The Effects of Meal Preloads
on Glycemia, Insulinemia and Satiety

by

Katie Fleming

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2012 by the
Graduate Supervisory Committee:

Carol Johnston, Chair
Christopher Wharton
Christina Shepard

ARIZONA STATE UNIVERSITY
May 2012
ABSTRACT

Background: Obesity is considered one of the most serious public health issues worldwide. Small, feasible lifestyle changes are necessary to obtain and maintain weight loss. Clinical evidence is inconclusive about whether meal preloading is an example of a small change that could potentially increase the likelihood of weight loss and weight maintenance.

Objective: The aim of this study is to determine if consuming 23 grams of peanuts, as a meal preload, before a carbohydrate-rich meal will lower post prandial glycemia and insulinemia and increase satiety in the 2 hour period after a carbohydrate-rich meal.

Design: 15 healthy, non-diabetic adults without any known peanut or tree nut allergies were recruited from a campus community. A randomized, 3x3 block crossover design was used. The day prior to testing participants refrained from vigorous activity and consumed a standard dinner meal followed by a 10 hour fast. Participants reported to the test site in the fasted state to complete one of three treatment meals: control (CON), peanut (NUT), or grain bar (BAR) followed one hour later by a carbohydrate-rich meal. Satiety, glucose and insulin were measured at different time points throughout the visit. Each participant had a one-week washout period between visits.

Results: Glucose curves varied between treatments (p=.023). Blood glucose was significantly higher one hour after ingestion of the grain bar compared to the peanut and control treatments (p<.001). At 30 minutes after the meal, the control glucose was significantly higher than for the peanut or grain bar (p=.048). Insulin
did vary significantly between treatments (p<.001). The insulin change one hour after grain bar consumption was significantly higher than after the peanut or control at the same time point (p<.001). The change in insulin one hour after peanut consumption was significantly higher than for the control treatment (p=.002). Overall satiety, expressed as the 180 minute AUC, differed significantly between treatments (p=.001). One hour after preload consumption, peanut and bar consumption was associated with greater satiety than the water control (p<.001). At 30 minutes post-meal, the grain bar was associated with greater satiety versus the water control (p=.049). The bar was also associated with greater satiety versus peanut and control at 60 and 90 minutes post-meal (p=.003 and .034, respectively). At 120 minutes post-meal, the final satiety measurement, the bar was still associated with greater satiety than the peanut preload (p=.023). Total energy intake, including test meal, on treatment days did not differ significantly between treatment (p=.233).

**Conclusions:** Overall satiety, blood glucose and blood insulin levels differed at different time points depending on treatment. Both meal preloads increased overall satiety. However, grain bar ingestion resulted in sustained satiety, greater than the peanut preload. Grain bar ingestion resulted in an immediate glycemic and insulinenic response. However, the response was not sustained after the test meal was ingested. The results of this study suggest that a low-energy, carbohydrate-rich meal preload may have a positive impact on weight maintenance and weight loss by initiating a sustained increase in overall satiety. More research is needed to confirm these findings.
DEDICATION

I dedicate this paper to my parents, Pat and Mary Fleming. Without the never-ending support of my parents, I would not be where I am today. They have always given me the confidence to pursue my dreams and the support to achieve them. I am very grateful to have such amazing influences in my life.
ACKNOWLEDGMENTS

I would like to acknowledge my thesis chairperson, Dr. Carol Johnston. Dr. Johnston guided me through the process of conducting research and writing a thesis. Upon starting the Master’s program at ASU, I did not have a passion or a great appreciation for conducting research. Dr. Johnston taught me the importance of research in the field of nutrition. Her passion for research was very motivating and inspiring.

I would also like to acknowledge Ginger Hook. Ginger was not only an amazing research phlebotomist, but she went above and beyond to do anything she could to help with my research. I could always count on Ginger and learned a lot from working with her.

