A summary of Richard Mattes' research since 2005: Effects of food form, feeding patterns, and specific nutrients on appetite, satiety, and metabolic responses in humans

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Abstract

Hunger, satiety, and thirst, are behaviors that influence food choice, meal patterns, and energy balance. However, there are many factors that have the capability to affect hunger, satiety and thirst such as properties of beverages and foods and human characteristics. Research is being conducted on food forms (beverage versus liquid), and meal-replacement strategies to observe their effects on appetitive responses, satiety, and hormone responses. It has been found that solid foods elicit greater appetitive responses than liquid foods. Current studies are also researching specific nutrients, like protein and nuts, and their effects on appetitive responses, satiety, hormonal responses, and body weight. Protein and nuts elicit greater feelings of fullness, reduced hunger, and have positive effects on weight loss.

Currently there are four accepted tastes each with their own transduction mechanism: sweet, sour, bitter, and salty. Recently there has been attention brought to fatty acids and the belief that “fatty” is also a taste. However studies have failed to find a transduction mechanism for fatty acids. Therefore current research is focusing on aspects of a transduction mechanism for fatty acids. Studies have found that humans can detect short-, medium-, and long-chained fatty acids, regardless of their saturation, and have the ability to detect threshold changes when fatty acids are the primary stimuli.

Dr. Richard Mattes is a professor of Food and Nutrition at Purdue University. This is a literature review of his most recent work. Since 2005, Dr. Mattes has done extensive research on both the factors that affect appetitive responses, as well as the effects of specific nutrients such as protein and nuts, and possible aspects of transduction mechanisms.
Introduction

Currently there is an obesity epidemic in America. In 1960, 12.7% of men and 19.4% of women were obese. By 2010, those numbers had risen to 32.2% and 35.5% respectively (Carroll et al, 2010). There are three major factors to the obesity epidemic: genes, level of physical activity, and over-consumption of high-fat and high-caloric food. Even though we know high fat foods are bad for the human body, we continue to eat them due to their palatability. But current research is trying to figure out if there is an adaptive value to fat, similar to that of sweets, salts, bitter, and sour foods that elicit humans desire to eat fatty foods.

Of all the senses, there is the least amount of conclusive evidence about taste. The physical stimuli of the gustatory system are the chemicals found in foods and they bind to taste receptor cells. Salt, sour, bitter, and sweet foods all have separate transduction mechanisms. Once the stimuli have been transduced, 3 cranial nerves transmit signals from the mouth to the central nervous system and converge at the brainstem. From there the signals are sent to the PBN and amygdala to assign emotional value to the stimuli associated with cravings and aversions. The signal also travels to the ventral medial posterior thalamus to detect the difference between sweet, sour, salty, and bitter. The hypothalamus is also involved with hunger and satiety as well as the insular and frontal operculum for primary taste perception. Taste and smell converge in the OFC to create flavor.

There are four prototypical tastes: salty, sweet, bitter, and sour. Each taste has a specific transduction mechanism. Recently, it has been argued that fatty is also a taste, but research to find a specific transduction mechanism for fatty acids has not been
successful. One possible mechanism are when delayed rectifying potassium channels are blocked by long-chain unsaturated fatty acids which therefore leads to depolarization of the cell (Mattes, 2009b). An additional possible mechanism is clusters of differentiation-36, which are membrane receptor proteins, which bind to long-chain unsaturated and saturated fatty acids. However it is unclear how these proteins cause depolarization of the cell (Mattes, 2009b). Also, G-protein coupled receptors bind to extracellular compounds and then activate intracellular signaling systems. There receptors have been reported for short-, medium-, and long-chain unsaturated and saturated fatty acids (Mattes, 2009b). However, all of these proteins have not been established as taste receptors or as functional in humans (Mattes, 2009b). Therefore much more additional research is needed on the topic.

The effects of fatty acids and other foods on appetitive responses and weight gain have also been researched. Factors such as palatability (taste), satiety (fullness), and mastication (chewing) are often measured as well as hormonal responses. Ghrelin is believed to increase before a meal (preprandially) and decrease after a meal (postprandially) (Ghrelin, 2011). Insulin and cholecystokinin (CCK) are also involved with acute and or chronic regulation of food intake and body weight (Campbell et al, 2007d). There are obviously other hormones affected by eating, but these three are commonly studied and measured to determine physiological effects of eating.

Dr. Richard Mattes is a professor of Foods and Nutrition at Purdue University (Mattes, 2011). He received his B.S. in biology from the University of Michigan, a masters of public health in public health nutrition from the University of Michigan, School of Public Health, and a Ph.D. in Human Nutrition at Cornell University. The primary aim
of his research is to, “better understand the independent and interactive influences of neural, genetic, metabolic, hormonal, cognitive, cultural and especially sensory factors on human dietary behavior, nutrient utilization and energy balance in healthy and clinical populations” (Mattes, 2011). He specifically studies the factors that modify hunger, satiety, and thirst, the influences of fat content on sensory properties, palatability, and consumption, as well as the health benefits of nut consumption. This literature review will explore Dr. Mattes’ recent research in these areas.

