Dishes	.17^	**.41****	**-.32****	**-.21***	.12
Protein	**.19***	**.41****	**-.29****	**-.24****	.05

**$P < 0.01$
*$P < 0.05$
^$P = 0.05$

Dietary restraint and disinhibition

Reported dietary restraint was negatively correlated to the total score for wanting but not significantly related to liking, whereas disinhibition was not significantly associated with either liking or wanting (Table 3.4). The relationship between wanting and dietary restraint was significant in lean (r = -0.24, $P < 0.05$), but not overweight individuals.

When analyzed by food category, restraint was negatively associated with wanting grains, vegetables, mixed dishes and protein, but was not related to fruits, discretionary foods or dairy (Table 3.4). Similar to the findings with hunger and fullness, the two highest rated categories i.e., discretionary foods and fruits, were not associated with restraint. Disinhibition was positively correlated with wanting discretionary foods (Table 3.4).

Higher level analyses

To further understand how liking and wanting relate regression models were built using liking, covariates (weight status, sex, fullness and dietary restraint) and interaction terms to predict wanting. The full model predicting wanting was strong ($r^2 = 0.39$, $P < 0.001$). When reduced, the model still accounted for 35% of the variance ($r^2 = 0.35$, $P < 0.001$) yet only liking ($P < 0.001$) and fullness ($P < 0.05$) remained in the model. The standardized β coefficients for both liking (0.54) and fullness (-0.16) were in the direction one would expect in that as liking increased, wanting increased and as fullness decreased, wanting increased.

We tested the influence of image quality on liking and wanting ratings using multiple regression techniques. The full model for liking including independent variables (image quality, weight status, sex, fullness and dietary restraint) was significant ($r^2 = 0.34$, $P < 0.001$). After the using the backward stepwise technique eliminating non-significant variables, only image quality ($P < 0.001$) significantly contributed to the model. In the model predicting wanting, only fullness ($P < 0.05$) and dietary restraint ($P = 0.06$), remained in the reduced model. In the reduced model predicting wanting, the standardized β coefficients for both fullness and restraint were negative (-0.20 and -0.17 respectively).

Portion size

Independent sample t-tests revealed that individuals rated large portions higher than small portions for both liking (mean difference score 2.6 ± 4.4; $P < 0.001$) and wanting (mean difference score 1.6 ± 3.9; $P < 0.001$). Regression analyses of the full model (including weight status, sex, fullness and dietary restraint as covariates) for liking yielded no significant main effect of portion size. In contrast, main effects of weight status and portion size were observed for ratings of wanting. Overweight participants' difference scores were significantly higher than lean individuals' scores for wanting (2.3 ± 0.5 v. 0.8 ± 0.5; $P < 0.05$). In addition, a significant weight status by sex interaction was observed ($P < 0.05$). Specifically, overweight men's difference scores were larger compared to lean men's scores (2.7 ± 0.7 v. -0.3 ± 0.8; $P < 0.05$).

Energy and sugar densities

Simple correlation analyses among scores for liking, wanting, and energy and sugar densities of the foods were analyzed. Liking and wanting were negatively correlated with energy density of the foods presented in the images ($r = -0.27$, $P < 0.01$; r

= -0.27, $P < 0.01$ for all foods respectively). In contrast to energy density, the sugar density of the foods was positively correlated with both liking ($r = 0.28$, $P < 0.01$) and wanting ($r = 0.23$, $P < 0.01$). That is, as the sugar density of the foods increased the hedonic ratings increased.

DISCUSSION

The primary aims of the study were twofold: 1) to develop a reliable paradigm that can differentiate between liking and wanting of a wide variety of food items; and 2) to assess the relationships among hedonic ratings, individual traits and food characteristics. Our results demonstrate that ImageRate is a reliable measure that can be used to study hedonic ratings in men and women of varying ages. As evident by differing relations with various dependent variables, we confirmed our hypotheses that liking and wanting were highly correlated and participants were able to differentiate between the two constructs. Differing from our hypotheses, we found that the fruit category, not the discretionary foods category, was rated highest. We confirmed our hypotheses that BMI was positively associated with hedonic ratings and dietary restraint was negatively associated with hedonic ratings. However, in both of these cases this was true for wanting, but not for liking. Our hypotheses regarding the negative relationship between hedonic ratings and reported fullness and hunger were partially correct. We confirmed that wanting ratings were positively associated with hunger and negatively associated with fullness. In addition, overweight individuals rated large portions of food higher than smaller portions for wanting. Contrary to our hypothesis, energy density of food was not positively associated with hedonic ratings.

Liking and wanting were highly correlated, but numerous results in the present study were significant in one of these constructs but not the other indicating participants discriminated between the two constructs. For example, liking was consistently rated higher than wanting, and hunger and fullness were associated with wanting but not liking. Rationale for these differences could be related to the satiating effects of the nutritional shake consumed. In other words, when feeling full, one would want to consume a food less, but might still prefer or 'like' that food item. Because fullness is a temporary state, we hypothesize that individuals interpreted wanting as an immediate, variable sensation (e.g., "I want this food right now"), whereas liking is more of a generalized, stable feeling. To directly address this hypothesis, one would have to assess ratings for liking and wanting in a fed and fasted state. Based on data reported by Finlayson et al., we hypothesize that if this study was replicated in the fasted state ratings for wanting would be more similar to liking (75). In addition, this hypothesis raises the question whether liking and wanting are developed in the same manner. It is a common theory that taste preference (in this case liking) is in large part based on conditioning from repeated exposure and positive reinforcement from highly palatable foods (102, 103). But it is unclear how individuals develop wanting and differentiate wanting from liking. The development and decision making underlying wanting may be more complex than liking given it is possibly more influenced by energy state and dietary behaviors such as restraint. For example, our data suggest that as lean individuals' restraint increases, their wanting a food decreases, while overweight individuals dietary restraint does not relate to their wanting to eat a food.

Additional observations in the present study suggest that the discrimination between liking and wanting might be mediated by weight status. For example, BMI was related to wanting, but not liking. This could indicate two things: 1) that a desire to eat a food item plays a larger role in weight status than a preference for a food item, and 2) heavier individuals reported wanting foods more possibly because food was presented , suggesting that overweight individuals in a fed state may be more susceptible to environmental food cues. Further, when separated by weight status, the relationship between hunger and liking was only significant for overweight individuals, indicating that lean individuals may be able to better differentiate between feelings of hunger and how much they like a food. The information that overweight individuals are less likely to differentiate between hunger and liking a food item, indicating that overweight individuals food intake could be more influenced by hedonic properties of food rather than homeostatic mechanisms, which has been hypothesized to be related in excess consumption and development of obesity (39, 42, 104, 105).

Interestingly we found that the fruit category was rated considerably higher than all other food categories in both liking and wanting. The seasonality of fruit could influence these ratings, because fruit's appearance, taste and cost vary by the time of year. A seasonality effect is unlikely given data collection occurred from late summer to mid-winter spanning multiple seasons. Fruit's sweetness and/or the colorful nature of fruit could be responsible for this finding. It has been reported that individuals are born with an innate preference for sweet (106) and thus it is possible that there is inborn foundation for the higher ratings of fruit. In addition, individuals' weight status was related to wanting to eat most foods, but not fruit, possibly because fruits are generally low in energy density due to the water content, sweet, and for the most part perceived as healthy.

Contrary to our hypotheses we found a negative relationship between hedonic ratings and energy density but a positive relationship with ratings and sugar density. This could be driven by high ratings for fruit which are high in sugar, but generally low in energy density and lower ratings for meats (which can be more energy dense). The energy state of the individuals could also play a role in this finding, where being in a fed state has been reported to reduce preference of higher fat foods (103).

However, analyses of energy state and wanting by food categories revealed that only the two 'sweetest' tasting (and highest rated) food categories, that is, discretionary foods and fruits, were not associated with hunger or fullness. Similar to these findings, these two categories were not associated with restraint. These data suggest that discretionary foods and fruits might be foods commonly eaten outside of hunger and continued to be consumed even when feeling full. Eating despite feeling full could play a role in weight regulation (107-110). Supporting this notion, we observed that BMI was positively associated with wanting discretionary foods, however discretionary foods' ratings had no association with hunger or fullness. This indicates that overweight individuals may perceive highly palatable foods as more desirable and thus may be more likely to consume them despite being in a fed state.

We found that increasing portion size of the foods presented had no effect on perceived liking of the food, but did increase how much individuals wanted to eat the foods. This effect was greater in overweight individuals, particularly overweight men. This also supports the hypothesis that individuals discriminated between liking and wanting and that differences in liking and wanting could be mediated by weight status. Specifically, overweight individuals could be stimulated to want to eat a larger amount of food, overriding homeostatic mechanisms of energy balance, by a visual food cue. This could play a role in weight regulation given an increased wanting to eat a large portion could trigger selection of a larger portion, which has been demonstrated to increase intake (29, 32, 85).

It is important to acknowledge that there are multiple sensory inputs and feedback mechanisms responsible for eating behavior. This study specifically focused on the individual's response to the visual cue of the foods, independent of smell, and taste while controlling for energy state. It is reasonable to suggest that visual food cues contribute to food selection and meal initiation, and thus can be thought of an anticipatory cue to consumption. It has been reported that food anticipation can elicit a greater neural response than consumption of food in reward related areas of the brain (111). It has also been reported that brain activation in reward related areas of the brain in response to food cues is positively correlated to BMI (51, 112). These data and results from the present study provide evidence of the importance of visual food cues on intake and weight regulation.

CONCLUSIONS

This study has resulted in a reliable computer paradigm that can assess and differentiate between liking and wanting of foods and has presented valuable information regarding these constructs. As evident by data presented here, liking and wanting relate to the perception of foods in different ways and weight status could play a role in mediating these relationships. It is also evident that food characteristics, i.e., portion size and energy and sugar densities, and individual characteristics that is, weight status and reported dietary behaviors, should also be considered when assessing the hedonic value of food images. It is unclear which construct, liking or wanting, is a better predictor of taste preference and food intake. Nor is it known if liking or wanting is associated with any physiological measure (e.g., neural activation in response to food images). Understanding these aspects of eating behavior will further increase the understanding the relation between eating behavior and weight regulation.