In addition to the above-mentioned individuals, I would like to acknowledge Alyssa Dukes. Alyssa analyzed the food logs for all of the participants. She was extremely helpful and very thorough in her work. I am so thankful that she was willing to help.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
</tbody>
</table>

## CHAPTER

1 **INTRODUCTION**

- Purpose of the Study ................................................................. 3
- Aim & Hypothesis ................................................................. 3
- Definition of Terms ............................................................ 4
- Limitations & Delimitations .................................................. 4

2 **LITERATURE REVIEW**

- Obesity and Wellness ............................................................. 5
- Addressing the Obesity Problem .................................................. 6
- Major Diet Trends ................................................................. 8
- Small Change Approach ............................................................. 10
- Meal Preloading ........................................................................ 11
- Glycemic Index ......................................................................... 15
- Glucostatic Theory ................................................................. 17
- Satiety ....................................................................................... 19
- Satiety Signals: CCK, GLP-1, and Ghrelin ................................... 22
- Summary .................................................................................... 25

3 **METHODS**

- Participants and Methodology .................................................. 26
| CHAPTER |
|------------------|------------------|
| Independent Variable | 28 |
| Statistical Analysis  | 28 |
| 4 DATA & RESULTS | 29 |
| Statistical Analysis | 29 |
| Results | 29 |
| 5 DISCUSSION & CONCLUSION | 36 |
| Limitations/Delimitations | 39 |
| Strengths | 40 |
| Future Studies | 40 |
| Conclusion | 40 |
| REFERENCES | 42 |
| APPENDIX |  |
| A SATIETY SCALE | 49 |
| B INFORMED CONSENT | 51 |
| C PARTICIPANT INSTRUCTIONS | 54 |
| D IRB APPROVAL | 56 |
| E VISIT TIMELINE | 58 |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nutrient Composition of Food Items</td>
<td>28</td>
</tr>
<tr>
<td>2.</td>
<td>Descriptive Characteristics of Participants</td>
<td>32</td>
</tr>
<tr>
<td>3.</td>
<td>Mean Energy Intake</td>
<td>35</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>Incremental Serum Glucose Over Time</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>Incremental AUC for Serum Glucose for the 3 Hour</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>Incremental Serum Insulin Over Time</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>Incremental AUC for Satiety</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>Perceived Satiety Over Time</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>24 Hour Energy Consumed on Treatment Day</td>
<td>34</td>
</tr>
</tbody>
</table>
Today, roughly sixty-six percent of adult Americans are overweight or obese. Obesity is a risk factor for type 2 diabetes, high cholesterol, heart disease, certain cancers, and stroke.\textsuperscript{1} It is considered one of the most serious public health issues worldwide. Although a great deal of effort has been focused on reducing obesity in the United States, treatment strategies to date for obesity have not been successful in the long term.\textsuperscript{1}

Long-term weight loss requires lifelong dietary and behavioral changes that can be very intimidating for many individuals. Many Americans struggle with weight loss diets since weight loss programs often require drastic lifestyle changes.\textsuperscript{2} Alternatively, simple diet strategies can be promoted to improve overall eating patterns. An article by Hill et al suggested a paradigm shift in prioritizing strategies to combat the obesity epidemic.\textsuperscript{2} The article suggests that efforts should focus on small lifestyle changes to promote gradual weight loss since small changes in lifestyle should not cause high levels of frustration or feelings of deprivation in individuals trying to lose weight.

Numerous research studies have focused on meal preloading as a small change approach to combat obesity.\textsuperscript{24,25,26} Current research is inconclusive about the type of meal preload (macronutrient content, texture, kilocalories, timing) that is most effective at increasing satiety, decreasing post-prandial glycemia and insulinemia, and decreasing subsequent energy intake.
Nuts vary in caloric content and fat composition, but are often excluded from weight-loss diets because of their high fat and kilocalorie content. However, nut consumption has been shown to be related to positive health outcomes. Interestingly, the epidemiological research indicates that nut consumers have a lower body mass index than people that do not eat nuts, and these data do not relate long-term nut consumption with obesity. According to a review by Sabate, data from the Nurses’ Health Study related lower body weights to increased nut consumption. A clinical study by Mattes et al found that almond consumption led to increased weight loss compared to complex carbohydrate consumption. According to a large survey conducted by Sabate, per capita nut consumption in Mediterranean populations was roughly double that of the United States; however, Mediterranean populations’ obesity rates are much lower than rates in the United States. A study done by Wien et al found that an almond-enriched low calorie diet improved weight loss and maintenance of weight loss better than a complex carbohydrate enriched low calorie diet.