Section 1: Effects of food form and feeding patterns on appetite, satiety, and metabolic responses

Throughout most of human evolution, the sensation of hunger has prompted feeding and thirst has prompted drinking. Recently however, these patterns have changed (Hollis et al, 2009). Drinking without food is now a daily routine and occurs under conditions of euhydration as eating also occurs in the absence of hunger (Hollis et al, 2009). Beverages have also become a significant source of dietary energy as there has been an increase of accessible, palatable, and inexpensive energy-yielding beverages (Campbell and Mattes, 2009). There is accumulating evidence linking energy-yielding beverage consumption to positive energy balance, weight gain, and an increase in body mass index because these beverages evoke weaker appetitive and dietary responses than energy-matched solid foods (Apolzan et al, 2008). Furthermore, carbohydrates have been the primary source of energy in these beverages for the past 2 decades, but recently there has been an increase in popularity of beverages with high fat content and high protein concentrations (Bressan et al, 2007). Another dietary factor influencing appetite and food intake is portion size (Apolzan et al, 2008). There is a
debate about an energy regulating mechanism that may or may not weaken with age (Hollis et al, 2008). There are many factors that may potentially lead to weight gain. The following studies examine food form on appetitive and satiety ratings, as well as feeding patterns and their influences on weight gain and the hunger sensation.

Differences in food form, such as beverages versus solids, have led to different appetitive and satiety responses. Lower levels of hunger and desire to eat were found when solid foods were ingested compared to liquid versions of the same food (Campbell et al, 2007d). The test was conducted with solid- and liquid-meal replacements with similar energy content. The solid-meal replacement elicited lower hunger and desire to eat compared to the liquid meal-replacement (Campbell et al, 2007d). Therefore beverage and solid meal replacements should not be used interchangeably for weight control or energy balance (Campbell et al, 2007d). An additional study investigated the effects of solid and liquid food forms as the initial food ingestions after a 12-hour fasting period in order to control for effects of prior meals (Apolzan et al, 2011). The results were consistent with previous research in that the liquid form elicited lower satiety (Apolzan et al, 2011). Furthermore, if the beverage and solid food forms are matched for energy content, fiber content, and macronutrient composition, beverages continue to elicit greater hunger and desire to eat sensations than the solid food (Apolzan et al, 2008). An additional study examined the effects of solid and beverage forms of carbohydrate, protein, and fat foods (Bressan et al, 2007). With all three stimuli, daily energy intake was significantly greater when the beverage form was ingested compared to the solid form (Bressan et al, 2007). Regardless of energy source (carbohydrate, protein or fat), daily energy intake was greater after the inclusion of a beverage with
lunch compared to an inclusion of a solid that was equivalent in calories, volume, and energy level. For example, the protein sample included a fat-free, low carbohydrate milk as the beverage and cheese fortified with whey to a concentration comparable to the milk as the solid protein form. Volume was matched by the additional drinking of water to match the liquids’ volume. Energy level was regulated by the subjects’ weight as heavier subjects received more calories in order to provide roughly comparable metabolic changes. Compared to the solid form, the beverage protein form, as well as the carbohydrate and fat forms, elicited greater daily energy intake.

Furthermore, the effects of food form as a snack or a meal were examined. The time the snack is ingested before the meal could affect satiety ratings during and after the meal. A snack ingested 2 hours prior to the meal would have greater lasting effects on satiety during the meal than a snack ingested 4 hours before the meal. Additional findings suggested that beverages, consumed alone as an afternoon snack or when incorporated into a meal led to weaker appetite effects compared to solid foods (Campbell and Mattes, 2009). This suggests that it does not change the effect of food form even if it is ingested as a snack or part of a meal; beverages still elicit weaker appetitive effects than solids of the same food (Campbell and Mattes, 2009). Food form also affected weight gain, as beverage consumption produced an 87% weight gain in obese adults and 84% in lean and therefore suggesting that energy containing beverages promote weight gain and positive energy balance (Burgess et al, 2011). Not only does food form affect satiety and appetitive ratings, but it also directly influences weight gain.
Another research experiment studied the associations between thirst, drinking, hunger and eating (Hollis et al, 2009). Thirst was not a significant predictor of or correlated with drinking. Hunger was significantly (even though only moderately) correlated with energy intake but only weakly predictive of eating (Hollis et al, 2009). These findings suggest that the rheological properties of the food effect satiety. Also there is evidence that texture is important to sensory specific satiety and that solid foods are expected to be more satiating before ingestions (Campbell and Mattes, 2009).

Appetitive and satiety ratings are not the only way to determine a solid or liquid food’s effects. Metabolic responses can also be tested to determine physiological changes due to food form. Ghrelin is believed to stimulate hunger and initiate meal ingestion. Therefore it increase before a meal and decreases after a meal (Frecka and Mattes, 2008). Insulin and cholecystokinin (CCK) are also involved with acute and or chronic regulation of food intake and body weight, but little is known about the influence of beverage and solid foods on these hormones (Campbell et al, 2007d). Following a test meal of either beverage or solid food, ghrelin levels were elevated and insulin levels reduced after the beverage meal (Apolzan et al, 2008). An additional study observed similar results with lower insulin and ghrelin levels after a solid-meal replacement compared to a liquid-meal replacement (Campbell et al, 2007d). Blood was drawn from the subjects before the meal, and after they ingested either a solid meal replacement bar or liquid meal replacement beverage. When the solid bar was ingested subjects were also required to drink 237mL of water to minimize the differences in thirst and oral wetting. When blood samples were drawn after the meals, there were lower insulin and ghrelin levels after the solid-meal replacements (Campbell et al, 2007d). In another
study subjects consumed 12.5% of their energy day as either a solid or a beverage. The solids and beverages were matched on energy and macronutrient content. The liquid forms elicited lower insulin and CCK level (Apolzan et al, 2011). However, there are some limitations that must be taken into account when studying some of these hormonal differences. Insulin responds to glucose and protein and is almost unaffected by dietary fats and fiber. Therefore changes in insulin levels may have been due to lower glucose and protein concentrations (Campbell et al, 2007d). Furthermore, CCK responds to dietary protein and fiber (Campbell et al, 2007d). It is imperative that future research studies take these differences into consideration when testing hormonal responses to solid and liquid foods and try to control the content of the food forms. Gastrointestinal transit time must also be taken into consideration when testing hormonal responses, as solid foods elicit increased (slower) time in the gastrointestinal tract and could possibly result in a different absorption profile than liquid forms of the same food (Apolzan et al, 2011). However, as more control for the content of liquid and solid food increases, metabolic responses will continue to be a conclusive procedure for studying their differing effects.