CHAPTER 4

HEDONIC RATINGS AND REPORTED EATING BEHAVIORS RELATIONS' WITH BRAIN ACTIVATION

INTRODUCTION

The omnipresence of visual food cues in today's environment is a likely contributor to the current obesity epidemic (7, 10). These visual cues can promote a shift from individuals adhering to internal homeostatic mechanisms that guide eating behaviors, to eating in response to external cues like the hedonic properties of food (41, 113). Neuroimaging studies that incorporate food-related visual stimuli have provided insight to the integration of physiologic and hedonic regulation of intake and weight regulation. Frequently these types of studies compare images of foods that are deemed highly palatable, considered to have a positive hedonic value (79, 80, 114, 115), or are calorically dense (50, 72, 116) to images of foods that are neutral or low calorie foods. The underlying premise in these studies is that the participants themselves prefer the highly palatable or calorically dense food items (e.g., ice cream, cakes). Yet personality-linked differences in neural responses to food images have been reported (53). The present knowledge of the association between food cue-elicited neural processes and individual food preferences is limited. The ability to draw conclusions about how much an individual likes a food, and their brain reactivity to that food will, add considerably to the understanding of the regulation of food intake.

The hedonic value of foods plays a large role in eating behavior. Studying food reward related to brain responses has greatly increased the understanding of the effects of food as a visual cue. The inferior visual cortex (associated with visual processing and attention), insula (related to memory of the rewarding effects of food and taste) orbitofrontal cortex (OFC; associated with desire for food and food reward), prefrontal cortex (PFC; food reward) and anterior cingulate cortex (ACC; food reward) have consistently been reported to be activated in response to images chosen by the investigators and thought to be highly palatable (79, 80, 117, 118) and high calorie foods (72, 112, 119, 120). Unfortunately, few studies have attempted to connect individuals' preferences of food (subjective hedonic value) to their neural activation (121, 122). Subjective preference of (non-food) odors has been reported to be associated with activation of the OFC and PFC (123). Taste preference of liquids have been linked with activation and the OFC (121) the PFC (122). Investigators are currently making assumptions about the food preference of their participants and interpreting results based on these assumptions. Without a better understanding about the relationship between the individuals' perceived hedonic value of foods presented in functional neuroimaging studies and their neural activation, we are significantly hindered in our ability to draw precise conclusions.

Dietary restraint, defined as 'a conscious effort to limit and control dietary intake, specifically to reduce or maintain weight, has been associated with altering individuals' biology and psychological attitudes surrounding food (87).' Neuroimaging studies of successful dieters have reported increased dorsal prefrontal cortex (DPFC; associated with behavioral control) in response to a meal (124) and food images (49, 114). DelPargi and colleagues also reported that, in response to feeding, individuals' dietary restraint scores were inversely correlated with activation of the OFC, indicating that when fed, restraint could operate to discourage further intake by suppressing activation of a reward-related area of the brain. On the contrary, Colletta and colleagues reported that when fed and shown pictures of palatable foods, restrained eaters showed activation in the OFC, the insula, as well as the PFC (114). They also reported that unrestrained eaters had activation in cingulate gyrus (shown to be activated at the termination of a meal and emotional response) and parahippocampus [connected with memory function and reward anticipation (114)]. These differences could be attributed to the way restraint was assessed (Restraint Scale (125) vs Three Factor Eating Questionnaire (67)) and the way it was treated statistically (dichotomization of restraint vs. treating restraint as a continuous variable).

Disinhibition indicates a general loss of control in relation to food consumption (87). There is consistent evidence that restrained eaters are likely to have episodes of disinhibited eating once restraint has been broken (87). To date, no functional neuroimaging study has reported relations between disinhibition and brain activation in response to food images. Binge eating and emotional eating are constructs that share behavioral characteristics of disinhibition. Unlike disinhibition, brain activation in response to food-related stimuli has been reported in binge eaters and emotional eaters. Bohon and colleagues reported that emotional eaters had significant activation in the parahippocampus gyrus (memory, reward anticipation) when anticipating food reward (126) whereas, binge eaters showed activation in the visual cortex, insula and OFC and anterior cingulate cortex (127, 128).

Differences in brain responses to food images when participants are fed versus when they are fasted have been reported throughout the literature. When men and women feel hungry or are in a fasted state, there is increased activation of the OFC, insula and visual cortex when shown pictures of food items compared to when they are fed (80, 117, 118, 129, 130). This suggests that when fasted, individuals have a heightened attention and reward-related reactivity to food stimuli. When normal weight individuals were shown pictures of food with positive hedonic value versus images of "neutral" foods in a eucaloric state, there was increased activation of the visual cortex and insula (79), indicating increased attention and possible memory of taste reward. When the same individuals were overfed for two days this activation attenuated. Using a similar paradigm, our lab reported that reduced obese individuals' activation of the visual cortex and insula remained despite two days of over feeding (80). Based on these data it is clear that energy state interacts with other individuals' characteristics (e.g., weight) and brain activation.

The primary aim of this exploratory study was to investigate relations between brain activation in response and food images to subjective hedonic ratings. Few functional neuroimaging studies to date have examined the association between brain activation and subjective ratings and reported eating behaviors. We examined regions of interest (ROI) based on the literature previously discussed. We hypothesized that subjective hedonic ratings would be positively correlated with brain regions associated with: visual attention (inferior visual cortex), memory of the rewarding effects of food and taste (insula) and the interface between emotion and memory, as well as evaluating reward/decision making and risk evaluation (cingulate gyrus). The secondary aim of this study was to examine the relationship between brain activation and reported eating behaviors, specifically dietary restraint and disinhibition. We proposed that the PFC and OFC would be inversely associated with restraint level, whereas the DPFC parahippocampus would be positively related to restraint level. And based on the binge and emotional eating literature, we chose to examine whether a relationship between disinhibition and the inferior visual cortex, insula, dorsal striatum and parahippocampus exists. The tertiary aim of this investigation was to explore the effect of energy state (fasted vs. fed) on the relationships listed in aims one and two. We anticipated that activation elicited by positive hedonic food images (primarily the visual cortex and insula) in the fasted state would be attenuated in the fed state.

METHODS

Participants

A total of 18 participants (13 women, 5 men) were studied. Eligible participants were free of metabolic, psychiatric and eating disorders. Data from these participants was collected as part of two separate ongoing studies at the University of Colorado, Denver. These studies have identical methods and all imaging took place on the same magnet at the Brain Imaging Center at the University of Colorado, Denver. All methods and procedures were approved by the Colorado Multiple Intuitional Review Board.

Study design and visual stimuli

Visual stimuli

Functional imaging was performed during which subjects were presented visual stimuli using a projector and screen system. Visual stimuli consisted of three different categories: foods of positive hedonic value (+H), foods of neutral hedonic or utilitarian value (N) and neutral nonfood objects (obj). The food images presented during the fMRI scan were primarily taken from a previous study that specifically assessed the hedonic value of food images in a large sample (see chapter 3). The +H images consisted of the top third and the N images consisted of the bottom third of the set rated in the previous study. To reduce the chance of habituation subjects were shown similar but different images during the two imaging sessions. Examples of +H images included: ice cream, chocolate cake, fruits, and pizza. Food images in the N category consisted of images of: a plain chicken breast, a bagel and a bowl of peas. In general, the +H foods were either highly palatable and/or very sweet whereas, the N foods were "plain" foods. Nonfood object images (obj) were drawn from the International Affective Picture System and previously validated to be neutral (100). Examples of obj included depicted animals, trees, books, furniture, and buildings

fMRI scan

Two fMRI scans, each lasting roughly 6 minutes, were performed with each run consisting of a pseudo-randomized block design with 6 blocks of +H pictures, 6 blocks of N, 6 blocks of obj and 6 blocks of a baseline period with no visual stimuli. Each block consisted of four stimuli shown for four seconds each, for a total of 16 seconds per block. The interscan interval (TR) was set at two seconds, thus acquiring two scans per each presentation of a picture resulting in a total of 192 scans per run. Previous investigations have successfully used similar methods on the same magnet (80, 130).

ImageRate

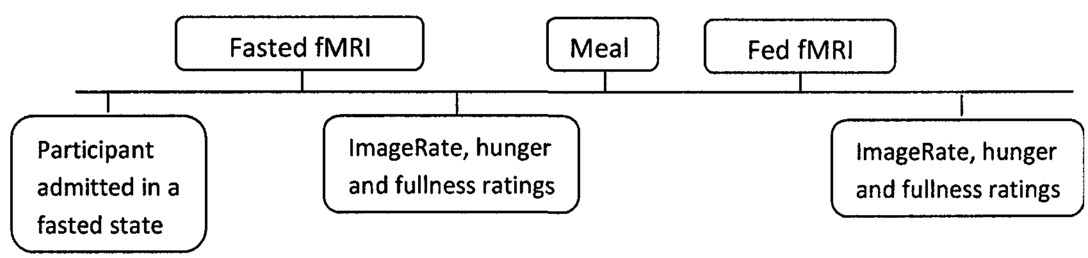
After each of the fMRI scans (fasted and fed) the participants rated food images using the ImageRate computer paradigm. In short, ImageRate presents a food image one at a time on a computer screen. The images of food were presented in a randomized order on a large computer monitor using ImageRate in a quiet room. ImageRate is computer program specifically designed to assess hedonic ratings using a scale of 0-100 (0 = not at all; 100 = extremely). ImageRate measured hedonic value by asking the participant to rate liking and wanting. Liking was assessed by asking, "how appealing the food appears in the image" and wanting was assessed by asking "participants desire to eat this food item." See chapter 3 for additional detail. Subjective hedonic ratings were only assessed for food images that were presented during the fMRI scan (+H and N). The participants rated the set of images used in the fasted scan in a randomized order after the fasted scan, and likewise for the images used in the fed scan.

