APPETITE MEASUREMENT AND INTERINDIVIDUAL VARIABILITY

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Appetitive sensations are widely viewed as important signals for eating decisions. Intra- and inter-individual variability have been reported in short-term studies, but it is still unknown whether individual differences are consistent over time and, whether individuals at the appetite extremes vary in energy intake. Therefore, a seventeen-week observational study was conducted to examine the stability of appetitive sensations (hunger, fullness, and thirst), implications of individual differences in appetite on energy intake and eating patterns, as well as associations between appetitive sensations and selected individual characteristics (age, gender, BMI). Ninety-seven (90 completers) healthy adults recorded the intensity of their hunger, fullness, and thirst hourly during all waking hours for three days at weeks 1, 9 and 17. There were marked and stable inter-individual differences for each sensation over the 17 weeks: hunger (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9, $r=0.72$ ($p<0.001$), week 1 vs week 17, $r=0.67$ ($p<0.001$), week 9 vs week 17, $r=0.77$ ($p<0.001$)), fullness (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9 $r=0.74$ ($p<0.001$), week 1 vs week 17, $r=0.71$ ($p<0.001$), week 9 vs week 17, $r=0.81$ ($p<0.001$)), and thirst (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9 $r=0.82$ ($p<0.001$), week 1 vs week 17, $r=0.81$ ($p<0.001$), week 9 vs week 17, $r=0.88$ ($p<0.001$)). Cross-correlation functions revealed energy intake and eating pattern exerted stronger effects on appetitive sensations than the reverse. However, the absolute effect sizes of the directional effects were small. No robust effects of the studied individual characteristics (gender, age, BMI) were observed. The primary finding is that acute and chronic sensations of hunger, fullness and thirst are stable across individuals, but are poor predictors of energy intake.

CHAPTER1. LITERATURE REVIEW

1.1 Appetite and Ingestive Behavior

Appetitive sensations and ingestive behavior are functionally related. It is assumed that when food is accessible, these sensations are important drivers of food choice and energy intake with implications for health and well-being. In addition to high intra-individual variability, there are marked inter-individual differences in appetitive sensations (1–3). This is attributable to biological (e.g., energy, endocrine, metabolic status) (4–6) and environmental (e.g., sensory cues, time, social custom) (7–10) determinants. Thus, understanding the nature of appetitive sensations, what influences them and their impact on ingestive behavior is vital for management of energy balance. These issues will be critically reviewed below focusing on intra- and inter individual variability of specific appetitive sensations (hunger, fullness, and thirst).

1.1.1 Definition of Appetitive Sensations

a. Hunger Sensations

Hunger is a sensation that motivates the initiation of food intake and stems from energy needs. Bodily sensations of hunger are generally unpleasant and when sufficiently strong, trigger eating. Though universally experienced and quantifiable at any point in time, the nature of the sensation is poorly characterized. Traditionally, hunger sensations have been localized to the stomach, but hunger is not lost or even markedly altered following gastrectomy (11). In fact, based on self-reports, hunger sensations have also been attributed to other body sites (11–14). In one study using a preset checklist of sensations (11), 800 participants described their physical sensations of hunger under hypothetical fasting conditions with varying durations. Ninety percent of participants who imagined being extremely hungry identified primarily gastric sensations while thirty percent of participants experienced two or more bodily sensations in the mouth, throat, and/or head (11). Similarly, in another trial using open-ended questionnaires instead of a preset checklist (12,13), 83 participants marked where they felt hunger on a human body (male or female) illustration under hypothetical conditions of mild to intense hunger. Participants reported fifteen sensations including stomach growls, stomach aches, weakness, headaches, pain, dizziness, and anxiety (12).

While the abdominal area was the most commonly cited area regardless of degree of hunger (about 48 – 87 % of responses), the proportion of other body areas increased, especially head (about 12 – 24 % of responses), as hunger increased. Some studies report that restlessness and excitability accompany gastric sensations (11), but this was not supported in other work (15). Psychological components such as anxiety, dizziness, lack of concentration on tasks are also described as hunger sensations (11,13–15). Therefore, feeling "hunger" embodies multiple physical and psychological sensations.

b. Fullness Sensations

Fullness is a sensation that contributes to the termination of eating. Gastric distention and feelings of satisfaction and relaxation are reported to be the primary symptoms of the fullness sensation (11,14,16). One study developed subjective terms to define fullness symptoms with eighteen participants and all agreed that fullness sensations are mainly physical sensations (16). Under increasingly intense conditions, fullness is rated as gastric stretch to stomach pain and under intense conditions respiratory sensations emerge with comments of difficulty breathing (14). Psychological sensations of fullness were more positive (satisfaction, comfortable, happiness, reenergized, ability to focus on tasks) under typical fullness. However, participants reported negative psychological sensations (sick of food, feeling of disgust with self, regret) under extreme fullness (14). In some work, psychological feelings of fullness after a large meal differed in men and women (14). Women felt regret and disgust towards themselves for having consumed so much food while men felt achievement and satisfaction from finishing a large meal (14). However, other work failed to confirm this (17). Satisfaction is a term that relates to fullness and is expected to be associated with eating termination, but its meaning is vague. For example, satisfaction has been characterized as an indication of physical fullness, while some consider pleasure as a more appropriate descriptor (18,19).

c. ***Thirst Sensations***

Thirst is also considered as one of the main appetitive sensations. Thirst is mainly related to the hydrational status of the body and motivates drinking through negative symptoms including mouth dryness, and bodily fatigue (20–22). People become thirsty in response to declining hydration level, which leads to drinking before body fluid deficits develop (23). These sensations motivate drinking fluids and drinking beverages other than water or diet soda can contribute to energy intake (24–26). The proportion of the energy intake from caloric beverages is substantive (about 13% of energy) although energy intake from beverages has declined in both the US and Canada (27,28) . Moreover, there has been an argument that thirst is associated with hunger (1) and food intake (27,28). Therefore, measuring and managing thirst is also important.

d. Other Appetitive Sensations

In addition to hunger and fullness, desire to eat and prospective consumption are major components of appetitive sensations. Desire to eat is also an index of motivation to initiate an eating event but stems more from cognitive and sensory cues. Unlike hunger, desire to eat is sensitive to food related cues (e.g., appetizing aroma and appearance of foods) and often explains eating without hunger (29,30). Thus, desire to eat may stimulate consumption of more calories than necessary (30) but other work has failed to support this (31). Prospective consumption refers to the anticipated portion that may be consumed. It is often related to food serving size. Prospective consumption and serving size are positively associated in several studies (26,32) but not others (33,34).

1.1.2 Appetitive Sensations and Energy Intake

Appetitive sensations are generally assumed to be associated with food intake. This was evaluated in a meta-analysis that combined appetite ratings and subsequent energy intake data from twenty- three randomized controlled trials (RCT). They examined the relationship between appetite and energy intake using correlation analysis, energy intake prediction equations, and minimum differences in visual analogue scale (VAS) scores impacting energy intake (35). Correlation coefficients differed markedly between studies. Median correlation coefficients for each pre-meal appetitive sensation and subsequent *ab libitum* energy intake showed only weak-moderate strength (hunger and energy intake: $r \approx 0.25$, fullness and energy intake: $r \approx -0.25$). The best fit model for energy intake prediction included pre-meal hunger ratings, basal metabolic rate, body weight, gender, and age. Estimated energy intake increased by 5.3% for each 10 mm increases in pre-meal hunger ratings. This predictive model accounted for 25% of the total variability in EI (kcal) and 19% of the variability without hunger ratings. Lastly, minimum differences in pre-meal hunger ratings impacting *ab libitum* EI were calculated. Rating intervals were grouped into either 5, 10, 15, 20, and 25 mm. For each grouped interval, corresponding mean energy intakes were compared using the least significant difference test (e.g., energy intake of 0-5 mm, 5-10 mm, 10-15 mm etc.). An interval of appetite difference of at least 15 mm in hunger ratings was required to yield a statistically significant impact on energy intake. Overall, results from this study proposed that hunger ratings can be a weak proxy for energy intake. However, it was a secondary analysis with different preload-test meals. Also, it is unclear whether higher hunger caused greater energy intake or is a result of less energy intake at the previous eating event because there is a lack of information on fasting status before administration of the pre-load-test meals.

However, a recent systematic literature review reported that appetite ratings are not a good proxy of energy intake (36). The review identified 462 studies that assessed energy intake and appetite ratings. 49% of studies demonstrated an association between self-reported appetite ratings and energy intake while 51% of the studies there was no significant association between appetite scores and energy intake. Among the studies showing a link between appetite ratings and energy intake, 24% reported both appetite ratings and energy intake were not changed from the baseline. Since this double negative does not always imply both measures are correlated, if double negative studies are excluded, the number of studies with a significant correlation decline to 37%. Inconsistent results may stem from multiple variables, including cognitive and environmental factors other than appetite sensations, that guide eating decisions (37–40).

In one study participants recorded hunger ratings every waking hour and daily energy intake for 7 consecutive days (41). Correlations between hunger ratings and energy intake were significant, albeit moderate (range of r: 0.44 - 0.7) during weekdays. However, correlations were not significant during weekends when the normal structure of the work week was not guiding eating patterns. No significant correlations were observed within individuals between absolute or change of hunger over 1, 2 or 3 hours and energy intake nor for the number of eating occasions. Indeed, eating occurred more often when hunger was low or eating did not occur when hunger was high more often than when the expected relationship (e.g., high hunger led to intake) was observed. Moreover, hunger sensations seem to adapt to changed eating patterns or energy balance. Hunger signals do not continuously increase with long-periods of energy deficit (42). Even though hunger increased for few days after energy restriction, hunger sensations returned to baseline levels within 4-8 weeks (42). Alternatively, when a snack was provided outside of regular meal times for five days, hunger ratings around the snaking time increased compared to hunger ratings prior to the intervention (43). Further research on appetite adaptation variability between individuals is required. Another explanation may be that individuals have different orientations to appetitive sensations (14). For example, one may enjoy fullness and decide to keep eating even though one feels high fullness. Also, one may strongly dislike fullness and decide to stop eating even though one feels only slight fullness. A qualitative study on attitudes towards appetitive sensations will allow the discovery of meaning beyond the number of appetite ratings.

1.2 Appetite Determinants

A robust literature exists for identification of factors that may influence appetitive sensations. The suggestive determinants are broadly divided into internal and external factors. Here, biological and environmental/psychological determinants will be reviewed followed by a consideration of next steps to understand appetite variability within and between individuals.

1.2.1. Biological Determinants

a. Obesity

Reports of associations between appetitive sensations and obesity are mixed (4,44,45). Some reports indicate individuals with obesity experience greater hunger and less fullness compared to individuals who are lean (44,45), but others do not support this finding (2,4,46). In addition, psychological traits such as impulsivity (47) and high disinhibition (48) rather than hunger may better explain BMI trajectories. The impact of BMI on desire to eat is also unclear (30,49).

Differences in fullness between individuals with varying weight status have been investigated under different levels of energy intake. In overfeeding conditions, individuals with obesity who lost weight but were still overweight reported less reduction in hunger and a lesser increment in fullness compared to controls (50) . Alternatively, other works show no significant differences in fullness with normal feeding, overfeeding, or underfeeding between individuals with obesity versus lean individuals (51,52). These mixed results indicate that individuals with obesity do not experience clearly different fullness sensations compared to those who are lean. Alternatively, these mixed findings may be due to measurement errors that will be discussed in the appetite measurement chapters (chapter 1.3 and chapter 5).

b. Gender

Some previous studies have suggested that there are differences between men and women in appetitive sensations. Mean fullness ratings of women are reportedly higher than men, and mean hunger, desire to eat, and prospective consumption ratings are lower (5,53,54). In one trial, 50% overfeeding resulted in a significantly greater reduction of pre-meal hunger in women compared to the reduction in men (44). The gender differences may due to the ability to inhibit brain activation by food stimuli (55) or different cognitive and emotional processing of hunger and satiation (54,56,57). Overall, appetitive sensations of women seem to change more markedly in response to a meal. There are nuances to this view in that women in the ovulatory phase felt less hungry than women in the menstrual phase (58,59). In contrast, other studies fail to report sex-based differences in either fasting (53,60) or post-prandial state (3,55,56).

c. Age

It has been also suggested that ageing is associated with early fullness and there is a biological basis for a decline in hunger and meal intake (5,61–63). According to a meta-analysis, older adults (aged 60–88 years) rated their hunger 25% and 39% lower after overnight fasting and in a postprandial state, respectively, and their fullness 39% and 37% greater after overnight fasting and in a postprandial state, respectively, than younger adults (aged 22-50 years) (61). Physiological changes that occur with ageing can cause difference in appetitive sensations including changes to the digestive system (64), hormonal changes (65), disease (64,66–69), pain (70), changes to the sense of smell, taste and vision (66,68), medication use (71) and a decreased need for energy (72–74). While these changes may be responsible for the declining appetite with ageing, the changes attributable to ageing itself remain equivocal and inconsistent (64,66,68,75,76). Most of the findings are based on one-day observations or short-term assessments. Long-term studies are required to confirm the impact of ageing on appetitive sensations.

d. Gastrointestinal peptides

Endocrine processes in the GI tract may also be involved in appetite regulation. Multiple peptides are secreted in the GI tract following nutrient stimulation and reportedly modulate appetite. Cholecystokinin (CCK), Peptide tyrosine tyrosine (PYY), and Glucagon-like peptide-1 (GLP-1) are related to fullness, and ghrelin is the only gut peptide that purportedly triggers a hunger cue (6,77). These gut peptides may work by paracrine and/or endocrine mechanisms.

CCK was the first discovered gut peptide related to appetite regulation and it reportedly functions primarily as a fullness signal (78). CCK is secreted from the endocrine I cells throughout the small intestine but mostly in the duodenum in response to nutrients (79,80).Circulating CCK activates the hindbrain by binding to vagal neurons, which integrates fullness sensations as well as hedonic signals, and other signals from different parts of the brain including the hypothalamus, where appetite signals are regulated (81,82). CCK also delays gastric emptying (83–85). However, the effect of CCK on appetitive sensations are unclear. Several studies report CCK infusion at greater than physiology doses are related to reduced hunger, increased fullness, and reduced food intake (86–88), while other studies revealed lowered meal sizes without influencing appetitive feelings (89–91). Interestingly, few reported that injected CCK did not augment plasma level in human while food intake was reduced (91,92). In addition, the roles of CCK in mediating appetite under physiological conditions are questionable (85). There is marked interindividual variation in appetite sensations corresponding to plasma CCK level (85). Only three out of nine individuals showed negative a correlations with hunger and plasma CCK levels and only four out of nine had positive correlations with fullness and plasma CCK levels (85). This may be due to contributions of other peptides affecting appetite like PYY and GLP-1 which have a role in stimulating fullness signals. The endocrine controls of appetite are highly integrated and redundant. Further studies involving co-administration of CCK with other gut peptides at physiological levels are required to strengthen the existing.

GLP-1 is another gut peptide associated with the sensation of fullness. It is released from L-cells located in both small and large intestine in response to all macronutrients (93–95). GLP-1 infusion at physiological doses enhance fullness and reduce energy intake (96,97). In addition, differences in plasma GLP-1 concentrations were related to differences in fullness ($r=0.38$, $p<0.05$), but not hunger ($p>0.05$) and *ab libitum* energy intake (97). However, other studies failed to find an effect of GLP-1 on fullness or energy intake (89,98). One potential mechanism by which

GLP-1 regulates appetite and food intake is by slowing gastric emptying and inhibiting gastric acid secretion (99,100). However, appetite reduction induced by GLP-1 administration is also observed in fasting state, which contradicts this potential mechanism (101). The role of GLP-1 on fluid intake by increasing sodium excretion has been suggested (102,103), but further studies with larger sample sizes are required to confirm this potential role.

Like GLP-1, PYY is synthesized by a posttranslational modification in L-cells and binds to Y receptors on afferent neurons inducing satiety (Michel 1998). PYY infusion at supraphysiologic levels reduces hunger and food intake (104). However, this effect was not found with physiological infusions of PYY as measured by meal size as well as fullness and hunger sensations (105,106). In addition, average baseline PYY levels were not significantly correlated with either *ab libitum* meal intake, fullness, or hunger ratings regardless of the macronutrient compositions of meals (107). Similarly, the reported effect of PYY is to reduce gastric emptying at supraphysiologic doses but not at physiological doses (108). Thus, current evidence does not consistently support the effect of GLP-1 on energy intake and appetitive sensations.

To date, ghrelin is the only known gut peptide that purportedly stimulates hunger sensations (6). Enteroendocrine cells in stomach produce ghrelin (109) and there are two forms of ghrelin: acylated ghrelin (active form) and non-acylated ghrelin (inactivate form) (110). Acylated ghrelin reportedly works as hunger stimulus via the vagus nerve (110,111). The level of the ghrelin rises sharply before a meal and falls within one hour of meal completion, indicating its effect is initiation of a meal rather than controlling meal size (112). However, like other peptides, the effect of ghrelin on food intake was only significant with injection of supraphysiologic doses. Other work indicates ghrelin injection does not affect hunger ratings at either physiological or supraphysiological doses (113,114). It has been suggested that supraphysiologic ghrelin infusion may enhance food hedonics rather than hunger (115). Moreover, ghrelin also increases GI motility in the fasting state (116,117) and the rate of gastric emptying in rats (117). Whether these effects are relevant in humans is uncertain.

Taken together, manipulation of gut peptides can affect appetitive sensations and food intake by supraphysiological dosing. However, it is still unclear whether gut peptides alone under physiological conditions exert an essential role in appetite regulation and food intake. In addition, gut peptides might reflect expected portion size and/or fullness based on previous experiences rather than gut peptides modulate energy intake or appetitive sensations (118–120). Further research on the relationship between learning and gut peptides with human is required to confirm this hypothesis.

e. Genetic Influences

The heritability of appetite sensations or appetite traits has been investigated in studies with twins. A prospective study compared appetitive traits between monozygotic and dizygotic twin infants using the baby eating behavior questionnaire revealed a higher correlation in satiety responses, slowness in eating, and food responsiveness between monozygotic infants compared to dizygotic infants suggesting a genetic contribution to appetitive sensations (121). Specific genetic variants have been associated with appetite variability (122–126). The FTO gene is one prominent gene reportedly related to appetite regulation. Several studies report that a genetic polymorphism in FTO is associated with satiety sensitivity (124,125), hunger (123) and energy intake (122,126) in both children and adults. However, recent findings fail to confirm a contribution of FTO gene variants to appetite variability in healthy adults (2,51). Even though fasting and postprandial appetite variation was observed between individuals who were lean or had obesity, there was no association between variations in FTO gene expression and appetite. Taken together, the role of the FTO gene in appetite sensations is still not clear and further elucidation on specific genes influencing appetite variability between individuals should be examined. However, given the small contribution of genetics to obesity (5-10% of variance in adiposity) (127), any genetic effect on appetitive sensation would likely be small.

Any genetic predispositions may be reshaped by individual environmental influences (128–132). At childhood, genetic influences outweigh environmental influences (131,133). A twin study investigated appetite traits of 5435 twin pairs 8 – 11 years of age using Child Eating Behavior Questionnaire (CEBQ) (131). Genetic influences on appetite traits (in contrast to direct assessments) were greater (63% for satiety responsiveness, 75% for food cue responsiveness (enjoyment of food)) than shared (21% for satiety responsiveness and 10% for enjoyment of food) and non-shared environmental influences (16% for satiety responsiveness and 15% for enjoyment of food) on appetite traits (131). In contrast, environmental influences were greater over time (128,134). Parenting style in childhood was associated with eating behavior and appetite traits (135). A one-year longitudinal study examined the association between parenting styles of 1275 children (mean age = 9 years) and their appetitive traits measured by questionnaire. They constructed five parenting styles: the authoritative (high support, high behavioral control, low psychological control), permissive (high support, low behavioral control, low psychological control), authoritarian (low support, high behavioral control, low psychological control), rejecting (low support, low behavioral control, high psychological control) and neglecting (low support, low behavioral control, low psychological control) parenting styles. There was a negative association between food-avoidant appetitive traits and child BMI only in children of permissive parents, while neglecting parenting strengthened the positive association between food-approaching appetitive traits and weight gain (135). In addition, one trial with adults (34 – 78 years) collected Eating Inventory Questionnaire data, including disinhibition, hunger, and restraint from female monozygotic twins (n=129) and female dizygotic twins (n=81). They reported that specific environmental influences were greater than genetic influences for hunger (76% and 8%, respectively), disinhibition (55% and 45%, respectively), and restraint (69% and 0%, respectively) (128). Therefore, while appetite traits are heritable, those inherent traits are modified by environment factors over time.

1.2.2. Environmental & Psychological Determinants

a. Diet (Macronutrient Composition)

Macronutrients are the source of dietary energy, and each has a unique metabolism that could theoretically differentially influence appetite. One mechanism entails modulation of gut peptides related to appetite regulation (such as CCK, GLP-1, PYY, and ghrelin). For example, carbohydrate and protein suppress ghrelin levels more effectively than fat in adults (8,136). However, hunger and fullness do not differ following ingestion of predominantly protein-, carbohydrate-, or fat-containing foods (8) or beverages (136). Alternatively, it has been proposed that supplementing a meal with fat can lower hunger and elevated fullness (137), but this also has not supported by other studies (138). Protein has often been thought as the most satiating macronutrient but a thorough review revealed that higher-protein interventions reduced hunger and promoted fullness in only 35% and 55% of acute feeding studies in humans, respectively (139). Taken together, cumulative evidence fails to support a robust role of diet composition in modulating appetitive sensations.

b. Eating pattern (eating frequency and portion size)

The interaction between the total number of eating events (eating frequency) and the energy per eating event (portion size) determines total energy intake. Without precise reciprocal compensation, increases or decreases in either component can lead to energy imbalance and weight change (140–142). Thus, both components are important targets for interventions to manage body weight (143–148).

Intuitively, larger portion sizes lead to greater fullness. However, empirical evidence for this is inconsistent (32,149–151). Although individuals generally consume more energy with larger portion sizes, there often are no differences in hunger and fullness ratings after relatively larger and smaller meal sizes (32,150–152). In addition, either reducing or increasing portion size does not consistently evoke compensatory eating (32,152) indicating modified portion size and appetitive sensations are not reliably linked to energy intake. Thus, the effect of portion size on appetitive sensations is vague and the effect of chronic inter-individual appetite differences on portion size is still unknown.

It is also not clear whether different eating frequencies lead to reliable differences of appetite sensations or regulation of energy intake. Some studies show that increased eating frequency more than 3 meals per day lowers the peak of hunger and greater fullness in some studies (153). Contradictory result have been obtained from another study where eating six times per day increased hunger ratings and decreased fullness ratings compared with 2 meals per day (154). Similarly, reducing eating frequency increased hunger and lowered fullness in some studies (147,155) but not others (148,156,157). Compensatory eating also was not observed with modified eating frequency (158,159). Food forms (solid liquid) (140,149) or habitual or social environments (160–162), rather than appetitive sensation, may mediate the effects of eating frequency or portion size on energy intake. Though a convincing case may be made that frequency of eating is directly related to energy intake and BMI (163,164), it is not clear that this can be attributed to a contribution of appetitive sensations. It could be true that there is no association between appetitive sensations and eating patterns or a current limitation in appetite measurement (detail discussion in chapter 5) may hamper collecting reliable data to determine a genuine relationship between appetitive sensations and eating patterns.

c. Psychological Influences

Previous eating experiences build expectation about appetite sensations. These expectations can modulate appetite ratings with the isocaloric foods (38,165,166). For example, in one trial, a plate of fruit was shown to participants telling them how much fruit is included in a fruit smoothie (165). Half of the participants saw a large portion of fruit and the other half saw a small portion of fruit (165). Even though the same amount of fruits was used and consumed, participants who saw the large portion of fruits had greater expected satiety, lower hunger, and greater fullness over time (165). Similar results have been found in other studies with food label information (167,168). Actual or expected physical properties of foods (e.g., beverage viscosity (169,170), and food form (38,149)) can affect appetitive sensations regardless of the energy content of foods. Given that every individual will have different food experiences and, as a consequence, different expectations about the post-ingestive effects of consuming an item, the importance of this is a source of variation on ingestive behavior will likely require individualized assessment.

1.3 Appetite Measurements

1.3.1. Methods of Appetite Measurements

Each appetitive sensation comprises multiple bodily sensations and these vary between individuals. Subjective measurements are taken of individualized bodily sensations and are expressed numerically (171). Most commonly, participants are asked to mark the strength of their appetitive sensations by answering questions such as: ‘how hungry do you feel now?’ for hunger, ‘how full do you feel now?’ for fullness, ‘how strong is your desire to eat now?’ for desire to eat, ‘how much do you think you can eat now?’ for prospective consumption, and ‘how thirsty do you feel now?’ for thirst (172).

Various types of response scales and questionnaires have been used for measuring subjective appetitive sensations. Visual analogue scales (VAS) are most widely used. VAS is a continuous line scale with end anchors of descriptors such as ‘not at all’ to ‘extremely’. Ratings are interpreted by measuring the distance from one anchor to the respondent’s mark. Recently, online software has reduced the researchers’ coding burden and error rate by measuring the distance electronically. The validity of electronic recordings have been established (172,173). The strength of VAS is that they provide convenient, and rapidly administered measurement. The weakness is that respondents must understand the line that represents a personal perception of an abstract concept (174). Thus, clear, and careful definition of measuring concepts and repeated measurement are important for using VAS. However, the most common method of measuring appetite is to ask untrained individuals to self-report appetitive sensations under the premise that they comprehend the concept of appetitive sensations. Alternatively, categorical scales comprised of a limited number of response options ranging from two to many categories may be used. Compared to VAS, categorical scales are easy and familiar response scales so requires less cognitive burden while the categorical interval may have too small number of options to capture actual level of perception (175). Thus it is hard to discriminate perceptual difference between two sequential categories at the low and high ends of the scale (175). Response scales may be monotonic or bipolar with a neutral point in the middle. The latter are most often used when there are an odd number of categories. Open-ended questionnaires may also be used to explore qualitative aspects of appetitive sensations such as bodily sensations (12,14,15). There have been attempts to identify biomarkers as more objective indices (e.g., gut peptides) while, as discussed above, most of biomarkers have not proven successfully (176,177).

1.3.1. Methodological Limitations

A fundamental limitation of measuring subjective appetitive sensations is relying on untrained respondents who may lack understanding of appetite concepts and terminology (178). One common confusion is that respondents view hunger and fullness as opposite sensations on a single continuum (1,14,156). That is, as one's hunger decreases, their fullness increases, and vice versa. Thus, the sum of hunger ratings and fullness ratings is approximately 100 % of the scale (1,156). However, this is not because they are causally reciprocally associated, but because both sensations usually fluctuate in opposite directions with food intake (179). They are independent sensations, driven by different physiological and behavioral processes and serv different purposes (i.e., hunger drive eating frequency while fullness influence portion size). For example, when people are hungry and drink a glass of water, their fullness increases but hunger may not be diminished (26). Indeed, individuals may report they sometimes felt both high hunger and fullness sensations at the same time (14). Another common confusion of appetite concepts is that hunger and desire to eat are similar sensations (156,180). Desire to eat can be stable or fluctuate when hunger decreases. Common experience indicates snacking and eating in the absence of hunger are common (181). These underlying confusions challenge the validity of appetite ratings obtained from naïve study participants as well as the interpretation from the ratings. Better understanding of appetitive terms through concept training may improve the validity of appetite ratings but this remains to be demonstrated.

Another primary limitation of subjective ratings are underlying assumptions about temporal changes (178). It is often assumed that in the absence of eating/drinking, appetitive sensations increase in a predictable way over time. However, the overnight fast is typically the longest interval between eating events and peak daily hunger is rarely reported at this time (182). Further, knowledge of food portions (small versus large portion), and food forms (thin versus thick liquid, solid verses liquid), at the last eating event may alter responses over time (38,165,183). Expectations of the effects of upcoming meals may also alter sensations (182,184).

To overcome the limitations of subjective ratings, more objective biomarkers of appetitive sensations have been explored (178,185). Several metabolites have been proposed as biomarkers for appetitive sensations including glucose, fatty acids and amino acids (186–188). Endocrine indices have also been proposed as objective markers of appetite. Considerable attention has been focused on insulin, and gut peptides (185,189). The carbohydrate-insulin model postulates that a high carbohydrate diet promotes fat storing through elevated insulin concentrations, and this induces energy intake, in part, by increasing hunger (190).The carbohydrate-insulin hypothesis holds that there is a negative correlation between blood glucose concentration and hunger (186), or positive correlation between glucose level and fullness ratings (187) and positive correlation between insulin level and hunger ratings (191,192). However, there is no difference in hunger or fullness following independent modulation of either glucose or insulin during euglycemic clamp studies (193,194), indicating the relationships are not casual but associative.

As discussed above, nutrient signaling in the gastrointestinal (GI) tract stimulates the release of a wide array of peptides that have been linked to appetite (195). The question is whether they are simply associated with appetitive sensations or play a causal role and how robust are the relationships. Most studies explore these hormones by injecting them, often in non-physiological does or temporal patterns, and monitor appetitive sensations. However, findings are inconsistent and it is unclear whether such non-physiological conditions reveal effects that would occur under naturalistic conditions (77,189,195). The relationships between gut peptide levels and appetite ratings are inconsistent. Further, they are known to interact with other hormones, such as insulin

(196), and are sensitive to diet composition (107). While the high-protein diet induced higher PYY and GLP-1 secretion compared to the isocaloric high-carbohydrate and high-fat diets, appetitive sensations or subsequent energy intake were not different among the diet conditions (176,177). These findings indicate that assessing one or two measurable biomarkers is not sufficient to fully explain the complexity of appetite regulation based on current evidence.

1.4 Intra- and Inter-individual Variability of Appetitive Sensations

Marked intra- and inter-individual variations have been documented in self-reported appetite ratings (1–3,197). In one observational study (1), participants (39 Female, 11 Male; mean ± SD age 30±11 years; BMI 26.3±5.9 kg/m^2) recorded hunger and thirst ratings hourly throughout the day for seven consecutive days. As expected, hunger and thirst ratings fluctuated over the day within individuals (about 30 - 85 mm, and about 15 -60 mm on a 100 mm scale, respectively), but the variations of mean hunger and thirst ratings were lower (about 15 - 50 mm, and about 10 – 50 mm on a 100 mm scale, respectively) (1). There were also large variations in mean ratings between individuals (maximum difference is about 50 mm on a 100 mm-scale) (1). Some individuals reported a 7-day mean daily hunger rating over 50 mm and a mean daily thirst ratings over 80 mm (on a 100 mm scale) while others reported values below 20 mm (1). These interindividual differences in appetitive sensations were consistent (correlation coefficients between days: hunger, r=0.52; thirst, r=0.78). A one-day observational study also reported variability in mean thirst ratings between 120 women (mean ± SD : age 20±2 years; height 165±7 cm; weight 62.1±11kg) (198). Some individuals had a mean thirst sensation greater than 7 on 9-categorical scale while some reported thirst less than 2 on 9-categorical scale over a day (198). Feeding and exercise trials also reported intra- and inter-individual variability in appetite responses. A randomized controlled trial provided two-repeated standardized meals and two repeated unstandardized meals (*ab libitum* meal) and measured hunger and fullness in response to the meals in eighteen healthy men (mean ± SD: age 28.5 ± 9.8 years; BMI: 27.0 ± 5.0 kg/m^2) (2). The appetitive sensations of participants were consistent between the two repeated measurements regardless of meal types (correlation coefficients between days: hunger, r=0.59; fullness, r=0.41; satisfaction, r=0.74; prospective consumption, r=0.65) (2). Differences between post and pre-meal appetitive sensations varied between individuals (2). The changes of hunger and fullness were more than 70 mm in some participants and less than 20 mm in others (2). One study conducted secondary analysis on changes of hunger ratings in response to exercise interventions in 17 trials (192 healthy male with 22.3 ± 2.7 years (mean±SD) (199). Healthy men 22.3±2.7 of age and 23.4±2.2 kg/m^2 of BMI involved in the trials and there was interindividual variation in hunger responses to exercise intervention (199). Mean hunger ratings during and after exercise were suppressed in 78% of the individuals while they were augmented in 19 % of the individuals or were not changed in 2% of the individuals (199). However, these heterogeneous responses were concealed when the changes were averaged out (199). Taken together, intra- and inter-individual variability in appetitive sensations have been reported but it is still unknown whether this variability persists in the longer-term and what the dietary implications may be.

CHAPTER 2. STUDY RATIONALE

Appetitive sensations have been considered as important modulators of food intake and weight management. Marked intra- and inter-individual variability in appetitive sensations have been reported, but the consistency and implications of this variability on long-term energy intake and eating pattern are not well understood. If appetitive sensations are effective modulators of energy intake, those who have relatively higher hunger, higher thirst, and lower fullness should be more susceptible to over-consumption with food exposure and may have higher risk of obesity. Similarly, knowing whether eating patterns (eating frequency vs portion size) are driven by appetitive sensations will provide beneficial insights on weight management strategies. In addition, there are multiple explanations for intra- and inter-individual differences in appetitive sensations since appetitive sensations are affected not only by what is ingested but also by biological, psychological, and environmental factors. If there are consistent differences within and between individuals, understanding the causes and implications could be of great clinical value. Therefore, the purpose of this research was to explore intra- and inter-individual variability in appetitive sensations, to determine directionalities between appetitive sensations and energy intake and between appetitive sensations and eating patterns, and to investigate characteristics of individuals at the extremes of chronic appetitive sensations.