Differences in food form, beverage versus solid, elicit different appetitive, satiety, and hormonal responses. Solid foods, matched on energy content and macronutrient composition elicited lower levels of hunger and desire to eat. Additionally, solid and liquid meal replacements caused different ghrelin, insulin, and CCK responses, all hormones involved with regulation of food intake and body weight. Specifically and most importantly, beverages cause greater levels of ghrelin, a hormone that initiates hunger
and desire to eat, after a meal than solids. Therefore beverage and solid meal
replacements should not be used interchangeably for weight control or energy balance.

Additional studies have examined how weight gain, appetite and satiety ratings
are affected by feeding patterns. Appetite varies according to portion size as greater
hunger and desire to eat sensations were observed following a smaller portion size of
12.5% of estimated energy need compared to a larger portion size of 25% of estimated
energy need (Apolzan et al, 2008). Prior research has also stated that after the age 4,
children consume more energy if the portion size is increased suggesting the
mechanism that dictates energy regulation becomes disordered after childhood (Hollis
et al, 2008). But a recent study observed evidence of short-term dietary compensation
in adults comparable to levels previously observed in children (Hollis et al, 2008).
Twenty-four hour dietary recalls were obtained for each subject for seven days. Each
24-hour period was divided into 7 different eating occasions (breakfast, morning snack,
lunch, afternoon snack, dinner, evening snack, and overnight eating). The recalls were
assessed on energy intake at meals and at snacks. The data suggested that older
adults regulate energy intake over 24 hours more closely than they do at individual
eating occasions, therefore indicating that the regulatory mechanisms might not
necessarily decline with age (Hollis et al, 2008). Furthermore, resistance training
(exercise) in older adults did not influence postprandial appetitive, metabolic, or
endocrine responses, however it reduced hunger and desire to eat. Fullness and
hunger are different dimensions of appetite and can therefore be affected differently by
the presence or absence of resistance training, as was found in this study (Apolzan et
al, 2011). Feeding patterns and exercise are important aspects of appetitive and satiety
ratings, as they may or may not influence the dietary compensation preprandially or postprandially, regardless of possible mechanisms that influence feeding patterns.

The dilemma of the causes of weight gain continues, even after thorough examination of many of the possible factors affecting weight gain. Research will continue on food forms and feeding patterns in individuals, but some limitations to many current studies must be taken into consideration, such as the nutritional content of the independent variables as well as the ingestion pattern of the food. However, the current research has exhibited that liquid foods elicit weaker appetitive and satiety responses than solid foods, as well as having different physiological responses. Specifically lower levels of hunger and desire to eat were found with solid foods compared to beverages matched on energy content, calories, and macronutrient composition. Furthermore, daily energy intake was greater when beverage forms of carbohydrates, proteins, and fats were consumed compared to the solid food form. Beverage consumption also caused weight gain in both obese and lean adults. Hormonal responses must also be considered as beverages cause greater levels of ghrelin than solid foods. Ghrelin should be low after meals because it induces hunger and desire to eat. Therefore beverage and solid foods must not be used interchangeably. However, many other factors must be taken into consideration as well when studying food form and feeding patterns, such as portion size and the habitual eating patterns of each individual. Smaller portion sizes elicit greater hunger and desire to eat, but adults are also providing evidence for a mechanism that regulates portions and intake. Exercising was also found to reduce hunger and desire to eat, but it did not affect hormonal responses. Finally, research must also continue to examine the effects of our society and societal
habits on feeding such as the desire to eat or simply the convenience of eating in order to ensure that hunger elicits eating and thirst elicits drinking.

Section 2: Effect of specific nutrients on appetite and energy intake.

Much of Dr. Mattes recent work has also examined the effects of specific nutrients, such as nuts or protein, on appetite status, energy intake, and mastication. Recent research has suggested that diets containing higher protein lead to greater reductions in energy intake, body weight, and fat mass while also preserving lean body mass (Armstrong et al, 2010). According to short-term feeding studies, dietary protein has been observed to be more satiating than carbohydrates and fat because subjects consumed less energy at the meal following the higher protein preload (Apolzan et al, 2007). Furthermore, higher protein meals have led to greater postprandial energy expenditure which overtime may lead to greater weight loss (Campbell et al, 2007c). This postprandial energy expenditure is caused by metabolic changes in the body because metabolism generates and uses energy. Metabolism is a set of chemical reactions that convert the fuel from food into the energy the body needs and can use. Therefore, even though there is no single dietary intervention for weight loss, higher protein diets are continually regarded as a popular approach (Campbell et al, 2007a).