Procedures

Subjects first underwent a 3-day diet diary, the Three Factor Eating Questionnaire (67), body composition measurement by dual-energy x-ray absorptiometry (DEXA; DPX whole-body scanner, Lunar Radiation Corp., Madison, WI) and measurements of resting metabolic rate (RMR) by hood indirect calorimetry (2900 metabolic cart, Sensormedics, Yorba Linda, CA). Based on baseline RMR (with an activity factor), lean body mass (via the DEXA scan), data from three day diet diary and the Harris-Benedict equation (69), daily energy needs were estimated. Results from these measures were used to calculate eucaloric energy needs, but will not be presented here.

The study day was preceded by three days of eucaloric food intake based on estimated calorie needs. All foods were prepared at the University of Colorado - Denver CTSI. Meals were either consumed at the CTSI or were given to the participants in coolers and consumed at home and uneaten food was returned. Calories from uneaten food were measured and added to the next day's meal. Participants were asked to maintain normal physical activity and refrain from consuming alcoholic and calorie containing beverages. In women, study periods were performed in the follicular phase of their menstrual cycle. Participants rated images of food for hedonic value and underwent fMRI scans twice (fasted and fed) in the same study day. Participants arrived on the study day after an overnight fast. Once the participants were admitted on the study day and the fasted scan and hedonic ratings were completed, the participants consumed a liquid meal that equaled 30% of their daily kcal needs. This was followed by the fed scan and hedonic ratings assessment. An overview of the study day can be seen in **Figure 4.1**.

Figure 4.1. Study day timeline



fMRI data acquisition and preprocessing stream

All studies were performed using a GE 3.0 T MR system equipped with high performance gradient coils (300μs rise time and maximum gradient strength 24mT/m), a head volume RF coil, whole-body RF coil, and echoplanar (EPI) capability. Functional images (fMRI) were acquired with a gradient-echo T2* Blood Oxygenation Level Dependant (BOLD) contrast technique, with TE=30 ms, TR = 2000 ms, FOV=220 mm^2, 64^2 matrix. Each data set included 30 slices, 4mm thick with no gap, angled parallel to the planum sphenoidale. These parameters have been successfully used before on this magnet in previous studies (79, 80).

Functional images were preprocessed and analyzed with SPM5 (Wellcome Department of Imaging Neruoscience, London, United Kingdom) implemented in MATLAB R2007b (The Mathworks Inc, Natick, MA). After discarding the first 4 scans from each run for saturation effects, images were realigned to the mean of that subject's images. Images were then resliced with sinc interpolation, normalized to an EPI template (resampled to a 3 x 3 x 3 mm^3) and spatially smoothed with a Gaussian kernel of 8mm full width at half maximum. In addition, data were high-pass filtered with a cutoff of 128 s to remove low frequency fluctuation in the BOLD signal.

STATISTICAL ANALYSES

fMRI analyses

At the first level of analysis, statistical parametric maps were generated for each subject by using the general linear model to describe the variability of the data on a voxel-by-voxel basis. Hypotheses expressed in terms of model parameters were assessed at each voxel with univariate statistics, yielding an image whose voxel values comprise a statistical parametric map (131). The model consisted of a hemodynamic response function-convolved boxcar function. Each individual participant's data for each condition of interest were summarized with one parametric map (accounting for within subject variance) and were then assessed across subjects in second level analyses (accounting for between-subject variance), employing a random effects model allowing inference to the population.

Whole brain analyses

The effect of image type (+H > obj and +H > N) in both the fasted and fed states was tested at the whole brain level. The resulting data are expressed in *t* maps and were considered to be significant at a threshold $P < 0.05$ corrected for multiple comparisons using the FDR (false discovery rate) technique (132).

Region of interest (ROI) analyses

In addition to the whole-brain analyses used to evaluate the main effects of stimulus type, region-of-interest analyses (ROI) were used to evaluate responses in less-powered comparisons (namely, the effect of eating conditions and regression analyses). Based on literature discussed in the introduction, the ROI's were selected for each of the comparisons of interest. The comparisons, ROIs and references of studies that the ROIs were based on can be seen in **Table 4.1**. ROI data with a $P < 0.05$ corrected using the FDR (false discovery rate) technique are considered to be significant (132). Because of the exploratory nature of the present study, if a contrast failed to yield a significant result at the $P < 0.05$; FDR, a more liberal level of significance was used. Specifically, data from the more liberal criteria are presented if $P < 0.05$ corrected for multiple comparisons on the cluster level with a threshold of $P < 0.005$. While these data are corrected for multiple comparisons, they should be interpreted with caution. The results will be identified as either as "($P < 0.05$; FDR)" for being statistically significant or "($P < 0.05$; cluster level)" for the more liberal criteria. All ROI analyses masks were based on the Talairach Daemon database (133) and were generated using the PickAtlas software toolbox (Version 2.4) in SPM5 (134, 135).

Table 4.1. Regions of Interest

Comparison	Regions of interest	Region function (Reference)
+H > N comparisons	Inferior visual cortex	Visual processing/attention (49, 79, 80, 116, 118)
	Insula	Taste/memory of food reward (50, 79, 80, 116-118, 136)
	Hypothalamus	Homeostatic intake regulation (79, 80)
+H > obj Comparisons:		
Regression with Hedonic Ratings	Inferior visual cortex	Visual processing/attention
	Insula	Taste/memory of food reward
	Cingulate gyrus	Craving, reward and emotion (50, 112, 137-139)
Regression with Restraint	Frontal lobe[1]	Food reward (114, 124)
	Hippocampus	Craving, memory (136, 137)
	Parahippocampus	Memory, reward anticipation, hunger (126, 136)
Regression with Disinhibition	Inferior visual cortex	Visual processing/attention
	Insula	Taste/memory of food reward
Regression BMI	Inferior visual cortex	Visual processing/attention
	Insula	Taste/memory of food reward
	Cingulate gyrus	Craving, reward and emotion
	Dorsal Striatum	Reward and reward anticipation (50)

[1]Areas included in the frontal lobe are the prefrontal cortex, orbitofrontal cortex and the anterior cingulate.

Neural activation regression analyses with hedonic ratings and reported eating behaviors

For the regression analyses between subjective hedonic ratings and neural activation, individual mean scores of the +H food images from ImageRate were calculated. These mean scores were then correlated with the neural activation from the +H > obj contrast. For the regression analysis between restraint and neural activation, the individual scores for restraint were regressed over activation from the +H > obj contrast. The same methods were used for disinhibition.

Functional results presented were superimposed onto the SPM single subject canonical T1-weighted anatomical template image and all coordinates are presented in standard stereotactic space as defined by the Montreal Neurological Institute standard brain (Internet: http://mni.mcgill.ca/).

Additional measures

Body mass index (BMI) of each participant was calculated as kg/m^2. Statistical analyses were performed using SAS Version 9.1 (SAS Institute Inc, Cary, NC 2003). Descriptive statistics were performed on all data including means, standard deviations, and standard error of the means as well as tests of normality for the distributions of the variables. Exploratory and graphical methods were used to examine data for outliers or other abnormalities. Independent sample t-tests were used to compare participant characteristics between men and women. Mixed model analyses (PROC MIXED, SAS Institute, Inc) were conducted to assess main effects (ImageRate question (i.e., liking & wanting,) hedonic value (+H images and Neutral food images), energy state (fasted and fed), and interactions (e.g., ImageRate question x energy state x hedonic value, ImageRate question x energy state, energy state x hedonic value). All interactions and covariates were entered into the models and removed if $P > 0.10$ according to backward stepwise regression methods. All tests were two-sided with significance levels set at $P <$ 0.05.

RESULTS

Participants

Participant characteristics are summarized in **Table 4.2**. The sample was overweight (BMI > 25 kg/m^2) and women tended to be heavier than men. Women reported higher dietary restraint scores than men ($P < 0.05$). When looking at hunger and fullness both men and women, reported hunger was higher pre-meal and fullness was higher post-meal (Table 4.2).

Table 4.2. Sample Characteristics[1]

	Men (n=5)	Women (n=13)	Total (n=18)
Age (y)	33.6 ± 3.7	32.9 ± 6.7	33.1 ± 5.9
BMI (kg/m^2)	23.4 ± 2.8	28.1 ± 6.9	26.7 ± 6.3
Dietary Restraint[2]	3.4 ± 2.9*	10.5 ± 5.4	8.4 ± 5.8
Dietary Disinhibition[2]	4.0 ± 2.3	6.8 ± 4.3	5.9 ± 3.9
Pre-meal hunger	76.0 ± 18.9	51.4 ± 29.4	58.2 ± 28.7
Pre-meal fullness	12.8 ± 13.1	22.6 ± 30.2	19.9 ± 26.6
Post-meal hunger	25.0 ± 11.7	26.5 ± 26.9	26.3 ± 23.4
Post-meal fullness	62.0 ± 25.3	63.1 ± 27.6	62.8 ± 26.3

[1]Means ± SD.
[2]Three Factor Eating Questionnaire (67).
*Significant difference between men and women ($P < 0.05$).

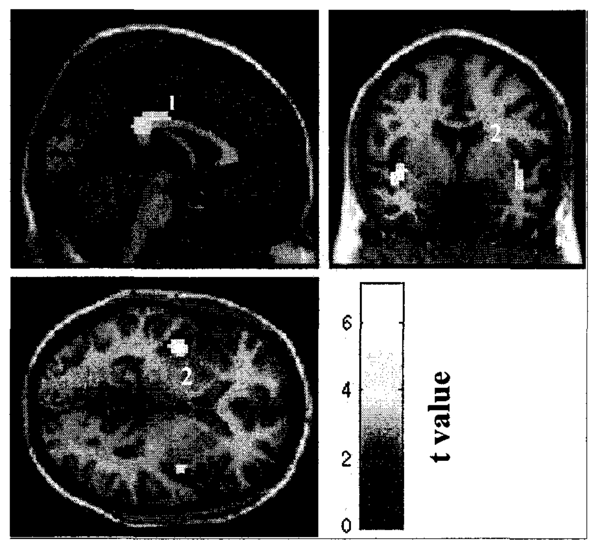
Subjective hedonic ratings

Participants' rated the +H images 18.7 points higher than the neutral food images ($P < 0.001$; scale 0-100) independent of energy state and ImageRate question (liking/wanting). Ratings in the fasted state tended to be higher than ratings performed when fed (3.4 points; $P = 0.05$). In addition, ratings for liking were significantly higher than ratings for wanting (7.3 points; $P < 0.001$) independent of energy state. No significant interaction was noted among hedonic value, the ImageRate question (liking/wanting) and energy state ($P = 0.35 - 0.62$).