This dissertation focuses on the questions above, but as part of the training experience, two additional studies were conducted. One entailed appetite concept training to improve the validity of appetite measurements. A potential barrier to accurate appetite measurement is low conceptual understanding by study participants and resulting poor sensitivity and accuracy of responses. While each appetitive sensation is independent and has a unique definition, reported similar patterns between appetitive sensations in multiple studies raise questions about whether participants fully comprehend appetite concepts and provide accurate responses. To overcome this potential limitation, appetite concept materials were developed, and two groups of individuals were provided training either with these materials or unrelated sensory information followed by measurement of appetite responses to five different pre-loads. This work will be discussed in Chapter 5.

A second study sought to gain insights on the sensory qualities of fatty acids as part of an effort to determine if oral fat detection is based, in part, on gustatory cues. It has been argued that if fat taste is a primary, the sensations imparted by fats should yield unique percepts and these may be determined by fatty acid chain length. In particular, because acids impart a sour taste, free fatty acids may simply be detected as sour. The fat taste study entailed measurement of intensity ratings with or without sour adaptation (to assess sour notes), tongue locations of taste detection, and subjective descriptors of fatty acids. The work is included as Appendix C.

CHAPTER 3. METHODS

3.1 Participants

Participants were recruited through public announcements including flyers (Appendix A), online advertisements (Purdue Today, social media) (Appendix A), and verbal advertisements (Appendix A) from April 2021 to March 2022. Eligibility criteria included healthy men and women, 18-64 years of age, body weight fluctuation < 2.5 kg in the 3 months prior to the start of the study, not taking medication known to affect appetite, and not planning to change lifestyle behaviors that could affect energy balance. All procedures involving human subjects were approved by the Purdue University Institutional Review Board. Written informed consent (Appendix A) was obtained from participants who met eligibility criteria. This study is registered in clinicaltrials.gov (NCT04836416).

3.2 Protocol

This was a 17-week observational study. At screening, participants reported demographic information including age, biological sex and race/ethnicity. This information was collected via questionnaire (Appendix A). Weight, height and BMI were measured once at the screening meeting. They also completed a battery of questionnaires addressing selected eating traits (Appendix A). The Meal Pattern Questionnaire (200) assessed an overall picture of each participant's eating pattern. The Power of Food Scale (201) assessed the psychological impact of living in food-abundant environments by measuring appetite for palatable foods at three levels of food proximity (food available, food present, and food tasted). The Emotional Eating Scale (202) identified eating in response to three negative emotions: anger, anxiety, and depression. The Eating Inventory (203) measured three dimensions of eating behavior: cognitive restraint, uncontrolled eating, and emotional eating. The Food Craving Inventory (204) measured general and specific food cravings: high fat foods, sweets, carbohydrate-starchy foods, and fast-food/high fat foods. The Adult Eating Behavior Scales (205) assessed food approach and avoidance traits by measuring eight traits: hunger, food responsiveness, emotional over-eating, enjoyment of food, satiety responsiveness, emotional under-eating, food fussiness, and slowness in eating. The Self-Regulation of Eating Behavior Questionnaire (206) assessed self-regulatory capacity for eating.

The Barratt Impulsiveness Scale (207) assessed the personality and behavioral constructs of impulsiveness. Lastly, participants completed a working environment questionnaire before and during/after the COVID-19 pandemic outbreak to understand the effects of the pandemic on ingestive behavior.

In addition, participants received appetite lexicon training (Appendix A) to increase the validity of their appetite ratings as well as general instructions on study activities including how to complete hourly appetite ratings, daily dietary recalls, and daily physical activity forms.

After the screening visit (week 0), participants participated in the study virtually at study weeks 1, 9, and 17. At each of these timepoints, data were collected on three randomly selected days. Two days were non-consecutive weekdays and one day was a weekend day. For each day, participants self-reported their appetite sensations (hunger, fullness, and thirst) hourly during their waking hours on a visual analog scale (VAS) using online survey software (Qualtrics) (Appendix A). The physical activities of participants were automatically recorded using an app (ActivityTracker Pedometer, Bits&Coffee LLC) on the same day that appetite ratings were recorded. Participants took a screenshot of the physical activity record and submitted the screenshot via Qualtrics on the following days. Participant dietary intake was recorded using the ASA24 system (online dietary recall system) (208) on a day after an hourly appetite rating day. Participants attended a virtual meeting one week before weeks 9 and 17 to remind them of study activities. During the reminder meetings, participants were informed that three days would be randomly selected for the upcoming week, and what study procedures they would be expected to follow on each of the selected days. The definitions of hunger and fullness were explained again and any questions were addressed.

3.3 Anthropometrics

Height and weight were measured once at the screening meeting. Participants were asked to remove shoes and socks and heavy jackets or coats and to empty their pockets. A medical wall-mounted stadiometer (Seca, Chino, CA) was used to measure height, and a Tanita Body Composition Analyzer (Model TBF-410GS, Tanita Inc., Arlington Heights, IL) was used to measure weight to permit calculation of BMI.

For those who were not able to visit the laboratory (e.g., due to geographical distance), height and weight were measured during a virtual meeting through Zoom. Participants were asked to join the meeting with a third party who was able to measure their weight and height at the beginning of the meeting. Before measuring weight and height, a participant was asked to remove shoes and socks and heavy jackets or coats and to empty their pockets. The participant stood straight against the wall, and the third party measured height from the floor to the highest point of the head using an augmented reality technology-based app (either one of the following: Measure app by Apple, AR Ruler App by Google Play, Quick Measure by Samsung). Weight was measured on a scale available to each participant. Participants stood on the scale, and a third party took a picture of the weight measurement when the number had not changed for three seconds. Both height and weight measurements were repeated three-times and the average of three values was used for the study estimate. All the measurements were consistent within ± 1 inch for height and ± 0.5 lbs for weight. A photo of the weight measurement and a screenshot of the height measurement were submitted through Qualtrics.

3.4 Appetite Lexicon Training

Participants watched a basic concept training video defining four appetitive sensations (hunger, fullness, desire to eat, and prospective consumption) (Appendix B) and a series of video tutorials about common confusions among appetite concepts. After they completed the training, participants took an online quiz to confirm their understanding of the concepts. A score of at least 90% correct responses was required to pass the appetite lexicon training. Failure to satisfactorily demonstrate an understanding of the concepts resulted in an offer to repeat the training up to two additional times with required testing to document satisfactory understanding after each attempt. Failure to meet training criteria resulted in disqualification from the study.

3.5 Appetite Sensation Assessment

Participants rated their perceived hunger, fullness, and thirst on their cell phones/computers via a web based Qualtrics survey every waking hour on three days that were randomly selected at weeks 1, 9, and 17. Two days were non-consecutive weekdays and one day was a weekend day. The questions for appetite sensations (hunger, fullness, and thirst) were “how hungry do you feel”, “how full do you feel?”, and “how thirsty do you feel?”, all rated from “not at all” anchored at the 0-% to “extremely” anchored at the 100% (171,209). Responses were provided on visual analog scales (VAS). All entries were time and date stamped to ensure the ratings were made at the intended times.

3.6 Physical Activity Assessment

Free-living energy expenditure was measured using an app (ActivityTracker Pedometer, Bits&Coffee LLC) on the same days that appetite ratings were recorded. Participants were asked to download the app at the screening visit and complete the app settings with their gender, weight and height. Participants were asked to carry their phones throughout the days they recorded hourly appetite ratings. They reported their recorded energy expenditure by submitting a screenshot of the records on the following day through the web-based survey (Qualtrics).

3.7 Dietary Assessment

Dietary intake was recorded by a dietary recall method using the automated self-administered 24-hour dietary recall (ASA24- version 2020-2022) system (208) of the same days that appetite ratings were reported. Participants recalled what they ate and drank over the prior 24 hours. The plausibility of the data was assessed using the Goldberg formula (Black, 2000) (Appendix A).

CHAPTER 4. APPETITE VARIABILITY, EATING PATTERN, AND ENERGY INTAKE

Eunjin Cheon, Richard D. Mattes

4.1 Footnotes

This is a manuscript about a long-term observational study investigating intra- and inter-individual variability in appetitive sensations (hunger, fullness, and thirst), directionalities between appetitive sensations, energy intake and eating pattern, and associations appetitive sensations and selected individual characteristics.

Abbreviations: AS, appetitive sensations; BMI, body mass index; EF, eating frequency; EI, energy intake; PS, portion size; VAS, visual analogue scale, CCF, cross-correlation function, DTW, dynamic time warping. WSR, Wilcoxon signed-rank test

4.2 Abstract

Appetitive sensations are signals that guide eating behaviors. Marked short-term inter-individual variability in appetitive sensations has been reported but the long-term stability of individual ratings and their dietary implications are not well characterized. This study explored the stability of inter-individual ratings of hunger, fullness and thirst for 17 weeks; determined the relationships between these sensations, eating patterns and energy intake; as well as the associations between ratings and selected individual characteristics (age, gender, BMI). Ninety-seven (90 completers) healthy adults recorded the intensity of their hunger, fullness, and thirst hourly during all waking hours for three days at weeks 1, 9 and 17. There were marked and stable inter-individual differences for each sensation over the 17 weeks: hunger (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9, $r=0.72$ ($p<0.001$), week 1 vs week 17, $r=0.67$ ($p<0.001$), week 9 vs week 17, $r=0.77$ ($p<0.001$)), fullness (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9 $r=0.74$ ($p<0.001$), week 1 vs week 17, $r=0.71$ ($p<0.001$), week 9 vs week 17, $r=0.81$ ($p<0.001$)), and thirst (ANOVA, $p<0.001$, correlation coefficients of ratings between weeks: week 1 vs week 9 $r=0.82$ ($p<0.001$), week 1 vs week 17, $r=0.81$ ($p<0.001$), week 9 vs week 17, $r=0.88$ ($p<0.001$)). Cross-correlation functions

revealed energy intake and eating pattern exerted stronger effects on appetitive sensations than the reverse. However, the absolute effect sizes were small. No robust effects of the studied individual characteristics were observed. The primary finding is that acute and chronic sensations of hunger, fullness and thirst are stable across individuals, but are poor predictors of ingestive behavior.

4.3 Introduction

Weight gain stems from sustained positive energy balance (i.e., over days, weeks, months and years). Appetitive sensations (AS) are viewed as drivers of energy intake (179,210). They oscillate markedly over hours. If they do so in ways that result in energy balance, no change of body weight would be predicted over time. However, if there is a sustained bias towards higher or lower motivation to eat, this may predispose individuals toward positive or negative energy balance and weight change. As both low and high body weight (adiposity) holds health risk, a key question is whether there are reliable inter-individual differences in the mean daily level of AS that may account for differences in longer-term energy intake and risk of unhealthy weight. Prior shorter-term studies with limited sample sizes suggest there are reliable inter-individual differences in AS (2,211). The first aim of this study was to more rigorously explore daily AS ratings over time to determine their stability and the magnitude of individual differences. Various hypotheses could be proposed to link AS to adiposity status. One holds that individuals with high chronic hunger or low chronic fullness will consume more energy to mitigate these unpleasant sensations and thereby be at increased risk of higher adiposity. Alternatively, high chronic hunger or low fullness may be the result of low energy intake, a condition likely to be associated with low adiposity. The counter arguments would apply at the other end of the appetitive scale (i.e., low chronic hunger and high chronic fullness). To clarify this issue (aim 2), we explored the directionality of the relationships between AS and energy intake and between AS and eating patterns. Multiple individual characteristics (e.g., BMI (body mass index) (212), age (213), gender (53,213)) have been hypothesized to modify appetite-diet associations and risk for obesity. A third aim was to determine whether these selected individual characteristics mapped onto patterns of AS intensity over time.

4.4 Methods

4.4.1 Participants

Participants were recruited through public announcements. Eligibility criteria included 1) healthy (e.g., no history of chronic disease such diabetes, hypertension, etc.), 2) 18-64 years of age, 3) weight stable (body weight fluctuation < 2.5 kg over the prior 3 months), 4) not taking medication known to affect appetite, and 5) not planning to change lifestyle behaviors that could affect energy balance. All procedures involving human subjects were approved by the Purdue University Institutional Review Board and this study was registered in clinicaltrials.gov (NCT04836416). (Appendix A)

4.4.2 Protocol

This was a 17-week observational study. At screening, participants reported demographic information including age, biological sex, and race/ethnicity; completed a battery of questionnaires addressing selected eating traits; and weight and height were measured. In addition, participants received appetite lexicon training to increase the validity of their appetite ratings as well as general instructions on study activities including how to complete hourly appetite ratings, daily dietary recalls, and daily physical activity forms. After the screening visit (week 0), participation was virtual at study weeks 1, 9, and 17 (Figure 1). At each of these timepoints, data were collected on three randomly selected days. Two days were non-consecutive weekdays and one day was a weekend day. For each day, participants self-reported their appetite sensations (hunger, fullness, and thirst) hourly during their waking hours on a visual analog scale (VAS) using online survey software (Qualtrics). The physical activities of participants were automatically recorded using an app (ActivityTracker Pedometer, Bits&Coffee LLC) on the same day that appetite ratings were recorded. Participants took a screenshot of the physical activity record and submitted the screenshot via Qualtrics on the days following recording. Dietary intake, 24-hour recall, was recorded using the ASA24 system (online dietary recall system). The dietary intake and appetite rating data were recorded on the same days. Participants attended a virtual meeting one week before weeks 9 and 17 to remind them that three days would be randomly selected during the upcoming week, and what study procedures they would be expected to follow on each of the selected days. The definitions of hunger and fullness were explained again, and any questions were addressed.

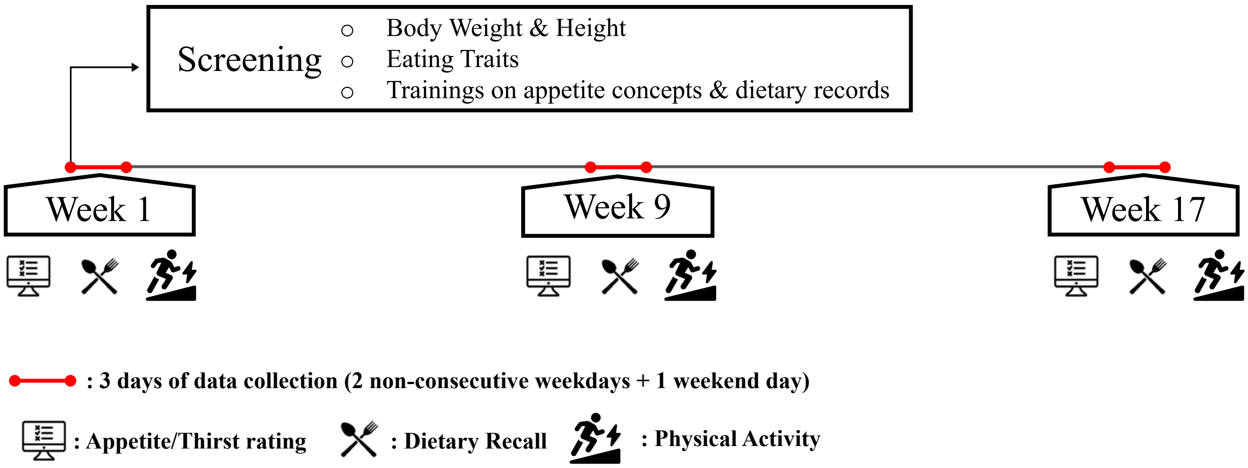

Figure 1. Study timeline

4.4.3 Anthropometrics

Height and weight were measured after participants removed their shoes, socks and coats and emptied their pockets. A wall-mounted stadiometer (Seca, Chino, CA) was used to measure height, and a Tanita Body Composition Analyzer (Model TBF-410GS, Tanita Inc., Arlington Heights, IL) was used to measure weight to permit calculation of BMI. For those unable to visit the laboratory due to geographical location (n=12), height and weight were measured during a virtual meeting through Zoom. Participants were asked to join the meeting with a third party who was able to measure their weight and height. Participants stood straight against the wall, and the third party measured height from the floor to the highest point of the head using an augmented reality technology-based app (Measure app by Apple, AR Ruler App by Google Play or Quick Measure by Samsung). Weight was measured on a scale available to each participant. Participants stood on the scale, and a third party took a picture of the scale reading. Both height and weight measurements were repeated three-times and the average of three values was used for the study estimate. All the measurements were consistent within ± 1 inch for height and ± 0.5 lbs for weight. A photo of the weight measurement and a screenshot of the height measurement were submitted through Qualtrics.

4.4.4 Appetite Lexicon Training

Participants watched a training video defining four AS (hunger, fullness, desire to eat, and prospective consumption) and a series of video tutorials about common confusions among appetite concepts. After they completed the training, participants took an online quiz to confirm their understanding of the concepts. A score of at least 90% correct responses was required to pass the appetite lexicon training. Failure to satisfactorily demonstrate an understanding of the concepts resulted in an offer to repeat the training up to two additional times with required testing to document satisfactory understanding after each attempt. Failure to meet training criteria resulted in disqualification from the study. All participants passed the quiz on their first attempt.

4.4.5 Appetite Sensation Assessment

Participants rated their perceived hunger, fullness, and thirst on their cell phones/computers via a web based Qualtrics survey every waking hour on three days that were randomly selected at weeks 1, 9, and 17. Two days were non-consecutive weekdays and one day was a weekend day. The questions for appetite sensations (hunger, fullness, and thirst) were “how hungry do you feel”, “how full do you feel?”, and “how thirsty do you feel?”, all rated from "not at all" anchored at the 0-% to “extremely” anchored at the 100% (171,209). Responses were provided on visual analog scales (VAS). All entries were time and date stamped to ensure the ratings were made at the intended times.

4.4.6 Physical Activity Assessment

Free-living energy expenditure was measured using an app (ActivityTracker Pedometer, Bits&Coffee LLC) on the same days that appetite ratings were recorded. Participants were asked to download the app at the screening visit and complete the app settings with their sex, weight, and height. Participants were asked to carry their phones throughout the days they recorded hourly appetite ratings. They reported their recorded energy expenditure by submitting a screenshot of the records on the following day through the web-based survey (Qualtrics).

4.4.7 Dietary Assessment

Dietary intake was recorded on the same days that appetite ratings were recorded. Data was obtained by a dietary recall method using the automated self-administered 24-hour dietary recall (ASA24- version 2020-2022) system. Because the intake data were based on recall of the prior day, it was collected the day after appetite logs were completed. The plausibility of the data was assessed using the Goldberg formula (Black, 2000).

4.4.8 Data Analysis

Aim1: Determine the magnitude and consistency of appetitive sensations (hunger, fullness, and thirst) between individuals.

One-way ANOVA was used to investigate within and between individual variance of each AS (hunger, fullness, and thirst). Pearson's correlation coefficients were calculated to examine the relationships between daily mean AS ratings; weekly mean appetite ratings across weeks (week 1, week 9, and week 17). A generalized regression model was used to explore the difference of total mean AS of the nine days (3 days X 3 weeks) and between weekdays and weekends. A linear mixed model was used with the Kenward-Roger approximation for degrees of freedom. Week was set as random effect and individual was nested within the week.

Aim2: Relationships between AS and energy intake and between AS and eating patterns.

Pearson's correlation coefficients were calculated to examine the relationships between daily mean AS and energy intake, portion size, and BMI. Spearman's correlation coefficients were calculated to investigate the relationship between daily mean AS and eating frequency (eating frequency was coded categorically).

A generalized linear regression model was used to determine the relationship between the total mean AS of the nine days (3 days X 3 weeks) and energy intake. Age, gender, BMI, and physical activity were included as covariates. Mean AS changes one-hour before and after meals was compared using the Wilcoxon signed-rank test (WSR).

The directionality of relationships between hourly energy intake and hourly appetite ratings and between hourly drinking events and hourly thirst ratings were determined using cross-correlation function (CCF) analysis. All data from time-series analyses of energy intake, drinking event, and AS were pre-whitened to reduce bias from autocorrelations. Hourly data of each variable (the original data) was regressed onto the 1 hour-lagged data. The unstandardized residuals of the regression were used as pre-whitened data. The largest correlation coefficients were used for the interpretation of the possible directionality between appetitive sensations and energy intake. If the largest correlation coefficient was significant at lag 0, it was concluded there was no clear directionality. If the largest correlation coefficient was significant at a positive lag, it was concluded that there was a possible directionality that appetitive sensations lead energy intake. If the largest correlation coefficient was significant at a negative lag, it was concluded that there was a possible directionality that energy intake leads appetitive sensations.

Time-series analysis of hourly appetitive ratings were clustered using dynamic time warping (DTW) clustering with the partitional method (214,215). The global alignment kernel distance was used for DTW clustering (216). Data were standardized before the DTW clustering. DTW calculated the closest distance between all data points (216,217). Clustering validity indices (CVIs) can be used to evaluate the result of the clustering algorithm. However, CVIs include subjective judgement rather than providing an absolute standard since clustering is an unsupervised procedure (214,218). For this study, we used the Dunn index which calculates the ratio of the smallest inter-cluster distance not in the same cluster to the largest intra-cluster distance (218). Thus, a larger value of the Dunn index represents good separation between clusters and closer intimacy within clusters (Figure S1).

Aim3: Individuals characteristics (sex, age, BMI) among AS tertiles

Individuals were divided into three groups based on mean of AS over the 17 weeks. One-way ANOVA was used to investigate differences in energy intake, eating frequency, portion size, age, and BMI between AS tertiles (based on the total mean AS of the nine days (3 days X 3 weeks)), and between the three DTW clusters. The homogeneity of variances were tested using the Levene's test. If the variance was not homogeneous, the Welch's ANOVA p-value was used. Tukey's adjustment was applied to correct for multiple comparisons.

The relationship between AS tertiles and categorical demographic characteristics including sex, age groups (18-30, 31-49, 50-64), and BMI groups (BMI 18.5 – 24.9 kg/m^2(normal), 25 – 29.9 kg/m^2 (overweight), 30 kg/m^2 or greater (obese)), and the relationship between the three DTW clusters of each AS and categorical demographic characteristics including sex (male, female), age groups (18-30, 31-49, 50-64), and BMI groups (normal, overweight, obese) was explored using the contingency test.

Data are expressed as mean ± SE. Statistical significance was determined by $\alpha < 0.05$, two-tailed for all analyses. SAS (version 9.4) software was used for correlation, ANOVA, general linear regression, WSR, and contingency testing. IBM SPSS (version 28th) software was used for CCF. R (version 4.2.1) was used for DTW clustering.

4.5 Results

4.5.1 Participants

A total of 1149 participants were screened, and 109 participants were enrolled in the study. Among them, 90 participants completed the study, 7 participants partially completed the study (Figure 2). Attrition was due to time conflicts in 2 cases, but most commonly, no specific reason was provided. Demographic characteristics of the participants are presented in Table 1. Participants were primarily white, non-Hispanic and female. They ranged in age from 18-64

Table 1. Characteristics of participants

Characteristic	
Total (n)	97
Sex	
Male (n)	20
Female (n)	77
Age (years)[1]	33.1 ± 1.2
18-30 (n)	48
31-49 (n)	35
50-64 (n)	14
BMI[2] (kg/m^2)[1]	26.8 ± 0.6
Normal weight (n)	48
Overweight (n)	28
Obese (n)	21

[1] Values are mean ± SE.
[2] BMI=Body Mass Index.

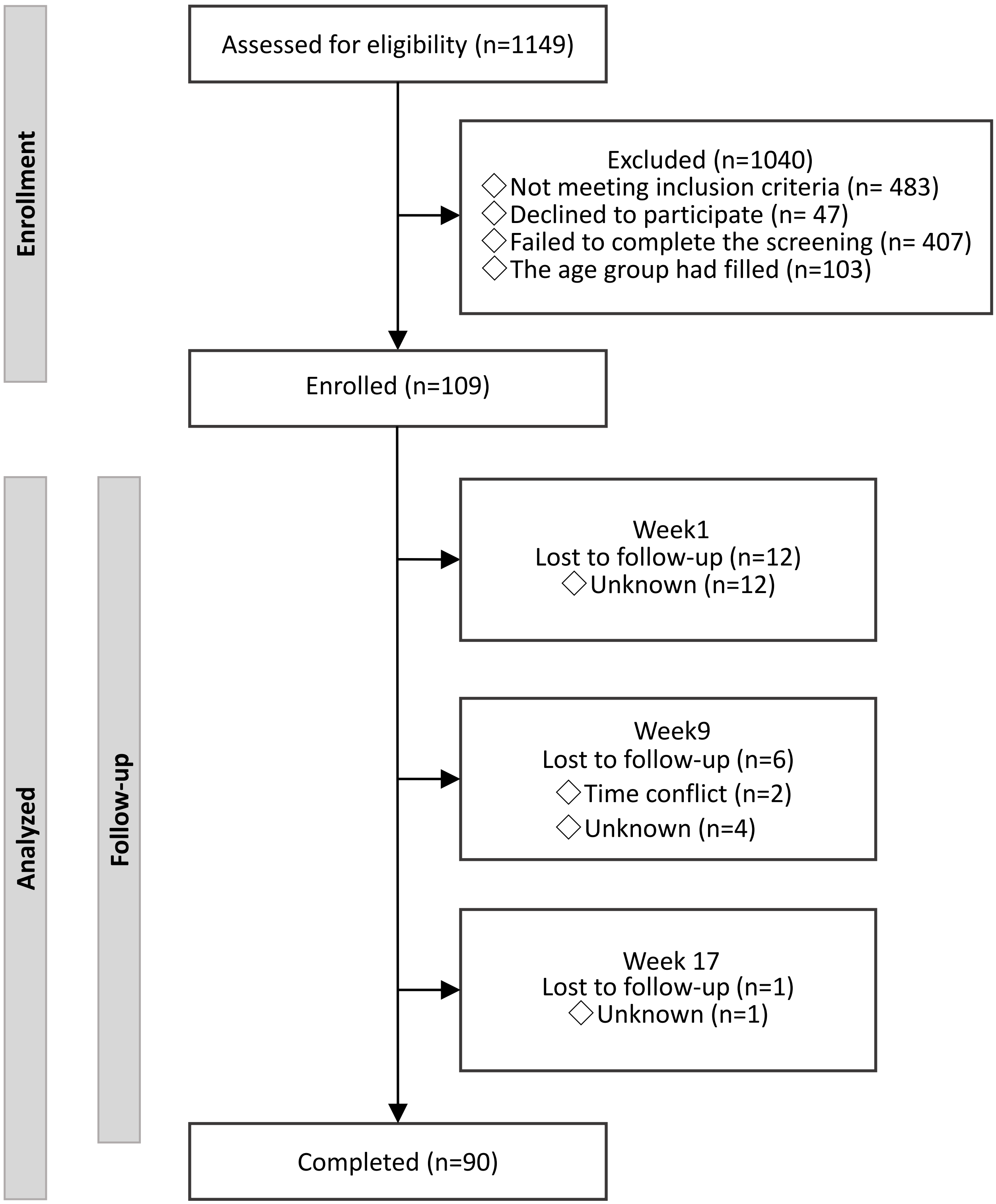

Figure 2. Flow diagram of participants

4.5.2 Appetite Variation Within and Between Individuals

Pearson's correlation coefficients for each weekly mean AS across weeks are presented in Figure 3. Correlations were strong and positive between weeks 1, 9 and 17 indicating AS ratings of individuals were consistent over time. There was no significant difference in any measured daily mean AS between weekdays and weekend days (hunger: $p=0.96$, fullness: $p=0.92$, thirst: $p=0.98$). The correlation between daily mean hunger ratings and daily mean fullness ratings were weak and statistically significant ($r=-0.07$, $p<0.05$). There was a moderate correlation between daily mean hunger ratings and daily mean thirst ratings ($r=0.47$, $p <0.001$).

The ranges of mean AS were large and consistent. Daily mean hunger ratings ranged from 2.9 to 62.5 % across individuals. The values for fullness and thirst were 13.4 to 87.7 % and 2.5 to 87.6 % respectively. Across all appetitive ratings (3 days X 3 weeks), the daily mean variance in ratings between individuals was greater than the mean variance within individuals (hunger: within variance=52.7 (7.3% of variance), between variance =670.1 (92.7% of variance), fullness: within variance = 69.0 (5.1% of variance), between variance = 1285.6 (94.9% of variance), thirst: within variance = 59.4 (3.3% of variance), between variance = 1738.9 (96.7% of variance)) (Figure 4). The demographic characteristics (including age, sex, BMI, and race/ethnicity) of those who reported higher and lower AS strengths, were examined by dividing the sample into tertiles. 1^{st} tertiles have the highest mean daily appetitive sensations and 3^{rd} tertiles have the lowest mean daily appetitive sensations. The mean age in 3^{rd} tertile of hunger was higher than the mean age in 2^{nd} tertile of hunger (Table 2). No robust significant differences in other demographic characteristics emerged in contrasts between the tertiles for the measured AS (Table 2).

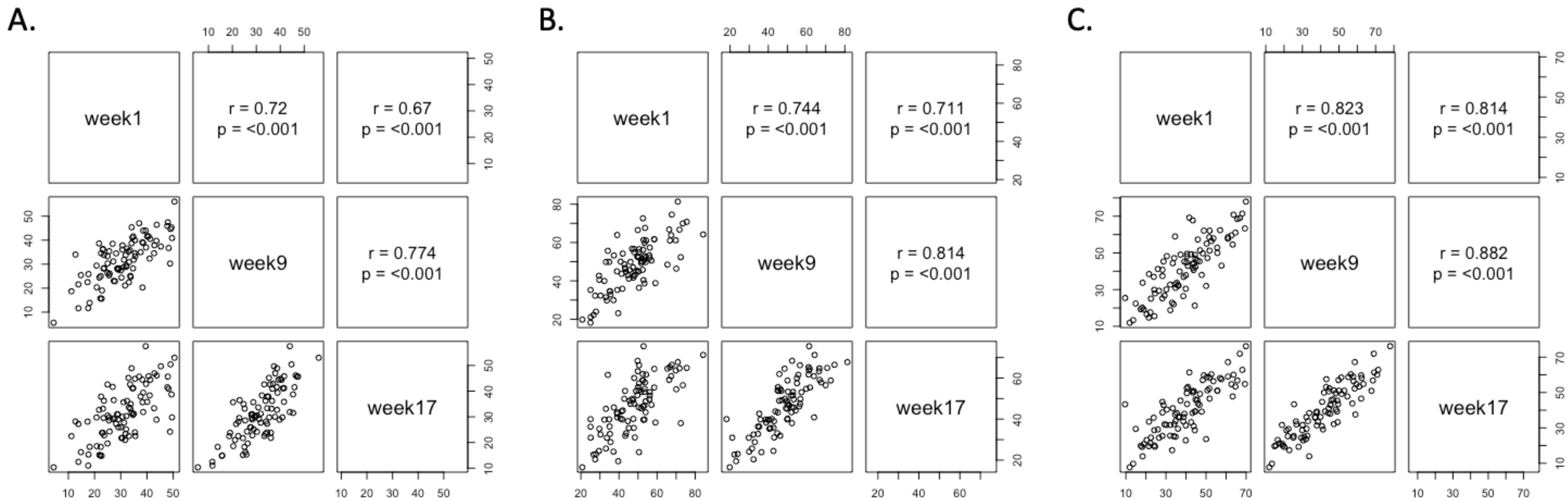

Figure 3. Pearson's correlations of weekly mean appetitive sensations between weeks. A: correlations of hunger sensations, B: correlations of fullness sensations, C: correlations of thirst sensations.