An additional study found that regardless of age, hunger and desire to eat were reported to be higher when a meal was consumed with inadequate protein (Apolzan et al, 2007). Subjects consumed either 125%, 94%, or 63% of the Recommended Dietary Allowance for protein. Therefore this study also examined the effects of moderate
changes of protein intake and found that differences in appetite are detected with a small change in protein consumption (Apolzan et al, 2007). An additional study also found that higher protein intake led to increased satiety (Armstrong et al, 2010). This study also explored the effects of increased eating frequency (specifically with protein) as the media has recently advocated that increased eating frequency is beneficial to the process of weight loss (Armstrong et al, 2010). The subjects consumed either 14% of daily energy intake or 25% of daily energy intake as protein at either 3 eating occasions or 6 eating occasions daily. Increased eating frequency, or 6 eating occasions daily, of protein did not have beneficial effects as it decreased satiety ratings as well as negatively altering hormonal responses as it lowered glucose and insulin concentrations (Armstrong et al, 2010). Additional research with protein intake was performed on the effects of increasing dairy consumption, as dairy is a form of protein. Subjects were either assigned a low dairy condition in which they could choose one dairy product from milk (white or chocolate), yogurt, or hard cheese. The other treatment group had 3 servings of dairy each day in which they were required to eat a milk serving, a yogurt serving, and a hard cheese serving (Hollis and Mattes, 2007). Consuming 3 dairy portions a day significantly increased energy intake compared to consuming a single dairy portion a day. But these differences in energy intake suggest the possibility of a metabolic advantage that may negate the increased energy intake (Hollis and Mattes, 2007). Increasing the dairy product intake did not alter hunger or fullness sensations even though the subjects were consuming more calories. Not only does this study raise questions about the importance of eating frequency, specifically increased protein
intake, but it also raises questions about dairy products, a high source of protein, fat, and calories, and their effects on satiating efficiency (Hollis and Mattes, 2007).

The effects of a higher protein versus a normal protein diet have been found on appetite as well as total fat intake, body weight, and body composition (Campbell et al, 2007a). A smaller reduction of satiety was found with the higher protein diet as well as a greater preservation of lean body mass and increased pleasure while losing body weight and body fat compared to those subjects who were consuming a normal protein diet while losing weight. The higher protein diet helped the subjects preserve lean body mass, and improved perceptions of satiety and pleasure during an energy restrictive diet aimed at weight loss (Campbell et al, 2007a). Additional data suggests that the protein content of an energy restrictive diet (either chicken or beef) does not affect changes in body mass and fat mass (Campbell et al, 2007b). For 9 weeks subjects were randomly assigned to an energy restrictive dietary intervention that varied in source and quantity of protein or a control group that contained the subjects’ normal diets. The treatment groups consisted of 1000 kcal/day of a basal diet (which was the same for all 3 treatment groups) with the addition of 250 kcal/day of beef, chicken, or a non-meat carbohydrate/fat food item. The study achieved reductions in body mass and fat mass for both the chicken and beef treatment groups, therefore with both sources of protein (Campbell et al, 2007b). This data suggests that including more protein in an energy restrictive diet may lead to better results of weight loss, regardless of the source of protein.

Additionally protein intake has been found to effect hormonal changes, specifically those dealing with appetitive sensations, through exploring the acute and
chronic effects of increased dietary protein (Campbell et al, 2007c). Subjects either ingested a higher protein chronic diet that consisted of a 30% protein content, or a normal protein chronic diet that consisted of 18% protein content for 9 weeks. On separate days the subjects consumed a higher protein acute meal in which 30% of the energy content was from protein, or a normal protein acute mean in which 18% of the energy content was from protein. Appetite and ghrelin responses were unaffected by chronic higher protein intake suggesting that dietary habitualization to protein intake leads to differential macronutrient use. However, the higher protein acute meal increased feelings of fullness and reduced hunger and desire to eat while the habitual protein intake did not affect these sensations (Campbell et al, 2007c). The data support the idea the ghrelin (a hormone involved in influencing hunger) is responsive to acute protein intake while being unaffected by chronic intake regardless of it being higher or normal chronic protein intake. Also the reduction of hunger and desire to eat, as well as increased fullness during the higher protein acute meal consumption suggest ghrelin may be involved in acute consumption and not chronic consumption (Campbell et al, 2007c). An additional study examined the effects of higher protein intake on overweight men and once again found inconsistent hormonal responses. Overall peptide YY concentrations (associated with appetite regulation) were greater following higher protein diet (Armstrong et al, 2010). However, inconsistent with other data that says ghrelin responses decreased with higher protein intake, this study found an increase in ghrelin following the higher protein diet. Blood samples were drawn and analyzed every 20 minutes for the 11 hours of testing in which the subjects consumed eucaloric diets at set eating times consisting of either 14% or 25% of energy intake as protein. The
protein quantity did not affect daily hunger, glucose, or insulin concentrations, but higher protein led to greater daily ghrelin concentrations (Armstrong et al, 2010). Both of these studies lead to questions about the effects of higher and chronic protein intake on hormonal responses and demonstrate the need for additional research on this topic.