Whole brain analysis of +H > obj and +H > N comparisons

While participants were in the fasted state, images of foods of positive hedonic value (+H) as compared to nonfood objects (obj) resulted in robust activation of bilateral insula and the mid/posterior limbic lobe as well as the posterior and mid cingulate ($P < 0.05$; FDR; **Figure 4.2**). Peak activation maxima coordinates were located at (-42, -7, -2) for the left insula, (42, -4, 2) for the right insula and (0, -34, 28) for the posterior cingulate. However when in the fed state, the +H > obj comparison all significant activation was attenuated. Non-significant activation was noted in the inferior visual cortex ($P = 0.33$; FDR) and corpus collosum ($P = 0.33$; FDR). The comparison +H > N failed to yield any significant results at this level. Although differences in activation between +H > N stimuli in lean individuals has been previously reported (79), the comparison of +H > N in the present study was insufficiently powered to detect significant differences.

Figure 4.2.
Activation of the bilateral insula[1] and posterior cingulate[2] in the positive hedonic foods > non-food objects (+H > obj) comparison in the fasted state.



Region of interest (ROI) analyses

+H > N comparisons

In the fasted state, activation was noted in the inferior visual cortex at ($P < 0.05$; cluster level). Conversely, the fed state +H > N contrast yielded no significant activation. Both fasted and fed failed to meet met the $P < 0.05$ FDR or cluster level criteria for the positive hedonic (+H) vs. neutral (N) foods contrast. A direct comparison of the fasted to the fed state yielded no significant results, likely due to inadequate power.

Regression of +H > obj with hedonic ratings

The regression between the subjective hedonic ratings and positive hedonic foods (+H) vs. non-food objects (obj) contrast only yielded one significant result. In the fed state, ratings of liking were correlated with the posterior cingulate gyrus ($P < 0.05$ FDR; **Table 4.3**). Wanting was not correlated with post cingulate and neither liking nor wanting correlated with this region in the fasted state. The inferior visual cortex and insula were not associated with ratings for liking or wanting in either the fasted or fed state.

Table 4.3.
Regions of interest with significant increased neural activation in response to positive hedonic compared to non-food objects (+H > obj).

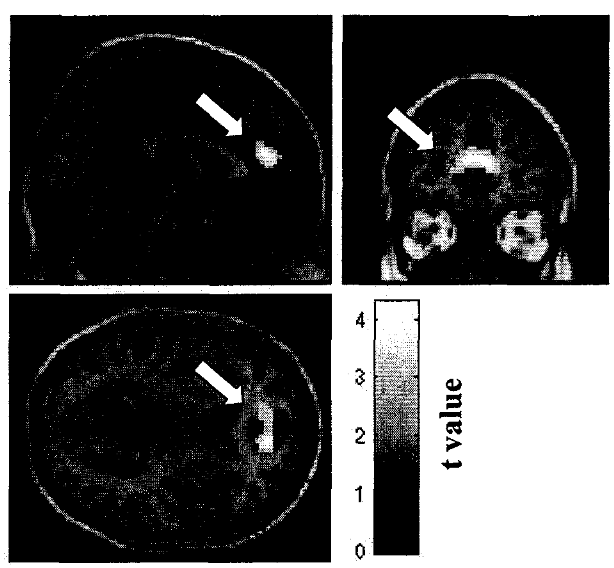
	Local maxima coordinates[1]				
	X	*y*	*z*	*t value*	*P value*[2]
Mid/posterior cingluate (L)	-3	-25	31	5.00	0.033
Posterior cingluate (L)	-12	-55	31	3.88	0.037
Posterior cingluate (R)	18	-49	28	3.78	0.041

[1]Sterotactic coordinates in MNI space (Internet: http://mni.mcgill.ca/).
[2]Correted for multiple comparisons using false discovery rate (FDR).

Regression of +H > obj with restraint and disinhibition

Dietary restraint-related activation was noted in both the fasted and fed state. Activation trending toward significance ($P = 0.08$; FDR) was observed in the fasted state in the area of left parahippocampus (-18 -19 -23). Although it was not an aim of this study to examine decreases in activation, negative restraint-related activation was detected in the anterior cingulate in the fed state ($P = 0.08$; cluster level/$P = 0.14$; FDR; **Figure 4.3**). This indicates that, in a fed state, as restraint increased, activation of this region decreased in response to +H foods. In contrast, dietary disinhibition was not associated with activation in the hypothesized ROIs (the inferior visual cortex and insula) in either the fed or fasted state.

Figure 4.3. Decreased restraint-dependant activation in the area of the anterior cingulate.



The increase in *t* value (lightening of the colorband) indicates greater decreases in activation.

Regression of +H > obj with BMI

There was non-significant BMI-related activation in the inferior visual cortex detected in the fed state ($P = 0.29$; cluster level). BMI was not associated with activation of any suprathreshold clusters in the fasted state (neither $P < 0.05$ FDR or cluster level).

DISCUSSION

The primary aim of the present study was to investigate relations between brain activation in response to positive hedonic food images and subjective ratings of liking and wanting to eat. We found that only ratings of liking in the fed state yielded significant brain activation in the region of the posterior cingulate cortex (PCC). Small and colleagues reported that the magnitude of activation of the PCC depends on the subjective appeal of available rewards (139). It has also been reported that this region is connected with the processing between memories and emotionally relevant stimuli (140, 141). Additionally, the PCC is related to risky decision making (142), choices when the amount of reward is uncertain (143) and the neuroeconomics/discounting aspects of choice and behavior i.e., evaluating immediate reward versus delayed reward or punishment (144). The PCC is located in an area that connects regions linked to processing reward, attention and action (145-147) and because of this it has been hypothesized that the PCC plays a large role in interpreting subjective assessments and evolving those signals into decisions that guide behavior (145-147).

We can interpret the liking-related PCC's activation in the present study as a result of a memory of liking a rewarding food. It is reasonable to suggest that a memory of the rewarding taste of a food was cued by the food image and the salience of this memory is correlated to how much a person reports liking a food. This suggests that liking a food is based in classical conditioning (memories of repeated exposures to food reward). To test this hypothesis, future research could present images of novel food items. If our memory hypothesis is true, one would expect not to see liking-related PCC activation in response to novel food items because there is no memory of tasting that food item.

Additionally, we can interpret the liking-related PCC's activation in response to viewing highly palatable/sweet foods while in the fed state in the context of assessing risk versus reward. While in the fed state viewing palatable/sweet foods, individuals could be cognitively evaluating the immediate reward of consuming a palatable/sweet food versus the longer term risk of consuming excess calories and possible subsequent negative consequences (e.g., weight gain resulting in poor health). A key factor in this risk/reward decision process is the amount of reward; in this case that is how much a person likes the food item. If the risk/reward hypothesis is true, one could hypothesize that risk takers might be more predisposed to consume highly palatable foods.

There was no observed liking-related activation in the fasted state. This is possible because the other aspects of the sensory system (taste) needed to be primed. It has been previously reported that the PCC response to alcohol was enhanced when primed with a relevant stimuli (smell of alcohol) (148). In this case, the priming was the taste of the meal the participants consumed prior to the fed fMRI. Also, if the risk/reward hypothesis was true, one would expect not to see activation in the PCC in the fasted state because there is less 'risk' of weight gain.

We found decreased dietary restraint-related activation in the region of the anterior cingulate cortex (ACC). The ACC (as well as the hypothesized neighboring regions the OFC, PFC) is associated with dopamine mediated pathways (149, 150) and positively associated to food reward (120, 121, 127, 151-153). Our data suggest that, in the fed state, increased levels of restraint suppress activation in food reward-related regions in the brain when exposed to palatable/sweet foods. Based on this, we hypothesize that in a fed state, restraint attempts to curb excess intake by blunting reward from highly palatable foods. If correct, this information can play a key role in developing and evaluating successful dieting strategies.

It is of note that our sample is predominantly overweight, and thus not necessarily ‘successfully’ restraining their eating. It is possible that the suppression of reward from food could increase intake (154-156). Stice and colleagues have reported that relations between lower dopamine D2 receptor density (resulting lower food reward) and overweight and weight gain (154-156). Based on this data, Stice et al. hypothesize that individuals with a suppressed level of food reward overeat in order to compensate to achieve a given level of food reward (154-156). In the context of this study, Stice’s hypothesis would suggest that restraint’s actions on the brain could result in an increase in intake. This could provide insight to the current sample’s overweight status.

The present study’s results are consistent with DelPargi and colleagues’ report that activation of the OFC in response to feeding was negatively correlated with restraint (124). In addition, DelPargi and colleagues also reported the dorsal prefrontal cortex (DPFC; related to control of inappropriate behavior responses) was positively correlated to restraint (124). We did not observe a similar activation in the DPFC. It is possible that dietary restraint functions by suppressing activation in the OFC/ACC, but is only successful in controlling weight when it is also related to DPFC activation.

DelPargi et al. and the present study's results appear to contradict those reported by Coletta and colleagues. Colletta et al. found that when fed, restrained eaters showed positive activation in the OFC and the PFC in response to palatable food images (114). These differences could be a result of differences in the feeding methods, sample characteristics, the way restraint was assessed and how restraint was treated statistically. In our and DelParigi studies, the test meals were based on a percentage of the individual estimated needs whereas in Coletta's study the test meal consisted of 500 kcal for every participant (114, 124). By basing the meal on individual needs we and DelParigi and colleagues accounted accounts for variability in body size and sex. Also, Coletta et al. reported on a considerably younger (~20 years old) sample with a lower BMI (~22.0) (114) compared to DelPagri et al.'s sample (~35 years old; BMI ~27) (124) and the present sample (33 years old; BMI ~27). Also, Colletta et al. used the Herman and Polivy's Restraint Scale (125) and dichotomized their sample into restrained and unrestrained eaters (114), whereas DelPargi et al. and the current study used the Three Factor Eating Questionnaire (67) and treated restraint as a continuous variable (124).