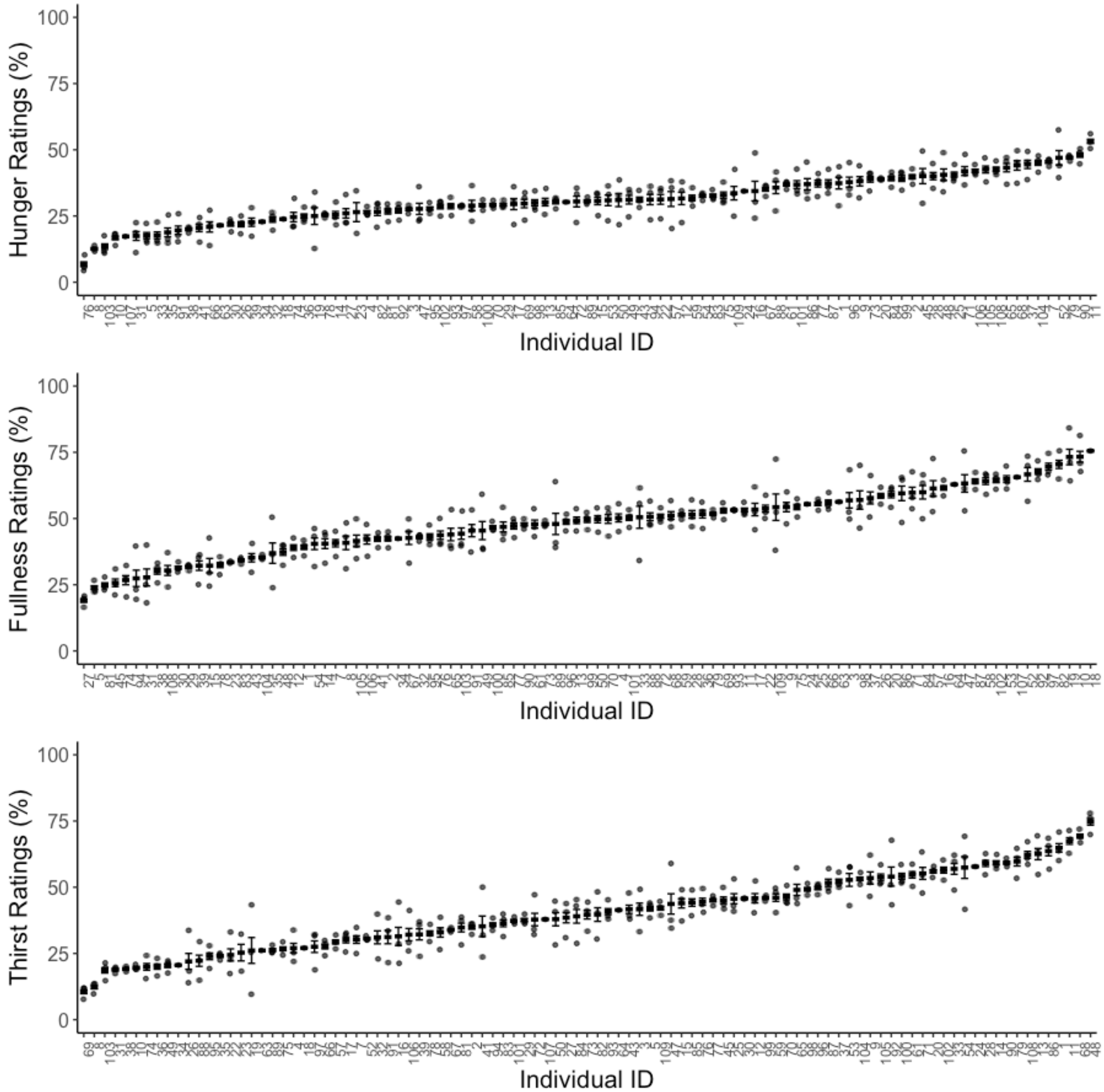

Figure 4. Appetitive sensations of participants in ascending order. (upper=hunger ratings, middle = fullness ratings, lower=thirst ratings, • =mean ratings of each week, −: mean of all weeks, |error bars = standard errors)

Table 2. Demographic characteristics of appetite tertile groups

Characteristic	Hunger			Fullness			Thirst		
	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile
Total (n)	32	33	32	32	33	32	32	33	32
Sex									
Male (n)	9 (28%)[5]	7 (21%)	4 (12%)	6 (19%)	8 (24%)	6 (19%)	6 (19%)	6 (18%)	8 (25%)
Female (n)	23 (72%)	26 (79%)	28 (88%)	26 (81%)	25 (76%)	26 (81%)	26 (81%)	27 (82%)	24 (75%)
p-value [1]		*0.29*			*0.82*			*0.75*	
Age group									
18-30 (n)	15 (47%)[5]	22 (67%)	11 (34%)	17 (53%)	14 (43%)	17 (53%)	15 (47%)	16 (48%)	17 (53%)
31-49 (n)	13 (41%)	9 (27%)	13 (41%)	11 (34%)	12 (36%)	12 (38%)	12 (38%)	14 (42%)	9 (28%)
50-64 (n)	4 (12%)	2 (6%)	8 (25%)	4 (13%)	7 (21%)	3 (9%)	5 (15%)	3 (9%)	6 (19%)
p-value [1]		*0.29*			*0.69*			*0.70*	
Age (year)[2]	32.7±2.0	29.1±1.7[a]	37.8±2.3[a]	32.8±2.2	34.5±2.1	32.1±1.9	33.8±2.3	31.5±1.8	34.2±2.2
p-value [3]		*0.01*			*0.72*			*0.62*	
BMI Category									
Normal weight (n)	19 (59%)[5]	13 (39%)	16 (50%)	12 (38%)	17 (52%)	19 (59%)	13 (41%)	16 (48%)	19 (59%)
Overweight (n)	5 (16%)	13 (39%)	10 (31%)	12 (38%)	9 (27%)	7 (22%)	13 (41%)	8 (24%)	7 (22%)
Obese (n)	8 (25%)	7 (22%)	6 (19%)	8 (24%)	7 (21%)	6 (19%)	6 (18%)	9 (27%)	6 (19%)
p-value [1]		*0.07*			*0.51*			*0.38*	
BMI[4] (kg/m^2)[2]	26.9±1.2	26.3±0.9	26.9±1.2	28.4±1.3	26.2±0.9	25.6±0.9	27.3±1.0	27.5±1.4	25.5±0.8
p-value [3]		*0.89*			*0.17*			*0.38*	

[1] χ^2 p-value of goodness-of-fit.
[2] mean ± SE
[3] p-value of one-way ANOVA
[4] BMI=Body Mass Index.
[5] within group percentage
[a] there is significant difference between 2nd and 3rd tertile (p<0.05)

4.5.3 Relationship between Appetitive Sensations and Energy Intake

Mean energy intake (EI) was not significantly associated with mean hunger (p=0.64), mean fullness (p=0.29), or mean thirst (p=0.28) for the nine test days (3 days X 3 weeks) in any age, sex, BMI, or physical activity adjusted regression model. Mean changes of AS over the one-hour period before and after meals were compared and are presented in Table 3. The changes 1-hour after meals were greater than the changes 1-hour before meals for all sensations (Table 3). This was especially true for the mean changes of hunger ratings (Wilcoxon signed-rank test (WSR), Hunger changes vs Fullness changes: $p < 0.0001$, Hunger changes vs Thirst changes: $p < 0.0001$). These results are consistent with the results of the CCF analysis and support the finding that the effect of EI on hunger is greater than effect of hunger on EI.

Table 3. Mean appetite changes 1-hour before and after Meals (%)

	Hunger	**Fullness**	**Thirst**
Mean Changes Before Meals	4.32	2.63	3.27
Mean Changes After Meals	-9.96	8.06	-5.52
Mean Difference (After – Before)	-14.28 [a, b]	5.43[a, c]	-8.79[b, c]
p-value[1]	<0.0001	<0.0001	<0.0001

[1] P-value of Wilcoxon signed-rank test (WSR) between before and after mean changes
[a] WSR between mean differences of hunger and fullness ratings, $p < 0.0001$
[b] WSR between mean differences of hunger and thirst ratings, $p < 0.0001$
[c] WSR between mean differences of fullness and thirst ratings, $p < 0.0001$

To examine the directionality of the relationship between AS and EI, cross-correlation function (CCF) analysis was conducted with a time series of hourly appetite ratings and hourly energy intake records. Overall, EI leads AS at -1 lag (Figure 5) meaning energy intake 1 hour earlier led to significant changes in AS. The most significant and largest coefficient value of CCF with hunger ratings and EI is -0.255 at -1 lag (Figure 5A). This reflects to the ability of EI to reduce hunger ratings. At +1 lag, there is a significant, but much weaker cross correlation between hunger ratings and EI (coefficient = 0.052, $p<0.05$) describing how hunger ratings influence energy intake (Figure 5A). The largest (and statistically significant) coefficient value of CCF with fullness ratings and EI is 0.228 at -1 lag indicating EI increases fullness ratings (Figure 5B). Again, there is only a weak cross correlation at +1 lag (coefficient = 0.052, $p<0.05$) (Figure 5B). The largest (and statistically significant) coefficient value of CCF with thirst ratings and EI was only -0.082 at -1 lag, indicating EI only weakly diminished thirst ratings (Figure 5C). CCF with thirst ratings and EI also had a significant, but weak cross correlation at +1 lag (coefficient=0.047, $p<0.05$) (Figure 5C). CCF with thirst ratings and drinking events at -1 lag was significant with a coefficient value =-0.1 and it was stronger than the correlation with EI at +1 lag (coefficient =-0.001, $p>0.05$) (Figure 5D).

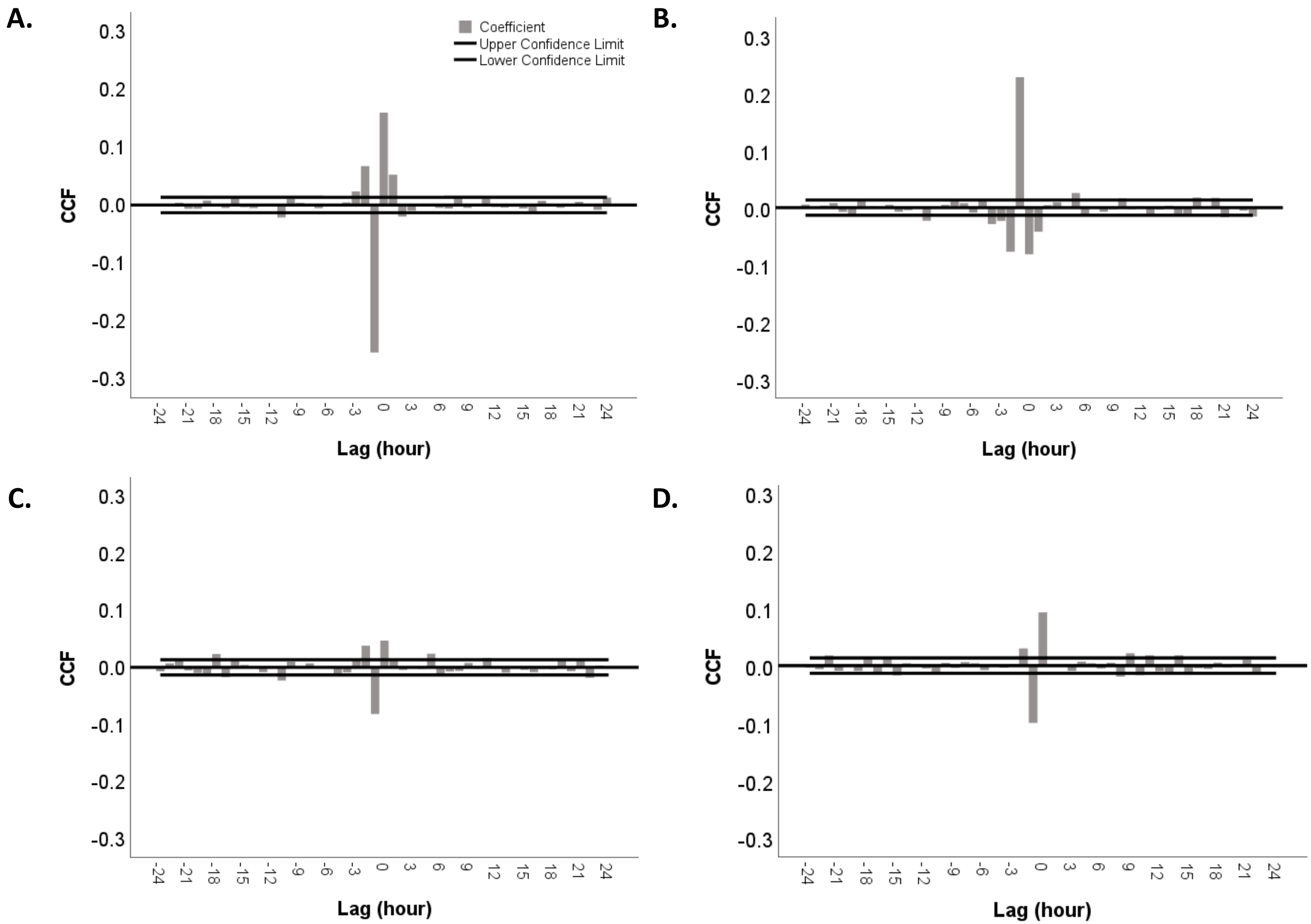

Figure 5. Cross correlation of appetitive sensations and energy intake with hourly time lags. A: hunger ratings with energy intake, B: fullness ratings with energy intake, C: Thirst ratings with energy intake, D: Thirst ratings with drinking event

4.5.4 Appetitive Sensations and Energy intake

Mean EI of the nine test days (3 days X 3 weeks) was not statistically different between tertiles of hunger, fullness or thirst groups (Table 4). Regardless of tertiles, within individual variances of EI are smaller than between individual variances of EI for all AS (Table 4). For hunger and thirst ratings, upper tertiles had greater between variance and lower within variance in EI compared to middle and lower tertiles. In contrast, variances of EI were greater in middle tertile compared to upper and lower tertiles for fullness ratings (Table 4). EI and BMI were positively associated ($p<0.01$). Separate regression analyses were conducted between EI and BMI for each AS tertile (Table 5 and Figure 6). The slope of 1^{st} tertile participants is lower compared to the slopes of the 2^{nd} and 3^{rd} tertile participants in hunger and thirst ranking analyses (Table 5 and Figure 6). Among 1^{st} tertile groups in hunger and thirst, no significant association was observed between BMI and EI (Table 5). In contrast, among the fullness tertile groups, 1^{st} and 2^{nd} tertiles had a significant association between EI and BMI, but the 3^{rd} tertile did not (Table 5).

Table 4. Energy intake of appetite tertile groups

	Hunger			Fullness			Thirst		
	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile
Mean Sensation (%)	41.0± 0.7	30.7± 0.3	21.6± 0.9	61.8± 1.1	48.8± 0.5	34.5± 1.2	56.5 ±1.2	39.6± 0.7	24.5± 1.0
Energy Intake (kcal)[2]	2098 ± 90	1888± 65	1848± 99	1856± 95	2107± 92	1865± 85	1958± 85	1915± 93	1960±101
p-value[3]		*0.12*			*0.09*			*0.93*	
Within ID[4] Variance of EI	411,263	357,196	276,132	342,290	393,077	313,365	370,610	357,992	321,977
Between ID[4] Variance of EI	2,306,323	2,061,648	2,390,401	2,220,820	2,505,646	1,969,888	1,970,709	2,458,850	2,629,089

[1] BMI = body mean index
[2] Mean ± SE
[3] p-value of one-way ANOVA for energy intake between tertiles
[4]ID = individual

Table 5. Regression analysis between energy intake and BMI of appetite tertile groups

	Hunger			Fullness			Thirst		
	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile
Slopes of Regression line[2]	2.21	33.97	37.45	30.96	18.14	18.72	3.96	25.36	48.13
p-value[2]	0.74	<0.0001	<0.0001	<0.0001	0.028	0.24	0.61	<0.0001	<0.0001

[1] BMI = body mean index
[2] Estimates of BMI for energy intake with the linear regression model (model: energy intake = BMI) for each appetite ranking group
[3] p-value of the general linear regression (model: energy intake = BMI) with each appetite ranking group

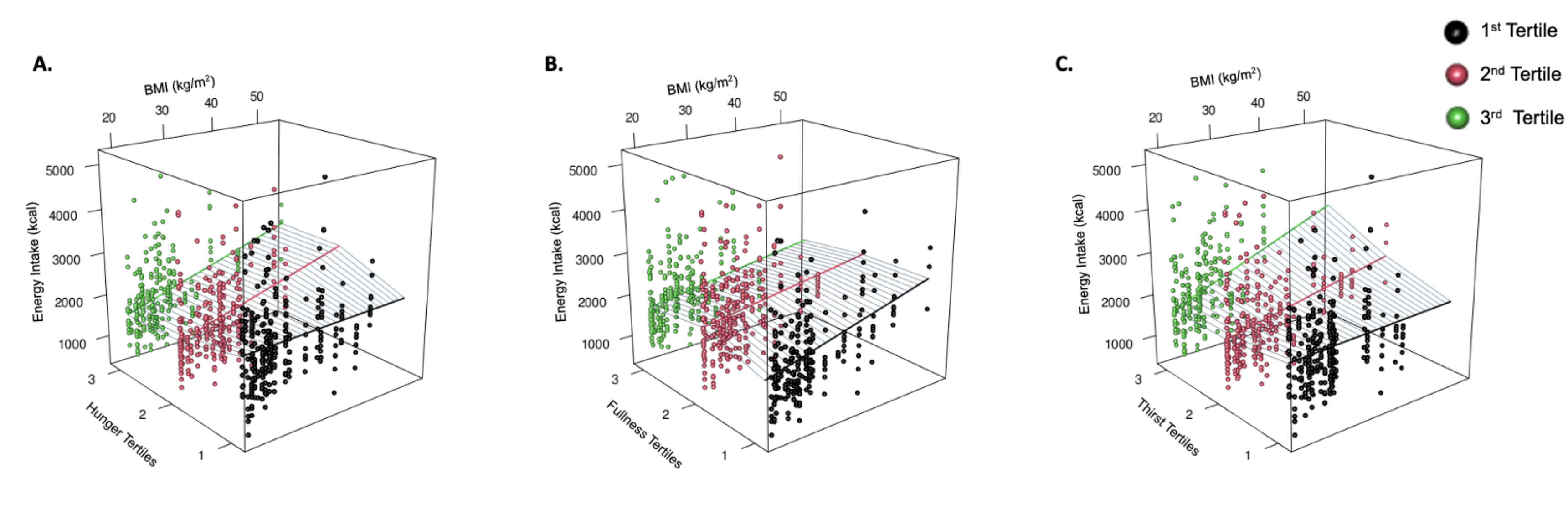

Figure 6. 3D scatter plots with regression lines between energy intake and BMI of hunger tertiles (A.), fullness tertiles (B), thirst ranking tertiles (C)

4.5.5 Relationship between Eating Patterns (Eating Frequency / Portion Size) and Appetitive Sensations

There were significant, but very weak, correlations between AS and eating patterns (Figure 7). Hunger and thirst ratings had negative correlations with eating frequency (EF) (hunger: r=-0.094, p=0.0066, thirst: r=-0.1, p=0.0037). Hunger and fullness ratings had positive correlations with portion size (PS) (Hunger: r=0.069, p=0.046, Fullness: r=0.092, p=0.0082).

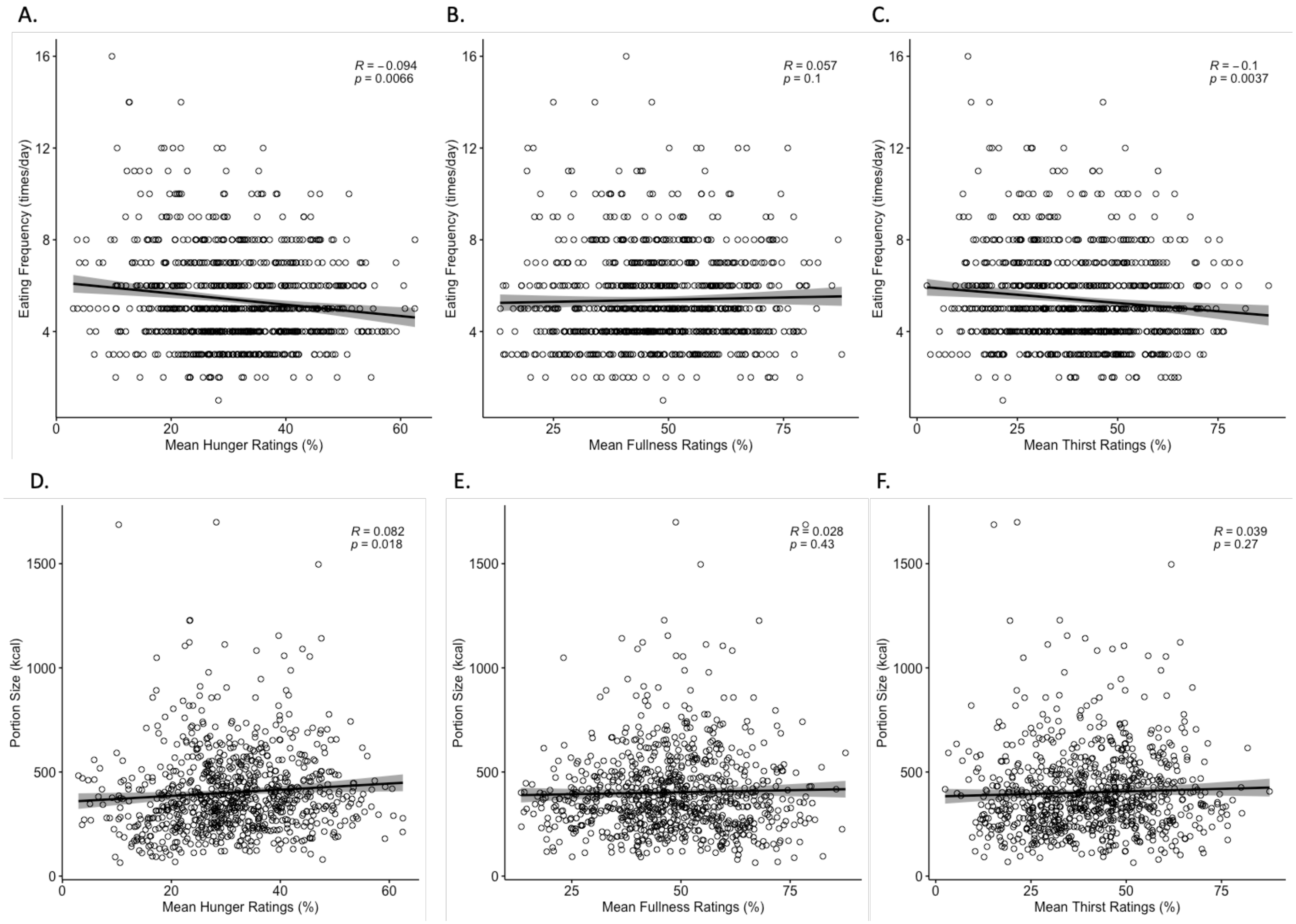

Figure 7. Correlations between eating patterns and appetitive sensations. A-C: Spearman's correlation between eating frequency (EF) and appetitive sensations (A: hunger ratings vs EF, B: fullness ratings vs EF, C: Thirst ratings vs EF), D-F: Pearson's correlation between portion size (PS) and appetitive sensations (D: hunger ratings vs PS, E: fullness ratings vs PS, F: Thirst ratings vs PS)

Hourly time-series analyses of appetitive ratings were conducted using dynamic time warping (DTW) clustering to examine patterns of rating fluctuations as well as the intensity of ratings. Ninety participants had 9 time-series of daily ratings, 1 participant had 6 time-series of daily ratings, and 6 participants had 3 time-series of daily ratings. As a total, 834 daily ratings were analyzed by DTW clustering. DTW calculates the distance between all time-series data points (a one-to-many match) and forms centroids based on the shortest distance between data points. Three clusters were generated for each AS time-series based on the three centroids (Figure S2) The clusters of hunger, fullness, and thirst time-series were independent each other. The characteristics of clusters are presented in Table S1. For clusters of all AS, cluster 1 has the lowest AS ratings and cluster 3 has the highest ratings. Among the hunger clusters, cluster 2 had greater mean hunger ratings and lower EF than cluster 1 (EF of cluster 1: 5.6 ± 0.1 times/day, EF of cluster 2: 5.1 ± 0.1 times/day, $p = 0.01$), but not between cluster 1 and cluster 3. Among the fullness clusters, cluster 3 had greater mean fullness ratings and greater PS compared to cluster 1 (PS of cluster 1: 158.5 ± 8.9 kcal, PS of cluster 3: 194.2 ± 6.9 kcal, $p = 0.007$). Among the thirst clusters, cluster 2 had greater mean thirst ratings and lower EF than cluster 1 (EF of cluster 1: 5.8 ±0.1 time/day, EF of cluster 2: 5.1 ±0.1, $p = 0.0006$), but not between cluster 1 and cluster 3. Overall, the characteristics of appetite clusters are consistent with the correlation findings, except that cluster 3 ratings for all AS were not consistent.

4.6 Discussion

Ingestive decisions are guided by a myriad of environmental and biological inputs. However, both external and internal cues manifest cognitively as AS. These sensations reportedly play multiple pivotal roles. AS may: 1) influence adherence to dietary regimens intended to achieve some preventive or therapeutic goal thereby supporting or undermining the efficacy of the dietary regimens (219–221); 2) be the primary effector of efforts to manage body weight (220,222,223); 3) contribute positively or negatively to the quality of life (220); and 4) serve as predictors of diet and weight change (219,224–232). Consequently, AS have been the target of considerable study. Behavioral, dietary, pharmacological and surgical approaches are all employed to modulate AS to correct energy imbalances. Yet, the ability to harness these sensations to achieve desired health effects has proven elusive. This may reflect inadequacies in appetite measurement and/or incomplete understanding of the nature and magnitude of AS contributions to intake. The primary aim of the present work was to gain new insights on inter-individual variability in AS and its stability over the long term, and the implications of these sensations under naturalistic conditions for eating patterns and energy intake using multiple data analytical approaches.

A key assumption in the study of AS is that they are reliable (i.e., under roughly similar conditions self-ratings will be stable). The present work revealed marked and sustained inter-individual differences in hunger, fullness, and thirst sensations. The stability of AS was strong across seventeen weeks (correlation coefficients between weeks were: weekly mean hunger (week 1 vs week 9: r=0.72, p<0.001; week 1 vs week 17: r=0.67, p<0.001; week 9 vs week 17: r=0.77, p<0.001), weekly mean fullness (week 1 vs week 9: r=0.74, p<0.001; week 1 vs wee 17: r=0.71, p<0.001; week 9 vs week 17: r=0.81, p<0.001), and weekly mean thirst (week 1 vs week 9: r=0.82, p<0.001; week 1 vs wee 17: r=0.81, p<0.001; week 9 vs week 17: r=0.88, p<0.001). This larger trial (N=90) conducted over a longer time period (17 weeks) and with participants representing a range of body mass indices and age confirms reports from several prior studies documenting consistent interindividual differences in AS (1–3). One observational trial collected appetite ratings from fifty free-living adults in good health and stable body weight (39 Female, 11 Male; Age 30±11 years; BMI 26.3±5.9 kg/m^2) over a one-week period (1). They observed a distinct and consistent distribution of inter-individual mean daily hunger and thirst ratings that were comparable in magnitude to our findings (correlation coefficients between days: hunger, r=0.52; thirst, r=0.78) (1). Similar results are reported from intervention trials. One study measured AS including hunger, fullness, and desire to eat hourly for 10 hours with six different pre-meals in nineteen healthy and weight stable adults (10 males with BMI 22.7 – 34.5 kg/m^2 and 9 females with BMI 21.2 – 32.6 kg/m^2) (3). The procedure was repeated on two different days. AS changes were not significantly different between meals nor between days (3). Notably, sex had no significant effect on fasting, intra-meal change, or postprandial appetitive score (3). An additional randomized controlled trial involving eighteen healthy men (mean ± SD age: 28.5 ± 9.8 y; BMI: 27.0 ± 5.0 kg/m^2) measured postprandial changes of hunger, satisfaction, fullness, and prospective consumption in response to two-repeated standardized meals and two repeated unstandardized meals (*ab libitum* meal) (2). The AS of participants were consistent between the two repeated measurements regardless of meal types (correlation coefficients between days: hunger, r=0.59; fullness, r=0.41; satisfaction, r=0.74; prospective consumption, r=0.65)(2). The strong consistency of inter-individual responses across these studies may reflect both genetic and behavioral contributions. A twin study involving 5435 twin pairs 8 – 11 years of age reported high heritability of appetite traits (63% for satiety responsiveness, 75% for food cue responsiveness (enjoyment of food)) as well as shared (21% for satiety responsiveness and 10% for enjoyment of food) and non-shared environmental influences (16% for satiety responsiveness and 15% for enjoyment of food) (131).

Documentation of large, stable differences in AS naturally raises questions about their dietary and health implications (129,130). Do individuals at the low and high ends of the distribution have lower or higher energy intake and/or unique eating patterns that explain their weight/adiposity status and do their appetitive ratings provide predictive power for ingestive behaviors? It is presumed that high hunger drives the initiation of eating and lower fullness facilitates the ingestion of larger portions. The present findings highlight a different interpretation. In the CCF analysis, energy intake precedes changes of AS more often than AS changes determine energy intake. Additionally, the mean changes of AS one-hour after an eating event were significantly greater than the mean changes of AS one-hour before an eating event (Table 3). The CCF analysis of hunger coefficients also showed a correlation of -0.255 at -1 lag: and only 0.052, at +1 lag meaning energy intake 1 hour earlier leads hunger reductions. Mean changes of hunger after eating dropped in 96.9 % (94 out of 97 participants) of individuals while only 77% of individual reported a rise in hunger sensation before eating. These findings are also consistent with an earlier cross-sectional study that noted the length of post-meal intervals was consistently positively correlated with energy intake ($r=0.41-0.5$, $p<0.05$) but not significantly correlated with premeal intervals (233). This association may also hold over longer time intervals as another trial reported prior day energy intake was negatively correlated with fasting hunger and fullness ($r=-0.56$, $r=0.5$, respectively, $p<0.05$) the following day (3). However, postprandial daily mean hunger and mean fullness ratings were not significantly correlated with prior day energy intake (3). Similarly, mean hunger and mean fullness were not changed with either increment or reduction of *ab libitum* energy intake in a 16-week study (234). Considering appetitive sensations are episodic rather than cumulative (158), fasting appetitive sensations may represent the effect of previous energy intake on AS better than daily averages. The present data suggests this directionality also holds for thirst and drinking (CCF coefficients: $r= -0.1$ at -1 lag, $r= -0.001$ at +1 lag, respectively) that drinking or eating 1-hour earlier leads thirst reduction. These outcomes indicate that AS are not good predictors of energy intake. Rather, they more strongly reflect the consequence of energy or fluid intake. The importance of this asymmetrical relationship has not been examined but may hold clinical significance. With respect to energy balance, it has been argued that an eating pattern of multiple smaller eating events, versus fewer larger eating events, will aid weight management (235). However, data from NHANES (236), the Seventh Day Adventist Trial (237) and others (238–241) indicate this is not the case. Failure to sufficiently reduce the drive to eat after an eating event may result in greater overall daily hunger (242) and thereby enable more unplanned eating events and greater daily energy intake.

The association noted between AS and energy intake was weak in this trial of individuals in relative energy balance, but the applicability of these findings to conditions of marked positive or negative energy balance is less clear. It may be hypothesized that at the extremes of energy balance, appetite holds a more important role in eating and weight management. In the larger literature, there are reports of augmented AS following weight loss (243); diminished AS (244) and uncoupling of appetite with intake (245). There are conflicting findings with overfeeding as well, with rapid accommodation of AS to elevated energy intake (246) and either uncoupling of AS or their ineffectiveness to drive compensation to marked stepwise increments in positive energy balance (197). This is an area that warrants further study. If AS are weak modulators of energy intake even under strong energy imbalance conditions, their role in guiding ingestive behavior and body weight to healthful levels is questionable.

There has been and continues to be great interest in the effects of eating frequency, eating timing and portion size on body weight (142,247,248). In the present trial, there was marginal or no significant correlation between AS and frequency of eating or between AS and portion size. Hunger and thirst ratings were significantly, but only very weakly related to eating frequency (hunger: $r=-0.09$, thirst: $r=-0.1$) while hunger and fullness ratings were significantly, but only very weakly related to portion size (hunger: $r=0.07$, fullness: $r=0.09$). This finding is consistent with prior work reporting that changes in thirst and hunger 1 – 3 hours prior to a drinking or eating event were only weakly correlated ($r=-0.06$ to -0.09) (211). A review of controlled-feeding studies showed that eating frequency more than three times per day reduced peaks of hunger and desire to eat sensations while reduced eating frequency to less than 3 times per day increased hunger and desire to eat sensations significantly (249). Subsequent energy intake with increased or reduced eating frequency reported conflicting results (249). In contrast, the effect of portion size on AS in

RCTs have generally been nonsignificant (150,250,251). Other work indicates AS may be affected, but not dramatically, by variations in portion sizes of eating events distribution over the day (252).

Individual characteristics such as BMI, age and sex have been proposed to influence AS, but with varying levels of experimental support. With respect to BMI, multiple RCTs and cross-sectional studies have compared fasting and/or postprandial appetitive ratings between people who are lean or have obesity and observed no significant group differences regardless of meal macronutrient composition (e.g., high fat vs low fat diet) or food form (e.g., liquid vs solid) (4,46,213,253–255). Where positive associations have been noted, they are not robust. For example, a significant correlation with BMI may be noted for one index (e.g., hunger but not fullness, desire to eat or prospective consumption) in one study (2); but a different index in another (49,253). Other work has failed to note a significant association between the FTO gene and postprandial appetitive responses (2). Among the tertiles of hunger and fullness sensations in the present study, there was no difference in energy intake, BMI or BMI category. There is a substantial literature suggesting macronutrient effects on appetite and corollary expectations that could influence adherence to different weight management approaches (256). However, strong evidence documents that energy content, rather than the source of energy (256–260) is the primary determinant of weight outcomes to dietary interventions. Macronutrient influences on AS over the longer term is uncertain and how or whether they manifest may be idiosyncratic (i.e., reflecting individual food preferences). Because thirst motivates/facilitates drinking, energy-yielding beverages are readily available and there is evidence individuals with obesity consume higher quantities of beverages (261,262), we hypothesized that higher thirst would be positively correlated with BMI. However, neither BMI nor BMI category was associated with thirst tertiles in this study. Some previous studies of free-living individuals also reported no associations between BMI and thirst ratings (1) or thirst sensations were even lower in dehydrated individuals with obesity (263). Many influences may mitigate appetite-BMI associations. For example, hunger, as measured globally by the Three-Factor Eating Questionnaire is consistently less strongly associated with BMI than disinhibition (48,49,264,265).