Additional research has examined the effect of nuts and their different food forms on appetite and hormonal responses. Much of Dr. Mattes’ research on nuts has been funded by the Almond Board of California and the U.S. Agency for International Development Peanut Collaborative Research Support Program. Currently there is accumulating evidence that consumption of a variety of tree and ground nuts is associated with reduced cholesterol and triglyceride concentrations, as well as stability of a lower body weight (Armar-Klemesu et al, 2007). There have been studies suggesting an inverse relationship between nut consumption and body mass index, but given that nuts are a rich source of fat, their role in dieting has been questioned (Boateng et al, 2006). On study found that the addition of 500k/cal each day of peanuts improved lipid profiles and quality of health in Ghanaians (Armar-Klemesu et al, 2007). The subjects were assigned to one of three treatment conditions and were instructed to eat 500kcal per day of peanuts in addition to their normal daily diet, replace 500kcal of their normal diet with 500kcal of peanuts, or consume 500kcal of peanuts in addition to or replacing part of their normal caloric intake. However, energy intake did not change significantly over the 8 week treatment period despite the introduction of an additional 500kcal/day (Armar-Klemesu et al, 2007). The inclusion of peanuts did improve overall diet quality due to increase in the intake of Vitamin E, folate, magnesium, copper, and fiber. The subjects were healthy Ghanaians, but the inclusion of peanuts in their diet
further improved their diet quality which may be important in fighting cardiovascular
diseases which are leading causes of mortality in developing countries (Armar-Klemesu
et al, 2007).

Peanuts have also assessed intake pattern and food properties on appetitive
ratings and energy intake (Bressan et al, 2011). In comparing the differences of
ingesting loads of 300kcal of peanuts as opposed to 300kcal of a snack mix matched on
energy, volume, and macronutrient content, no significant differences were found on
total daily energy intake (Bressan et al, 2011). This study also examined the effects of
consuming 300kcal of peanuts as a mid-day snack or with a lunch meal and the data
suggests that timing of peanut ingestion may influences the amount of energy
compensation response they elicit (Bressan et al, 2011). When the peanuts were
ingested as a snack they elicited larger energy compensation at the meal 120 minutes
after the provided snack than when ingested as part of a lunch meal therefore
suggesting the salient attributes of peanuts that cause energy compensation may be
partially masked when there are influences of other foods (i.e. ingested with a meal)
(Bressan et al, 2011). This is also consistent with the strong satiety qualities of nuts and
perhaps suggestive of an effect of a peanut pattern use as peanuts elicited larger
energy compensation when ingested 120 minutes before a meal (Bressan et al, 2011).

The effect of chronic peanut oil consumption on appetite and food choice was
studied in comparison to the effects of olive and safflower oil (Boateng et al, 2006).
Consistent with previous research, this study did not find a significant effect of diets
containing peanut, olive, or safflower oil on appetitive responses (hunger, desire to eat,
or fullness) (Boateng et al, 2006). While this may seem to contrast previous research
with whole peanuts, peanut oil does is not rich in protein while whole peanuts are. Therefore the non-fat fraction of peanuts may be the attribute contributing to satiety (Boateng et al, 2006).

The effects of different forms of almonds (whole, almond oil, and almond butter) were evaluated on impaired glucose intolerant adults. Almonds are a low-glycemic index food with unsaturated fat (Considine et al, 2011). Low-glycemic foods help regulate insulin and glucose levels so that sudden increases of these hormones will not occur therefore preventing sudden increases of hunger. Unsaturated fats lower cholesterol and triglycerides, which are the most common type of fat in our bodies. Because there is an inverse relationship between nut consumption and risk of developing type-2 diabetes, almond consumption may be an effective strategy in insulin resistant individuals who would benefit from replacement of saturated with unsaturated fats (Considine et al, 2011). Unsaturated fats benefit insulin sensitivity. The data showed significantly greater insulin concentrations with whole almonds and almond oil which therefore led to less calculated insulin sensitivity (Considine et al, 2011). Type-2 diabetes patients make insulin, but their bodies do not respond well to it. They need insulin shots to help their body store and use glucose for energy. The almonds and almond oil led to greater insulin concentrations and therefore less calculated insulin sensitivity because their bodies were responding to the insulin (normally with type-2 diabetes the body does not respond). Furthermore, consumption of whole almonds and almond oil in the morning decreased blood glucose levels. Consumption of whole almonds and almond oil increased concentrations of glucose and insulin therefore indicating an improved hormonal profile when consumed by impaired glucose intolerant
adults (Considine et al, 2011). An improved hormonal profile would allow the subjects to better control their bodily functions, specifically hunger and appetite.

Additionally, research has supported that the reason chronic nut intake does not increase weight is due to the poor bioaccessibility of energy from nuts. By studying fecal analysis, it has been documented that there is increased energy loss with nut consumption (Alfenas et al, 2008). In a study of nut form (whole peanuts, peanut oil, flour or butter), supplements of whole peanuts significantly increased energy loss in fecal fat. Furthermore, more fecal fat was lost when consuming whole peanuts. Whole peanuts also led to greater fecal fat percent of wet weight and greater energy per gram of feces. The other food forms of peanuts did produce such results. This result is consistent with the earlier finding of low bioaccessibility in nuts due to inefficiency in mastication and digestions of whole peanuts.

Through studying nuts and their effects on appetitive ratings and body weight, a researcher must take into consideration mastication effects on the nuts. A primary function of mastication is to reduce the particle size of foods so they may be swallowed (Frecka et al, 2008). But there is limited data on masticatory influences on nutrient bioaccessibility and satiety (Frecka et al, 2008). Mastication breaks down food into small particles, therefore releasing nutrients and other food constituents from the food matrix which ultimately signal the digestive and absorptive processes (Frecka et al, 2008). One mechanism responsible for the lack of influence of nuts on increasing body weight is attributed to the loss of the nut energy in the stool due to the resistance of the nut parenchyma walls and the lack of lipids that are liberated through the mastication of the cell wall (Cassady et al, 2009). If the cell wall is not ruptured, many of the energy-
yielding compounds are lost in feces (Mattes and McKiernan, 2010). Whether mastication alters the health effects of peanuts and tree nuts by altering the bioaccessibility of their healthful components needs to be researched (Mattes and McKiernan, 2010).