In concert with previous research (79, 80, 117, 118), we have shown robust activation in the visual cortex and insula in response to food images of positive hedonic value in the fasted state. These data suggest that, when viewing these types of foods in the fasted state, attention is heightened as evident by the activation of visual cortex. Rationale for the activation of the insula is somewhat less clear. The insula is primarily considered the primary taste cortex, but has been shown to be associated with regulation of eating behavior (139), memories of food reward (136) and hunger (139, 157). It is possible that, in the fasted state, the insula is activated in response to images of palatable/sweet foods and relates to an interplay between negative energy balance, memory of and anticipating taste of highly palatable, energy dense foods.

We also found that all significant activation in the fasted state was attenuated in the fed state. Our lab and others have reported similar findings (79, 158-160). We have recently reported that reduced obese individuals did not respond to overfeeding in the same manner as their lean counterparts. Specifically, reduced obese individuals' neural activation in the fasted state was not as blunted by feeding when compared to lean individuals (80). These data suggest that (even previous) weight status impacts neural responses to feeding, which could promote weight gain and regain. While the current study did not have enough power to detect differences in weight status by energy state, we did note a finding that supports this concept. We observed BMI-related activation in the visual cortex in the fed state. Although not significant at our criteria, this finding indicates that, in a fed state, overweight people are more responsive to highly palatable foods which could encourage eating outside of hunger and result in excess energy intake.

In the present study, there were a number of proposed research questions that yielded trending or non-significant results, which can be explained by the sample size and their characteristics. As in many functional neuroimanging studies, frequently due to the high cost of an fMRI scan, the study was underpowered. In addition, our sample had a disproportionate number of women. The women's BMI, although not statistically significant, were higher than the men (mean BMI of 28.1 compared to 23.4).

Another rationale for the lack of significant findings lies in the images themselves. Due to concern regarding habituation effects, additional previously unrated images were added to the image set. These images were chosen by the research staff based on similarities to images in the top (for +H foods) and bottom (for N foods) tertiles from the study presented in chapter 3. Nevertheless, the validity and reliability of these images has not been assessed.

Also one can consider the study design, specifically the manner in which the food images were presented. The present study was a secondary analysis of data collected from two separate studies, each with different aims. The images were presented in the scanner in a block design. For example, four +H images were shown in a row to make one block of +H images. This reduces the food images into a dichotomy (+H or N); whereas the manner in which the food images were subjectively rated by ImageRate was in a continuous fashion. Thus, there is a possibility that the blocks presented in the scanner in the current study did not consistently match the subjective hedonic ratings scored by the current sample. One of two alterations in future studies can be made to address this issue. One option is to base the +H and N blocks of food images on each participant's own ratings. That is, have each participant rate the images for hedonic value prior to the scan and use that individual's top and bottom tertiles as the +H and N blocks. It is likely that each individual will rate images into different blocks, but this method will directly address the relations of brain activation and subjective hedonic ratings while controlling for individual variation in food preferences. The second consideration is to alter the scanning procedures from a block design to an event related design. An event related design would enable measuring brain activation in response to each presentation of a food cue. By doing this, one could correlate neural activation to subjective hedonic rating image by image, i.e., in a continuous fashion. Either method would likely increase the ability to detect a relationship.

CONCLUSION

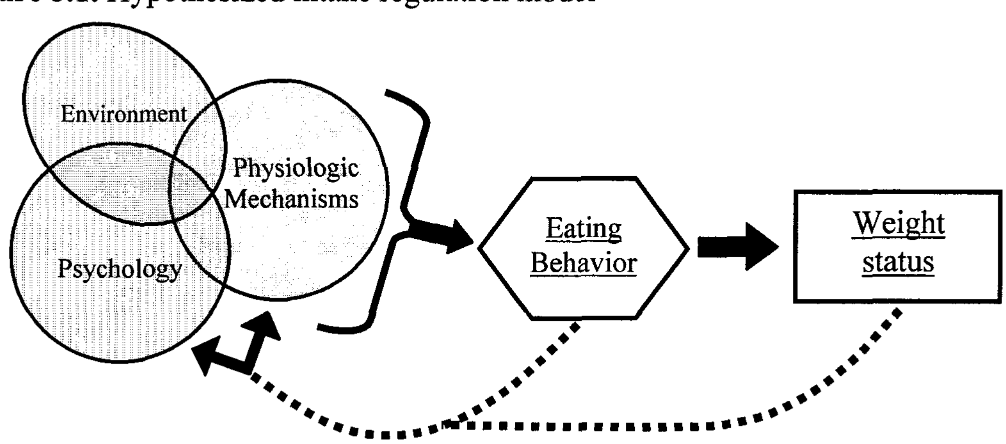
In conclusion, the present study has replicated previous research that reported activation of the visual cortex and insula in response to highly palatable/sweets foods in the fasted, but not fed state. In addition, we found evidence to suggest that the posterior cingulate cortex is related to subjective ratings of foods and the dietary restraint may operate by cognitively suppressing activation of reward related regions of the brain. Additional analyses and studies are needed to further investigate these results.

CHAPTER 5

DISCUSSION

Eating behavior is a highly complex process including physiologic mechanisms, aspects of psychology and environmental influences (**Figure 5.1**). Using this model as a framework we were able to study the effects of food as a visual cue on food intake, perception and physiology. Each of the three constructs of our model is represented by at least one of the presented studies. Alterations in visual presentation of food, that is portion size in studies one and two, characterized the influence of the environment. The psychology construct corresponded to measuring the hedonic value of visual food cues in studies two and three. Finally, to represent the physiology construct, we assessed brain activation in response to visual foods cues in study three.

Figure 5.1. Hypothesized intake regulation model



The primary aim of the first study (the feeding study) was to investigate the effects of visibility and portion size on energy intake, specifically the mechanisms underlying the portion size effect. Two of the three hypotheses were confirmed: 1) an increase in portion size resulted in a greater energy intake, particularly in overweight individuals and; 2) bite size increased in response to an increase of portion size. We also hypothesized that the removal of the visual cue of food by blindfolding would attenuate the effect of the increase in portion on energy intake. This hypothesis was not substantiated and we observed that the portion size effect remained despite blindfolding; indicating either a lasting effect of the initial visual cue or that the physical availability of more food influences intake.

In the second study (the hedonic image rating study) we aimed to develop a set of food images reliably rated for hedonic value and to investigate the relations among subjective ratings and participant and food characteristics. Confirming our hypothesis, we observed that: the images were rated reliably, that measures of liking and wanting were correlated, and individuals differentiated between the two constructs (e.g., liking was rated higher in a fed state). Overweight individuals compared to their lean counterparts reported wanting to eat larger portions of food higher without a difference in ratings of liking for these foods. Contrary to our hypothesis, the fruit category was rated the highest followed by the discretionary food category, possibly due to the innate preference for sweet taste.

In the final study (the fMRI study), we aimed to correlate brain activation in response to food images with subjective hedonic ratings of food images and reported eating behaviors. In the fed state we observed hedonic rating-related activation of the posterior cingulate cortex (PCC) as well as restraint-related decreases in activation of the anterior cingulate cortex (ACC). The PCC has been linked to emotional memories and decision making that guides behavior, particularly when evaluating risk and reward. This suggests that while fed, 'liking' ratings of palatable/sweet foods could be a result of a memory or directed by a risk/reward decision process. The ACC is commonly associated with food reward and our results indicate the dietary restraint could operate by suppressing activation of food reward regions of the brain in a fed state to discourage further intake.

Despite the different aims of the studies, under the context of our model, we can draw conclusions about intake regulation by looking at the common characteristics of the studies. For example, each study examined some aspect of the visual characteristics of food. In the case of study one the visual cue was the amount of food available, whereas in study three we explored the hedonic value based on visual characteristics of foods and in study two we assessed both the effects of the amount and hedonic value of the food.

We observed an increased energy intake in response to an increase in portion size in study one and higher ratings of wanting to eat a large portion in study two. In both of these studies individuals were visually presented with both small and large portions of the same food item. But can we infer that the subjective ratings relate to eating behavior in the context of altering the portion size? Perhaps. Although it was not previously described, the 30 participants that completed study one were among the 129 participants that completed study two. This enabled us to examine the difference scores between the large and small portions in energy intake (from study one) and hedonic ratings (from study two). The mean increase in intake as a result of the portion increase was positively correlated to the difference score in ratings for wanting ($P < 0.01$; $r = 0.37$), but not liking ($P = 0.19$; $r = -0.12$). These data support the notion the visual cue-elicited desire to eat ratings could translate into actual eating behavior, whereas reporting a preference for a food is not predictive of intake in a fed state.

The largest response to an increase in portion size in studies one and two were noted in overweight individuals suggesting that overweight individuals are more susceptible to the changes in the food environment. This notion is supported by the parallel increases in obesity and portion size over the past three decades (31). One could make a case that this increase in food intake and wanting ratings that overweight individuals demonstrated is a result of increased energy needs due to their weight status. However, all participants in study one consumed in excess of their estimated needs and hedonic ratings were assessed in a fed state. Therefore the observed differences in our data between lean and overweight are not likely associated with differences in energy needs due to weight status.

Our two primary hypotheses drawn from study one were: 1) the initial visual cue of the amount presented may influence intake independent of residual food or plate space, and 2) the physical amount of food affects how much is transferred to the spoon for a bite. The second interpretation is far less complex and is quantifiable. A study could be designed where individuals repeatedly scoop what they deem to be a normal bite size from foods varied by portion without consuming the food. We have successfully used a similar method with the aim of correlating self-served portion size to BMI (86). If the physical property hypothesis is true, individuals' scoop sizes will vary by portion in a similar matter as the bite size did in study one. However, the hedonic ratings/portion size data from study two supports the initial visual cue hypothesis. Overweight individuals responded to an increase in portion size with: 1) an increase in intake despite blindfolding (study one) and, 2) increased wanting ratings (study two). In addition, we have presented data that wanting ratings are positively correlated to intake. The visual cues in these studies were similar. The same food was presented in a small portion and then doubled to create the large portion. Also, informal observations suggest that the times that the food was presented before blindfolding in study one and the amount of time that an image was presented in study two were similar (30 seconds to 1 minute). It is highly possible that both of these hypotheses play a role in the portion size effect, but further research is needed.