Some evidence suggests males and females differ in AS (e.g., Bédard et al., 2015; Gregersen et al., 2011; Leone et al., 2022) (53,60,213) but the preponderance of evidence indicates hunger and fullness ratings are not significantly different between men and women in either the fasting (3,60) or post-prandial state (3,53,55,56). Thirst was also similar between free-living males and females (1) and after endurance exercise (266). The current study also did not find sex differences in AS.

Inconsistent findings have been reported on the effects of age on AS by multiple small trials (76,267,268). Our somewhat larger sample of healthy individuals failed to reveal significant differences. A meta-analysis reported that the hunger ratings of older adults (aged 60 – 88 years) were 25% and 39% lower after overnight fasting or in a postprandial state, respectively, compared to younger adults (22-50 years old) and fullness ratings of older adults were 39% and 37% greater after overnight fasting or in a postprandial state, respectively, than younger adults (61). However, these findings may reflect deteriorating health (269), medication use (71) and reduced physical activity (270,271) rather than the aging process. Mixed findings are also reported on the relationship between thirst and fluid intake in older adults (272–277) that may, again, be related more to medication use and disease burden (278,279). Thus, the largely negative findings on associations between AS and BMI, sex and age are generally in line with the literature. It is not argued that these individual characteristics are unrelated to AS, but rather that they are often superseded by other factors, especially environmental influences (161,245,280).

This study has several strengths. Much effort was made to improve data validity. All participants received appetitive training to resolve any confusion on appetitive sensations they might have. There has been an issue in measuring appetitive sensations with untrained respondents (281). Even though hunger and fullness are independent sensations, reciprocal relationships between the two sensations are commonly found in multiple studies (156,281). The potential confounding factor was eliminated by training participants on the appetite concepts in this study. In addition, the hourly appetite ratings were time-stamped to make sure the ratings data were collected on time. Compared to previous studies (1,2,41), data were collected from larger sample size for a longer duration. Also, for each week 1, 9, and 17, non-consecutive three days (two weekdays and one weekend day) were randomly selected to collect representative data.

Some limitations are inherent in this study. Due to the nature of observational study, there are many unknown factors that might affect appetite ratings such as relative energy balance of participants, environmental factors (e.g., social and cultural environment, and food accessibility and food exposure). Moreover, we did not measure desire to eat and prospective consumption to reduce the respondents' burden. These two sensations are also unique appetitive sensations and further research with these sensations will shed light on further insights. In addition, only 10 % of the reported energy intakes fell within the Goldberg cutoffs, which often happen in clinical studies and underreporting is prevalent (282,283). Although this may give a room for the weak relationship between appetitive sensations and energy intake, overall directionality of the relationship was supported by multiple analyses including CCF, and correlation.

In summary, this study discovered marked and consistent inter-individual differences in hunger, fullness, and thirst sensations. While the implications for quality-of-life issues were not explored, the associations between AS and dietary patterns and energy intake were very weak across the range of AS ratings. Stronger associations were observed for the effect of intake on AS than the reverse. If true, this suggests AS hold limited impact on or predictive power for intake. Further, no robust associations between AS and age, BMI, or sex were observed. However, importantly, participants in this trial were in relative energy balance. Whether the relationships between AS and ingestive behaviors differs under more extreme conditions of energy balance warrants further study. We also did not assess desire to eat ratings and the role these sensations hold is also important to examine.

4.7 Supplementary Tables and Figures

Table S 1. Characteristics of clusters for each appetitive sensation

Characteristic	Hunger			Fullness			Thirst		
	Cluster 1	**Cluster 2**	**Cluster3**	**Cluster 1**	**Cluster 2**	**Cluster3**	**Cluster 1**	**Cluster2**	**Cluster 3**
Total (n)	362	297	175	135	322	377	254	375	205
Mean Sensations (%)[1]	21.7 ± 0.3^{ab}	34.7 ± 0.3^{ac}	45.8 ± 0.5^{bc}	25.9 ± 0.5^{ab}	42.5 ± 0.3^{ac}	60.4 ± 0.4^{bc}	22.3 ± 0.5^{ab}	41.7 ± 0.4^{ac}	60.6 ± 0.5^{bc}
p-value[2]		*<0.0001*			*<0.0001*			*<0.0001*	
Eating Pattern									
Eating Frequency (times/day)	5.6 ± 0.1^{a}	5.1 ± 0.1^{a}	5.4 ± 0.1	5.1 ± 0.2	5.4 ± 0.1	5.5 ±0.1	5.8 ± 0.1^{a}	5.1 ± 0.1^{a}	5.4 ± 0.1
p-value[2]		*0.01*			*0.14*			*0.0006*	
Portion Size (kcal)	177.9 ± 5.8	180.5 ± 6.3	202.8 ± 11.9	158.5 ± 8.9^{b}	182.8 ± 6.2	194.2 ± 6.9^{b}	190.2 ± 8.4	185.5 ± 6.0	173.8 ± 7.9
p-value[2]		*0.07*			*0.007*			*0.34*	
Energy Intake (kcal)	1912 ± 40^{b}	1897 ± 43^{c}	2100 ± 60^{b,c}	1717 ±56^{ab}	1960 ± 39^{a}	2016 ±42^{b}	1958 ± 47	1923 ± 40	1973± 53
p-value[2]		*0.01*			*<0.0001*			*0.72*	
Sex									
Male (n)	58 (16%)[5]	66 (22.2%)	56 (32%)	66 (11.1%)	56 (25.5%)	58 (22%)	61 (24%)	77 (20%)	42 (20%)
Female (n)	304 (84%)	231 (77.8%)	119 (68%)	231 (88.9%)	119 (74.5%)	304 (78%)	193 (76%)	298 (80%)	163 (80%)
p-value[3]		*0.0001*			*0.003*			*0.53*	
Age group									
18-30 (n)	168 (46%)[5]	171 (58%)	72 (41%)	60 (44%)	177 (55%)	174 (46%)	131 (51%)	193 (52%)	87 (42%)
31-49 (n)	125 (35%)	98 (33%)	74 (42%)	54 (40%)	105 (33%)	138 (37%)	78 (31%)	131 (35%)	88 (43%)
50-64 (n)	69 (19%)	28 (9%)	29 (17%)	21 (16%)	40 (12%)	65 (17%)	45 (18%)	51 (13%)	30 (15%)
p-value[3]		*0.0004*			0.10			0.10	
Age (year)[1]	34.7 ± 0.7^{a}	30.6 ± 0.6^{a,c}	34.9 ± 0.9^{c}	33.4 ± 1.1	32.2±0.6	34.2 ±0.6	34 ± 0.7	32.3 ± 0.6	34.2 ± 0.9
p-value[2]		*<0.0001*			*0.09*			*0.11*	

Table S 1. Continued.

Characteristic	Hunger			Fullness			Thirst		
	Cluster 1	Cluster 2	Cluster3	Cluster 1	Cluster 2	Cluster3	Cluster 1	Cluster2	Cluster 3
BMI Category									
Normal weight (n)	171 (47%)[5]	157 (53%)	98 (56%)	76 (56%)	174 (54%)	176 (47%)	163 (64%)	160 (43%)	103 (50%)
Overweight (n)	123 (34%)	83 (28%)	28 (16%)	44 (33%)	77 (24%)	113 (30%)	45 (18%)	128 (34%)	61 (30%)
Obese (n)	68 (19%)	57 (19%)	49 (28%)	15 (11%)	71 (22%)	88 (23%)	46 (18%)	87 (23%)	41 (20%)
p-value[3]		*0.0003*			*0.009*			*<0.0001*	
BMI[4] (kg/m^2)[1]	26.4 ± 0.3	26.3 ±0.3	27 ± 0.5	25.1 ± 0.4[b]	26.2 ±0.3	27.3 ± 0.3[b]	25.2 ± 0.3[a,b]	27.2 ± 0.3[a]	26.8 ± 0.4[b]
p-value[2]		*0.46*			*0.0002*			*<0.0001*	

[1] Mean ± SE
[2] p-value of one-way ANOVA.
[3] p-value of chi-square test.
[4] BMI=Body Mass Index.
[5] within group percentage
[a] there is a significant difference between cluster 1 and cluster 2 (p<0.05)
[b] there is a significant difference between cluster 1 and cluster 3 (p<0.05)
[c] there is a significant difference between cluster 2 and cluster 3 (p<0.05)

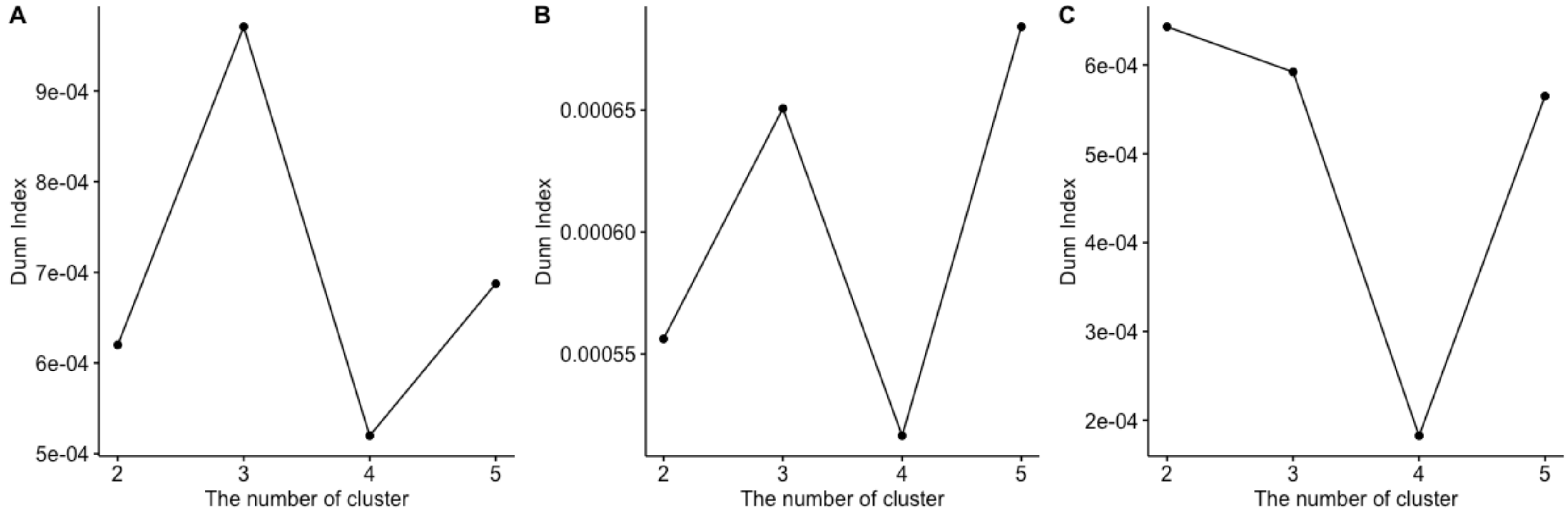

Figure S 1. Cluster validity index: Dunn index. A: hunger time-series data, B: fullness time-series data, C: thirst time-series data. (a larger value of the Dunn index represents good separation between clusters and closer intimacy within clusters)

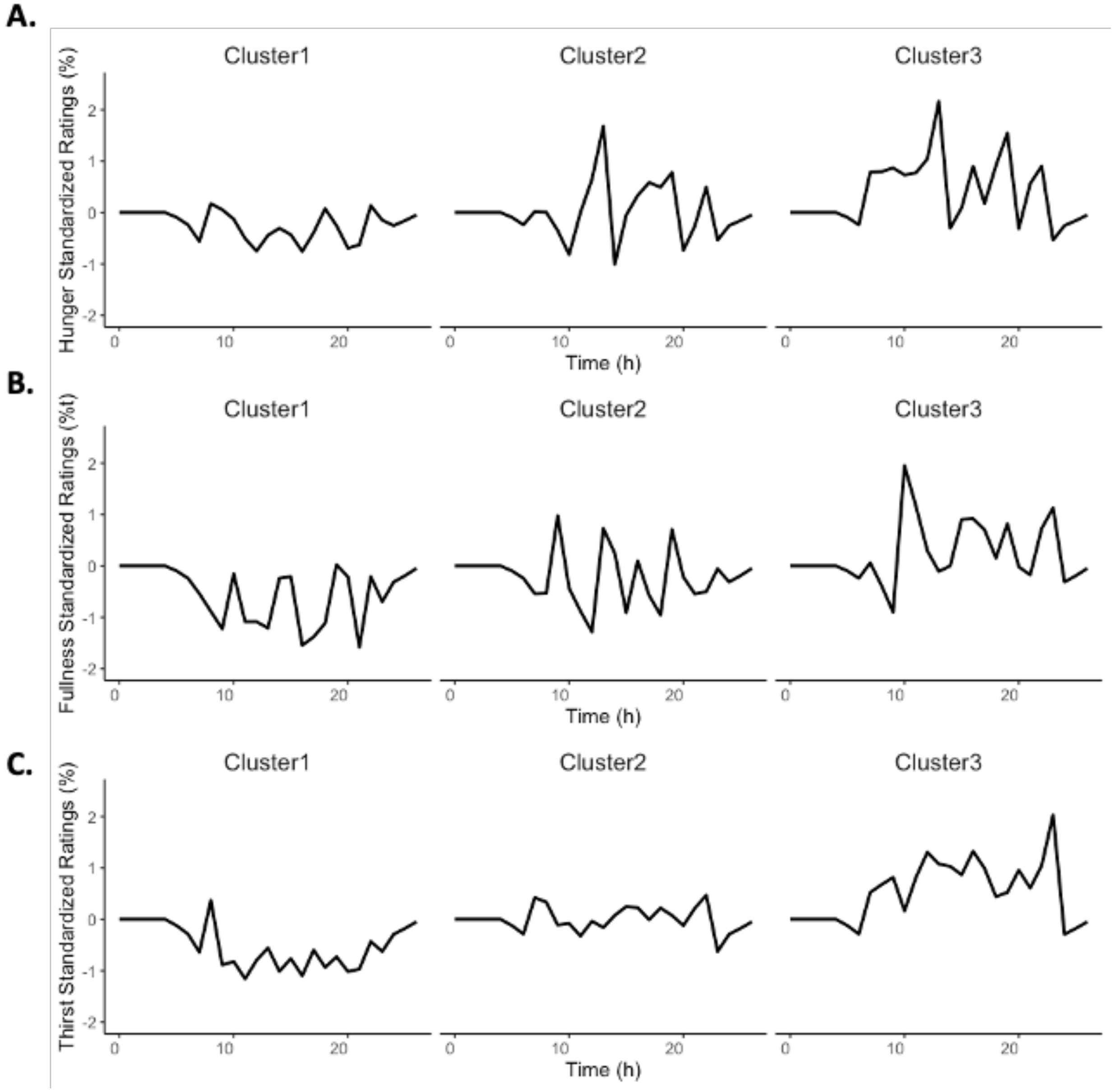

Figure S 2. Cluster centroids of hourly appetite rating time-series. A: clusters of hunger ratings, B: clusters of fullness ratings, C: clusters of thirst ratings.

CHAPTER 5. APPETITE CONCEPT TRAINING AND VALIDITY OF APPETITE MEASUREMENT

5.1 Footnotes

This is a summary of the appetite training project. It was a 9-week parallel-arm study to improve the validity of appetite measurement by training participants on appetite concepts (hunger, fullness, desire to eat, and prospective consumption). Test-retest repeatability and meal-specificity in appetite ratings were tested.

5.2 Introduction

A fundamental limitation to the application of appetitive sensations is how they are measured. Each appetitive sensation has a unique definition, and they are all independent of each other. The most common measurement approach relies on untrained individuals to self-report the sensations they experience under a given set of conditions. However, untrained respondents may not differentiate between similar appetitive sensations (e.g., desire to eat and hunger) or may assume they are interdependent each other (e.g., hunger and fullness). Potential common confusions have been found in numerous studies. For example, hunger and fullness were rated as opposite poles on a common continuum (281,284). Similarly, desire to eat and hunger are assumed to be the same sensations and rated similarly (284,285). However, the distinction between these sensations is clinically important. Hunger and fullness do not always change reciprocally and equally in clinical conditions. Hunger can change without a shift in fullness, and the reverse has also been reported (14). Therefore, we hypothesized that training respondents on the terminology of appetitive sensations prior to testing could improve sensitivity, selectivity, and reliability of measurements. We also hypothesize that different preloads addressing selective properties of each sensation will induce different magnitudes of appetite sensations (hunger, fullness, desire to eat, and prospective consumption). Preloads was water, egg white, peanut butter, and peanut butter with pre-exposure of peanut butter. Water, egg white, and peanut butter represent no, low, and high energy respectively. Consuming water will alter fullness but not hunger because water has no energy. Hunger, fullness, and desire to eat will be altered by consuming egg white and peanut butter while the changes by peanut butter will be more robust compared to the changes by egg whites. Also, pre-exposure to peanut butter will reduce desire to eat greater compared to peanut butter without pre-exposure due to sensory specific satiety.

5.3 Methods

5.3.1 Participants

Participants were recruited through public announcements including flyers, online advertisements (Purdue Today, social media), and verbal advertisements from April 2021 to March 2022 (Appendix B). Eligibility criteria included healthy men and women, 18-60 years of age, 18-25 kg/m^2 of BMI, body weight fluctuation < 2.5 kg in the 3 months prior to the start of the study, not taking medications known to affect appetite, not planning to change lifestyle behaviors that could affect energy balance, having no acute disease or allergies to eggs, peanuts, macaroni, cheeses, and carrots, and willing to eat all test foods. All procedures involving human subjects were approved by the Purdue University Institutional Review Board. Written informed consent (Appendix B) was obtained from participants who met eligibility criteria. This study was registered in clinicaltrials.gov (NCT04576585).

5.3.2 Protocol

This was a 9-week parallel trial. At screening, participants reported demographic information including age, biological sex and race/ethnicity. This information was collected via questionnaire (Appendix B). Weight, height and BMI were measured once at the screening meeting. After screening, participants were randomly assigned to one of two groups. One group (appetite group) received training in the lexicon of appetite (Hunger, Fullness, Desire to Eat, and Prospective Consumption), and the other group (taste group) was trained on properties of basic tastes (Sweetness, Sourness, Bitterness, and Saltiness) as an attention control. Participants in taste group were asked to complete an appetite confusion quiz to collect the baseline understanding on appetitive sensations and participants in appetite group were asked to complete a taste confusion quiz. All participants participated in two preload trials with mixed meals before training and six paired preload trials after training over 9 weeks.

On testing days, participants visited the laboratory the same time of day for each trial. They were asked to refrain from ingesting foods for at least 4 hours prior to arrival. They reported their appetitive sensations (hunger, fullness, desire to eat, and prospective consumption) on 100-mm visual analogue scales at -15, and 0 minutes before consuming a preload and at 30, 60, 90, 120, 180 minutes after they consumed the preload (Appendix B). At weeks 1,2, 4, and 5, participants consumed a mixed meal consisting of macaroni & cheese (136g, 440 kcal) with carrot sticks (61g, 25 kcal) and water (100ml) (meal = 30% fat, 56% carbohydrate, 14% protein). At week 6, 7, 8, and 9, participants consumed one of the followings: 1 liter of water, 300g (150kcal) of microwaved egg whites, 50 g (300kcal) of peanut butter, and 50 g (300kcal) of peanut butter with pre-exposure to 50 g (300 kcal) of peanut butter three times per day for the two days prior to their test sessions (150 kcal of peanut butter per day as a total for two days). The order of these preloads was randomly assigned.

5.3.3 Anthropometrics

Height and weight were measured once at the screening meeting. Participants were asked to remove shoes and socks and heavy jackets or coats and to empty their pockets. A medical wall-mounted stadiometer (Seca, Chino, CA) was used to measure height, and a Tanita Body Composition Analyzer (Model TBF-410GS, Tanita Inc., Arlington Heights, IL) was used to measure weight to permit calculation of BMI.

5.3.4 Appetite Lexicon Training

At week 3, appetite group received training on the lexicon of appetite on up to 3 days during the training week. This entailed reading written definitions, watching an instructional video, eating exercises and completing training exams demonstrating they understood the distinctions between appetitive terms (hunger, desire to eat, fullness, and prospective consumption) (Appendix B). To ensure the success of training, participants completed an online quiz with at least 90 % correct responses to confirm their understanding of the concepts (Appendix B). Failure to satisfactorily convey understanding of the concepts resulted in an offer to repeat the training 2 more times or be rejected from the study. Taste group was only trained on the basic tastes (sweetness, sourness, bitterness, and saltiness). Thus, the two groups received equal time and attention for a similar task.

5.3.5 Appetite Ratings

Participants rated their perceived hunger, desire to eat, fullness, and prospective consumption on their cell phones/computers via Qualtrics, web-based software (Appendix B). The questions for appetite sensations (hunger, fullness, and thirst) were “how hungry do you feel”, “how strong is you desire to eat?”, “how full do you feel?”, and “How large a portion do you think you could eat now? ,” all rated from "not at all" anchored at 0-% to “extremely” anchored at 100-% (171,209). Responses were provided on visual analog scales. All entries were time and date stamped to ensure the ratings were made at the intended times.

5.3.6 Statistical analysis

Correlation - Pearson’s correlation coefficients were calculated to examine the relationships between hunger, fullness, desire to eat, and prospective consumption ratings before and after the concept trainings. In addition, test-retest repeatability was tested by comparing Pearson’s correlations between appetitive sensations during week 1 and week2 in response to the mixed meal (before trainings) and correlations between appetitive sensations in week 4 and week5 in response to the mixed meal (after trainings).

General Linear Regression - A linear regression model was used to determine the effect of different pre-meals on appetitive sensations between appetite group and taste group.

Statistical significance was determined by $\alpha < 0.05$, two-tailed for all analyses. SAS (version 9.4) software was used for correlation, and general linear regression.

5.4 Results

5.4.1 Participants

A total of 79 participants were screened, and 29 participants were enrolled in the study. Among them, 20 participants completed the study, and 7 participants withdrew at week 1. Attrition was due to time conflicts in 1 case, but most commonly, no specific reason was provided. Participants ranged in age from 18-31 years and their BMIs ranged from 19.6 – 24.5 kg/m^2 (Table 6).

Table 6. Characteristics of participants

Characteristic	Appetite group	Taste group	Total
Total (n)	13	7	20
Sex			
Male (n)	4	2	6
Female (n)	9	5	14
Age (years)[1]	24.8±1.2	24.1±1.9	24.6±1.2
BMI[2] **(kg/m^2)**[1]	21.8 ± 0.5	22.4±0.6	22.0±0.4

[1] Values are mean ± SE.

[2] BMI=Body Mass Index.

5.4.2 Confusions on appetite concepts

All participants completed a concept training either on appetite lexicon or on taste lexicon at week 3. All participants passed the comprehension test on the first attempt. Before the training, 75% of participants (15 out of 20 participants) were confused with the concept of hunger and energy intake (Question 7: When you are hungry, which food would be the most efficient to reduce your hunger?). The answer to the question is sugar-sweetened beverage (since it contained higher energy), but 10 out of 15 participants chose celery sticks and 5 out of 15 participants chose plain water with lemon slice. 60% of participants were confused with the concepts of hunger and fullness sensations (Question 1: Hunger vs. Fullness: Are they opposite sensations on a single continuum?). 45% of participants were confused with the concepts of hunger and prospective consumption (Question When a person says, " I can eat a horse now." which sensation does this statement reflect?) and those who chose the incorrect answer, chose “hunger” (the sensation that initiates and eating event, not portion size). 40% of participants were confused with the concepts of desire to eat and prospective consumption (Question 3: What is the proper question to measure the sensation that makes you decide to choose a small size popcorn?) and the most frequent answer was “desire to eat”. (Figure 8)

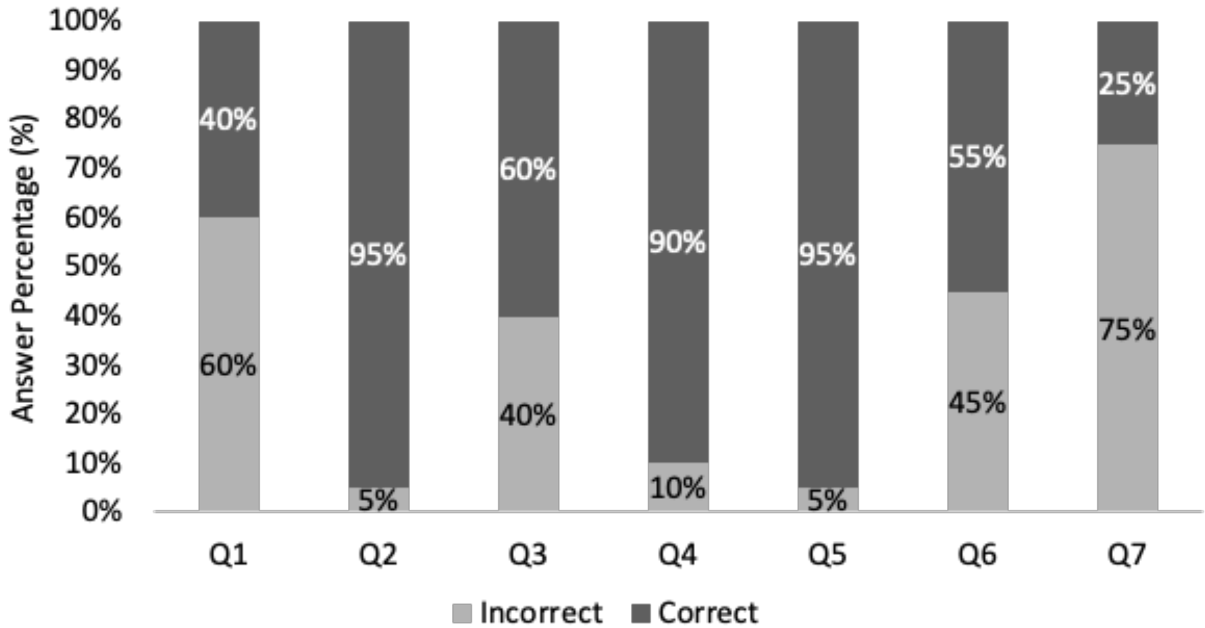

Figure 8. Correct and incorrect rate (%) of the appetite confusion quiz. Q1: confusion between hunger and fullness, Q2: confusion between desire to eat and hunger, Q3: confusion between desire to eat and prospective consumption, Q4: confusion between fullness and prospective consumption, Q5: confusion between fullness and desire to eat, Q6: confusion between hunger and prospective consumption, Q7: confusion on hunger and energy intake.

5.4.3 Correlation between appetitive sensations before and after training

All appetitive sensations were significantly correlated before and after trainings in both groups. There were significant negative correlations between hunger and fullness in both groups, but those correlations were reduced after training in both groups (Table 7). In addition, the correlations between hunger and desire to eat were positively correlated before and after training in both groups (Table 7). However, the correlation between hunger and desire to eat was reduced after training in appetite group compared to taste group (Table 7). Similarly, the correlations between desire to eat and prospective consumptions were positive, but after the training, the correlation was reduced in appetite group while the correlation increased in taste group (Table 7).

Table 7. Pearson's correlation coefficients between appetitive sensations before and after training

Appetite group	H & F	H & DE	H & PC	F & DE	F & PC	DE & PC
Before	-0.81 $p < 0.0001$	0.93 $p < 0.0001$	0.85 $p < 0.0001$	-0.79 $p < 0.0001$	-0.77 $p < 0.0001$	0.92 $p < 0.0001$
After	-0.79 $p < 0.0001$	0.78 $p < 0.0001$	0.81 $p < 0.0001$	-0.62 $p < 0.0001$	-0.69 $p < 0.0001$	0.75 $p < 0.0001$

Taste group	H & F	H & DE	H & PC	F & DE	F & PC	DE & PC
Before	-0.56 $p < 0.0001$	0.95 $p < 0.0001$	0.86 $p < 0.0001$	-0.58 $p < 0.0001$	-0.46 $p = 0.0004$	0.82 $p < 0.0001$
After	-0.41 $p=0.0019$	0.94 $p < 0.0001$	0.87 $p < 0.0001$	-0.27 $p=0.05$	-0.37 $p=0.005$	0.90 $p < 0.0001$

H = Hunger
F = Fullness
DE = Desire to Eat
PC = Prospective Consumption

5.4.4 Repeatability ratings before and after training

Overall, correlation coefficients were reduced in appetite group after the concept training while correlations were mostly consistent in taste group after the training (Table 8). Correlation coefficients were most markedly reduced for the desire to eat concept in appetite group after the training (Table 8).

Table 8. Test-retest repeatability in appetitive sensations with a mixed meal before and after a concept training

Appetite group	Hunger	Fullness	DE	PC
Before (week1 & week2)	0.84 $p < 0.0001$	0.81 $p < 0.0001$	0.84 $p < 0.0001$	0.84 $p < 0.0001$
After (week4 & week5)	0.72 $p < 0.0001$	0.74 $p < 0.0001$	0.56 $p < 0.0001$	0.81 $p < 0.0001$

Taste group	Hunger	Fullness	DE	PC
Before (week1 & week2)	0.80 $p < 0.0001$	0.79 $p < 0.0001$	0.66 $p < 0.0001$	0.69 $p < 0.0001$
After (week4 & week5)	0.81 $p < 0.0001$	0.78 $p < 0.0001$	0.76 $p < 0.0001$	0.93 $p < 0.0001$

H = Hunger
F = Fullness
DE = Desire to Eat
PC = Prospective Consumption

5.4.5 Preload effect on appetitive sensations

For all appetitive sensations, there were significant meal and time effects ($p<0.0001$) (Figure 9-10). Hunger and desire to eat sensations were greatest after consumption of water followed by peanut butter, peanut butter with pre-peanut butter exposure, egg white, and mixed meal. Fullness sensations were greatest following consumption of the mixed meal and egg white followed by peanut butter with pre-exposures, peanut butter, and water. Desire to eat was the highest with water and peanut butter followed by peanut butter pre-peanut butter exposure, egg white, and mixed meal. Prospective consumption was lowest with mixed meal and egg white ingestion followed by peanut butter with pre-exposure, peanut butter, and water. For hunger and prospective consumption sensations, there was no difference between the two groups ($p=0.8$ and $p=0.7$, respectively) while there were significant group effects for fullness and desire to eat ($p<0.0001$ and $p=0.006$, respectively). Appetite group reported greater fullness than taste group with water ($p<0.0001$), but not difference with other preloads ($p>0.05$). Taste group reported greater desire to eat than appetite group ($p<0.0001$) but there was no difference in desire to eat between two groups for each meal types ($p>0.05$).

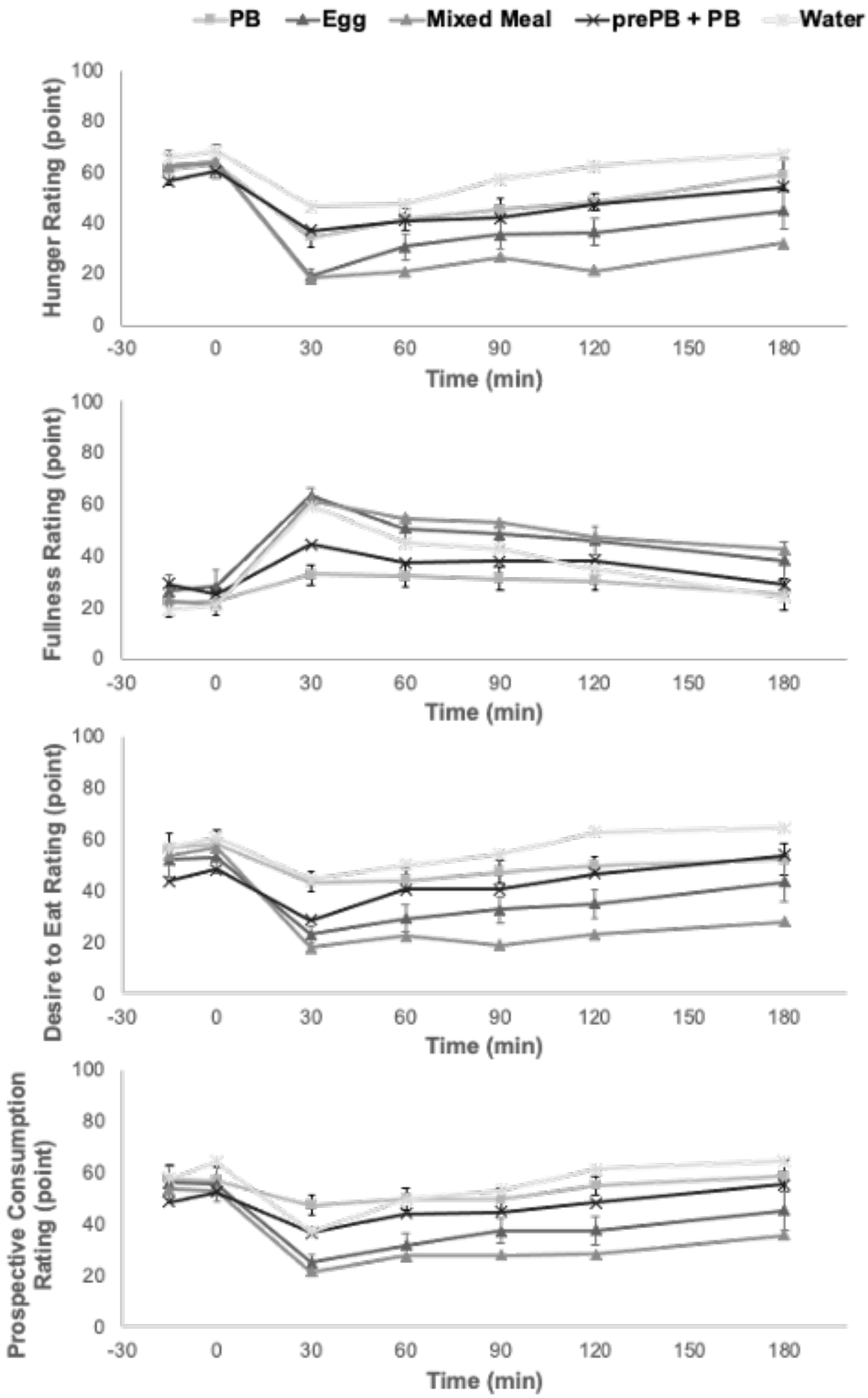

Figure 9. Appetite ratings of appetite group in response to different preloads. PB: peanut butter, prePB+PB: pre-exposure to peanut butter and peanut butter preload at a testing day.