The role of mastication has been frequently studied to observe its effects on the mechanical fracture of nuts cell walls and its effects on appetitive responses. Mastication significantly influences energy absorption and appetitive responses independently. Mastication was manipulated as each subject was instructed to chew 55 grams of almonds either 10, 25, or 40 times before swallowing (Cassady et al., 2009). This data is consistent with reports that lipid bioaccessibility is determined by the mechanical rupture of the nut cell wall. Increased mastication led to an increase in fecal fat (Cassady et al., 2009). These results do not suggest that increased mastication of food causes a decrease in weight. Rather the study highlights the important effect of chewing on lipid absorption, release of gut peptides, and increased satiety (i.e. various factors that influence weight management) (Cassady et al., 2009).

Mastication has also been used to study the effects of different food forms on differences in particle size because mastication breaks down food particles and therefore increases the surface area available to enzymes and subsequently influencing the digestive and absorptive processes (Frecka et al., 2008). Through studying 5 forms of almonds (raw, dry unsalted roasted, roasted salted, honey roasted, and natural sliced) data suggested that while the palatability of food may affect eating, it does not appear to affect mastication. Nut shape exerted a stronger effect on mastication (Frecka et al., 2008). Compared to the whole almonds, sliced almonds elicited a lower maximum
bite forces, lower mean bite forces, and greater number of chews. The shape, texture, and sensory properties of almonds influenced mastication (Frecka et al, 2008). Furthermore, an additional study researching the effects of processed versus unprocessed peanuts indicated that the processed versus unprocessed properties of peanuts significantly influenced mastication and particle size distribution at swallowing. These results had no significant associations with palatability (Mattes and McKiernan, 2010). The processed peanuts required significantly less muscle work, were held in the mouth for a significantly shorter amount of time and therefore contained significantly larger particles in the bolus (Mattes and McKiernan, 2010). This data exhibits that all food does not have to be reduced to a certain particle size before swallowing and the particle size swallowing threshold varies significantly for processed and unprocessed peanuts (Mattes and McKiernan, 2010).

Nutrients, specifically protein and nuts, can affect appetite and energy intake. Meals with inadequate protein lead to greater hunger and desire to eat while higher protein meals lead to greater satiety. Additionally, small changes in protein content can affect appetite responses. Higher protein diets also helped subjects preserve lean body mass and improved perceptions of satiety and pleasure during an energy restrictive diet aimed at weight loss. However, increased dairy consumption, a product high in protein, did not alter fullness or hunger sensations even though more calories were being consumed. Furthermore, there were increases in ghrelin, a hormone that initiates hunger and desire to eat, after a higher protein diet. Therefore much more research is needed to clarify the effects of protein on weight loss diets and appetitive and hormonal responses. Additional research has been performed on nuts and their effects on
appetite and energy intake. Peanuts cause more energy compensation as a snack ingested before a meal than as part of a meal. There is also increased energy loss with nut consumption which could be a possible explanation for the lack of weight gain with the consumption of nuts. Specifically, whole peanuts elicited more energy loss than peanut oil, flour, or butter. Mastication and properties of the nuts can also affect appetitive responses. Increased mastication led to increased fecal fat, highlighting the importance of chewing effects on lipid absorption, release of gut peptides, and increased satiety (not necessarily a decrease in weight). Sliced nuts required lower bite forces and greater number of chews compared to whole nuts, while processed nuts required less muscle work and had larger particles in the bolus than unprocessed nuts. This also indicates that not only do different nut form affect mastication, but all food particles do not have to be the same size in order to be swallowed. Additionally, almonds and almond oil caused greater insulin concentrations in impaired glucose intolerant adults which is beneficial because the usually need insulin shots to help their bodies store and use glucose for energy.

**Section 3: Research of components of a possible fatty acid transduction mechanism**

Currently there are four “tastes” that each have specific transduction mechanisms: sweet, sour, salty and bitter. Research is suggesting that “fatty” be added as a taste, but the transduction mechanism has yet to be determined. Each proposed mechanism is responsive to fatty acids that vary in chain length and saturation (Mattes, 2009b). There have also been many recent studies trying to determine if the basis of fatty acid detection is due to taste or tactile cues as well as finding and effective test
stimuli. Furthermore, it has been found that oral exposure to dietary fats elicits physiological responses in the body (Mattes, 2000a). Current research is focusing on the possibilities of physical and chemical attributes of fatty acids and their role on isolating a taste component.

There is not much evidence for humans’ ability to detect short-, medium-, and long-chain fatty acids (Mattes, 2009b). The ligand specificity of each of the proposed free fatty acid receptors differs for chain length and saturation (saturated versus unsaturated). If the proposed fatty acid receptors are present, then it may be predicted that humans could be capable of detecting a wide array of fatty acids without input from other sensory systems (Mattes, 2009b). The data from one study documents the ability of humans to detect all three chains of saturated fatty acids (Mattes, 2009b). This provides evidence of humans’ ability to detect fatty acids that vary in chain length as long as they have common saturation. Furthermore, it provides evidence of multiple fatty acid transduction mechanisms (Mattes, 2009b).