It has been previously reported that liking and wanting occur via two different neural pathways (37), but it has been questioned whether behavioral researchers can experimentally detect these differences (40). We were able to demonstrate that individuals can subjectively differentiate between liking and wanting using the ImageRate paradigm in studies two and three where participants rated liking higher than wanting. We also found that in response to increased portion size, wanting, but not liking, ratings were associated with intake, whereas only liking ratings were related to brain activation. This provides evidence that a distinction can be made between liking and wanting both on the behavioral and physiological level. Further studies are needed to understand these findings. For example, one could conduct a study where participants completed food intake, hedonic rating and fMRI protocols. This within-subject design would allow comparisons to determine whether attention and/or reward regions of the brain are activated in the response to foods varied by portion.

It was observed that ratings for wanting were consistently higher than liking. Our hypothesis for this was founded in the participants' energy state. Specifically, the participants were in a fed state and had a decreased desire to eat. This could be a result of a physiologic change (stomach distention), hormonal responses (e.g., increases in leptin and insulin concentrations) and/or a cognitive choice (dietary restraint). From study three, we hypothesized that, when fed, dietary restraint functioned by decreasing potential food reward via suppression of brain activity in food reward related regions. Therefore, it is reasonable to propose that the lower ratings for wanting (compared to liking) might also be a result of the blunting of potential food reward.

In conclusion, we found evidence demonstrating the importance of food as a visual cue on the behavioral, psychological and physiological levels, as well as how these levels interact with one another. In addition, we believe that these results support the future study of an integrated intake regulation model. We propose that similar within-subject design studies that evaluate individuals' intake behavior, perception and physiological responses to variables of interest will greatly improve the understanding food intake and weight regulation.

References

1. Mokdad AH, *et al.* (2001) The continuing epidemics of obesity and diabetes in the United States. *Journal of the American Medical Association* 286(10):1195-1200.

2. de Graaf C, Blom WAM, Smeets PAM, Stafleu A, & Hendriks HFJ (2004) Biomarkers of satiation and satiety. *Am. J. Clin. Nutr.* 79(6):946-961.

3. Brunstrom JM, Yates HM, & Witcomb GL (2004) Dietary restraint and heightened reactivity to food. *Physiology & Behavior* 81(1):85-90.

4. Greeno CG & Wing RR (1994) Stress-induced eating. *Psychol. Bull.* 115(3):444-464.

5. Heatherton TF, Herman CP, & Polivy J (1991) Effects of Physical Threat and Ego Threat on Eating Behavior. *J. Pers. Soc. Psychol.* 60(1):138-143.

6. Herman CP & Polivy J (2005) Normative influences on food intake. *Physiology & Behavior* 86(5):762-772.

7. Hetherington MM (2007) Cues to overeat: psychological factors influencing overconsumption. *Proceedings of the Nutrition Society* 66(1):113-123.

8. Brunstrom JM (2007) Associative learning and the control of human dietary behavior. *Appetite* 49(1):268-271.

9. Epstein LH, Leddy JJ, Temple JL, & Faith MS (2007) Food reinforcement and eating: A multilevel analysis. *Psychol. Bull.* 133(5):884-906.

10. Hill JO & Peters JC (1998) Environmental contributions to the obesity epidemic. *Science* 280(5368):1371-1374.

11. Rolls ET (2007) Sensory processing in the brain related to the control of food intake. *Proceedings of the Nutrition Society* 66(1):96-112.

12. Rolls BJ (2003) The Supersizing of America: Portion Size and the Obesity Epidemic. *Nutr.Today* 38(2):42-53.

13. Schachter S (1968) Obesity and eating. Internal and external cues differentially affect the eating behavior of obese and normal subjects. *Science* 161(843):751-756.

14. Schachter S, Goldman R, & Gordon A (1968) Effects of Fear Food Deprivation and Obesity on Eating. *J. Pers. Soc. Psychol.* 10(2):91-97.

15. Schachter S & Gross LP (1968) Manipulated time and eating behavior. *J Pers Soc Psychol* 10(2):98-106.

16. Bandettini P (2007) Functional MRI today. *Int. J. Psychophysiol.* 63(2):138-145.

17. Tataranni PA & DelParigi A (2003) Functional neuroimaging: a new generation of human brain studies in obesity research. *Obesity Reviews* 4(4):229.

18. de Castro JM (1990) Social facilitation of duration and size but not rate of the spontaneous meal intake of humans. *Physiology & Behavior* 47(6):1129-1135.

19. de Castro JM (1991) Social facilitation of the spontaneous meal size of humans occurs on both weekdays and weekends. *Physiology & Behavior* 49(6):1289-1291.

20. de Castro JM (1994) Family and friends produce greater social facilitation of food-intake than other companions. *Physiology & Behavior* 56(3):445-455.

21. Bellisle F & Dalix A-M (2001) Cognitive restraint can be offset by distraction, leading to increased meal intake in women. *Am J Clin Nutr* 74(2):197-200.

22. Crespo CJ, *et al.* (2001) Television watching, energy intake, and obesity in US children - Results from the Third National Health and Nutrition Examination Survey, 1988-1994. *Archives of Pediatrics & Adolescent Medicine* 155(3):360-365.

23. Halford JC, *et al.* (2008) Beyond-brand effect of television food advertisements on food choice in children: the effects of weight status. *Public Health Nutr.* 11(9):897-904.

24. Ledikwe JH, Ello-Martin JA, & Rolls BJ (2005) Portion sizes and the obesity epidemic. *Journal of Nutrition* 135(4):905-909.

25. Smiciklas-Wright H, Mitchell D, Mickle S, Goldman J, & Cook A (2003) Foods Commonly eaten in the U.S., 1989-1991 and 1994-1996: Are Portion Sizes Changing? *J.Am.Diet.Assoc.* 103 (1):41-47.

26. Nestle M (2003) Increasing portion sizes in American diets: more calories, more obesity. *J.Am.Diet.Assoc.* 103(1):39-40.

27. Rolls BJ, Morris EL, & Roe LS (2002) Portion size of food affects energy intake in normal-weight and overweight men and women. *Am.J.Clin.Nutr.* 76(6):1207-1213.

28. Rolls BJ, Roe LS, Kral TVE, Meengs JS, & Wall DE (2004) Increasing the portion size of a packaged snack increases energy intake in men and women. *Appetite* 42(1):63-69.

29. Rolls BJ, Roe LS, & Meengs JS (2007) The effect of large portion sizes on energy intake is sustained for 11 days. *Obesity (Silver Spring)* 15(6):1535-1543.

30. Rolls BJ, Roe LS, Meengs JS, & Wall DE (2004) Increasing the portion size of a sandwich increases energy intake. *J. Am. Diet. Assoc.* 104(3):367-372.

31. Young LR & Nestle M (2002) The contribution of expanding portion sizes to the US obesity epidemic. *Am.J.Public Health* 92(2):246-249.

32. Rolls BJ, Morris EL, & Roe LS (2002) Portion size of food affects energy intake in normal-weight and overweight men and women. *Am. J. Clin. Nutr.* 76(6):1207-1213.

33. Nielsen AJ & Popkin BM (2003) Patterns and trends in food portion sizes, 1977-1998. *Jama-Journal of the American Medical Association* 289(4):450-453.

34. Smiciklas-Wright H, Mitchell DC, Mickle SJ, Goldman JD, & Cook A (2003) Foods commonly eaten in the United States, 1989-1991 and 1994-1996: Are portion sizes changing? *J. Am. Diet. Assoc.* 103(1):41-47.

35. Fisher JO, Rolls BJ, & Birch LL (2003) Children's bite size and intake of an entree are greater with large portions than with age-appropriate or self-selected portions. *Am. J. Clin. Nutr.* 77(5):1164-1170.

36. Colapinto CK, Fitzgerald A, Taper LJ, & Veugelers PJ (2007) Children's preference for large portions: Prevalence, determinants, and consequences. *J. Am. Diet. Assoc.* 107(7):1183-1190.

37. Berridge KC (1996) Food reward: Brain substrates of wanting and liking. *Neuroscience and Biobehavioral Reviews* 20(1):1-25.

38. Robinson TE & Berridge KC (2000) The psychology and neurobiology of addiction: an incentive-sensitization view. *Addiction* 95(8):S91-S117.

39. Finlayson G, King N, & Blundell JE (2007) Liking vs. wanting food: Importance for human appetite control and weight regulation. *Neuroscience and Biobehavioral Reviews* 31(7):987-1002.

40. Finlayson G, King N, & Blundell JE (2007) Is it possible to dissociate 'liking' and 'wanting' for foods in humans? A novel experimental procedure. *Physiology & Behavior* 90(1):36-42.

41. Del Parigi A, Chen KW, Salbe AD, Reiman EM, & Tataranni PA (2003) Are we addicted to food? *Obes. Res.* 11(4):493-495.

42. Yeomans MR, Blundell JE, & Leshem M (2004) Palatability: response to nutritional need or need-free stimulation of appetite? *British Journal of Nutrition* 92:S3-S14.

43. Jequier E & Tappy L (1999) Regulation of body weight in humans. *Physiological Reviews* 79(2):451-480.

44. Saper CB, Chou TC, & Elmquist JK (2002) The need to feed: Homeostatic and hedonic control of eating. *Neuron* 36(2):199-211.

45. Del Parigi A, *et al.* (2000) Gender differences in brain representation of taste in obese humans: a positron emission tomography study. *Obes. Res.* 8:15S-15S.

46. Berthoud HR (2006) Homeostatic and non-homeostatic pathways involved in the control of food intake and energy balance. *Obesity (Silver Spring)* 14:197-200.

47. Davis C & Fox J (2008) Sensitivity to reward and body mass index (BMI): Evidence for a non-linear relationship. *Appetite* 50(1):43-49.