In addition to effects on body weight, nuts have been shown to affect the glycemic response to meals. In general, nuts contain little available carbohydrate and contribute minimally to the postprandial glycemic response. However, due to the fat and protein content in nuts, nut ingestion reduces the glycemic response to a standard carbohydrate load. A study done by Johnston et al found that peanut ingestion reduced the 60 minute glucose response after a meal by 50-55%. This study noted that peanuts have high levels of arginine which causes insulin
secretion. Therefore, peanut consumption can affect glycemia by rapid stimulation of insulin release and glucose uptake.

Although numerous studies have been done on the effects of nut consumption, previous studies have not focused on the relationship between modest peanut consumption as a meal preload and increased satiety and reduced postprandial glycemia/insulinemia. Much of the published research focuses on unrealistic intakes of nut products (3-5 servings per day).

In order to make strides in combating the obesity epidemic, it is important to assess the effects of realistic intakes of nuts, as a meal preload, on appetite suppression and blood glucose and insulin levels. This study will fill an important gap in the research literature by focusing on a simple diet strategy to help overweight individuals control hunger and decrease total energy intake.

**Purpose of Study:**

The purpose of this study is to determine the short-term effects of meal preloads on post-prandial glycemia, insulinemia, and satiety in healthy adults.

**Aim and Hypothesis:**

The aim of this study is to determine if consuming 23 g of peanuts, as a meal preload, before a carbohydrate-rich meal will lower post prandial glycemia and increase satiety in the 2 hour period after the meal.

The hypothesis, based on past research, is that adults consuming 23 g of peanuts 60 minutes prior to a carbohydrate-rich meal will exhibit reduced 2 hour post prandial glycemia and insulinemia and increased satiety as compared to an isocaloric grain bar treatment.
**Definition of Terms:**

1. 1 serving of peanuts is 23 grams and roughly 140 kilocalories.

2. 1 grain bar serving is 1 bar and roughly 140 kilocalories.

3. Satiety is the state of being fed and satisfied. Satiety will be assessed using a validated scale.

**Limitations and Delimitations of Study:**

One limitation of this study is the small sample size. With the small sample size, it will be difficult to generalize the results to a broader population. Without random selection, the generalizability of the results will be limited to healthy, non-diabetic adults similar to the individuals that participated in the study.
Chapter 2

LITERATURE REVIEW

**Obesity and Wellness**

Obesity is currently recognized as a serious public health issue in the United States.\(^1\) Obesity is a consequence of inactivity and overconsumption. Body weight and BMI have been steadily increasing in all United States demographics. Currently, more than 30% of adults in the United States are obese and 35% are overweight. According to statistics from the National Health and Nutrition Examination Surveys (NHANES), only 15% of the United States population was overweight prior to 1980.\(^1\) The increase in obesity rates has caused obesity to be one of the most important public health challenges for the United States and most other countries around the world.\(^1\)

Overweight and obesity are labels for weight ranges that are higher than what is considered healthy. A body mass index of 25 or higher is considered overweight.\(^1\) Individuals become overweight and/or obese due to an energy imbalance. However, body weight regulation can be very complex. Biological, behavioral and environmental factors all play a role.\(^1\) The term “obesogenic” has been used to explain the current environment in the United States.\(^10\) The “obesogenic” environment is characterized by a variety of readily available, inexpensive foods that lack nutritional value and the lack of physical activity, much of which is a consequence of energy-saving tasks such as escalators. It is important to consider the different factors of obesity when trying to develop effective strategies to prevent and treat the problem.\(^10\)
Overweight and obesity are associated with certain diseases such as cardiovascular disease, cancer, stroke, and type 2 diabetes. A study published in the Journal of the American Medical Association observed a substantial prevalence of chronic health conditions associated with higher than average BMI. Specifically, this study found strong cross-sectional associations for overweight and obesity with type 2 diabetes and hypertension. Since these diseases are serious and can be life threatening, it is important to strive to prevent them in whatever ways possible. Finding successful strategies to combat obesity is necessary in order to reduce the prevalence of diseases and conditions related to obesity.