There has been difficulty developing appropriate stimuli for fatty acids so that the stimuli documents fatty acid thresholds (Burgess et al, 2007a). There are many physical and chemical attributes, such as texture, viscosity (thickness), lubricity (slipperiness), and oral irritation, that can provide a signal to incorrectly be interpreted as “fat.” Furthermore, the stimuli must minimize fatty acid oxidation and achieve stable dispersions of the fatty acid in aqueous environments so as to ensure fatty acid threshold is being tested (Burgess et al, 2007a). After testing linoleic, oleic, and stearic fatty acids, and minimizing input from the olfactory, capsaicin, and viscosity-assessing tactile systems, all three acids were detectable in the oral cavity. These findings are
consistent with fatty acids having a specific taste component, but can only suggest, not confirm, a common transduction mechanism for these fatty acids. The findings do lack certainty because it cannot be confirmed that all other potential sensory cues did not contribute. Measureable thresholds were also obtained from all three fatty acids, which is further possible evidence of a common transduction mechanism for these long-chain fatty acids that is not influenced by saturation (Burgess et al, 2007a).

Additional studies have been performed on humans’ abilities to detect fatty acids without cues from other sensory systems. One study found that even when nongustatory cues are minimized, humans were still able to detect fatty acids in the oral cavity (Mattes, 2009d). The study tested three different fatty acids (stearic, lauric, and caproic) and threshold concentrations were similar for all three. Three ascending measures of each fatty acid were given to the subjects and they were instructed to sip and spit. Regional thresholds were assessed through spatial testing. Suprathreshold ratings were also taken for each fatty acid (Mattes, 2009d). The threshold and suprathreshold ratings for each type of fatty acid are consistent with evidence for a taste mechanism. The study also found that threshold and suprathreshold ratings were obtained from regions of the tongue not believed to support transduction mechanisms (Mattes, 2009d). There are many possible explanations for this such as current knowledge of the distributions of identified fatty acid binding proteins may be incorrect. Or the ligand specificity of each receptor may be incorrect. Also, uncharacterized receptors may be present at these sites that are also capable of transducing fatty acids. This study provides many challenges to the current research on transduction mechanisms because not only were subjects able to reliably scale the intensity of the
fatty acids, they also found reaction to receptors at tongue sites previously not
associated with fatty acid transduction (Mattes, 2009d). However, an additional study
found that fat perception actually does involve gustatory, olfactory, and somatosensory
cues (Burgess et al, 2007b). Much of the research has been focused on individual
chemosensory routes for detection of fatty acids instead of considering a multimodal
perception of fats (Burgess et al, 2007b). The evidence from this study supports a
multimodal perception because the fatty acids were effective stimuli for multiple sensory
systems. The sensory systems had similar thresholds for the fatty acids, but lacked
correlations between them therefore suggesting they may function independently
(Burgess et al, 2007b). The broad sensitivity of detection in multiple sensory systems
may reflect the importance of fatty acids on humans’ health. If this were the case, a
system for their detection would have an adaptive value like that of the detection of
sweet, sour, bitter, and salty tastes (Burgess et al, 2007b).

Prior research has suggested that fatty acids are not primary taste stimuli, but
rather they sensitize taste receptor cells so they are more reactive to the primary stimuli
(Mattes, 2010b). Therefore, hypothetically, taste thresholds for sweet, and possibly
other taste qualities should be lower in the presence of fatty acid (Mattes, 2010b).
However, no significant effect of fatty acid was observed for sucrose, and thresholds for
salty, sour, and bitter were significantly higher (i.e. sensitivity was lower) in the presence
of a fatty acid. Furthermore, suprathreshold for each taste and addition of a fatty acid
was tested. For salty and bitter, the addition of a fatty acid significantly decreased
intensity ratings. Intensity ratings were unaffected in the sweet solution and sour was
the only taste that intensity ratings increased and this was only by a small amount for
the two smallest concentrations (Mattes, 2010b). These findings suggest humans can detect fatty acids on their taste alone and support that fatty acids might act as a primary stimuli (Mattes, 2010b).

Furthermore, dietary fat has been proven to affect the hormonal responses associated with eating (Mattes, 2000a). Dietary fats alter hormones in the gastrointestinal track and promote the mobilization of triacylglycerol (TAG) into circulation. The presence of dietary fats increases the TAG response (Mattes, 2000a). Humans can detect and scale the intensity of dietary fats varying in chain length and saturation, but unsaturated fats appear to elicit a stronger TAG response. The data from a study confirmed that oral fat exposure independently increases TAG concentrations (Mattes, 2000a). The exposure of dietary fat caused a TAG response as well as eliciting a response after less than 20 minutes; the TAG response was high even with minimal oral exposure to fat (Mattes, 2000a). An additional study examined the amount of dietary needed to elicit a TAG response. There was an absence of a significant TAG response with a 10 gram load and a significant increase with a 30 gram load. This confirms the need for a minimal load of fatty acid to observe an oral effect (Mattes, 2009c). However, there was not a greater TAG response to the full fat food in comparison to the TAG response of a nonfat version of the same stimuli (Mattes, 2009c). The study confirmed a TAG response to conditions mimicking ingestions of a fat-containing food/meal (Mattes, 2009c).

Future research will continue to examine possible fatty acid transduction mechanisms and humans’ abilities to detect fatty acids in different solutions and differing loads. Dr. Mattes’ current research has shown that humans cans detect all 3
chains for saturated fatty acids which is evidence of multiple fatty acid transduction mechanisms. Furthermore, 3 types of fatty acids were detectable when nongustatory cues were minimized. Thresholds of each type of fatty acid were also found on regions of the tongues not previously noted in possible transduction mechanisms. This suggests that either current possible fatty acid transduction mechanisms are incorrect, or that there are more possible receptors for fatty acids. When fatty acids were added to sucrose, the thresholds were not altered suggesting humans can detect fatty acids on their own and they therefore may be a primary stimuli. Oral fat exposure was also shown to independently increase TAG concentrations, a hormone that normally responds to dietary fats. Fats are essential to the human diet, so it will be interesting to see with future research if fats are treated by the body the same way the essential sweet, salty, bitter, and sour tasting foods are and how they are transduced.