48. Roy CS & Sherrington CS (1890) On the Regulation of the Blood-supply of the Brain. *The Journal of Physiology* 11(1-2):85-158.

49. McCaffery JM, *et al.* (2009) Differential functional magnetic resonance imaging response to food pictures in successful weight-loss maintainers relative to normal-weight and obese controls. *Am J Clin Nutr*:ajcn.2009.27924.

50. Rothemund Y, *et al.* (2007) Differential activation of the dorsal striatum by high-calorie visual food stimuli in obese individuals. *Neuroimage* 37(2):410-421.

51. Stoeckel LE, *et al.* (2008) Widespread reward-system activation in obese women in response to pictures of high-calorie foods. (Translated from English) *Neuroimage* 41(2):636-647 (in English).

52. Anonymous (2005) *Dietary Guidelines for Americans* (US Department of Agriculture and Department of Health and Human Services, Washington, DC) 6th Ed.

53. Beaver JD, *et al.* (2006) Individual differences in reward drive predict neural responses to images of food. *J. Neurosci.* 26(19):5160-5166.

54. Rolls BJ, Roe LS, & Meengs JS (2006) Larger portion sizes lead to a sustained increase in energy intake over 2 days. *J. Am. Diet. Assoc.* 106(4):543-549.

55. Smith JM & Ditschun TL (2009) Controlling satiety: how environmental factors influence food intake. *Trends in Food Science & Technology* 20(6-7):271-277.

56. Wansink B & Payne CR (2007) Counting bones: Environmental cues that decrease food intake. *Perceptual and Motor Skills* 104(1):273-276.

57. Diliberti N, Bordi PL, Conklin MT, Roe LS, & Rolls BJ (2004) Increased portion size leads to increased energy intake in a restaurant meal. *Obes. Res.* 12(3):562-568.

58. Flood JE, Roe LS, & Rolls BJ (2006) The effect of increased beverage portion size on energy intake at a meal. *J. Am. Diet. Assoc.* 106(12):1984-1990.

59. Jeffery RW, *et al.* (2007) Effects of portion size on chronic energy intake. *International Journal of Behavioral Nutrition and Physical Activity* 4.

60. Fisher J, Rolls BJ, & Birch L (2003) Children's bite size and intake of an entree are greater with larger portions that with age-appropriate or self-selected portions. *Am.J.Clin.Nutr.* (77):1164-1170.

61. Wansink B, Painter JE, & Lee YK (2006) The office candy dish: proximity's influence on estimated and actual consumption. *International Journal of Obesity* 30(5):871-875.

62. Wansink B, Painter JE, & North J (2005) Bottomless bowls: Why visual cues of portion size may influence intake. *Obes. Res.* 13(1):93-100.

63. Linne V, Barkeling B, Rossner S, & Rooth P (2002) Vision and eating behavior. *Obes. Res.* 10(2):92-95.

64. Barkeling B, Linne Y, Melin E, & Rooth P (2003) Vision and eating behavior in obese subjects. *Obes. Res.* 11(1):130-134.

65. Wansink B & van Ittersum K (2003) Bottoms up! The influence of elongation on pouring and consumption volume. *Journal of Consumer Research* 30(3):455-463.

66. Wansink B & van Ittersum K (2005) Shape of glass and amount of alcohol poured: comparative study of effect of practice and concentration. *Br. Med. J.* 331(7531):1512-1514.

67. Stunkard A & Messick S (1985) The Three Factor Eating Questionnaire to Measure Dietary Restraint, Disinhibition, and Hunger. *Journal of Psychosomatic Research* 29 (1):71-83.

68. Williamson DA, *et al.* (2007) Measurement of dietary restraint: Validity tests of four questionnaires. *Appetite* 48(2):183-192.

69. Harris JAB, F.G. (1919) *A biometric study of basal metabolism in man* (Carnegie Institution of Washington, Washington DC).

70. Wansink B, van Ittersum K, & Painter JE (2006) Ice cream illusions - Bowls, spoons, and self-served portion sizes. *Am. J. Prev. Med.* 31(3):240-243.

71. Lieberman LS (2006) Evolutionary and anthropological perspectives on optimal foraging in obesogenic environments. *Appetite* 47(1):3-9.

72. Killgore WDS, *et al.* (2003) Cortical and limbic activation during viewing of high- versus low-calorie foods. *Neuroimage* 19(4):1381-1394.

73. Drobes DJ, *et al.* (2001) Food deprivation and emotional reactions to food cues: implications for eating disorders. *Biol. Psychol.* 57(1-3):153-177.

74. Stoeckel LE, Cox JE, Cook EW, & Weller RE (2007) Motivational state modulates the hedonic value of food images differently in men and women. *Appetite* 48(2):139-144.

75. Finlayson G, King N, & Blundell J (2008) The role of implicit wanting in relation to explicit liking and wanting for food: Implications for appetite control. *Appetite* 50(1):120-127.

76. Polivy J, Herman CP, & Coelho JS (2008) Caloric restriction in the presence of attractive food cues: External cues, eating, and weight. (Pergamon-Elsevier Science Ltd), pp 729-733.

77. LaBar KS, *et al.* (2001) Hunger Selectively Modulates Corticolimbic Activation to Food Stimuli in Humans. *Behavioral Neuroscience* 115(2):493-500.

78. Stockburger J, Weike AI, Hamm AO, & Schupp HT (2008) Deprivation Selectively Modulates Brain Potentials to Food Pictures. *Behavioral Neuroscience* 122(4):936-942.

79. Cornier MA, Von Kaenel SS, Bessesen DH, & Tregellas JR (2007) Effects of overfeeding on the neuronal response to visual food cues. *American Journal of Clinical Nutrition* 86(4):965-971.

80. Cornier M-A, *et al.* (2009) The Effects of Overfeeding on the Neuronal Response to Visual Food Cues in Thin and Reduced-Obese Individuals. *PLoS ONE* 4(7):e6310.

81. Rissanen A, *et al.* (2002) Acquired preference especially for dietary fat and obesity: a study of weight-discordant monozygotic twin pairs. *Int. J. Obes.* 26(7):973-977.

82. Unusan N (2006) Linkage between stress and fruit and vegetable intake among university students: an empirical analysis on Turkish students. *Nutrition Research* 26(8):385-390.

83. Cox DN, Perry L, Moore PB, Vallis L, & Mela DJ (1999) Sensory and hedonic associations with macronutrient and energy intakes of lean and obese consumers. *Int. J. Obes.* 23(4):403-410.

84. Fisher JO, Liu Y, Birch LL, & Rolls BJ (2007) Effects of portion size and energy density on young children's intake at a meal. *Am. J. Clin. Nutr.* 86(1):174-179.

85. Levitsky DA & Youn T (2004) The more food young adults are served, the more they overeat. *Journal of Nutrition* 134(10):2546-2549.

86. Burger KS, Kern M, & Coleman KJ (2007) Characteristics of self-selected portion size in young adults. *J. Am. Diet. Assoc.* 107(4):611-618.

87. Hawks SR, Madanat HN, & Christley HS (2008) Behavioral and biological associations of dietary restraint: A review of the literature. *Ecology of Food and Nutrition* 47(5):415-449.

88. Schiele BC & Brozek J (1948) "Experimental neurosis" resulting from semistarvation in man. *Psychosom. Med.* 10(1):31-50.

89. Provencher V, *et al.* (2004) Eating behaviours, dietary profile and body composition according to dieting history in men and women of the Quebec Family Study. *British Journal of Nutrition* 91(6):997-1004.

90. Ruderman AJ, Belzer LJ, & Halperin A (1985) Restraint, anticipated consumption and overeating. *J. Abnorm. Psychol.* 94(4):547-555.

91. Beiseigel JA & Nickols-Richardson SA (2004) Cognitive eating restraint scores are associated with body fatness but not with other measures of dieting in women. *Appetite* 43(1):47-53.

92. Heatherton TF, Polivy J, & Herman CP (1989) Restraint and internal responsiveness - Effects of placebo manipulations of hunger state on eating. *J. Abnorm. Psychol.* 98(1):89-92.

93. Nishizawa T, *et al.* (2006) Emotional stress enhanced ghrelin secretion from the stomach. *Journal of Clinical Biochemistry and Nutrition* 38(1):33-37.

94. Del Parigi A, *et al.* (2003) Dietary restraint is associated with increased neural activity in cortical areas involved in the volitional control of behavior. *Obes. Res.* 11:A35-A35.

95. Polivy J (1976) Perception of calories and regulation of intake in restrained and unrestrained subjects. *Addict. Behav.* 1(3):237-243.

96. Vohs KD & Heatherton TF (2000) Self-regulatory failure: A resource-depletion approach. *Psychological Science* 11(3):249-254.

97. Ward A & Mann T (2000) Don't mind if I do: Disinhibited eating under cognitive load. pp 753-763.

98. Mitchell GL & Brunstrom JM (2005) Everyday dietary behaviour and the relationship between attention and meal size. *Appetite* 45(3):344-355.

99. Herman CP & Polivy J (1975) Anxiety, Restraint, and Eating Behavior. *J. Abnorm. Psychol.* 84(6):666-672.

100. Lang PJ, Bradley MM, & Cuthbert BN (2005) International affective picture system (IAPS): Affective ratings of pictures and instruction manual. . *Technical Report A-6. University of Florida, Gainesville, FL.*

101. U.S. Department of Agriculture ARS (2008) USDA National Nutrient Database for Standard Reference.

102. Bray S, Rangel A, Shimojo S, Balleine B, & O'Doherty JP (2008) The neural mechanisms underlying the influence of Pavlovian cues on human decision making. *J. Neurosci.* 28(22):5861-5866.

103. Kern DL, McPhee L, Fisher J, Johnson S, & Birch LL (1993) The postingestive consequences of fat condition preferences for flavors associated with high dietary-fat. *Physiology & Behavior* 54(1):71-76.

104. Berthoud HR & Morrison C (2008) The brain, appetite, and obesity. (Translated from English) *Annu. Rev. Psychol.* 59:55-92 (in English).

105. Salbe A, Venti C, DelParigi A, Drewnowski A, & Tataranni PA (2003) Taste hedonics predict ingestive behavior. *Obes. Res.* 11:A59-A59.