**Addressing the Obesity Problem**

There is an urgent need to address the obesity problem in the United States. However, finding strategies to combat obesity is not an easy task. Although the changes that need to be made might seem obvious, it is very difficult for people to adopt and sustain these changes. Calorie control and physical activity are key components in most long-term weight loss plans. A recent report concluded that energy consumption may play a greater role in body weight than physical activity. The report compared a group of African American women in Chicago and a group of Nigerian women. Both groups of women expended similar amounts of energy daily; yet, the African American women in Chicago averaged 184 pounds compared to women in rural Nigeria averaging 127 pounds. In this study, calorie control appeared to be responsible for lower body weights.
Altering food intake can be a drastic change for individuals who have never considered restricting food choices. Due to the intense commitment required for most weight-loss/weight-maintenance programs, individuals do not usually have long-term success.\(^\text{13}\) In addition to struggling with losing weight, most people who achieve weight loss through lifestyle changes eventually regain most of the weight that they lost. A 2005 review found that individuals who follow a comprehensive program including low-calorie diets can expect to lose roughly 15%-25% of their starting weight in about 3 to 6 months.\(^\text{14}\) Unfortunately, these individuals usually only maintain a 5% weight loss after 4 years. The authors of this review noted that these numbers represent the best case scenario with motivated, compliant individuals. Another study obtained follow-up weights on 112 subjects that had lost weight by following a very low-calorie diet.\(^\text{15}\) This study found that roughly 73% of the weight lost was rapidly regained within three years of the weight-loss program. In this study, only 25% of the individuals had maintained a weight loss of >10% of their initial body weight. A study by Stunkard et al followed 100 obese individuals that had been referred to a nutrition weight loss program.\(^\text{52}\) Stunkard et al found that two years after completing the weight loss program, only 2% maintained a weight loss of at least 20 pounds. Overall, studies have shown that long-term weight maintenance is difficult for individuals.\(^\text{53,54}\)

Regular physical activity has been shown to be associated with long-term weight loss maintenance.\(^\text{55,56}\) Increasing physical activity in the United States is one of the ten “leading indicator” areas focused on by Healthy People 2010.
Several organizations issue guidelines for physical activity. Some guidelines recommend 60-90 minutes per day depending on the goal of the individual. It can be very challenging for individuals to meet these recommendations. According to the Centers for Disease Control and Prevention in 2007, less than half of individuals in the United States obtained the recommended amount of physical activity, 30 minutes per day on most days of the week. According to a cross-sectional study by Brownson et al, some of the most commonly reported barriers to physical activity were lack of time, lack of energy, and lack of motivation. Of these barriers, lack of time was the most frequent response.

Overall adherence and success in weight loss and weight maintenance programs are low for most individuals. In order to tackle the obesity problem, it is important to consider the factors that make adherence and success so difficult. After considering the various factors involved in weight loss and weight maintenance programs, it is necessary to formulate a realistic approach that is easy for individuals to follow.

**Major Diet Trends**

A traditional weight loss strategy includes increasing physical activity and decreasing energy intake. However, in today’s obesiogenic environment, alternative diet approaches are becoming increasingly popular. Many Americans desire a “quick-fix” weight-loss solution. Numerous diet trends and weight-loss programs exist. Some of the most popular diets are the Atkins diet, the Zone diet and the Ornish diet. The Atkins diet advises individuals to limit carbohydrate
intake and focus on fats and protein food sources. The theory behind the Atkins diet is that when carbohydrate intake is high, the body does not burn off fat. The Zone diet instructs individuals to fill one-third of a plate with low-fat protein and the other two-thirds of the plate with vegetables and fruits. The Ornish diet promotes eating a high-fiber, low-fat vegetarian diet for weight loss and overall health. The diet has categories of food that should be consumed freely, consumed in moderation and not consumed at all. The above mentioned plans are only a few of the major diet plans that are popular for weight loss and weight maintenance.