Discussion

Dr. Mattes’ research has focused on a variety of aspects of food and nutrition while also specifically studying components of fatty acids. Throughout many of his studies he has consistently proven that beverages tend to elicit weaker responses than solid food forms. Beverages elicit greater levels of hunger and desire to eat, as well as higher ghrelin concentrations, a hormone that initiates hunger and desire to eat, than solid meals matched on energy content and macronutrient composition. This is important, as well as future research on this subject, due to the intense media support of beverage meal-replacement diets.

Even thought current literature has indicated that beverages elicit weaker responses than solids, liquid meal-replacements are continuously regarded as a popular
dietary measure for weight loss. Therefore future studies should continue to focus on the different effects of solids and beverages. It would be interesting to see how the body responds to liquid and solid meals after exercise. Perhaps after exercising the body would response differently to liquids as they pass through the intestinal tract faster than solids. Solids would take longer to digest. Perhaps consuming a low-caloric beverage meal after exercising would prolong the desire to eat a full meal, therefore allowing the body to continue to burn stored fat and increase weight loss.

There are many limitations in Dr. Mattes’ research on beverage versus solid food forms such as the age of subjects. One study gave solid and beverages food forms to two different treatment groups. One treatment group was significantly older than the other treatment group (Alpozan et al, 2008). Future research needs to try to control better across subjects and treatment groups in order to produce results that are more applicable to the general population. Perhaps a within-subjects design would also be more beneficial to control for individual differences among the subjects. There were also limitations to beverage versus solid foods testing because many of the designs were based off of observations and therefore cannot infer causality. Future research also needs to try to measure responses in a way that causality, and not simply linearity, can be inferred.

Specific nutrients have also been found to affect appetitive responses and therefore weight gain and body mass index. Protein tends to elicit greater feelings of fullness and decreased feelings of hunger. Furthermore, Dr. Mattes’ research implied that small changes in protein cause significant difference in appetite. It would be interesting to continue researching the different effects of protein on appetite.
Specifically how much protein would be needed to suppress the feeling of hunger so as to decrease snacking between meals and therefore lead to greater weight loss. It would also be interesting to continue to research the effects of dairy, a source of protein, fat and calories, since Dr. Mattes found that dairy does not alter sensations of hunger or fullness.

There were limitations to the research on protein and the effects of frequency of eating. One limitation was the absence of an acclimation period to the different eating periods or different protein intakes. This would be an important aspect of experiments to consider in the future so researchers could also consider any habitualization effects that may occur. Furthermore, many of the studies on protein were performed with older adults. Older adults have a reduced resting metabolic rate as well as a higher postprandial respiratory exchange ratio. This indicates that they have an increased carbohydrate and reduced fat oxidation compared with younger adults (Campbell et al, 2007c). Therefore it would be interesting if future research would consider both younger and older adults in the research to investigate if increases in protein affect the two age groups differently.

Nuts, even though they are a high source of fat, have also been found to have beneficial effects on the body as well as on satiety and appetitive responses. It is interesting to note that when nuts are consumed as a snack, rather than added to a meal, the effects on satiety and appetite appear to be stronger. It will be fascinating to see if future research addresses possible masking issues of nuts when consumed with other foods. Future research should also continue to investigate why this high fat food has such beneficial effects on appetite and weight management since this is such an
unusual effect of high fat foods. There were also limitations to the nut studies. Of most importance was the fact that several of the studies did not control the meals eaten prior to nut ingestion. These meals could easily have an effect on appetitive responses and should therefore be controlled for in future research.

Additional studies have explored the possible transduction mechanisms of fatty acids. There are many components that effect the transduction of fatty acids such as short-, medium-, or long-chained fatty acids, as well as saturated or unsaturated. Recent research has proven that humans can detect differences in fatty acid chain length which supports possible transduction mechanisms. Three different fatty acids were detectable in the oral threshold when nongustatory cues were minimized and thresholds were obtained from tongue sites that were not previously believed to be part of the transduction mechanism of fatty acids. This either means that there are possible transduction mechanisms that have not been previously considered, or the current possible transduction mechanisms are incorrect as they cannot explain these new detection sites. Future research should continue to investigate these new transduction sites and the possible detection of fatty acids with the control of nongustatory cues. Finally, the addition of fatty acids to the already known tastants (sweet, sour, bitter, and salty) should continue as it will continue to give new insight into the ability for humans to detect fatty acids alone therefore indicating fatty acids as a primary stimuli. Dr. Mattes’ research has specifically tested the effects of sucrose, a sweet tastant, and fatty acids. It would be interesting for future research to also investigate sour, bitter, and salty tastants and fatty acids. Perhaps fatty acids would make the usually repulsive sour and bitter tastants more appealing. As further research continues to improve stimuli and
testing apparatuses of fatty acids, improved information about possible transduction mechanisms will also continue.

As the obesity epidemic in America does not seem to be decreasing, research on different types of food and their affects on the human body should continue, especially those regarding fatty acids. Compared to the other sensory systems, there is not much known about the gustatory system. However, future research, including Dr. Mattes’ research, will continue to improve and make new findings and conclusions about this complex system.
References