106. Beidler LM (1982) Bioloigcal basis of food selection. *The Psychobiology of Human Food Selection*, ed Barker LM (England Ellis Horwood Limited, Chichester, United Kingdom), pp 3-15.

107. Faith M, *et al.* (2004) Eating in the absence of hunger: A gender-related genetic marker for childhood obesity? *Obes. Res.* 12:A6-A6.

108. Faith MS, *et al.* (2006) Eating in the absence of hunger: a genetic marker for childhood obesity in prepubertal boys? *Obesity.14(1):131-8.*

109. Fisher J, Butte N, & Jaramillo S (2003) Eating in the absence of hunger as a behavioral phenotype of overweight Hispanic children. *Obes. Res.* 11:A97-A97.

110. Fisher JO & Birch LL (2002) Eating in the absence of hunger and overweight in girls from 5 to 7 y of age. *Am. J. Clin. Nutr.* 76(1):226-231.

111. O'Doherty JP, Deichmann R, Critchley HD, & Dolan RJ (2002) Neural responses during anticipation of a primary taste reward. *Neuron* 33(5):815-826.

112. Killgore WDS & Yurgelun-Todd DA (2005) Body mass predicts orbitofrontal activity during visual presentations of high-calorie foods. (Translated from English) *Neuroreport* 16(8):859-863 (in English).

113. Zheng HY & Berthoud HR (2007) Eating for pleasure or calories. *Current Opinion in Pharmacology* 7(6):607-612.

114. Coletta M, *et al.* (2009) Brain Activation in Restrained and Unrestrained Eaters: An fMRI Study. *J. Abnorm. Psychol.* 118(3):598-609.

115. Santel S, Baving L, Krauel K, Munte TF, & Rotte M (2006) Hunger and satiety in anorexia nervosa: fMRI during cognitive processing of food pictures. *Brain Res.* 1114:138-148.

116. Killgore WDS & Yurgelun-Todd DA (2007) Positive affect modulates activity in the visual cortex to images of high calorie foods. *International Journal of Neuroscience* 117(5):643-+.

117. Porubska K, Veit R, Preissl H, Fritsche A, & Birbaumer N (2006) Subjective feeling of appetite modulates brain activity: An fMRI study. *Neuroimage* 32(3):1273-1280.

118. Uher R, Treasure J, Heining M, Brammer MJ, & Campbell IC (2006) Cerebral processing of food-related stimuli: Effects of fasting and gender. (Translated from English) *Behav. Brain Res.* 169(1):111-119 (in English).

119. Killgore WDS & Yurgelun-Todd DA (2006) Affect modulates appetite-related brain activity to images of food. *International Journal of Eating Disorders* 39(5):357-363.

120. Schur EA, *et al.* (2009) Activation in brain energy regulation and reward centers by food cues varies with choice of visual stimulus. *Int. J. Obes.* 33(6):653-661.

121. Kringelbach ML, O'Doherty J, Rolls ET, & Andrews C (2003) Activation of the human orbitofrontal cortex to a liquid food stimulus is correlated with its subjective pleasantness. *Cerebral Cortex* 13(10):1064-1071.

122. McClure SM, *et al.* (2004) Neural correlates of behavioral preference for culturally familiar drinks. *Neuron* 44(2):379-387.

123. Grabenhorst F & Rolls ET (2009) Different representations of relative and absolute subjective value in the human brain. *Neuroimage* 48(1):258-268.

124. Del Parigi A, *et al.* (2007) Successful dieters have increased neural activity in cortical areas involved in the control of behavior. *Int. J. Obes.* 31(3):440-448.

125. Herman CP & Polivy J (1980) Restrained eating. *Obesity (Silver Spring)*, ed Stunkard AJ (W. B. Saunders, Philadelphia).

126. Bohon C, Stice E, & Spoor S (2009) Female Emotional Eaters Show Abnormalities in Consummatory and Anticipatory Food Reward: A Functional Magnetic Resonance Imaging Study. *International Journal of Eating Disorders* 42(3):210-221.

127. Geliebter A, *et al.* (2006) Responsivity to food stimuli in obese and lean binge eaters using functional MRI. *Appetite* 46(1):31-35.

128. Schienle A, Schafer A, Hermann A, & Vaitl D (2009) Binge-Eating Disorder: Reward Sensitivity and Brain Activation to Images of Food. *Biological Psychiatry* 65(8):654-661.

129. Fuhrer D, *et al.* (2008) Brain activity in hunger and satiety: an exploratory visually stimulated FMRI study. (Translated from English) *Obesity (Silver Spring)* 16(5):945-950 (in English).

130. Cornier MA (2009) The effects of overfeeding and propensity to weight gain on the neuronal responses to visual food cues. *Physiology & Behavior* 97(5):525-530.

131. Ashburner J & Friston KJ (2000) Voxel-based morphometry - The methods. *Neuroimage* 11(6):805-821.

132. Genovese CR, Lazar NA, & Nichols T (2002) Thresholding of statistical maps in functional neuroimaging using the false discovery rate. (Translated from English) *Neuroimage* 15(4):870-878 (in English).

133. Lancaster JL, *et al.* (2000) Automated Talairach Atlas labels for functional brain mapping. *Human Brain Mapping* 10(3):120-131.

134. Maldjian JA, Laurienti PJ, & Burdette JH (2004) Precentral gyrus discrepancy in electronic versions of the Talairach atlas. *Neuroimage* 21(1):450-455.

135. Maldjian JA, Laurienti PJ, Kraft RA, & Burdette JH (2003) An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage* 19(3):1233-1239.

136. Pelchat ML, Johnson A, Chan R, Valdez J, & Ragland JD (2004) Images of desire: food-craving activation during fMRI. *Neuroimage* 23(4):1486-1493.

137. Del Parigi A, *et al.* (2004) Persistence of abnormal neural responses to a meal in postobese individuals. *Int. J. Obes.* 28(3):370-377.

138. Killgore WDS & Yurgelun-Todd DA (2005) Developmental changes in the functional brain responses of adolescents to images of high and low-calorie foods. *Dev. Psychobiol.* 47(4):377-397.

139. Small DM, Zatorre RJ, Dagher A, Evans AC, & Jones-Gotman M (2001) Changes in brain activity related to eating chocolate - From pleasure to aversion. *Brain* 124:1720-1733.

140. Maddock RJ, Garrett AS, & Buonocore MH (2003) Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Human Brain Mapping* 18(1):30-41.

141. Fink GR, *et al.* (1996) Cerebral representation of one's own past: Neural networks involved in autobiographical memory. *J. Neurosci.* 16(13):4275-4282.

142. McCoy AN & Platt ML (2005) Risk-sensitive neurons in macaque posterior cingulate cortex. *Nat. Neurosci.* 8(9):1220-1227.

143. Smith K, Dickhaut J, McCabe K, & Pardo JV (2002) Neuronal substrates for choice under ambiguity, risk, gains, and losses. *Management Science* 48(6):711-718.

144. Kable JW & Glimcher PW (2007) The neural correlates of subjective value during intertemporal choice. *Nat. Neurosci.* 10(12):1625-1633.

145. Vogt BA, Finch DM, & Olson CR (1992) Functional Heterogeneity in Cingulate Cortex: The Anterior Executive and Posterior Evaluative Regions. *Cereb. Cortex* 2(6):435-a-443.

146. McCoy AN, Crowley JC, Haghighian G, Dean HL, & Platt ML (2003) Saccade reward signals in posterior cingulate cortex. *Neuron* 40(5):1031-1040.

147. Olson CR, Musil SY, & Goldberg ME (1996) Single neurons in posterior cingulate cortex of behaving macaque: Eye movement signals. *Journal of Neurophysiology* 76(5):3285-3300.

148. Bragulat V, *et al.* (2008) Alcohol sensitizes cerebral responses to the odors of alcoholic drinks: An fMRI study. *Alcoholism* 32(7):1124-1134.

149. Miller EK & Cohen JD (2001) An integrative theory of prefrontal cortex function. *Annu. Rev. Neurosci.* 24:167-202.

150. Schultz W (2002) Getting formal with dopamine and reward. *Neuron* 36(2):241-263.

151. Del Parigi A, Chen KW, Salbe AD, Reiman EM, & Tataranni PA (2005) Sensory experience of food and obesity: a positron emission tomography study of the brain regions affected by tasting a liquid meal after a prolonged fast. *Neuroimage* 24(2):436-443.

152. Kringelbach ML & Rolls ET (2004) The functional neuroanatomy of the human orbitofrontal cortex: evidence from neuroimaging and neuropsychology. (Translated from English) *Prog. Neurobiol.* 72(5):341-372 (in English).

153. Stoeckel LE, *et al.* (2009) Effective connectivity of a reward network in obese women. *Brain Research Bulletin* 79(6):388-395.

154. Stice E, Spoor S, Bohon C, & Small DM (2008) Relation between obesity and blunted striatal response to food is moderated by TaqIA A1 allele. *Science* 322(5900):449-452.

155. Stice E, Spoor S, Bohon C, Veldhuizen MG, & Small DM (2008) Relation of Reward From Food Intake and Anticipated Food Intake to Obesity: A Functional Magnetic Resonance Imaging Study. *J. Abnorm. Psychol.* 117(4):924-935.

156. Stice E, Spoor S, Ng J, & Zald DH (2009) Relation of obesity to consummatory and anticipatory food reward. *Physiology & Behavior* 97(5):551-560.

157. Wang GJ, *et al.* (2004) Exposure to appetitive food stimuli markedly activates the human brain. *Neuroimage* 21(4):1790-1797.

158. Gautier JF, *et al.* (2000) Differential brain responses to satiation in obese and lean men. *Diabetes* 49(5):838-846.

159. Gautier JF, *et al.* (2001) Effect of satiation on brain activity in obese and lean women. *Obes. Res.* 9(11):676-684.

160. Siep N, *et al.* (2009) Hunger is the best spice: An fMRI study of the effects of attention, hunger and calorie content on food reward processing in the amygdala and orbitofrontal cortex. *Behav. Brain Res.* 198(1):149-158.