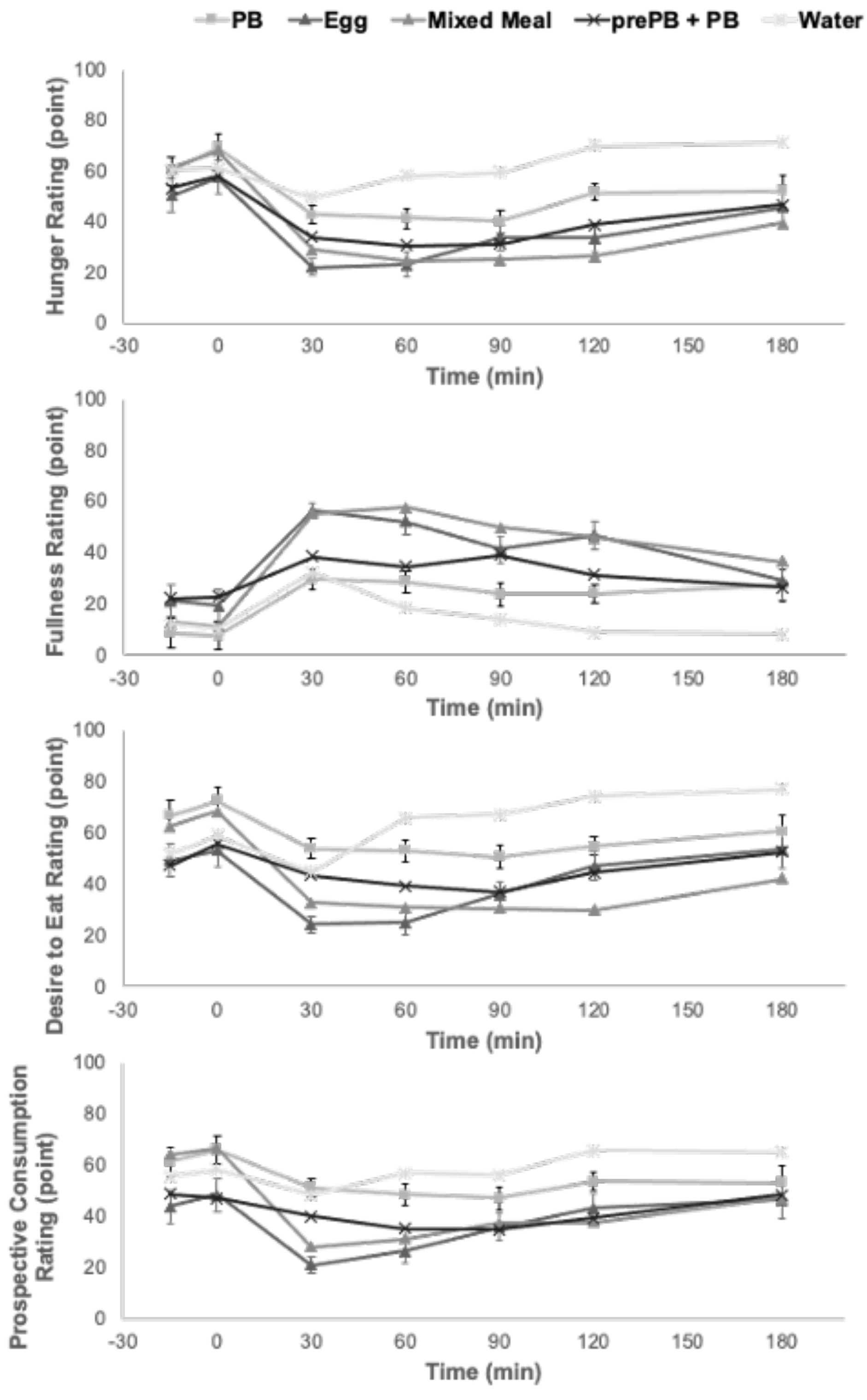

Figure 10. Appetite ratings of taste group in response to different preloads. PB: peanut butter, prePB+PB: pre-exposure to peanut butter and peanut butter preload at a testing day.

5.5 Discussion

As we expected, there were confusions between appetite concepts; especially between hunger and fullness (60%), desire to eat and prospective consumption (40%), hunger and prospective consumption (45%), and hunger and energy intake (75%). However, only a participant had a confusion between hunger and desire to eat (5%), fullness and desire to eat (5%), fullness and prospective consumption (10%). Appetite training did not increase test-retest repeatability. However, there was a trend of reduction in correlations between hunger and desire to eat in appetite group but not taste group, meaning participants distinguished hunger and desire to eat more clearly after the appetite concept training. In addition, appetitive sensations were altered by different meal types, but those changes were not different between appetite group and taste group, indicating the training either did not adequately educate participants on the appetite concepts or the interventions were not sufficient to evoke different appetitive responses. Taken together, there were no robust changes in test-retest repeatability and meal-specificity in appetite ratings with the concept training.

This study had severe limitations. Due to the outbreak of COVID-19 in the middle of study, a limited number of participants were recruited. Thus, the study was under-powered due to premature closure.

CHAPTER 6. CONCLUSION AND FUTURE DIRECTION

6.1 Summary and Conclusions

Inter-individual differences in self-reported ratings of hunger, fullness and thirst are marked and stable over 17 weeks. However, the implications of these differences for energy balance are limited, at least on a population basis, as no differences in energy intake were observed in the upper and lower tertiles of any of the three appetitive indices studied. Hypotheses for higher and lower intake could be posed for both ends of the appetitive distributions. Examination of these hypotheses revealed no clear trends. The analysis did reveal that energy intake leads changes in appetitive sensations more often than the reverse. This indicates fewer larger eating events will be a better strategy for controlling appetite than multiple smaller eating events that fail to evoke strong reductions in hunger or peaks of fullness. Similarly, the effect of eating patterns on appetitive sensation was greater than the effect of appetitive sensations on eating patterns. However, the overall associations between appetitive sensations and energy intake and between appetitive sensations and eating patterns were weak. No statistically significant association was observed between mean daily appetitive sensations and sex, age, or BMI. Thus, the present findings suggest a limited role for appetitive sensations in ingestive behavior. However, extrapolation of findings must be made with caution as not all appetitive sensations were tested, the sample tested was not representative of any segment of the population and individuals were only assessed under conditions of relative energy balance. These data answer some questions but raise many more that should be pursued in future studies.

6.2 Future Directions

Appetitive Sensations at Energy Balance Extremes

We found a weak association between energy intake and appetitive sensations. Whether stronger relationships hold under marked positive or negative energy balance is uncertain. If human physiology is predisposed towards maintenance of energy balance through interactions between energy intake and energy expenditure (286), it may be postulated that at the extremes of energy balance, appetitive sensations may play a more essential role in eating and weight control. However, there are mixed results on appetite responses to either negative or positive energy balance. Appetitive sensations were augmented in weight loss trial (243) while they were reduced in another (244). Additionally, appetitive sensations were not diminished with a overfeeding trial (246) or low physical activity trial (287). Whether appetitive sensations are more important mediators of body weight under negative balance and positive balance requires further investigation.

Additional Indices of Appetite

People frequently eat when they are not hungry and are reasonably full. They also commonly fail to eat when hungry and are not full. These apparently non-homeostatic behaviors likely reflect a strong influence of other determinants of feeding that overwhelm sensations of hunger, fullness and thirst. Desire to eat refers to a sensation that motivates eating in the absence of hunger. Those who have high desire to eat may consume more calories due to a strong motivational drive. Alternatively, prospective consumption reflects an amount of food they could be eaten, and thus high prospective consumption after a meal may reflect poor inhibition of a motivational drive to eat. Further studies with desire to eat and prospective consumption are required to understand relationship between appetitive sensations and energy intake.

Individual Characteristics

No association was observed between hunger, fullness or thirst and age, sex, or BMI. Our findings may be true, or this may be attributable to limited statistical power. Even though this study included a larger sample size compared to previous studies, sample sizes were low, especially for males, older adults, and overweight and obese individuals. Larger sample sizes with more power may reveal associations not detected here. Also, speed of aging is relative between individuals. Thus, age may explain within individual variance not between individuals. A longitudinal cohort study would be very informative to investigate the effects of age on changes of appetitive sensations.

Still, it might be because environmental influences were getting more influential in appetitive sensations as getting older. A cross-sectional study with children reported genetic influences were greater than environmental influences (288) while environmental influences were greater than genetic influences in a cross-sectional study with adults (128). Thus, examination on what environmental factors shape appetitive traits and how that impact works in longitudinal study may provide vital insights on regulating appetitive sensations and energy balance.

In part, weights of biological and environmental determinants may vary from person to person because each individual may have different sensitivities to each determinant. For instance, one study divided obese individuals into two groups based on ability to detect the relationship between appetitive sensations and energy intake (49). Individuals who do not detect the relationship had greater prospective consumption compared to those who are able to detect the relationship after fixed-energy breakfast and lunch (49). This study showed that appetitive sensations have more power on some obese individuals than others. Variability in bodily sites for each appetitive sensation has been reported (11,12). Whether certain appetitive sensations are more strongly associated with some patterns of sensation than others has not been studied. This may be especially useful clinically where more extreme sensations may be experienced.

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APPENDIX A. STUDY MATERIALS OF APPETITE VARIABILITY STUDY

Recruiting materials – Flyer

IRB Protocol #: IRB-2020-1651

RESEARCH STUDY

Purdue University

 

Participants are needed by the Purdue Nutrition Science Department for a study of examining the relationship between appetite ratings and eating pattern.

We are looking for men and women (18 – 64 y) in good physical health who are not diabetic, or other health problems/disease.

For more information, please contact:
Eunjin Cheon
cheone@purdue.edu

Principal Investigator – Professor Richard Mattes

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Recruiting materials – Online Advertisements

Participants are needed for a research study to examine the relationship between appetite ratings and eating pattern. Men and women ages 18 to 64 with no physical health problems/disease. Participants will be compensated $100.
The principal investigator for the study is Richard Mattes, Distinguished Professor of Nutrition Science. Those interested in participating should contact Eunjin at cheone@purdue.edu . (IRB-2020-1651)

Recruiting materials – Verbal Advertisements

We are looking for healthy participants who are aged between 18 to 64 to examine the relationship between appetite ratings and eating pattern. Principal Investigator is Professor Richard Mattes. If you are interested in this study and would like to get further information, please contact me through e-mail (cheone@purdue.edu).

RESEARCH PARTICIPANT CONSENT FORM
[Appetite Ratings and Eating Patterns]
[Principal Investigator: Richard Mattes, PhD. R.D.]
[Department of Nutrition Science]
Purdue University

Key Information

Please take time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask researchers questions about the study whenever you would like. If you decide to take part in the study, you will be asked to sign this form. Be sure you understand what you will do and any possible risks or benefits.

- This research study aims to determine the association between appetite/thirst ratings and eating patterns.
- You are being asked to participate for 17 weeks. There will be one face-to-face meeting for screening and virtual meetings during weeks 1, 9, and 17.

What is the purpose of this study?

- This study will examine the relationship between appetite/thirst sensations and eating patterns.
- We would like to enroll 180 people in this study.

What will I do if I choose to be in this study?

You will either meet through Zoom or come to our lab (Room 226 of Stone Hall, Purdue University, West Lafayette, IN) once for screening and have three virtual meetings at weeks 1, 9, and 17. Throughout the 17-week study period, appetite/thirst ratings, dietary records, and physical activity will be measured at fixed intervals (as described below).

Specific Procedures

Baseline visit

a. You will record selected basic personal information including age, biological sex, race/ethnicity.
b. Your weight, height, BMI, fat% will be measured.
c. You will complete multiple questionnaires about your eating habits and eating environment.
d. You will get instruction on how to record your dietary intake through the ASA-24 system.
e. You will receive appetite concept training for about 30 minutes.
    i. After training, you will take a quiz for about 20 minutes to check your understanding of the method.
    ii. If you score at least 90%, you will pass the training.
    If not, you will have two more opportunities to be trained. If you do not pass the quiz after three trainings, you will not be able to continue the study.

Weeks 1, 9, and 17

a. Virtual meetings:
    i. You will have a virtual meeting through Zoom.
    ii. You will be reminded about the necessity and method for recording of appetite/thirst ratings, dietary recalls, and physical activity to be completed during three days (2 non-consecutive weekdays and 1 weekend day).

b. Hourly appetite and thirst rating:
   i. You will be asked to record your hunger, fullness, and thirst sensations on a visual analog scale hourly during all waking hours for 24 hours.

c. 24-Dietary Recall:
   i. You will be asked to record your food intake through the ASA-24 system on the same days you record your hourly appetite ratings.

d. Physical activity
   i. You will be asked to record your physical activity through smart-phone app on the same days you record your hourly appetite ratings.

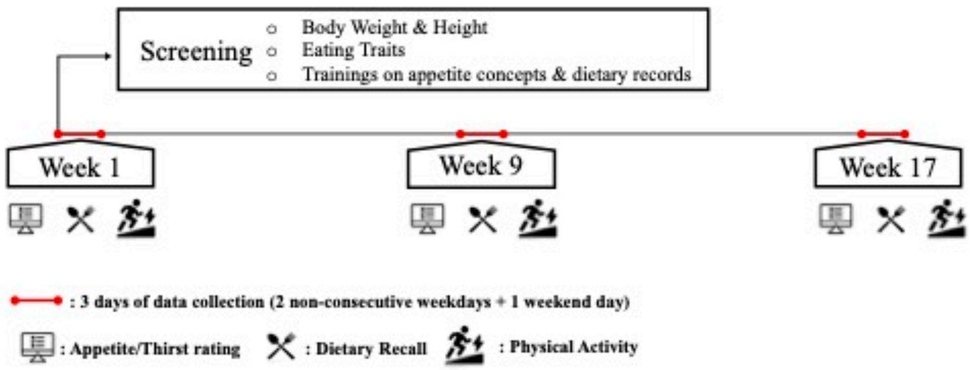

Figure1. Study Timeline

How long will I be in the study?

This study will require one physical visit and three virtual meetings as well as three days of data collection on three occasions over 17 weeks

The lengths of the visit and meetings are:

a. Screening: 1-1.5 hours
b. Virtual meeting on week 1, 9, 17: 0.5 hour (30 minutes)

What are the possible risks or discomforts?

All research has risk. This research has minimal risk, defined as the risk found in everyday life. Some inconvenience may be experienced when you rate appetite and record food intake on three days of weeks 1, 9, and 17.

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section below.

COVID-19 presents new risks. In order to best protect participants, certain new procedures will be enacted, including the wearing of a mask by participants and study staff when in contact with one another. All equipment and surfaces used will be disinfected at the end of use. Participant study times will be staggered so that social distancing can be maintained. Lastly, participants will be screened 24-48 hours before each study appointment with the following question: "Have you had a new cough, shortness of breath, sore throat, vomiting, diarrhea, muscle ache or fever in the last 14 days OR have you traveled out of the country in the last 14 days?" The participant will not be allowed to come in for their appointment unless the answer is "No" for each system.

Are there any potential benefits?

You will receive no foreseeable direct benefit from your participation. The knowledge gained may provide insights for studying appetite with the intent to reduce energy intake and manage body weight.

Will I receive payment or other incentive?

You will receive a total payment of $100 as compensation for any inconvenience caused by your participation in the full 17-week study. The compensation will be paid by check when your participation in the study is completed.

A payment of $20 will be made for completion of week1, $30 for completion of week 9, and $50 for completion of week 17 should you withdraw or be withdrawn from the study.

You will need to complete a payment log with the Department of Nutrition Science Business Office to receive payment, and some personal information will be required including, name, address and social security number. Non-resident participants will be required to complete additional payment procedures via the Purdue Glacier system.

Are there costs to me for participation?

There are no anticipated costs to participate in this study.

This section provides more information about the study

Will information about me and my participation be kept confidential?

You understand that the record of your progress in the study will be kept in a confidential file in a locked filing cabinet in a secure location on the Purdue Campus. A copy of this consent form and the record of your progress will be retained for three years after termination of the study. At that time, the records will be destroyed. The confidentiality of any computer record will also be carefully guarded by never including your name on any data file. The information will be stored electronically on a password-protected computer file. No information by which you can be identified will be published. However, you understand that it will be necessary to provide your name, social security number and address to the University business office to process any compensation payments. In addition, research records may be inspected by the Purdue University Institutional Review Board or its designees, and (as allowable by law) state or federal agencies including the National Institutes of Health.

Clinicaltrials.gov

"A description of this clinical trial will be available on ClinicalTrials.gov, as required by U.S. Law. This website will not include information that can identify you. At most, the Website will include a summary of the results. You can search this Website at any time"

What are my rights if I take part in this study?

- Your participation in this study is voluntary. You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty.
- If you do not pass the quiz after three trainings, you will not be able to continue the study.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Eunjin Cheon (cheone@purdue.edu) would be the point of contact. You may also contact Richard Mattes (765-494-0062, mattes@purdue.edu), the principal investigator of the project.

To report anonymously via Purdue's Hotline see www.purdue.edu/hotline

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

______________________________ ______________
Participant's Signature Date

____
Participant's Name

______________________________ ______________
Researcher's Signature Date

Demographic questionnaire

Demographic Information:

1) Gender: Female _______ Male _______

2a) Age: _______ **2b)** Date of Birth: _____________________ (mm-dd-yyyy)

3) Race:

- American Indian/Alaska Native
- Asian
- African American
- Native Hawaiian/Pacific Islander
- Caucasian
- Mexican
- Other, please indicate _____________

4) Ethnicity:

- Hispanic/Latino
- Non-Hispanic/Latino

Eating Trait questionnaires 1 (Meal Pattern Questionnaire)

In this questionnaire we ask you how often you have had meals or snacks during the last 28 days. Please read these instructions thoroughly and indicate your answers by circling the number that best correspond to your situation. When you answer, please remember to take into account whether your eating habits are different during the weekdays or weekends.

A meal or snack is in this case warm or cold food, sandwiches, salad, yoghurt, cereals, porridge, fruits, nuts, smoothies, or similar.
Foods high in sugar and/or fat such as candy, cake, cookies, buns, crackers, potato chips, chocolate, energy bars, ice cream, dried fruits and similar are NOT considered meals or snacks.

Beverages (e.g. coffee, tea, soft drinks, energy drinks, juice) are NOT considered meals or snacks.

Please note that if you have had "brunch", it should be coded as lunch.

If you find it difficult to choose between two numbers, please circle the higher of the two.

If you find it very difficult to classify your meals (e.g. if you have a night job) please state the reason here ______________________________________
____.

Please circle the appropriate number on the right. Remember that the question refers to the past four weeks (28 days) only.

On how many of the past 28 days have you had …	**No days**	**1–5 days**	**6–12 days**	**13–15 days**	**16–22 days**	**23–27 days**	**Every day**
Breakfast	0	1	2	3	4	5	6
Mid-morning snack	0	1	2	3	4	5	6
Lunch	0	1	2	3	4	5	6
Mid-afternoon snack	0	1	2	3	4	5	6
Evening meal (dinner)	0	1	2	3	4	5	6
Evening snack	0	1	2	3	4	5	6
Nocturnal eating (eating during the night after having been to sleep)	0	1	2	3	4	5	6

Eating Trait questionnaires 2 (Power of Food Scale)

		I don't agree (1)	*I agree a little (2)*	*I agree somewhat (3)*	*I agree quite a bit (4)*	*I strongly agree (5)*
Q1	I find myself thinking about food even when I'm not physically hungry	(1)	(2)	(3)	(4)	(5)
Q2	I get more pleasure from eating than I do from almost anything else	(1)	(2)	(3)	(4)	(5)
Q3	If I see or smell a food I like, I get a powerful urge to have some	(1)	(2)	(3)	(4)	(5)
Q4	When I'm around a fattening food I love, it′s hard to stop myself from at least tasting it	(1)	(2)	(3)	(4)	(5)
Q5	It's scary to think of the power that food has over me	(1)	(2)	(3)	(4)	(5)
Q6	When I know a delicious food is available, I can't help myself from thinking about having some	(1)	(2)	(3)	(4)	(5)
Q7	I love the taste of certain foods so much that I can't avoid eating them even if they're bad for me	(1)	(2)	(3)	(4)	(5)
Q8	Just before I taste a favorite food, I feel intense anticipation	(1)	(2)	(3)	(4)	(5)
Q9	When I eat delicious food, I focus a lot on how good it tastes	(1)	(2)	(3)	(4)	(5)
Q10	Sometimes, when I'm doing everyday activities, I get an urge to eat 'out of the blue' (for no apparent reason)	(1)	(2)	(3)	(4)	(5)
Q11	I think I enjoy eating a lot more than most other people	(1)	(2)	(3)	(4)	(5)
Q12	Hearing someone describe a great meal makes me really want to have something to eat	(1)	(2)	(3)	(4)	(5)
Q13	It seems like I have food on my mind a lot	(1)	(2)	(3)	(4)	(5)
Q14	It's very important to me that the foods I eat are as delicious as possible	(1)	(2)	(3)	(4)	(5)
Q15	Before I eat a favorite food, my mouth tends to flood with saliva	(1)	(2)	(3)	(4)	(5)

Eating Trait questionnaires 3 (The Emotional Eating Scale)

We all respond to different emotions in different ways. Some types of feelings lead people to experience an urge to eat. Please indicate the extent to which the following feelings lead you to feel an urge to eat by checking the appropriate box.

		No Desire to Eat (1)	*A Small Desire to Eat (2)*	*A Moderate Desire to Eat (3)*	*A Strong Urge to Eat (4)*	*An Overwhelming Urge to Eat (5)*
Q1	**Resentful**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q2	**Discouraged**	**(1)**	**(2)**	**(3)**	**(4)**	**(1)**
Q3	**Shaky**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q4	**Worn Out**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q5	**Inadequate**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q6	**Excited**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q7	**Rebellious**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q8	**Blue**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q9	**Jittery**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q10	**Sad**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q11	**Uneasy**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q12	**Irritated**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q13	**Jealous**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q14	**Worried**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q15	**Frustrated**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q16	**Lonely**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q17	**Furious**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q18	**On edge**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q19	**Confused**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q20	**Nervous**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q21	**Angry**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q22	**Guilty**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q23	**Bored**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q24	**Helpless**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Q25	**Upset**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**

Eating Trait questionnaires 4 (The Eating Inventory)

Cognitive Restraint		(1)	(2)	(3)	(4)
Q1	I deliberately take small helpings as a means of controlling my weight.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q2	I consciously hold back at meals in order not to gain weight.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q3	I do not eat some foods because they make me fat.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q4	How frequently do you avoid `stocking up' on tempting foods?				
		Almost never	*Seldom*	*Usually,*	*Almost always*
Q5	How likely are you to consciously eat less than you want?				
		Unlikely	*Slightly likely*	*Moderately likely*	*Very likely*
Q6	On a scale of 1 to 8, where 1 means no restraint in eating (eating whatever you want, whenever you want it) and 8 means total restraint (constantly limiting food intake and never `giving in'), what number would you give yourself? Your score: ______________________				
		Eat whatever I want, whenever I want it (1)			*constantly limiting food intake, never `giving in' (8)*
Uncontrolled eating		**(1)**	**(2)**	**(3)**	**(4)**
Q1	When I smell a sizzling steak or a juicy piece of meat, I find it very difficult to keep from eating, even if I have just finished a meal.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely False*
Q2	Sometimes when I start eating, I just can't seem to stop.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q3	Being with someone who is eating often makes me hungry enough to eat also.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q4	When I see a real delicacy, I often get so hungry that I have to eat right away.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*
Q5	I get so hungry that my stomach often seems like a bottomless pit.				
		Definitely False	*Mostly False*	*Mostly True*	*Definitely True*

Q6	**I am always hungry, so it is hard for me to stop eating before I finish the food on my plate.**				
		Definitely False	***Mostly False***	***Mostly True***	***Definitely True***
Q7	**I am always hungry enough to eat at any time.**				
		Definitely False	***Mostly False***	***Mostly True***	***Definitely True***
Q8	**How often do you feel hungry?**				
		Only at mealtimes	***Sometimes between meals***	***Often between meals***	***Almost always***
Q9	**Do you go on eating binges though you are not hungry?**				
		Never	***Rarely***	***Sometimes***	***At least once a week***
Emotional eating		**(1)**	**(2)**	**(3)**	**(4)**
Q1	**When I feel anxious, I find myself eating.**				
		Definitely False	***Mostly False***	***Mostly True***	***Definitely True***
Q2	**When I feel blue, I often overeat.**				
		Definitely False	***Mostly False***	***Mostly True***	***Definitely True***
Q3	**When I feel lonely, I console myself by eating.**				
		Definitely False	***Mostly False***	***Mostly True***	***Definitely True***

Eating Trait questionnaires 5 (Food Craving Inventory)

Over the past month, how often have you experienced a craving for the food?

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always/almost every day (5)
Factor 1: High fats					
Fried Chicken					
Sausage					
Gravy					
Fried fish					
Bacon					
Corn bread					
Hot dog					
Steak					
Factor 2: Sweets					
Brownies					
Cookies					
Candy					
Chocolate					
Donuts					
Cake					
Cinnamon rolls					
Ice cream					
Factor 3: Starches/Carbohydrates					
Rolls					
Pancakes or waffles					
Biscuits					
Sandwich bread					
Rice					
Baked potato					
Pasta					
Cereal					
Factor 4: Fast-food fats					
Hamburger					
French fries					
Chips					
Pizza					

Eating Trait questionnaires 6 (Adult Eating Behavior Scales)

AEBQ	AEBQ item
H	I often feel so hungry that I have to eat something right away
	I often notice my stomach rumbling
	If I miss a meal, I get irritable
	If my meals are delayed, I get light-headed
	I often feel hungry
FR	I often feel hungry when I am with someone who is eating
	When I see or smell food that I like, it makes me want to eat
	Given the choice, I would eat most of the time
	I am always thinking about food
EOE	I eat more when I'm annoyed
	I eat more when I'm worried
	I eat more when I'm upset
	I eat more when I'm anxious
	I eat more when I'm angry
EF	I love food
	I look forward to mealtimes
	I enjoy eating
SR	I often leave food on my plate at the end of a meal
	I often get full before my meal is finished
	I get full up easily
	I cannot eat a meal if I have had a snack just before
EUE	I eat less when I'm worried
	I eat less when I'm angry

AEBQ	AEBQ item
	I eat less when I'm upset
	I eat less when I'm annoyed
	I eat less when I'm anxious
FF	I refuse new foods at first
	I often decide that I don't like a food, before tasting it
	I enjoy tasting new foods*
	I am interested in tasting food I haven't tasted before*
	I enjoy a wide variety of foods*
SE	I eat slowly
	I am often last at finishing a meal
	I eat more and more slowly during the course of a meal
	I often finish my meal (s) quickly*

H, 'hunger'; FR, 'food responsiveness'; EOE, 'emotional over-eating'; EF, 'enjoyment of food'; SR, 'satiety responsiveness'; EUE, 'emotional under-eating'; FF, 'food fussiness'; SE, 'slowness in eating'.

Response options for the CEBQ: 'never', 'rarely', 'sometimes', 'often' and 'always'.

Response options for the AEBQ: 'strongly disagree', 'disagree', 'neither agree not disagree', 'agree' and 'strongly agree'.

*Indicates item should be reverse scored for calculating scale means or Cronbach's alphas

Eating Trait questionnaires 7 (Self-regulation of Eating Behaviour Questionnaire)

Screening questions:

1. Do you find any of these foods tempting (that is, do you want to eat more of them than you think you should)? (Tick those which apply)

☐	Chocolate	☐	Fizzy drinks	☐	Pizza
☐	Crisps	☐	Biscuits	☐	Fried foods
☐	Cakes	☐	Sweets	☐	Chips
☐	Ice cream	☐	Popcorn	☐	Other foods
☐	Bread/toast	☐	Pastries	☐	I don't find any food tempting

If you have ticked other foods, please specify:

2. Do you intend NOT to eat too much of these foods you find tempting in the previous question?

☐ Yes

☐ No

3. Do you intend to have a healthy diet?

☐ Yes

☐ No

Self-Regulation of Eating Behavior Questions:

4. Please read the following statements and tick the boxes most appropriate to you.

For the next few questions, please, understand that:

- 'Tempting foods' are any food you want to eat more of than you think you should.
- 'Eating intentions' refer to the way you are aiming to eat, for example you may intend to avoid tempting foods or eat healthy foods.

		Never	Rarely	Sometimes	Often	Always
1	I give up too easily on my eating intentions	☐	☐	☐	☐	☐
2	I'm good at resisting tempting food	☐	☐	☐	☐	☐
3	I easily get distracted from the way I intend to eat	☐	☐	☐	☐	☐
4	If I am not eating in the way I intend to I make changes	☐	☐	☐	☐	☐
5	I find it hard to remember what I have eaten throughout the day	☐	☐	☐	☐	☐

Eating Trait questionnaires 8 (Barratt Impulsiveness Scale)

DIRECTIONS: People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and put an X on the appropriate circle on the right side of this page. Do not spend too much time on any statement. Answer quickly and honestly.

① Rarely/Never ② Occasionally ③ Often ④ Almost Always/Always

1	I plan tasks carefully.	①	②	③	④
2	I do things without thinking.	①	②	③	④
3	I make-up my mind quickly.	①	②	③	④
4	I am happy-go-lucky.	①	②	③	④
5	I don't "pay attention."	①	②	③	④
6	I have "racing" thoughts.	①	②	③	④
7	I plan trips well ahead of time.	①	②	③	④
8	I am self controlled.	①	②	③	④
9	I concentrate easily.	①	②	③	④
10	I save regularly.	①	②	③	④
11	I "squirm" at plays or lectures.	①	②	③	④
12	I am a careful thinker.	①	②	③	④
13	I plan for job security.	①	②	③	④
14	I say things without thinking.	①	②	③	④
15	I like to think about complex problems.	①	②	③	④
16	I change jobs.	①	②	③	④
17	I act "on impulse."	①	②	③	④
18	I get easily bored when solving thought problems.	①	②	③	④
19	I act on the spur of the moment.	①	②	③	④
20	I am a steady thinker.	①	②	③	④
21	I change residences.	①	②	③	④
22	I buy things on impulse.	①	②	③	④
23	I can only think about one thing at a time.	①	②	③	④
24	I change hobbies.	①	②	③	④
25	I spend or charge more than I earn.	①	②	③	④
26	I often have extraneous thoughts when thinking.	①	②	③	④
27	I am more interested in the present than the future.	①	②	③	④
28	I am restless at the theater or lectures.	①	②	③	④
29	I like puzzles.	①	②	③	④
30	I am future oriented.	①	②	③	④

Patton, Stanford, Barratt (1995). *J Clin Psy*, vol. 51, pp. 768-774

Appetite Rating Questionnaire

Please enter the last three digits of your participant ID. (e.g. 055-054-xxx)

What time is it now? (HH:MM AM/PM) (e.g. 8:05 AM)

Please rate your appetite sensations below.

How hungry do you feel? (0 = I am not hungry at all , 100 = Extremely hungry)

I am not hungry at all 0 — Extremely hungry 100

How full do you feel? (0 = I am not full at all , 100 = Extremely full)

I am not full at all 0 — Extremely full 100

How thirsty do you feel? (0 = I am not thirsty at all, 100 = I am extremely thirsty)

I am not thirsty at all 0 — I am extremely thirsty 100

Goldberg cut-offs

$$EI_{rep}:BMR\ > PAL\ \times exp\left[s.d._{min}\frac{(S/100)}{\sqrt{n}}\right]$$

$$EI_{rep}:BMR < PAL\ \times exp\left[s.d._{max}\frac{(S/100)}{\sqrt{n}}\right]$$

$$S = \sqrt{\frac{CV_{wEI}^2}{d} + \ CV_{wB}^2 + \ CV_{tP}^2}$$

EI_{rep}: Reported Energy Intake
BMR: Basal Metabolic Rate
PAL = 1.55
CV_{wEI}= 23
CV_{wB}= 8.5
CV_{tP}= 15
d = 9
S = 18.87
$s.d._{min}$ = -3 (99% confidence interval)
$s.d._{max}$ = 3 (99% confidence interval)

1.46 < EI_{rep}: BMR < 1.65

APPENDIX B. STUDY MATERIALS OF APPETITE TRAINING STUDY

Recruiting materials – flyers

IRB Protocol #: IRB-2020-214

RESEARCH STUDY

Purdue University

Participants are needed by the Purdue Nutrition Science Department for a study evaluating the effect of concept trainings on appetite measurement.

We are looking for men and women (18 – 60 y) in good physical health who are not diabetic, and not obese.

For more information, please contact:
Eunjin Cheon
cheone@purdue.edu

Principal Investigator – Professor Richard Mattes

Social Media Recruiting Script

Participants are needed for a research study evaluating the effect of concept trainings on appetite measurement. Men and women ages 18 to 60 with a body mass index (BMI) between 18 and 25 are eligible to participate. Participants will be compensated $100.
The principal investigator for the study is Richard Mattes, Distinguished Professor of Nutrition Science. Those interested in participating should contact Eunjin at cheone@purdue.edu . (IRB-2020-214)

Verbal Recruiting Script

We are looking for healthy participants who are aged between 18 to 60 to evaluate the effect of concept trainings on appetite measurement. Principal Investigator is Professor Richard Mattes. If you are interested in this study and would like to get further information, please contact me through e-mail (cheone@purdue.edu).

RESEARCH PARTICIPANT CONSENT FORM
[Appetite Lexicon Training]
[Principal Investigator: Richard Mattes, PhD. R.D.]
[Department of Nutrition Science]
Purdue University

Key Information

Please take time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. You should be certain you understand what you will be asked to do and any possible risks or benefits associated with your participation before agreeing to participate. If you decide to take part in the study, you will be asked to sign this form.

- This randomized controlled trial aims to improve the reliability and sensitivity of appetite ratings by training on different response scales.
- This research study will last 9 weeks. Visits occur once a week and vary in length from about 1.5 hours to 3.5 hours.

What is the purpose of this study?

This study will examine the effects of two types of trainings on the reliability and sensitivity of appetite ratings. We would like to enroll 100 people in this study.

What will I do if I choose to be in this study?

You will come to our laboratory (Room 226 of Stone Hall, Purdue University) every week at about the same time of a day. You will be randomly assigned to appetite lexicon training group or the basic taste lexicon training group. After training, you will take a quiz to check your understanding of the method. If you score 90%, you will pass the training. If not, you will have two more opportunities to be trained. If you do not pass the quiz, you will not be able to continue the study. Throughout the 9-week study period, weekly assessments will be performed at fixed intervals (as described below).

Specific Procedures

Baseline visit

a. You will record your basic demographic information including age, biological sex, and race/ethnicity.
b. Your weight and height will be measured.
c. You will complete multiple questionnaires about your health (e.g., disease history, medication, use smoking habit, pregnancy status, body weight history, diet history, allergies)

Week 1-2, 4-9

a. Pre-load testing:

i. You will arrive at the laboratory having fasted more than 4 hours once a week. You will rate the magnitude of your hunger on a scale and a sample of blood will be collected to check your blood sugar concentration.
ii. You will rate your appetite sensations (hunger, fullness, desire to eat, and prospective consumption) 7 times (15 and 0 minutes before the preload and 30, 60, 90, 120 and 180 minutes after a small meal).

b. Daily Appetite rating:
   i. On a separate day of the week, you will be asked to record your appetite sensations hourly during waking hours for 24 hours.

Week 3: Lexicon Training
a. You will receive appetite or basic taste rating training for about 30 minutes.
b. You will take a quiz for about 20 minutes.
c. If you pass the quiz, you will be asked to record your hourly appetite ratings during all waking hours for 24 hours in a separate day of the week.
d. If you do not pass the quiz, you will be asked to visit another day and undergo training again and take a quiz to verify your understanding of the technique.

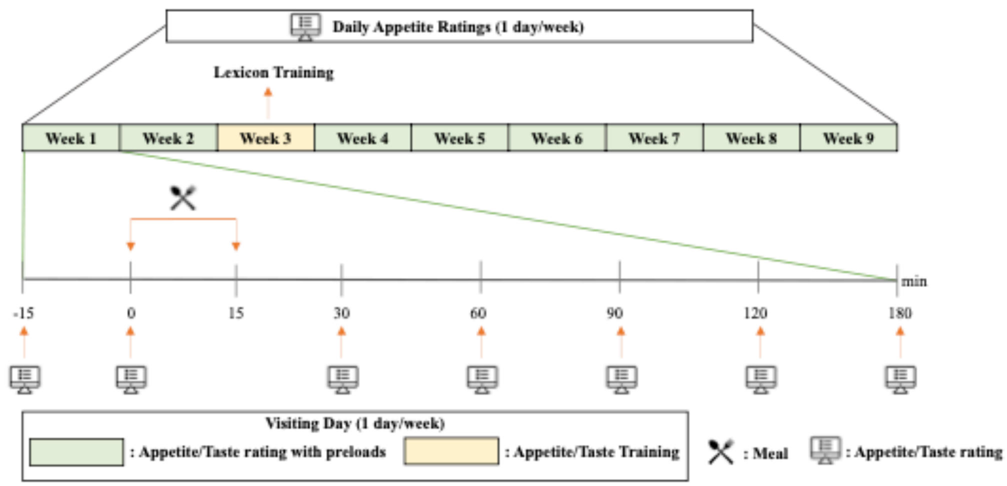

Table 1. Study Timeline

How long will I be in the study?

This study will require ten visits over a ten-week period. On a separate day of the week, you will record your appetite hourly during waking hours for 24 hours.

The length of each visit is:
a. Screening: 1 – 1.5 hours
b. Week1-2, 4-9: 4 – 3.5 hours
c. Week 3: 1 – 1.5 hours

What are the possible risks or discomforts?

All research has risk. This research has minimal risk, defined as the risk found in everyday life. The food and beverage samples you will be asked to consume are commercially available and pose no foreseeable risk. Some inconvenience may be experienced when you rate appetite during the visit and record appetite hourly on selected days.

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

COVID-19 presents new risks. In order to best protect participants, certain new procedures will be enacted, including the wearing of a mask by participants and study staff when in contact with one another. All equipment and surfaces used will be disinfected at the end of use. Participant study times will be staggered so that social distancing can be maintained. Lastly, participants will be screened 24-48 hours before each study appointment with the following question: "Have you had a new cough, shortness of breath, sore throat, vomiting, diarrhea, muscle ache or fever in the last 14 days OR have you traveled out of the country in the last 14 days?" The participant will not be allowed to come in for their appointment unless the answer is no.

Are there any potential benefits?

You will receive no foreseeable direct benefit from your participation. The knowledge gained may provide insights for studying appetite with the intent to reduce energy intake and manage body weight.

Will I receive payment or other incentive?

You will receive $10 for each week that they remain in the study and you will be compensated up to $100 for the completion of the study. If you do not meet pre-set eligibility criteria during the screening assessment, a payment of $10 will be made. A payment of $10 will be made for each completed week of study (except if training testing is repeated) should you withdraw or be withdrawn from the study. If the tablet is damaged or stolen, the whole compensation ($100) will be deducted for replacing the tablet.

You will need to complete a payment log with the Department of Nutrition Science Business Office to receive payment, and some personal information will be required including, name, address and social security number. Non-resident participants will be required to complete additional payment procedures via the Purdue Glacier system.

Are there costs to me for participation?

There are no costs to participate in this study. There is an electronic tablet we ask you to use during the weekly trials. There is no cost to you if the tablet is broken. However, if you lose the tablet or it is stolen, we will use part of your payment to replace the tablet.

This section provides more information about the study

What happens if I become injured or ill because I took part in this study?

If you feel you have been injured due to participation in this study, please contact Richard Mattes (765-494-0662; mattes@purdue.edu). Purdue University will not provide medical treatment or financial compensation if you are injured or become ill as a result of participating in this research project. This does not waive any of your legal rights nor release any claim you might have based on negligence.

Will information about me and my participation be kept confidential?

You understand that the record of your progress in the study will be kept in a confidential file in a locked filing cabinet in a secure location on the Purdue Campus. A copy of this consent form and the record of your progress will be retained for three years after termination of the study. At that time, the records will be destroyed. The confidentiality of any computer record will also be carefully guarded by never including your name on any data file. The information will be stored electronically on a password-protected computer file. No information by which you can be identified will be published. However, you understand that it will be necessary to provide your name, social security number and address to the University business office to process any compensation payments. In addition, research records may be inspected by the Purdue University Institutional Review Board or its designees, and (as allowable by law) state or federal agencies including the National Institutes of Health.

"A description of this clinical trial will be available on ClinicalTrials.gov, as required by U.S. Law. This website will not include information that can identify you. At most, the Website will include a summary of the results. You can search this Website at any time"

Clinicaltrials.gov

"A description of this clinical trial will be available on ClinicalTrials.gov, as required by U.S. Law. This website will not include information that can identify you. At most, the Website will include a summary of the results. You can search this Website at any time"

What are my rights if I take part in this study?

Your participation in this study is voluntary. You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. You may also contact Richard Mattes (765-494-0062, mattes@purdue.edu), the principal investigator of the project.

To report anonymously via Purdue's Hotline see www.purdue.edu/hotline

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

____ ____________________________

Participant's Signature Date

____

Participant's Name

____ ____________________________

Researcher's Signature Date

Appetite confusion questionnaires for taste training group (group2) to collect baseline understanding on appetite concept

Please enter your participant ID below. (e.g. 055-053-XXX)

Question 1

Hunger vs. Fullness: Are they opposite sensations on a single continuum?

- ○ Yes, they are opposite sensations
- ○ No, they are not opposite sensations.

Question 2

Let's move on to the next question.

Please imagine you are in the situation below:

You just had lunch.

However, when you see desserts like ice cream or cakes, you still want to eat them and feel you can eat them even after the satisfying meal.

Which sensation motivates you to eat the desserts?

- ○ Hunger
- ○ Desire to Eat
- ○ Prospective Consumption
- ○ Fullness

Question 3

Now, let's assume you had dinner and went to a movie theater.

When you get into the theater, you smell popcorn.

Even though you are full, you still want to eat popcorn.

So, you decide to eat a small size popcorn that you think you could finish.

What is the proper question to measure **the sensation** that makes you decide to choose a small size popcorn?

- ○ How large a portion do you think you could eat now?
- ○ How full do you feel?
- ○ How much hungry do you feel?
- ○ How strong is your desire to eat?

Question 4

Let's explore another situation.

You went to a buffet which has 50 different kinds of foods.

You have had 5 dishes so far and you feel full.

Even though you can eat more foods, you would like to stop eating.

What is the proper question to measure ***the* sensation** that makes you stop eating?

- ○ How strong is you desire to eat?
- ○ How full do you feel?
- ○ How large a portion do you think you could eat now?
- ○ How much hungry do you feel?

Question 5

Is the statement below always true?

When your fullness increases, your desire to eat decreases.

- ○ No, it is not always true.
- ○ Yes, it is always true.

Question 6

When a person says, " I can eat a horse now." which sensation does this statement reflect?

- ○ Hunger
- ○ Prospective Consumption
- ○ Desire to Eat
- ○ Fullness

Question 7

Now, you have one last question!

When you are hungry, which food would be the most efficient to reduce your hunger?

- ○ Diet (sweetened with low-calorie sweeteners) beverages
- ○ Sugar sweetened beverages
- ○ Plain water with lemon slices
- ○ A celery stick

Taste confusion questionnaires for appetite training group (group1) to collect baseline understanding on taste concept

Please enter your participant ID below. (e.g. 055-053-XXX)

Question 1

Flavor vs. Taste: Are they the same sensations?

- Yes, they are the same sensations.
- No, they are not same sensations.

Question 2

Let's move on the next question.

Is there a specific region on the tongue to detect a specific taste quality as proposed in the picture below?

- No, there is no specific region for a specific taste quality.
- Yes, one taste can be detected in specific regions of the tongue

Question 3

Let's imagine you have a cup of sour solution like lemon juice.

If you add one tablespoon of sugar into a sour solution, will the intensity of sourness change?

○ Yes, sourness will be changed.

○ No, there is no change in sourness

Question 4

Please drag items into the proper box.

Items

Spinach

Green Tea

Vinegar

Coffee

Lemon

Bitter

Sour

Question 5

Now, let's assume that you are asked to rate the salty intensity of a salty soup after consuming either a piece of bread or potato chips.

In which case do you think you rate salty intensity of the soup highest?

- ○ After consuming bread.
- ○ After consuming potato chips.
- ○ There will be no difference in salty intensity with both cases.

Question 6

Soy sauce vs Salt

Which taste quality is mainly different between soy sauce and salt?

- ○ Sour taste
- ○ Umami taste
- ○ Bitter taste
- ○ Sweet taste
- ○ Salty taste

Question 7

Now, we have one last question.

Is a metallic sensation in your mouth a taste response or response from another sensory system?

- ○ Yes, metallic sensation is a taste response.
- ○ No, metallic sensation is a response from another sensory system.

Appetite rating questionnaires at visiting day

(at -15 , 0 (right before the meal), 30, 60, 90, 180 min)

PURDUE
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Please enter your participant ID. (e.g. 055-053-xxx)

→

Please rate your appetite sensations below.

How hungry do you feel? (0 = I am not hungry at all , 100 = Extremely hungry)

Ii am not hungry at all   Extremely hungry

How full do you feel? (0 = I am not full at all , 100 = Extremely full)

I am not full at all   Extremely full
0   100

How strong is your desire to eat? (0 = I have no desire to eat, 100 = I have an extremely strong desire to eat)

I have no desire to eat 0

I have an extremely strong desire to eat 100

How large a portion do you think you could eat now? (0 = Nothing at all , 100 = An extremely large amount)

Nothing at all 0

An extremely large amount 100

Taste questionnaires at visiting day (right after participants finished their meals)

How sweet does the food taste? (0 = Not sweet at all , 100 = Extremely sweet)

Not sweet at all
0

Extremely Sweet
100

How bitter does the food taste? (0 = Not bitter at all , 100 = Extremely bitter)

Not bitter at all
0

Extremely bitter
100

How sour does the food taste? (0 = Not sour at all , 100 = Extremely sour)

Not sour at all
0

Extremely Sour
100

How savory does the food taste? (0 = Not savory at all , 100 = Extremely savory)

Not savory at all
0

Extremely Savory
100

Appetite Concept Training Handouts

Appetite Rating Training

Mattes Lab

Eunjin Cheon
(cheone@purdue.edu)

1

What is appetite?

An array of sensations that guide food intake.

Major Indices

HUNGER

FULLNESS

DESIRE TO EAT

PROSPECTIVE CONSUMPTION

2

1 Hunger

A Sensation that
motivates the initiation of an eating event
and stems from a biological need for energy.

Q: How hungry do you feel?

I am not hungry at all 0 ——————————————— 100 *Extremely hungry*

3

2 Desire to Eat

A Sensation that
motivates the initiation of an eating event,
but stems more from cognitive and sensory cues.

Q: How strong is you desire to eat?

I have no Desire to eat 0 ——————————————— 100 *I have an Extremely Strong Desire to eat*

4

3 Fullness

A Sensation that terminates an eating event.

Q: How full do you feel?

Not at all full — 0 ———————— 100 — *Extremely full*

5

4 Prospective Consumption

An anticipated portion that may be consumed.

Q: How large a portion do you think you can eat now?

Nothing at all — 0 ———————— 100 — *An extremely Large amount*

6

Appetite Concept Training

PURDUE UNIVERSITY

Default Question Block

Welcome to Appetite Training!

Please enter your participant ID below. (e.g. 055-053-XXX)

Please watch the basic training video carefully.

Great! Let's discuss **common confusions** in appetite sensations by answering the following questions.

Please click the arrow to continue.

Hunger vs. Fullness: Are they opposite sensations on a single continuum?

○ No, they are not opposite sensations.
○ Yes, they are opposite sensations

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Hunger vs. Fullness: Are they opposite sensations?

○ No, they are not opposite sensations.
○ Yes, they are opposite sensations

(If they correct, they move on to the explanation video.)

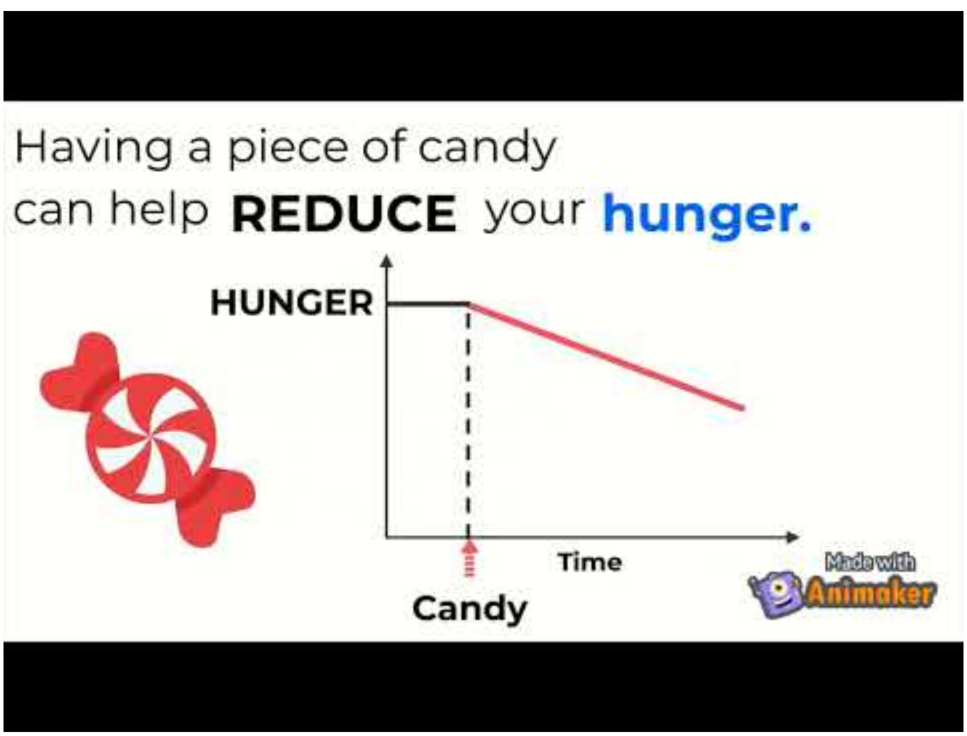
You are correct!

They are NOT opposite sensations.

Please click the arrow to learn about why hunger and fullness are not opposite sensations.

Confusion 1 - explaination

Please watch the explaining video carefully.



Confusion 2 - Hunger vs Desire to eat

Let's move on to the next question.

Please imagine you are in the situation below:

You just had lunch.

However, when you see desserts like ice cream or cakes, you still want to eat them and feel you can eat them even after the satisfying meal.

Which sensation motivates you to eat the desserts?

- ○ Prospective Consumption
- ○ Hunger
- ○ Desire to Eat
- ○ Fullness

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Let's move on the next question.

Please imagine you are in the situation below:

You just had lunch.

However, when you see desserts like ice cream or cakes, you still want to eat them and feel you can eat them even after the satisfying meal.

Which sensation motivates you to eat the desserts?

- ○ Prospective Consumption
- ○ Desire to Eat
- ○ Hunger
- ○ Fullness

(If they correct, they move on to the explanation video.)

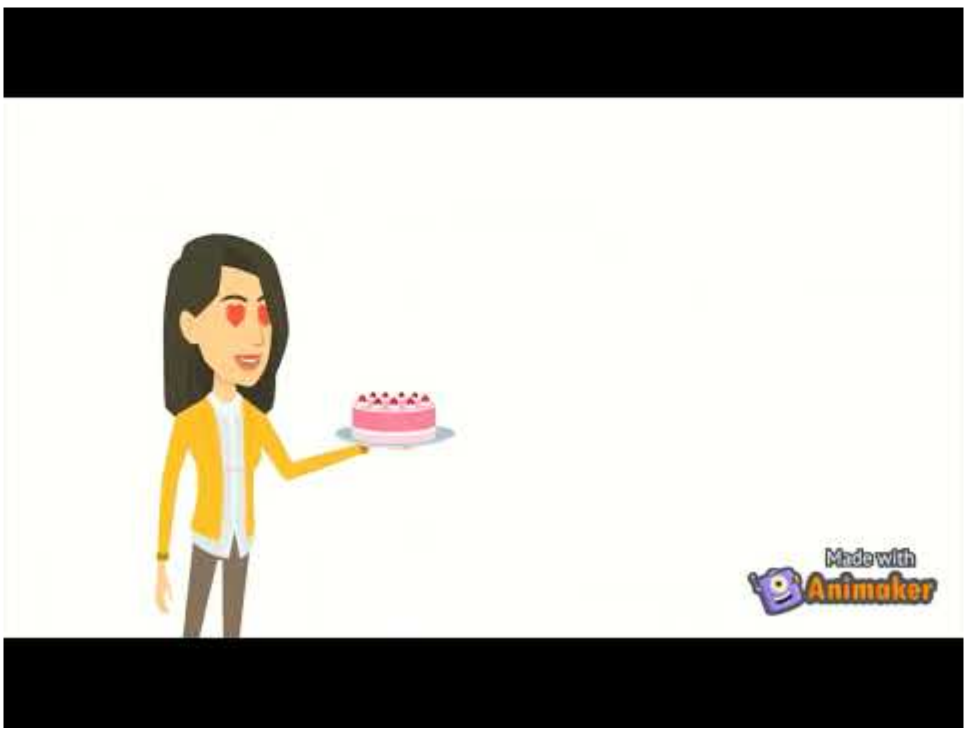
You are correct!

It is a DESIRE TO EAT sensation.

Please click the arrow to learn more about how our desire to eat is different from hunger

Confusion 2 - explanation

Please watch the explaining video carefully.



Confusion 3 - Desire to eat vs. prospective consumption

Now, let's assume you had dinner and went to a movie theater.

When you get into the theater, you smell popcorn.

Even though you are full, you still want to eat popcorn.

So, you decide to eat a small size popcorn that you think you could finish.

What is the proper question to measure **the sensation** that makes you decide to choose a small size popcorn?

○ How full do you feel?
○ How much hungry do you feel?
○ How strong is your desire to eat?
○ How large a portion do you think you could eat now?

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Now, let's assume you had dinner and went to a movie theater.

When you get into the theater, you smell popcorn.

Even though you are full, you still want to eat popcorn.

So, you decide to eat a small size popcorn that you think you could finish.

What is the proper question to measure **the sensation** that makes you decide to choose a small size popcorn?

○ How full do you feel?
○ How large a portion do you think you could eat now?
○ How strong is your desire to eat?
○ How much hungry do you feel?

(If they correct, they move on to the explanation video.)

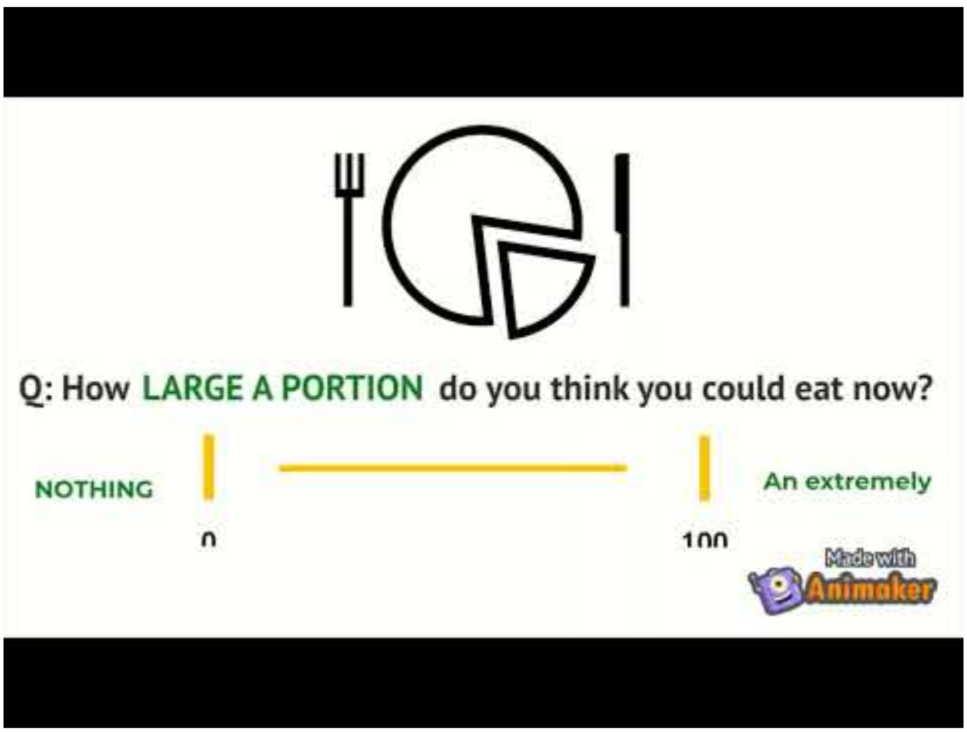
You are correct!

"How large a portion do you think you could eat now?" is the right question to ask "Prospective Consumption" and it decides the size of popcorn.

Please click the arrow to learn the difference between Desire to Eat and Prospective Consumption.

Confusion 3 - explanation

Please watch the explaining video carefully.



confusion 4 - prospective consumption vs Fullness

Let's explore another situation.

You went to a buffet which has 50 different kinds of foods.

You have had 5 dishes so far and you feel full.

Even though you can eat more foods, you would like to stop eating.

What is the proper question to measure ***the* sensation** that makes you stop eating?

- ○ How much hungry do you feel?
- ○ How full do you feel?
- ○ How large a portion do you think you could eat now?
- ○ How strong is you desire to eat?

(If incorrect, participant retried until they chose the right answer.)

Confusion 4 - answer

Oops! Please try it again.

Let's assume that you went to a buffet which has 50 different kinds of foods.

You have had 5 dishes so far and you feel full.

Even though you can eat more foods, you would like to stop eating.

What is the proper question to measure **this sensation** that makes you stop eating?

- ○ How large a portion do you think you could eat now?
- ○ How full do you feel?
- ○ How much hungry do you feel?
- ○ How strong is you desire to eat?

(If they correct, they move on to the explanation video.)

You are correct!

"How full do you feel?" is the right question to measure "Fullness" that makes you stop eating.

Please click the arrow to learn the difference between Fullness and Prospective Consumption.

confusion 4 - explanation

Please watch the explaining video carefully.

confusion 5 - Fullness vs desire to eat

Is the statement below always true?

When your fullness increases, your desire to eat decreases.

- ○ No, it is not always true.
- ○ Yes, it is always true.

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Is the statement below always true?

When your fullness increases, your desire to eat decreases.

- ○ No, it is not always true.
- ○ Yes, it is always true.

(If they correct, they move on to the explanation video.)

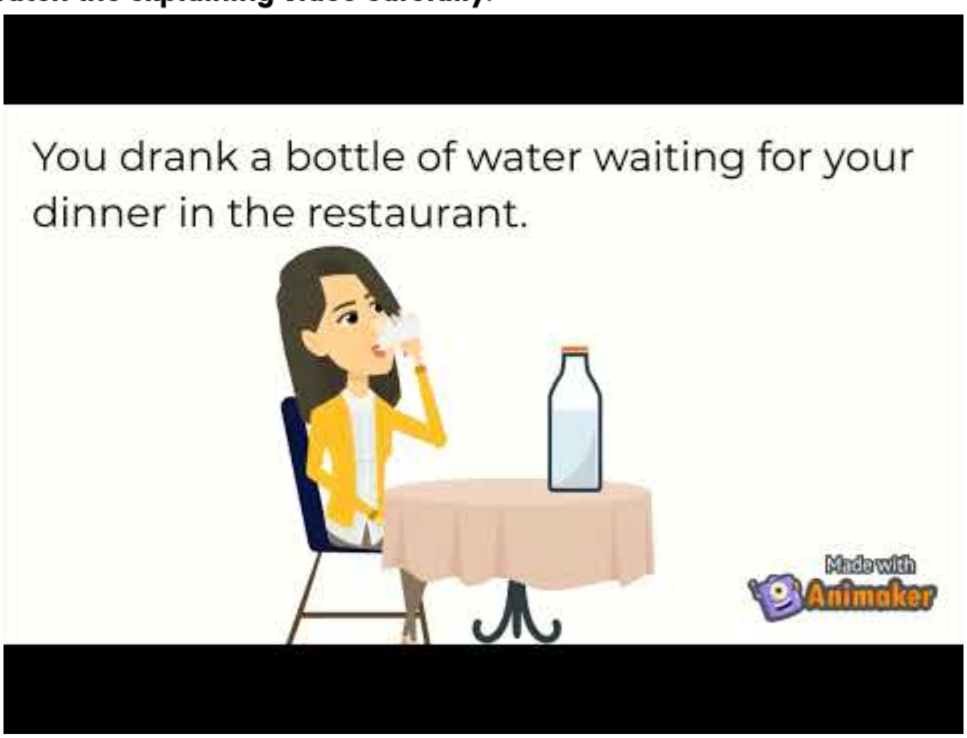
You are correct!

"Fullness" and "Desire to Eat" are independent each other.

Please click the arrow to learn the difference between Fullness and Desire to Eat.

Confusion 5 - explanation

Please watch the explaining video carefully.



confusion 6 - Hunger vs prospective consumption

When a person says, " I can eat a horse now." which sensation does this statement reflect?

- Hunger
- Prospective Consumption
- Desire to Eat
- Fullness

(If incorrect, participant retried until they chose the right answer.)

Confusion 6 - answer

Oops! Please try it again.

When a person says, " I can eat a horse now." which sensation does this statement reflect?

- Desire to Eat
- Fullness
- Hunger
- Prospective Consumption

(If they correct, they move on to the explanation video.)

You are correct!

"Prospective Consumption" is about "how LARGE a PORTION" that you could eat now.

Please click the arrow to learn the difference between Hunger and Prospective Consumption.

Confusion 6 - explanation

Please watch the explaining video carefully.

confusion 7 - Hunger : Energy based

Now, you have one last question!

When you are hungry, which food would be the most efficient to reduce your hunger?

- ○ Plain water with lemon slices
- ○ Diet (sweetened with low-calorie sweeteners) beverages
- ○ Sugar sweetened beverages
- ○ A celery stick

(If incorrect, participant retried until they chose the right answer.)

Confusion 7 - answer

Oops! Please try it again.

When you are hungry, which food would be the most efficient to reduce your hunger?

- ○ Sugar sweetened beverages
- ○ Diet (sweetened with low-calorie sweeteners) beverages
- ○ Plain water with lemon slices
- ○ A celery stick

(If they correct, they move on to the explanation video.)

You are correct!

"Energy" is required to reduce "Hunger".

Please click the arrow to learn about how to reduce hunger.

Confusion 7 - explanation

Please watch the explaining video carefully.

Appetite Lexicon Quiz (20 mins)

: Answer

1. Define each of the appetite sensations listed below.
   a. Hunger

   b. Fullness

   c. Desire to Eat

   d. Prospective Consumption

2. Explain the difference between each of these two concepts
   a. Hunger vs. Fullness

   b. Hunger vs. Desire to Eat

   c. Desire to Eat vs. Prospective Consumption

   d. Hunger vs. Prospective Consumption

   e. Desire to Eat vs. Fullness

   f. Fullness vs Prospective Consumption

3. Please choose one BEST answer. (True or False)
    a. If the sensation of hunger decreases, the sensation of the fullness must increase.
       True / False

    b. After a satisfying meal, people eat dessert because they still feel a desire to eat.
       True / False

    c. Prospective consumption is very high, your hunger level must be very low.
       True / False

    d. Hunger and fullness are attributable to the high concentration of the same hormone.
       True / False

    e. Having a piece of candy decrease the sensation of hunger but not the sensation of fullness.
       True / False

4. Please choose one BEST answer. (Multiple Choice)
    a. Hunger is a sensation that determines how much you could eat.
    b. Hunger is a sensation that motivates the termination of an eating event.
    c. Hunger is a sensation that motivates the initiation of an eating event and stems from psychological cues.
    d. Hunger is a sensation that motivates the initiation of an eating event and stems from energy needs.

5. Please choose one BEST answer. (Multiple Choice)
    a. Fullness is a sensation that determines when you stop an eating event.
    b. Fullness is a sensation that only stems from sensations from the stomach.
    c. When fullness increases, hunger must decrease.
    d. When fullness decreases, prospective consumption must increase.

6. Please choose one BEST answer. (Multiple Choice)
    a. Prospective consumption is a degree of desire to eat.
    b. Prospective consumption is an anticipated portion that may be consumed.
    c. Prospective consumption is an anticipated eating frequency.
    d. Prospective consumption is an index of energy density.

7. Please choose one BEST answer. (Multiple Choice)
    a. Desire to eat is derived from energy needs
    b. Desire to eat is an index of liking foods regardless of hunger.
    c. Desire to eat is an index of wanting foods regardless of hunger.
    d. If desire to eat is high, hunger must be high.

Taste Concept Training Materials

Taste Rating Training

Mattes Lab

Eunjin Cheon
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1

What is taste?

A sensation in the mouth
when a substance is detected by taste receptors.

Major Taste Qualities

SWEET **BITTER** **SOUR** **SALTY** **UMAMI**

2

1 Sweetness

A taste sensation from sugar.

Sugar (sucrose), Low-calorie sweeteners [aspartame (Equal), Sucralose (Splenda), saccharin (Sweet'N Low)]

Q: How sweet does the food taste?

Not Sweet at all 0 ———————— 100 *Extremely Sweet*

3

2 Bitterness

A taste sensation from black unsweetened coffee.

Coffee (caffeine), cacao (chocolate), tea (phytochemicals)

Q: How bitter does the food taste?

Not Bitter at all 0 ———————— 100 *Extremely Bitter*

4

3 Sourness

A taste sensation from lemon.

Vinegar (acetic acid), lemon (citric acid), and sour-patch candy

Q: How sour does the food taste?

Not Sour at all 0 — 100 *Extremely Sour*

5

4 Saltiness

A taste sensation from salt.

Salt (sodium chloride), soy sauce, salty chips

Q: How salty does the food taste?

Not Salty at all 0 — 100 *Extremely Salty*

6

5 Umami taste

A taste sensation from meats.

Meats, soy sauce, seaweeds

Q: How savory does the food taste?

Not Salty at all	0	————————————	100	*Extremely Salty*

7

Taste Concept Training

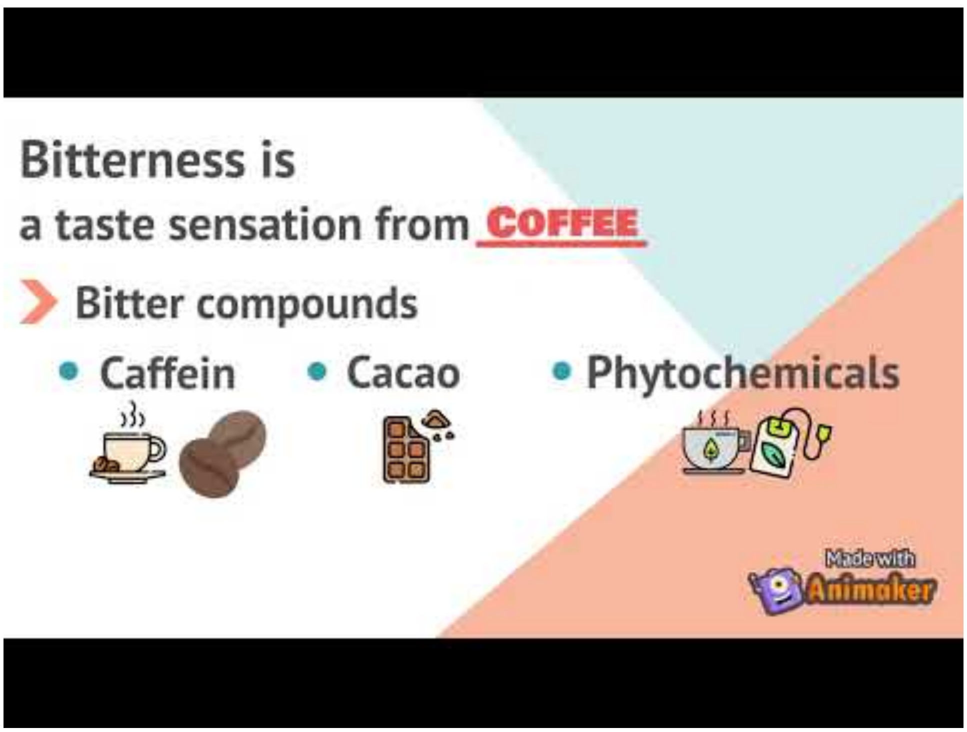
PURDUE UNIVERSITY

Default Question Block

Welcome to Taste Rating Training!

Please enter your participant ID below. (e.g. 055-053-xxx)

Please watch the basic training video carefully.



Confusion 1 - flavor vs. taste

Great! Let's discuss **common confusions** in taste sensations by answering the following questions.

Please click the arrow to continue.

Flavor vs. Taste: Are they the same sensations?

○ No, they are not same sensations.

○ Yes, they are the same sensations.

(If incorrect, participant retried until they chose the right answer.)

confusion 1 - answer

Oops! Please try it again.

Flavor vs. Taste: Are they the same sensations?

○ Yes, they are the same sensations.

○ No, they are not the same sensations.

(If they correct, they move on to the explanation video.)

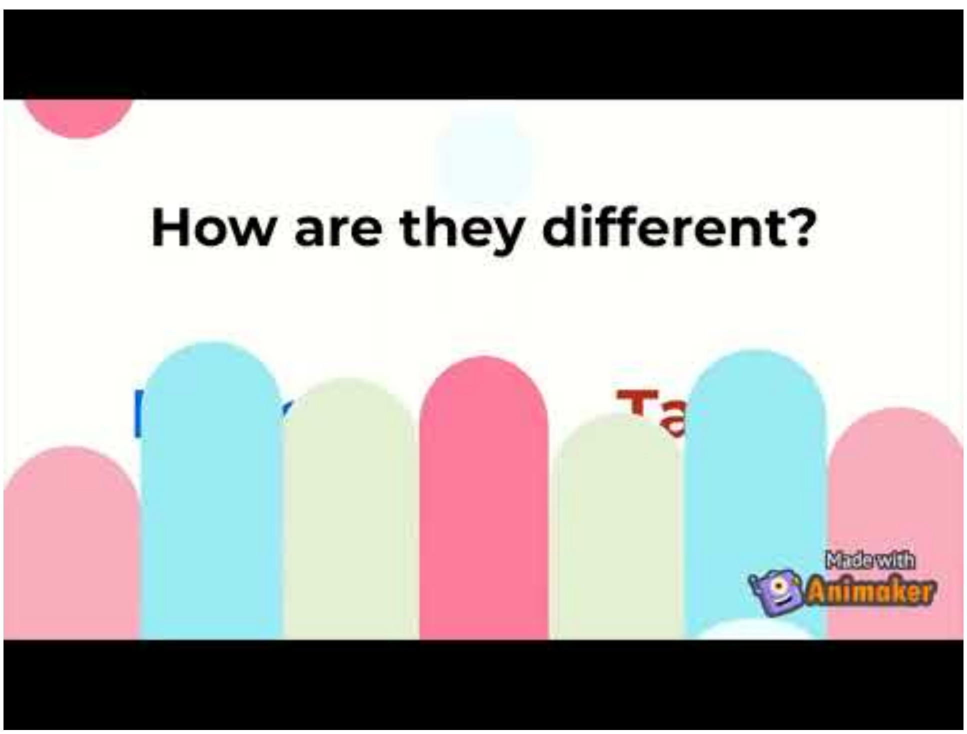
You are correct!

Flavor and Tate are NOT the same sensations!

Please click the arrow to learn about how taste and flavor are different.

Confusion 1 - explaination

Please watch the explaining video carefully.



Confusion 2 - tongue map

Let's move on the next question.

Is there a specific region on the tongue to detect a specific taste quality as proposed in the picture below?

○ Yes, one taste can be detected in specific regions of the tongue

○ No, there is no specific region for a specific taste quality.

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Is there a specific region to detect a specific taste quality?

○ Yes, one taste can be detected in specific regions of the tongue

○ No, there is no specific region for a specific taste quality.

(If they correct, they move on to the explanation video.)

You are correct!

There is NO tongue map.

Please click the arrow to learn more about truth of tongue map.

Confusion 2 - explanation

Please watch the explaining video carefully.

Confusion 3 - taste interactions

Let's imagine you have a cup of sour solution like lemon juice.

If you add one tablespoon of sugar into a sour solution, will the intensity of sourness change?

- ○ Yes, sourness will be changed.
- ○ No, there is no change in sourness

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Let's imagine you have a cup of sour solution like lemon juice.

If you add one table spoon of sugar into the sour solution, will the intensity of sourness change?

○ Yes, sourness will be changed.
○ No, there is no change in sourness

(If they correct, they move on to the explanation video.)

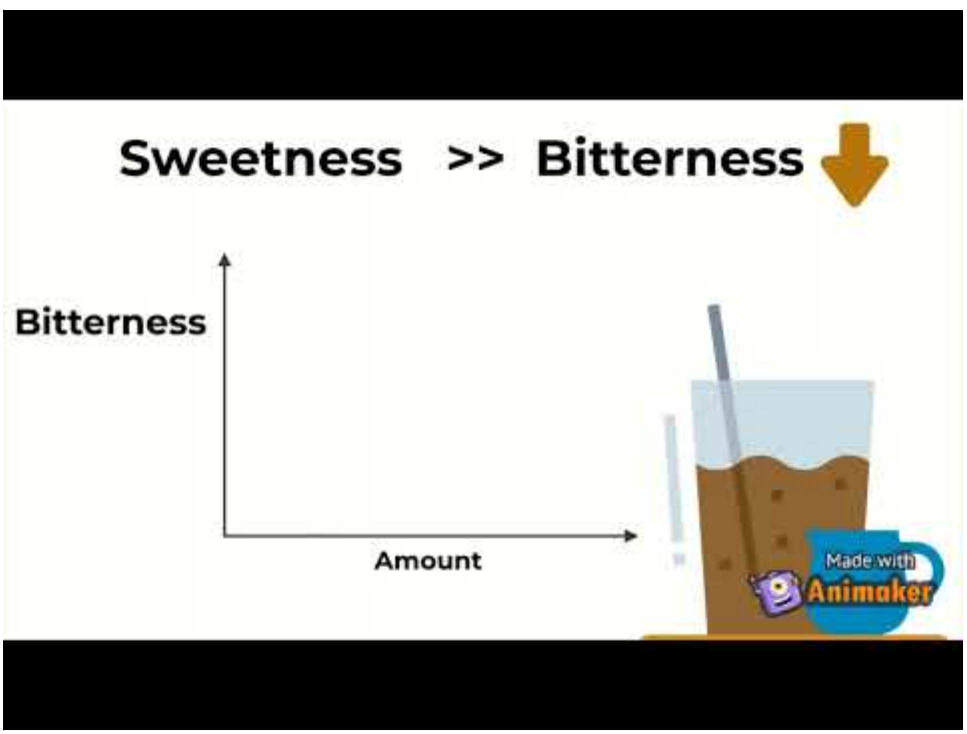
You are correct!

Sugar (sweet compounds) can affect an intensity of lemon juice (Sour compounds).

Please click the arrow to learn the impact of one taste quality to the other taste qualities.

Confusion 3 – explanation

Please watch the explaining video carefully.



Confusion 4 - Bitter vs sour

Please drag items into the proper box.

Items	Bitter
Coffee	
Green Tea	
Lemon	
Spinach	Sour
Vinegar	

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Please drag items into the proper box.

Items	Bitter
Coffee	
Lemon	
Green Tea	
Spinach	Sour
Vinegar	

(If they correct, they move on to the explanation video.)

You are correct!

Spinach, coffee, and green tea are bitter compounds while lemon and vinegar are sour compounds.

Please click the arrow to learn the reason of bitter/sour confusion.

Confusion 4 - explanation

Please watch the explaining video carefully.

confusion 5 - taste adaptation

Now, let's assume that you are asked to rate the salty intensity of a salty soup after consuming either a piece of bread or potato chips.

In which case do you think you rate salty intensity of the soup highest?

- ○ After consuming bread.
- ○ After consuming potato chips.
- ○ There will be no difference in salty intensity with both cases.

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Now, let's assume that you are asked to rate the salty intensity of a salty soup after consuming either a piece of bread or potato chips.

In which case do you think you rate salty intensity of the soup highest?

○ After consuming potato chips.
○ There will be no difference in salty intensity with both cases.
○ After consuming bread.

(If they correct, they move on to the explanation video.)

You are correct!

The intensity of soup is higher after consuming bread compared to potato chips.

Please click the arrow to learn about the effect of repeated exposure of the same taste quality on the taste intensity.

Confusion 5 - explanation

Please watch the explaining video carefully.

confusion 6 - umami taste

Soy sauce vs Salt

Which taste quality is mainly different between soy sauce and salt?

- ○ Sweet taste
- ○ Bitter taste
- ○ Salty taste
- ○ Sour taste
- ○ Umami taste

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Soy sauce vs Salt

Which taste quality is mainly different between soy sauce and salt?

- ○ Sour taste
- ○ Sweet taste
- ○ Salty taste
- ○ Bitter taste
- ○ Umami taste

(If they correct, they move on to the explanation video.)

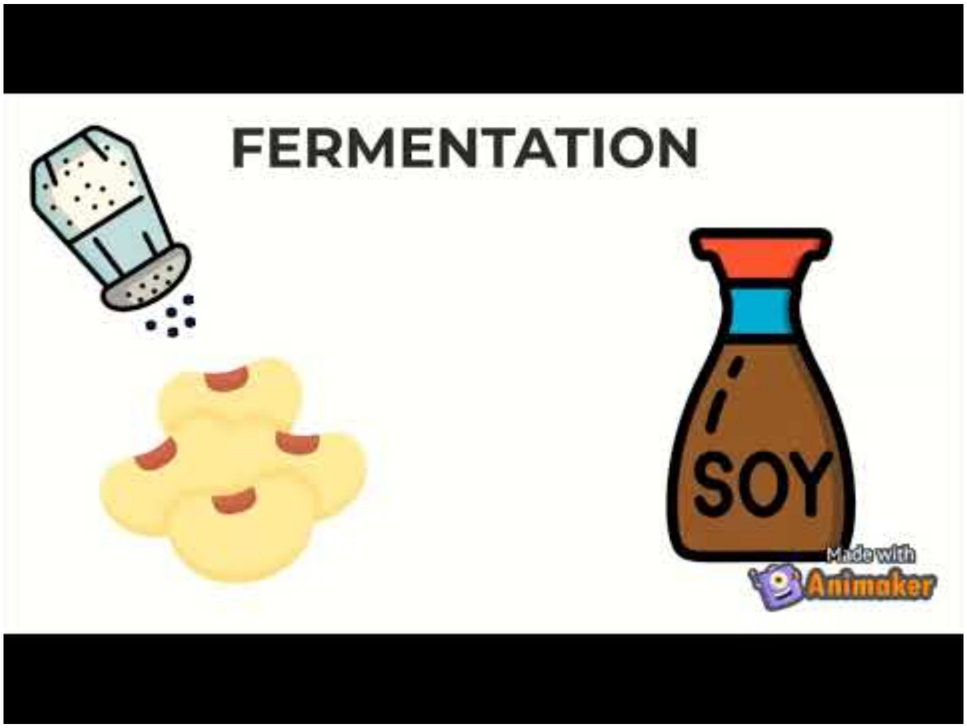
You are correct!

Soy sauce has umami taste that salt doesn't have.

Please click the arrow to learn how soy sauce has umami taste.

Confusion 6 - explanation

Please watch the explaining video carefully.



Confusion 7 - metallic taste

Now, we have one last question.

Is a metallic sensation in your mouth a taste response or response from another sensory system?

- ○ No, metallic sensation is a response from another sensory system.
- ○ Yes, metallic sensation is a taste response.

(If incorrect, participant retried until they chose the right answer.)

Oops! Please try it again.

Is a metallic sensation in your mouth a taste response or response from another sensory system?

○ Yes, metallic sensation is a taste response.

○ No, metallic sensation is a response from another sensory system.

(If they correct, they move on to the explanation video.)

You are correct!

Metallic taste is not a taste response.

Please click the arrow to learn about metallic taste.

Confusion 7 - explanation

Please watch the explaining video carefully.

Taste Lexicon Quiz (20 mins)

: Answer

1. Define of each taste sensation with the reference taste.
    a. Taste
    b. Sweetness
    c. Bitterness
    d. Sourness
    e. Saltiness
    f. Umami taste

2. Explain the concepts / phenomenon below.
    a. Flavor vs. Taste
    b. Tongue map
    c. Repeating exposure of one taste quality
    d. Impact of one taste quality to another taste quality
    e. Difference between salt and soy sauce in taste quality.

3. Please choose one BEST answer. (True or False)
    a. There is a metallic taste receptor on the tongue.
    True / False

b. People feel the saltiness in the specific area of the tongue.
True / False

c. Lemon is a representative compound of bitterness.
True / False

d. Sour-patch candies are less sweet than jellybeans due to sour compounds.
True / False

e. The sweetness of chocolate can be reduced after the repeated exposure to a candy.
True / False

4. Please choose one BEST answer. (Multiple Choice)
    a. Major taste qualities are sweet, bitter, sour, salty, and umami tastes.
    b. Major taste qualities are sweet, bitter, umami and metallic tastes.
    c. Major taste qualities are sweet, bitter, sour and umami.
    d. Major taste qualities are sweet, bitter, umami and fatty acids.

5. Please choose one BEST answer. (Multiple Choice)
    a. Adding sugar does not reduce bitterness of coffee.
    b. There is only one taste receptor in the tongue.
    c. Sodium chloride is a reference compound for the saltiness
    d. Flavor refers to taste.

6. Please choose one BEST answer. (Multiple Choice)
    a. Aspartame is a sour compound.
    b. Acetic acid is a sour compound.
    c. Phytochemical is a sour compound.
    d. Caffeine is a sour compound.

7. Please choose one BEST answer. (Multiple Choice)
    a. Sweet taste is only detected in the frontal tongue.
    b. Sour taste is detected in the side of the tongue.
    c. Bitter taste is detected in the back of the tongue.
    d. Salty taste is detected in all areas of the tongue.

APPENDIX C. PERCEPTUAL QUALITY OF NON-ESTERIFIED FATTY ACIDS VARIES WITH FATTY ACID CHAIN LENGTH

Footnotes

This study is a part of my doctoral training. Perceptual qualities of fatty-acids with different chain-length were explored. This manuscript was published by the Chemical Sciences on April 30, 2021. (Eunjin Cheon, Richard D Mattes, Perceptual Quality of Non-esterified Fatty Acids Varies with Fatty Acid Chain Length, Chemical Senses, Volume 46, 2021, bjab023, https://doi.org/10.1093/chemse/bjab023)

Keywords

Fat taste, fatty acids, sour taste, sour adaptation, taste quality

Author Contribution: EC contributed to the design of the trial, tested participants, analyzed the data and prepared the first draft of the manuscript. RM conceived of the project, secured funding, contributed to study design and analysis and revised drafts of the manuscript.

Abbreviations:

NEFA: nonesterified fatty acids

gLMS: generalized labeled magnitude scale

DRK: Delayed rectifying potassium channels

GPCR: G-protein coupled receptor

Abstract

Non-esterified fatty acids (NEFA) are effective taste stimuli. The quality they impart has not been well characterized. Sourness, and “fattiness” have been reported, but an irritation component has also been described and how these transition with gradations of aliphatic chain length has not been systematically studied. This study examined intensity and quality ratings of NEFA's ranging from C2 to C18. Oral sites and the time course of sensations were also monitored. Given all NEFA contain carboxylic acid moieties capable of donating hydrogen ions, the primary stimulus for sour taste, testing was conducted with and without sour adaptation to explore the contribution of sour taste across the range of NEFA. Short chain NEFA (C2-C6) were rated as predominantly sour, and this was diminished in C2 and C4 by sour adaptation. Medium chain NEFA (C8-C12) were rated as mainly irritating with long chain NEFA (C18) described mostly as bitter. The latter may reflect the lack of “fatty” lexicon to describe the sensation. Short chain NEFA were mostly localized to the anterior tongue and were of rapid onset. The sensation from medium chain NEFA was attributed to the lateral tongue while medium and long chain NEFA sensations were predominantly localized to the back of the tongue and throat and had a longer lag time. The findings indicate there is a systematic transition of NEFA taste quality and irritation with increments in chain length and this is consistent with multiple modes of transduction.

Introduction

Increasing evidence indicates that dietary fat can be detected, scaled for intensity and, to a limited degree, characterized for its quality by the sense of taste (289–297). The effective stimuli are non-esterified fatty acids (NEFA), defined by a terminal carboxyl group with various aliphatic chain lengths (294). Chain length is a primary determinant of the sensory qualities of NEFA (294,298). There is a strong consensus that NEFA’s with chain lengths of 2-6 carbons are predominantly sour. Medium-chain NEFAs (C10, C12) reportedly impart a predominantly “scratchy” sensation (292) likely reflecting trigeminal activation. The sensation evoked by longer chain NEFA (C18:1, C18:2, C18:3, C20:4) is more complex. Some work indicates these fatty acids impart a mixture of “scratchy” and “fatty” sensations with greater sensitivity (lower threshold) to the fatty note (292). Other work used a perceptual mapping approach that does not require the use of semantic labels (294). The latter was not designed to capture the irritancy component, but documented the quality imparted by a medium (C10) and two long-chain fatty acids (C18:1; C18:2) was differentiated from prototypical stimuli for sweet sour, salty, bitter and umami sensations.

A more definitive characterization of the sensations imparted by fatty acids has not been reported. An improved description would facilitate better identification of its effective stimuli and likely receptors; help elucidate the role of long-chain NEFA's in the flavor profile of foods containing them; and contribute to the evidence base that the "taste" of fatty acids is or is not a primary taste quality. Given the clear sour signal generated by short-chain fatty acids and ability of all NEFA's to donate hydrogen ions, one hypothesis holds that fatty acids of longer chain length retain a sour component. This study examined taste intensity ratings of NEFA's ranging from C2 to C18 with or without sour adaptation to explore this possibility. It was expected that sour adaptation would blunt the perceived intensity of long-chain NEFA and/or alter their sensory quality if sourness is responsible in whole or part for the sensation from these fatty acids. To explore the latter, we analyzed the self-reported sensation quality descriptions of the range of NEFA's by participants via NVivo 12 software. Finally, our pilot studies revealed taste intensity ratings systematically differed before and after expectorating NEFA samples of varying chain-length and that the fatty acid taste sensation was stronger at the back of the mouth than other locations in the oral cavity. Thus, we also quantified taste intensity ratings at different locations (front of the tongue, side of the tongue, back of the tongue, and back of the mouth) before and after expectorating the range of NEFA's to gain further understanding of the time course and site-specificity of the sensation.

Materials and methods

Participants

Participants were recruited through public announcements. Eligibility criteria included: 18 to 64 years of age, self-reported normal taste function, good health, and no known allergies or sensitivities to study stimuli. Demographic information was provided by a questionnaire, and weight and height were measured.

Procedures

Participants were tested once per week in 2-h sessions over 2 weeks with fasting 2-h prior to each visit. The experiment entailed two sets of taste intensity ratings without (Test A) or with (Test B) sour taste adaptation. The order of testing procedures was randomized. All responses were recorded via RedJade Online Sensory Software. For test A, participants rinsed their mouth with distilled water for 15 seconds and held one of the eight solutions in their mouth for 15 seconds or one of the solid fatty acids for 2 minutes. Then, they rated its taste intensity on a generalized labeled magnitude scale (gLMS, a logarithmic scale used in sensory studies (299)) and chose one or more oral locations (front of the tongue, side of the tongue, back of the tongue, back of the mouth) as the predominant site of sensation on a provided picture before and after expectorating. They were also asked to retain the quality of the sensation in their memory. They rinsed their tongues thoroughly with 1% ethanol solution for 15 seconds and distilled water for an additional 15 seconds after expectorating the solution. They then masticated about 3 g of unsalted saltine cracker and rinsed their tongue thoroughly again with 1% ethanol and distilled water for 15 seconds. Finally, they described the sensation quality of the sample (without prompts). They then rested for 1 minute and repeated this procedure with the balance of the samples. For test B, participants followed the same procedure but with sour taste adaptation. For sour taste adaptation, the participants held 0.0149 M acetic acid (same concentration as the test sample) in their mouth for 5 seconds and rated its taste intensity. This was repeated with rating the sourness intensity on a gLMS until the intensity of the adapting stimulus was rated as less than weak. Once this criterion was met, participants sampled one of ten NEFA samples and repeated the same procedure as described for test A. They were asked to rest for 1 minute and readapted with the sour solution between each sample. Participants wore nose clips while tasting the samples, and all samples were served in opaque cups with lids. All procedures were approved by Purdue University's Human Subjects Institutional Review Board.

Samples

Ten non-esterified fatty acids of graded chain length were tested. These included: Acetic acid (C2), butyric acid (C4), hexanoic acid (C6), octanoic acid (C8), decanoic acid (C10), lauric acid (C12), palmitic acid (C16), stearic acid (C18), oleic Acid (C18:1), and linoleic acid (C18:2).

All were food-grade and purchased from Sigma Aldrich. The blank was prepared by adding 1% sucrose esters, 0.01% disodium-EDTA, 0.01% TBHQ, and 0.05% xanthan gum to distilled water, and mixing with an IKA T18 digital ULTA UTRRAX at 14000 rpm for 5 minutes. Sucrose esters (Modernist Pantry), tert-butylhydroquinone (TBHQ, Aldrich), ethanol (200 proof, Fisher Scientific), disodium EDTA (Sigma) were all food-grade and purchased from commercial vendors. Xanthan Gum (Bob's Red Mill brand), and unsalted saline crackers (Meijer brand) were purchased from local grocers, and the same batch was used for all study procedures. Blank solutions sat overnight to hydrate the xanthan gum fully. This blank was used as a base solution for all samples except for palmitic acid and stearic acid, as the melting points of these compounds were higher than room temperature, so they were solids. Liquid samples were provided as 15 ml and solid samples were provided as 2 g solid portions. Samples were prepared on the day of the experiment. The blank was homogenized at 14000 rpm for 5 minutes and microwaved for 1 minute to reach the lauric acid (C12) melting temperature (43.2 °C). Solutions were prepared by adding each NEFA to the heated blank solution and mixed at 14000 rpm for 10 minutes under N_2 to minimize oxidation. All liquid sample solutions were prepared and stored in amber bottles to reduce exposure to light and were held at 40°C to prevent solidification of solutions during the experiment. However, each liquid solution was cooled to room temperature before providing it to participants (test solution temperature: 26-27°C). The solid samples were provided at room temperature. The rinsing solutions were 1% ethanol and distilled water. Samples were assigned random 3-digit codes. **Table 1** lists the concentrations of each NEFA. Concentrations were selected based on pilot work indicating the sensations were comparable in taste intensity (Supplementary Data 1). This was determined by having different participants taste five concentrations of each fatty acid in random order and rate the intensity of each on a gLMS. The regression line comparing intensity ratings and sample concentrations was computed, and the concentration corresponding to "moderate intensity" was selected for the test concentration.

Statistical Analysis

SAS 9.4 was used for statistical analysis. Continuous data are reported as mean±SEM and categorical data as n (%). The criterion for statistical significance was $p<0.05$, 2-tailed. The taste intensity ratings were analyzed by two-way repeated measures ANOVA to determine the effect of sour taste adaptation and time of ratings (before vs. after expectorating sample) on taste intensity ratings. Text descriptions were analyzed using NVivo 12 software. It identified words that were used in the sensation descriptions and quantified the reported frequency of each descriptor. Words not related to the sensation (e.g., the, a, I, think, like, etc.) were excluded manually. Associations between age, BMI, weight, height, fat mass or fat mass % with intensity ratings were examined by Pearson correlation and the association between gender and intensity ratings was explored by Polyserial correlation. Descriptors were categorized into either sour, bitter, spicy, other sensation groups. For example, terms like acidic and lemon were classified into the sour taste description group. Fatty acids were classified according to chain-length: short (C:2-C:6) -, medium (C:8-C:12)-, and long (C16-C:20). The percentages of descriptor group usage were compared among the three fatty acid groups using one-way ANOVA for each descriptor group, followed by post hoc analysis using Tukey's test for correction of multiple testing if there was a significant difference in descriptors among the three groups. Localization of sensations for the ten samples was compared between the three fatty acid groups using chi-square analyses because these data were categorical.

Results

Thirty-eight adults (male=16 women=22, mean age±SE = 26±1.6 yr) participated. They had a mean BMI of 25.6±0.9 kg/m^2 and body fat% of 25.5±1.8 %. There was no sex, age, BMI, weight, height, fat mass, or fat mass% difference in taste intensity ratings ($p > 0.05$).

Overall Taste Intensity Ratings

The taste ratings with and without sour adaption are shown in Figure F1. There was no interaction between sour adaptation status and time of sensation ratings (before vs. after expectorating) for any sample (two-way ANOVA– C2, p = 0.2297; C4, p=0.9398; C6, p=0.2995; C8, p=0.5025; C10, p=0.8515; C12, p=0.2181; C18:1, p=0.9584; C18:2, p=0.3507). There was a significant reduction of taste intensity response following adaptation compared with no adaptation for C2 ($p<0.001$) and C4 (p=0.038). No significant differences were observed in comparisons for the other fatty acid samples ($p>0.05$). As expected, the two solid samples (C16, C18) were rated less than 'weak' regardless of sour adaptation.

The results of the taste ratings before and after expectorating a sample are provided in Figure F2. Overall, taste intensity ratings before expectorating a sample were significantly greater than after expectoration with short-chain fatty acids (C2, C4, C6) (C2 - $p=0.0037$, C4 - $p=0.002$, C6 - $p<0.0001$) while taste intensity ratings after expectorating a sample were significantly greater in medium- (C10, C12), and long-chain fatty acids (C18:1, C18:2) (C10 $p<0.0001$, C12 $p=0.0080$, C18:1 $p=0.0006$, C18:2 $p=0.0002$) compared to before expectoration. Without adaptation, the taste intensity before expectorating a sample was greater for short-chain fatty acids (C2 - $p=0.0031$, C4 - $p=0.0490$, and C6 - $p<0.001$) while the taste intensity after expectorating a sample was greater with C10 ($p= 0.0008$) a medium-chain NEFA and among the long-chain NEFA's (C18:1 - $p=0.0096$, and C18:2 - $p=0.0001$). With adaptation, the taste intensity before expectorating a sample was greater in short-chain fatty acids (C4 - $p=0.0114$, and C6 - $p= 0.0023$) while the taste intensity after expectorating a sample was greater in medium- (C10 - $p=0.0014$, C12 - $p=0.0123$) and the long-chain fatty acid C18:1 ($p=0.0212$). The solid samples showed no difference between before and after expectorating samples.

Text Quality Description

A total 874 words related to taste and irritancy were recorded. Five hundred ninety-eight distinct words were identified, with 199 descriptors actually related to taste or irritancy. Terms related to tasteless (21.1%) (e.g., no taste, tasteless, not detectable, can't tell, etc.) and terms accounting for less than 5% of a particular sensation quality (e.g., salty, savory) were categorized into an 'other' group (33.2%). The descriptors used predominantly were "sour" (22.4 %), "bitter" (10.9%), "spicy" (33.5%) related. Because over 90% of the descriptors were "tasteless" for the solid samples (C16, 18), they were excluded from further analyses. As shown in Figure F3 and Figure F4, there were significant differences in the incidence of "sour", "spicy", and "bitter" descriptors used among the three NEFA groups (One-way ANOVA - sour $p=0.02$; spicy $p=0.0153$; bitter $p=0.0027$). Sour related words were used significantly more frequently for short-chain fatty acids (C2, C4, C6) compared to medium-chain fatty acids (C8, C10, C12) ($p=0.0186$) and a trend for a difference between short- and long-chain fatty acids (C18:1, C18:2) ($p =0.0868$). There was no significant difference between medium- and long-chain fatty acids ($p < 0.5870$) (Figure F4 A). Medium-chain fatty acids elicited a greater incidence of spicy descriptors compared to short- ($p=0.0159$) and long-chain fatty acids ($p=0.0477$) (Figure F4 B). Descriptors related to bitterness were more frequently used for long-chain fatty acids compared to short- (p=0.0042) and medium-chain fatty acids (p=0.0033) (Figure F4 C).

Location of Taste Sensations

As no descriptors were provided for the solid fatty acids (C:16, C:18), they were excluded from analyses related to sensation location. The locations of taste sensations used in the analyses were front, side, and back of the tongue as well as and back of the mouth which included the posterior roof of the mouth and throat. There was a "none" option for participants if they reported no taste sensation (short 9%, medium 3%, long 8%). Taste sensations on the front of the tongue were more frequently reported for short- (C2, C4, C6) ($p<0.0001$) and medium- (C8, C10, C12) chain fatty acids compared to long-chain (C18:1, C18:2) fatty acids ($p<0.0001$) (Figure F5). Medium-chain fatty acids were more frequently detected on the side of the tongue compared to short- ($p<0.0001$) and long-chain fatty acids (p=0.0076). Taste sensations from the back of the tongue were more frequent for medium- (p=0.0002) and long-chain fatty acids ($p<0.0001$) compared to short-chain fatty acids. Taste sensations at the back of the mouth were greater in medium- ($p<0.0001$) and long-chain fatty acids ($p<0.0001$) compared to short-chain fatty acids, while there was no difference between medium- and long-chain fatty acids (p=0.6).

Table F 1. Concentrations of fatty acids for liquid samples.

Fatty acids	Molarity
Acetic acid	0.0149 M
Butyric acid	0.0306 M
Hexanoic acid	0.0258 M
Octanoic acid	0.0361 M
Decanoic acid	0.0511 M
Lauric acid	0.0734 M
Oleic acid	0.6833 M
Linoleic acid	0.0428 M

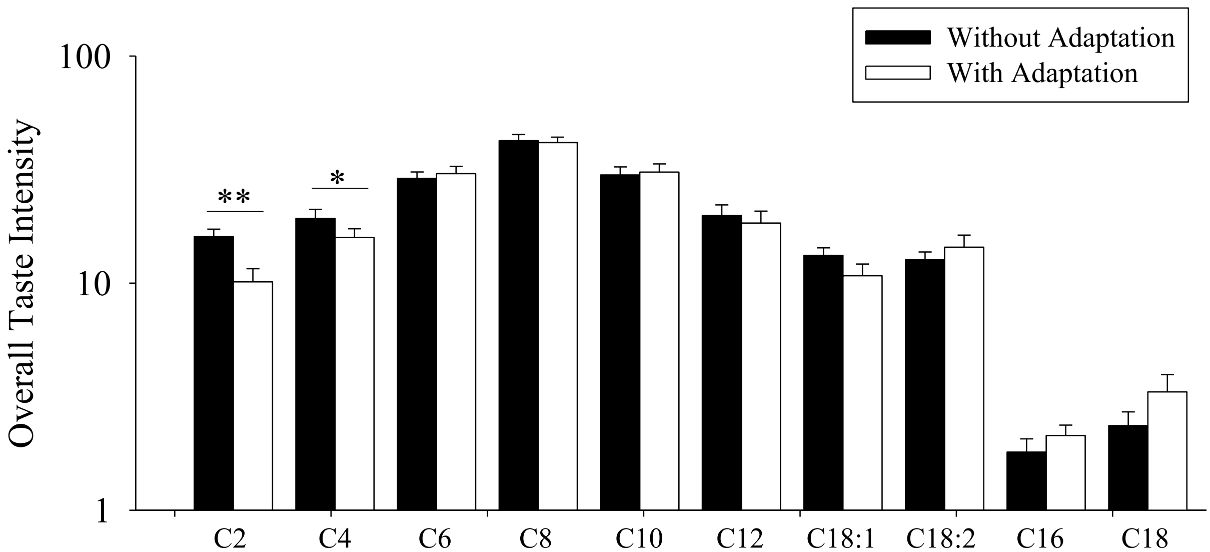


Figure F 1. Taste intensity ratings with without or sour adaptation (mean ± SEM; $*P < 0.05$, $**P < 0.001$).

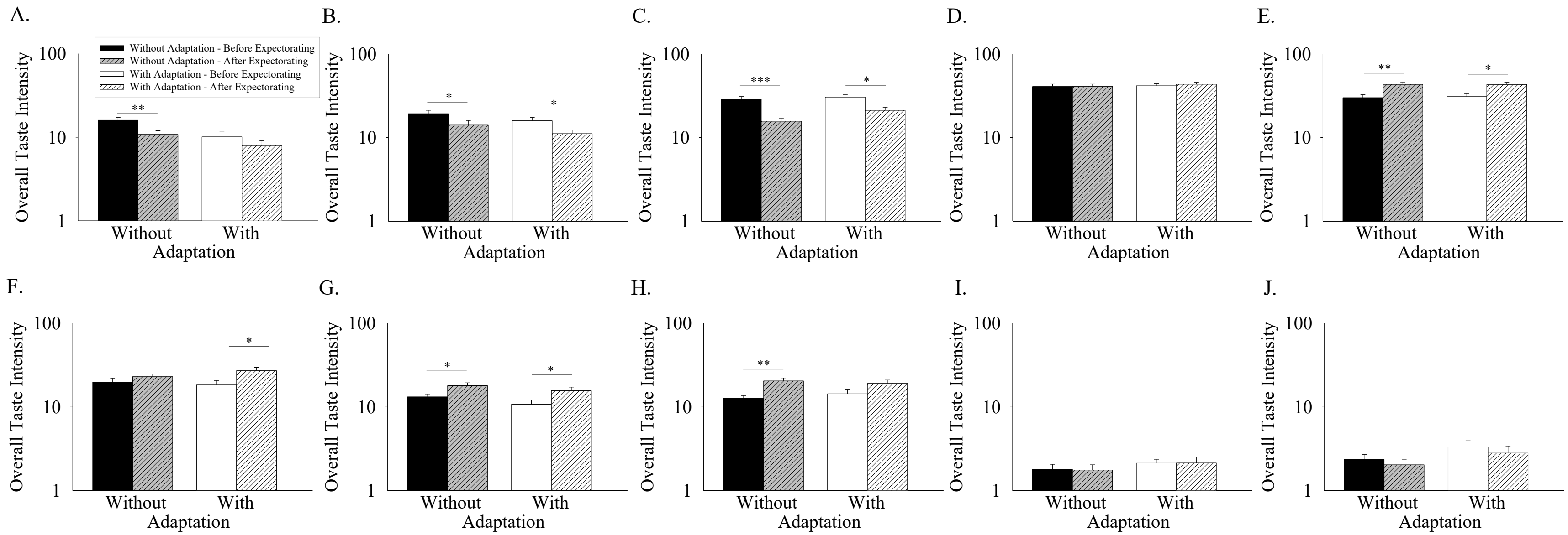


Figure F 2. The taste intensity ratings before (bars with no pattern) and after (slashed bars) expectorating samples without and with sour adaption (mean ± SEM; *P < 0.05, **P < 0.01, ***P < 0.001). Sample solutions are shown in graph A–J: (A) with C2 solution, (B) with C4 solution, (C) with C6 solution, (D) with C8 solution, (E) with C10 solution, (F) with C12 solution, (G) with C18:1 solution, (H) with C18:2 solution, (I) with C16 solid sample, and (J) with C18 solid sample.

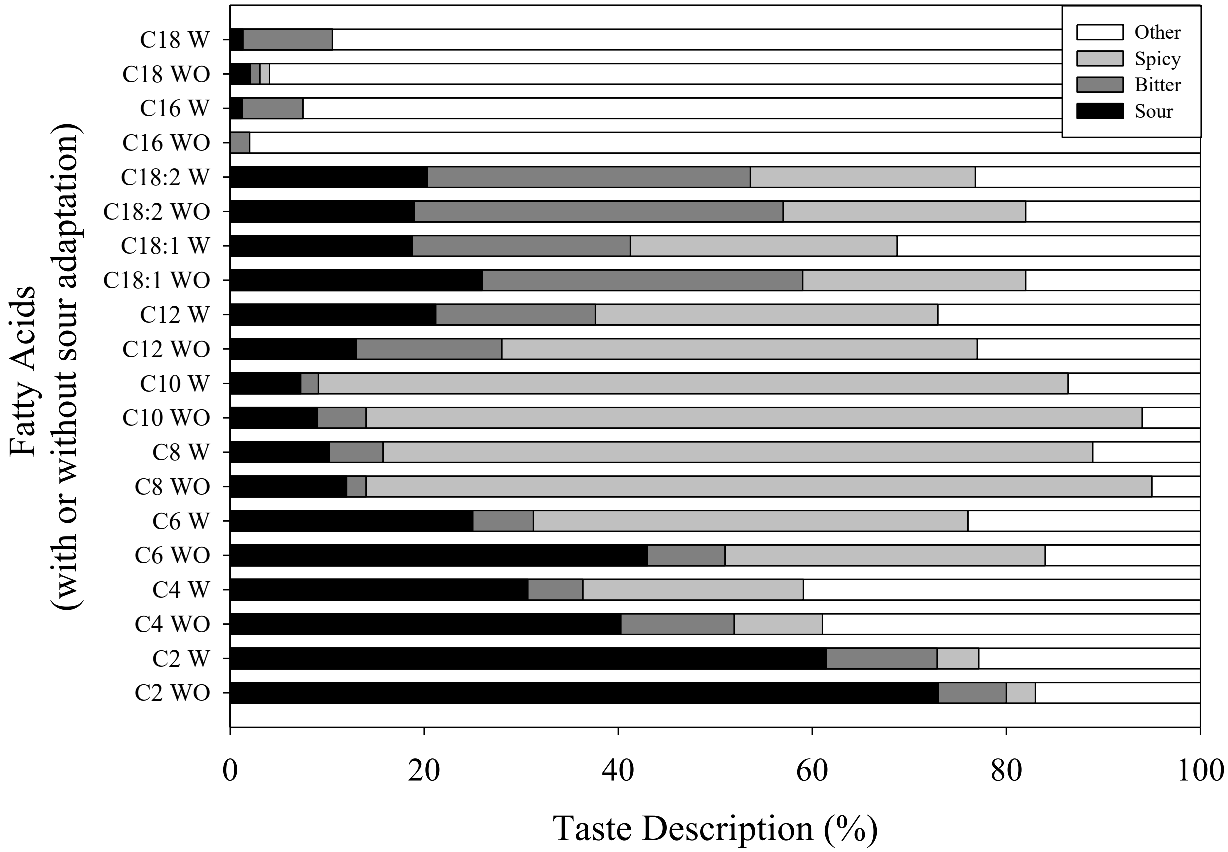


Figure F 3. The percent of sensation descriptors (sour, bitter, spicy, other) for 10 NEFA samples varying from C2 to C18.

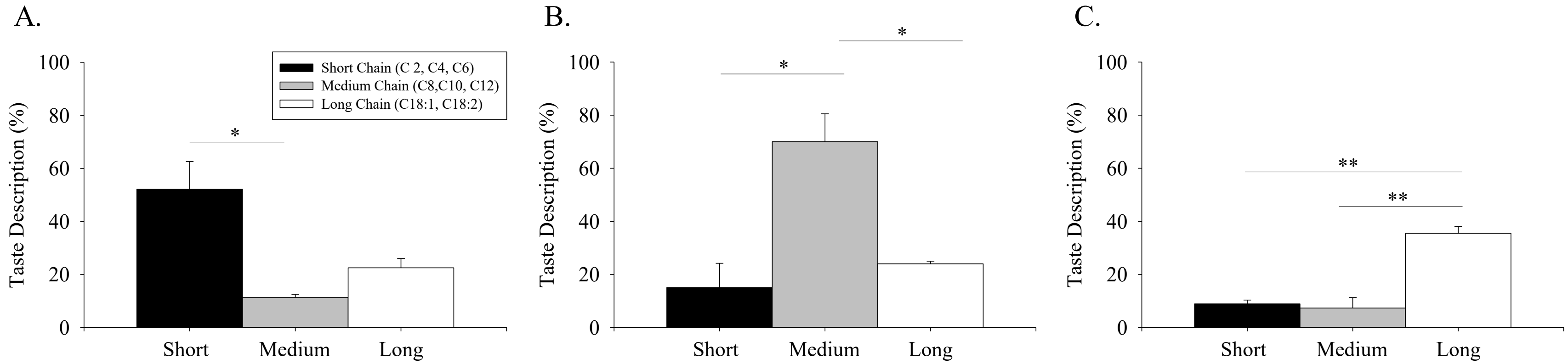


Figure F 4. Sensation descriptors for short-, medium-, and long-chain fatty acids. (A) “Sour”-related words, (B) “Spicy”-related words, and (C) “Bitter”-related words (mean ± SEM; *P < 0.05, **P < 0.01

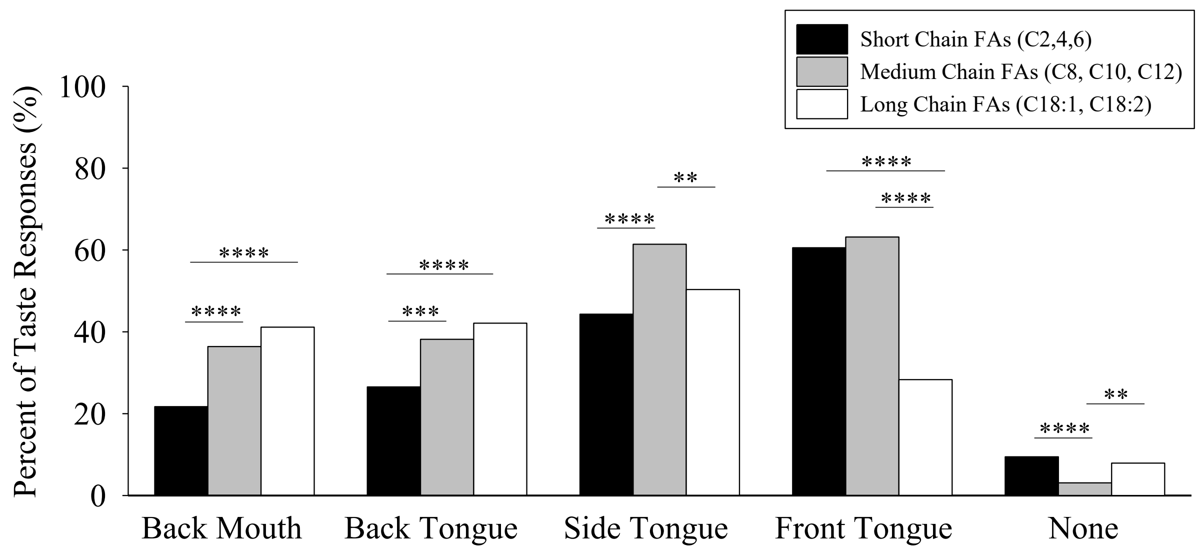


Figure F 5. Percent of sensation responses from 4 locations (back of the mouth, back of the tongue, side of the tongue, and front of the tongue) and none in short-, medium-, and long-chain NEFA (mean %, **P < 0.01, ***P < 0.001, ****P < 0.0001).

Discussion

Fatty acids are signaling molecules throughout the body (300). Numerous evidence supports the efficacy of NEFA as effective taste stimuli in both rodents and humans (289–297,301). However, the taste quality of fatty acids is poorly defined and differs based on chain-length (292,294). The quality of long chain NEFA is subtle and, to-date, defined primarily only as different from the commonly identified basic taste sensations (294). The present study sought to more positively characterize the oral sensation of fatty acids. It was hypothesized that there may be a sour contribution since all fatty acids have a carboxyl group capable of releasing H^+ ions, the effective stimulus for activation of the Otop1 channel on taste receptor cells (302,303).

To explore the sensation quality, the taste intensity of 10 fatty acids ranging in alkyl chain length from C2 to C18 was determined with and without sour adaption. Adaptation to sourness was expected to blunt a potential sour contribution to each of the NEFA tested. As expected, there was a significant reduction in the sensation intensity of the short-chain fatty acids, acetic acid (C2), and butyric acid (C4). It was also predicted that hexanoic (C6) would be rated less intense following sour adaptation, but this was not observed. Based on the sensation quality analysis, 43% of descriptors for C6 were "sour" related words, 33% were "spicy" related words, and 8% were "bitter" related words. In contrast, for C2 and C4 fatty acids, no non-sour quality was reported by more than 20% of respondents. Thus, C6 may be at a transition point with less distinct sourness and growing contributions of other qualities that dominated ratings under the conditions of this trial. Additionally, acetic and butyric acids are more water soluble than hexanoic (Small 1992); potentially contributing to their greater efficacy as sour taste stimuli. There was no statistically significant difference in taste intensity for NEFA's with chain lengths longer than C6 attributable to adaptation. This suggests sourness is not a significant contributor to the intensity of medium and long-chain fatty acids.

Previous work indicated that medium-chain fatty acids (C8, C10, C12) evoke scratchy sensations as measured by thresholds (292). The present findings confirm these reports with suprathreshold stimuli and, given the irritancy nature of the sensation, suggest these fatty acids are more effective somatosensory stimuli than gustatory. 'Spicy' related words accounted for about 80% of C8 and C10 descriptors and about 50% of C12 descriptors. C12 may be another sensory transition point NEFA. Other descriptor groups accounted for less than 15% of the quality. It is reported that medium-chain fatty acids are also detected under capsaicin desensitization (304). Thus, the irritancy of medium-chain fatty acids may also reflect activation of a receptor different from the TRPV1 receptor such as two-pore-domain potassium channels (KCNK3, KCNK9, and KCNK19) (305).

In the concentrations used, the long chain fatty acids were characterized by a blend of sour, bitter and irritancy terms. Sourness contributed only 26% and 19% of the sensation for C18:1 and C18:2 respectively. The predominant reported sensation was bitterness comprising 33% and 38% of the overall quality. As reported previously (292) spiciness was also present and added 23% and 25% of the quality for C18:1 and C18:2 respectively. Each of the other descriptors represented less than 5% of the total. Thus, in this study, there was no clear representation of "fatty." One interpretation of this observation is that the quality uniqueness reported previously (294) reflects the complexity of the sensation (i.e., mixture of bitter and irritancy) rather than a single unique quality. Alternatively, as hypothesized previously, the generally negative terms used were applied to describe an unpleasant sensation in the absence of a clear, commonly accepted descriptive term. A third possible explanation is that the present study may not have used an effective stimulus. In prior work, it was noted that the "fatty" quality was present only in a vehicle that contributed viscosity to the stimulus and that the sensation may stem from a combination of gustatory and somatosensory inputs (292). This may be the case or the compound used in the vehicle to mask viscosity, lubricity, mouthfeel sensations could also alter solution stability and effective free fatty acid availability (298). Further study will be required to differentiate between all of these hypotheses.

An anatomical taste map is largely discounted (306). However, spatial variation in intensity ratings (307,308) and onset/decay times (309) may still hold. The fatty acids tested in this trial were all detected in all regions of the oral cavity but varied in intensity and time course according to chain length. Medium- and long-chain fatty acids were predominantly detected at the back of the mouth or on the back of the tongue compared to short-chain fatty acids which were localized more to the anterior tongue. Numerous putative fatty acid receptors may exist which vary in ligand specificity and distribution across the oral cavity (292,310–313). Lack of detailed knowledge of this is a substantive gap in understanding of the sensations attributable to fatty acids in the oral cavity.

Taste intensity ratings also varied systematically with NEFA chain length. Ratings were stronger for short-chain fatty acids (C2, C4, C6) before expectorating compared to intensity ratings after expectorating these samples while medium- (C10, C12) and long-chain fatty acids (C18:1, C18:2) showed greater intensity after expectoration. This pattern of results indicates that the taste impression of short-chain fatty acids is rapid and, consistent with prior work, acute (314). The short duration of sensation may stem from greater sensitivity to salivary buffering (315). The longer latency to peak intensity for medium and long-chain fatty acids may be due to different transduction mechanisms and/or interactions with salivary compounds that may delay or block the binding of alkyl chains of fatty acids to their receptors (315–317). It is well established that von Ebner's gland secretion of organic transporter proteins may enable detection of hydrophobic molecules by facilitating their access to taste receptors (316,318). In that fatty acids are amphipathic, perhaps, NEFA with long alkyl chains require transport to receptors in the circumvallate papillae resulting in delayed onset of sensation. It has also been suggested that increased ATP release by long chain NEFA taste transduction signaling leads to serotonin secretion resulting in increased signaling duration (319,320). The present observed differences in onset time for fatty acids of varying chain length in different regions of the oral cavity also support the possibility of multiple transduction mechanisms.

The present study has several limitations. First, the participants did not have a lexicon to describe the quality of long-chain free fatty acids and the stimuli were novel. Pre-test training to improve familiarity and development of a descriptive vocabulary could improve the sensitivity, specificity and accuracy of responses. Second, there are multiple reports that responses to NEFA are non-normal (321–323). This may be because of learning, genetic and/or recent dietary effects (296,322,324–326) Participants in this trial were not recruited based on these potential confounding effects. This would have reduced study power by adding variability to responses. Third, the mechanism of sour taste transduction has yet to be fully resolved (302,327,328) so it is possible the approach of adapting to a single NEFA (acetic acid) may not have fully captured the role of sourness of FA responses. Fourth, we asked participants to rate the taste intensity of samples, but it is possible they reported the overall sensation intensity (i.e., taste and irritancy). It now appears NEFA have complex qualities and, if true, it would be useful to quantify the contribution of each component. This may be best approached with panelists trained to evaluate the sensory qualities of fatty acids. Lastly, we did not test a range of NEFA concentrations, and this could be revealing as different receptors may be recruited at different concentrations (i.e., role of GPCR 120 versus CD36) (293).

In summary, the present findings indicate that fatty acids have distinct sensory qualities that range from sour to scratchy to bitterness with increasing chain length. The sour component for the short-chain fatty acids tested was demonstrated through adaptation effects, perceptual self-reports by participants, and distinct topical and temporal specificity. In contrast, there was little overlap in these outcomes between long and short-chain NEFA, indicating the basis of the sensations they impart is likely distinct and partly based on a sourness gradient. Long-chain NEFA were mostly rated as bitter, but it remains unclear if this is a default term for an unpleasant sensation or a true bitter perception. The predominant sensation of medium-chain NEFA was irritancy suggesting they most effectively activate the trigeminal system, though there was some overlap in spatial and temporal properties with long-chain NEFA. These observations suggest the involvement of multiple receptors for the range of NEFA detectable to humans – sour for short chain; trigeminal for medium chain and fat or a mixture of receptors for long-chain NEFA.

VITA

Eunjin Cheon

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700 West State St., Rm G4, West Lafayette, IN 47907-2059

EDUCATION

2017- 2022 (anticipated)
Doctor of Philosophy (Ph.D.) in *Nutrition Science*
(Interdepartmental Nutrition Program & Ingestive Behavior Research Program)
(Dietetic Program in Nutrition and Dietetics)
Purdue University, West Lafayette, IN, USA.
Dissertation: *"Appetite Measurement and Management"*
Primary advisor: Dr. Richard D. Mattes, PhD, MPH, RD

2012 - 2017
Bachelor of Science (B.S.) in *Food & Nutrition Sciences*
Seoul National University, Seoul, South Korea.
Primary advisor: Dr. Hoonjeong Kwon, PhD, RD

RESEARCH EXPERIENCE

Graduate Research Assistant

Sensory & Ingestive Behavior Research (Human model)

2019 – Present Research Topic*: Appetite Measurement and Management*
(Purdue University, West Lafayette, IN, USA - Dr. Richard D. Mattes Lab)

- Developed appetite concept training materials including training videos, comprehensive questionnaires, and protocol documentation to improve the validity of appetite measurement
- Tested efficacy of appetite concept training by executing a 9-week randomized controlled trial with five different preloads
- Investigated variability of appetite sensations within and between individuals by conducting a 17-week observational study
- Communicated with 200 + recruited participants and collected and managed study progress using Qualtrics
- Characterized attributes of appetite variation by analyzing data through time series analysis and multiple regression using SAS

2018 – 2021 Research Topic: *Fat Taste Spectrum Depending on Chain-Length*
(Purdue University, West Lafayette, IN, USA - Dr. Richard D. Mattes Lab)

- Designed and conducted sensory studies by evaluating quantitative and qualitative aspects of fat taste.

- Performed sample formulation studies to develop stable fat solutions not interfering with taste quality and fat oxidation.
- Screened 100 + people and trained 40 recruited participants on sensory tests to collect valid data.
- Collected, analyzed, and interpreted data to get new insights on taste qualities of fats with different chain-length using Red Jade, SAS, and NVivo software.

2018 Sep. – 2018. Dec. Research Topic: *Systemic Review and Meta-analysis of the Effect of Portion Size and Ingestive Frequency on Energy Intake and Body Weight Among Adults.*
(Purdue University, West Lafayette, IN, USA - Dr. Richard D. Mattes Lab)

- Conducted systematic review using six electronic databases
- Collaborated with 10+ researchers for study selection, quality rating, data extraction and statistical analysis

Biochemical & Molecular Research (Animal model)

2017 – 2018 Research Topic: *Dlk1 Expression Regulation on Dedifferentiated Liposarcoma (DDLPS) of Notch1 Activation Mouse.*
(Purdue University, West Lafayette, IN, USA - Dr. Shihuan Kuang Lab)

- Designed animal study with genetically modified mice.
- Generated and managed genetical modified mice breeding and performed mice dissection, primary cell-culture, vector recombination expression and liposarcoma (lipid cancer) transplantation

Undergraduate Research Assistant

Clinical & Eating Behavior Research (Human model)

2016 - 2017 Research Topic: *Physiological Differences between Korean Diet and Western Diet*
(Seoul National University, Seoul, Republic of Korea - Dr. Dong-Mi Shin Lab supported by Korean Rural Development Administration)

Contribution: Sampling serum of PBMC and urine

2016 Mar. – 2016 May Research Topic: *The Effects of Bisphenol A on Human Health*
(Seoul National University, Seoul, Republic of Korea - Dr. Dong-Mi Shin Lab)

Contribution: Literature review, NCBI GEO data deposit survey, Meta-analysis

Biochemical & Molecular Research (Animal Model)

2016 - 2017 Research Topic: *The Effect of Sweet Taste on Appetite Regulation with Hunger*
(Seoul National University, Seoul, Republic of Korea - Dr. Dong-Mi Shin Lab supported by Seoul Nation University Undergraduate Research Program)

Contribution: High-throughput microarray data analysis using Python, RT-qPCR measurement and analysis, Literature review, and Project budget management, Writing a funding proposal

2016 May – 2016 Dec. Research Topic: *Elucidating the Impact of Chronic Dehydration on Depression and Cognitive Function in Aged Mice*
(Seoul National University, Seoul, Republic of Korea - Dr. Dong-Mi Shin Lab)

Contribution: Mice tail suspension test

Database Development

2013 Sep. – 2013 Dec. Research Topic: *Development of Naver World Food Encyclopedia Database*
(Seoul National University, Seoul, Republic of Korea – Dr. Jihyun Yoon Lab collaborated with Naver Corporation)

Contribution: Researching origins, stories, and recipes of world foods

2013. Jun - 2013. July Research Topic: *Development of Food and Nutrient Database*
(Seoul National University, Seoul, Republic of Korea – Dr. Jihyun Yoon Lab collaborated with Korea Health Industry Development Institute)

Contribution: Converting unit of measurement, Measuring weight and volume of food

PUBLICATIONS

Published Articles

1. **Cheon, E**., Davis L. A., Valicente V. M., Wang Y. & Mattes, R. D.* (2022). Chapter 35: Obesity and Dietary Intake, Handbook of Obesity 5th edition, CRC Press (In process).

2. Higgins, K. A.* , Hudson, J.L., Hayes, A.M.R., Braun, E., **Cheon, E.,** … Mattes, R. D. Systematic Review and Meta-Analysis on the Effect of Portion Size and Ingestive Frequency on Energy Intake and Body Weight among Adults in Randomized Controlled Feeding Trials, Advances in Nutrition, Volume 13, Issue 1, January 2022, Pages 248–268 DOI: 10.1093/advances/nmab112.

3. **Cheon, E**. & Mattes, R. D.* (2021). Perceptual Quality of Nonesterified Fatty Acids Varies with Fatty Acid Chain Length, *Chemical Senses,* 46, bjab023. DOI:10.1093/chemse/bjab023.

4. **Cheon, E**., Reister, E. J., Hunter, S. R., & Mattes, R. D.* (2020). Finding the Sweet Spot: Measurement, Modification, and Application of Sweet Hedonics in Humans, *Journal of Academy of Nutrition and Dietetics*, nmab055. DOI: 10.1093/advances/nmab055.

5. **Cheon, E.*,** Kazandjian, M., Jones, T., & Henry, B. (2020). Session 5: End of life feeding. *Physiology & behavior*, 224, 113049. DOI: 10.1016/j.physbeh.2020.113049.

6. Hunter, S. R., Reister, E. J., **Cheon, E.**, & Mattes, R. D.* (2019). Low calorie sweeteners differ

in their physiological effects in humans. *Nutrients*, 11(11), 2717. DOI: 10.3390/nu11112717

7. Higgins, K., Hudson, J., Mattes, R.*, Gunaratna, N., McGowan, B., Hunter, S., Braun, E., Reister, E., **Cheon, E.**, ... & Couture, S. (2019). Systematic Review and Meta-analysis of the Effect of Portion Size and Ingestive Frequency on Energy Intake and Body Weight Among Adults in Randomized Controlled Trials (P08-007-19). *Current Developments in Nutrition*, 3(Supplement_1), nzz044-P08. DOI: 10.1093/cdn/nzz044.P08-007-19

PROFESSIONAL PRESENTATIONS

1. **Cheon, E.**, Mattes, R. D., "Fatty Acids Taste Intensity Ratings Before and After Sour Taste Adaptation", *ASN Annual Meeting*, 2020. Mar., Virtual Meeting (https://www.eventscribe.com/2020/ASN/).
2. **Cheon, E.**, Mattes, R. D., "Barriers of Ethical Food Labels to Encourage Consumption of the Sustainability Produced Foods", 8th *Ingestive Behavior Research Center (IBRC) Conference*, 2019. Sep., Purdue, U.S.
3. **Cheon, E.**, Son, W., Shin, D., "Effects of Aspartame Consumption on Appetite Regulation through Modification of Hypothalamic Fatty Acid Metabolism in Mice", *51st International Conference of the Korean Nutrition Society*, 2016. Oct., Jeonju, Republic of Korea.
4. **Cheon, E.**, Kim, Y., Shin, D., "Functions and Signalings of Retinoic Acid in Embryonic Development and Investigation of Actual Vitamin A Consumption of Korean Childbearing Females", *Undergraduate Graduation Conference*, 2015. Dec., Seoul, Republic of Korea.
5. **Cheon, E.**, Kwon, H., "Physiological Effect of Coffee Consumption and Biological Active Quantity", Undergraduate Food and Nutrition Symposium, 2015. Dec., Seoul, Republic of Korea.

FUNDING & AWARD

Funding

08/15/2022-12/23/2022 Bilsland Dissertation Fellowship
Department of Nutrition Science, Purdue University
Amount: **$ 24,697**

08/16/2021 – Present Research & Teaching Assistantship
Department of Nutrition Science, Purdue University
Amount: **$20,706**

08/17/2020 – 08/15/2021 Research Assistantship
Department of Nutrition Science, Purdue University
Amount: **$20,706**

05/18/2020 –
08/12/2019

Research & Teaching Assistantship
Department of Nutrition Science, Purdue University
Amount: **$20,706**

08/15/2018 –
05/17/2020

Teaching Assistantship
Department of Nutrition Science, Purdue University
Amount: **$20,706**

08/15/2017 –
08/14/2018

Lynn Fellowship
(Students who receive admission to a PhD interdisciplinary program at Purdue are considered for the Lynn Fellowship)
Purdue University
Amount: **$19,900**

04/25/2016 –
03/28/2017

Seoul National University
Seoul Nation University Undergraduate Research Program
Amount: **$3,000**

06/01/2014 –
12/20/2016

Korea Student Aid Foundation
National Scholarship for Science and Engineering Student
Amount: **$3,000** (Full scholarship)

Award

05/06/2022 Purdue University Teaching Academy Graduate Teaching Award

10/21/2016 Best Poster Presentation Award in 51th International Conference of the Korean Nutrition Society
Amount: **$100**

TEACHING EXPERIENCE

Teaching Certificate

- Certificate of Foundations in College Teaching, Purdue University Center for Instructional Excellence in 2018 (https://www.purdue.edu/cie/CTDP/index.html)

2018 Certificate of Foundations in College Teaching, Purdue University Center for Instructional Excellence

Teaching Assistant

2018 Fall *NUTR 205: Food Science*
Teach 3-hour lab to 20 sophomore nutrition science students on chemical and physical changes of foods during processing, storage, and preparation with hands-on experiences. Generating quiz/exam questions related to teaching materials and grading with feedback.

2018 Fall
2019 Fall

NUTR 453: Food Chemistry
Teach 3-hour lab to 20 junior and senior nutrition science students on application of fundamental laws and concepts of chemistry, physics, and biology to foods and eating. Generating quiz/exam questions related to teaching materials and grading with feedback.

2019 Spring
2020 Spring
2022 Spring

NUTR 436: Nutrition Assessment
Teach 3-hour lab to junior and senior nutrition science students on techniques used to assess the nutrition status of individuals and groups in clinical, community and research settings including principles of anthropometry, biochemical, analysis, clinical assessment, and assessment of dietary intakes. Generating quiz/exam questions related to teaching materials and grading with feedback.

2019 Summer
2020 Summer

NUTR 437: Macronutrients and Metabolism
Leading discussion on metabolism of the macronutrients, carbohydrate, lipid and protein in humans integrating physiology, biochemistry, and nutrition with a focus on maintaining optimal health and preventing disease. Grading with feedbacks.

2019 Summer

NUTR 438: Micronutrients and Phytochemical Metabolism
Leading discussion on regulation of micronutrients including vitamin, minerals, and phytochemical metabolisms. Generating quiz/exam questions related to teaching materials and grading with feedback.

2021 Fall

NUTR 303: Essentials of Nutrition
Teach 1-hour hybrid (face-to-face/virtual) lecture to about 100 students on basic nutrition and its application in meeting nutritional needs of all ages. Grading assignments with feedback and interacting with students in virtual discussion space (Packback).

PRACTICAL EXPERIENCE

2015 – 2016

Practice in Dietetics at Seoul National University Hospital, Republic of Korea
: Learning medical nutrition therapy in practice, Meal planning, and preparing for specific disease states, Assessing nutrition status, Communicating with patients.

2014 – 2015

Internship at KOFRUM (Korean Food Forum), Republic of Korea
: Writing articles, Project design, and Assistant of public hearing for food product

CERTIFICATES & LICENSES

April 2022 **ServSafe Food Protection Manager Certification**
National Restaurant Association Educational Foundation, United Sates

2014 – 2015 **Certificate of Foundations in College Teaching**
Center for Instructional Excellence, Purdue University

PROFESSIONAL AFFILIATIONS

2020 – Present Academy of Nutrition and Dietetics (AND)

2018 – Present American Society for Nutrition (ASN)

2017 – Present American Association for the Advancement of Science (AAAS)

2016 – Present Korean Nutrition Society (KNS)

ENGAGEMENT & SERVICE

2018 – 2020 **Nutrition Science Graduate Student Organization (NSGSO)**
Social Chair
- *Organize social activities for nutrition department (Under/Graduate students, faculty, and staff) (Monthly Yoga class, Coffee & Bagels, Department Picnic, Thanksgiving Dinner)*
- *Community engagement (Canned food donation to Food Bank)*

2018 – 2020 **Ingestive Behavior Research Center Graduate Student Association (IGSA)**
Social Chair
Organize social activities for IGSA Members (Visit corn fields and farm)

2018 – 2020 **Volunteer of Science Night** hosted by PULSe (Purdue University Interdisciplinary Life Science Program)
:Sharing the science knowledge with kids and their family using fun experiments who have low accessibility to learning sciences

2012 – 2014 **Volunteer of SNU (Seoul National University) Buddy**
:Volunteering club for helping foreign students in Korea.