Research studies have focused on the efficacy of different diet plans for weight loss and long-term weight maintenance. The A to Z weight-loss study aimed to determine the success of different weight-loss plans (Atkins, Zone, and Ornish) based on the level of dietary adherence of participants. The results of this study showed that weight change was greater in the most adherent participants, regardless of the assigned weight-loss plan. The results suggest that general adherence may be more important than following a certain weight-loss plan. Another study by Dansinger et al assessed adherence rates and the effectiveness of four popular diets (Atkins, Zone, Weight Watchers, and Ornish) for weight loss. This study found that each diet plan resulted in modest weight loss, but overall dietary adherence rates were low. Both of these studies found similar results.

Overall, popular diet plans generally require strict adherence for weight loss success and long-term commitment for weight loss maintenance. Studies
suggest that adherence is an issue for individuals following strict diet plans. In order to increase the likelihood that individuals will adhere to a weight-loss plan, it is necessary to ensure that the plan does not include drastic changes that are difficult to make.

**Small Change Approach**

In 2003, Hill et al published an article that suggested promoting small lifestyle changes to address the obesity problem. Hill noted that “despite heightened awareness of the problem and many suggestions on how obesity can be reduced, there has been no real long-term success in tackling the problem”. According to the article, the lack of long-term success is partly due to individual inabilities to maintain healthy diet and exercise routines in today’s world.

The article focused on reducing the gradual excessive weight gain rather than focusing on weight-loss and obesity prevention. Hill recruited a task force that included individuals from the American Society for Nutrition, the Institute of Food Technologists, and the International Food Information Council to decide whether a small-change approach could be used to address the obesity issue. The individuals came up with several convincing reasons as to why the approach could be a viable option to address the obesity epidemic. Some of the reasons were that small changes are easier to achieve and maintain than large changes, small changes can have important impacts on body weight, achieving small changes may lead to increased self-efficacy which could lead to additional positive changes, and small changes could lessen the negative environmental issues related to obesity over time.
Since the publication of Hill’s article, the small-changes approach has been implemented in different ways by numerous organizations. The US Department of Health and Human Services started a new initiative focused on small changes. The initiative included television and radio commercials and a website. Another non-profit organization called America On the Move was created to promote small changes in physical activity and diet.

The small-changes approach can be used for both physical activity and diet. In order to increase physical activity, small changes can be very beneficial. Hill et al suggested that adding an extra 2,000 steps per day would be a sufficient change to stop weight gain in most adults. Using pedometers to monitor steps provides a simple and measurable way to set physical activity goals. A review by Bravita et al showed that pedometer use resulted in 2,491 extra steps per day, on average.

**Meal Preloading**

Taking into consideration the ideas in the small change approach, a simple, unintimidating diet strategy may be a practical tool for weight loss and weight management. A simple diet strategy that improves eating patterns and controls hunger may help promote lifestyle changes that would eventually work to combat obesity. An example of a potentially beneficial, small dietary change is the inclusion of a meal preload in the daily diet. A meal preload is a small “snack” eaten one hour or less before a regular meal. A meal preload has the potential to increase satiety and reduce glycemia resulting in a decrease in caloric intake during mealtime. Not only does the concept of meal preloading follow
Hill’s small approach theory, it also avoids the restrictive nature of many weight loss strategies.

Due to the increased focus on obesity and obesity prevention methods, a variety of meal preload studies have been conducted.\textsuperscript{25,26,27} Many meal preload studies have focused on the effect of preloads on weight, satiety, glycemia, and hormone levels. Some preload studies are focused on determining if the specific characteristics of a preload influence the overall effect of the preload. Macronutrient content, energy content, timing of the preload, and texture of the preload are all important characteristics that need to be considered when conducting preload research. Meal preload studies generally focus on the immediate impact of the preload on satiety, glucose, insulin, subsequent food intake, and other hormone levels. However, other studies have followed subjects for a longer period of time to determine if preloading can result in long-term weight loss.

One preload study by Flood et al tested the effects of soup preloads on subsequent meal intake in normal weight adults.\textsuperscript{26} The preload was given fifteen minutes before a standard meal. The subjects in this study ate significantly less energy from the test meal when a soup preload was consumed, compared to when no soup was consumed. In this study, the type of soup had no significant effect on the subsequent meal intake. Overall, the researchers concluded that consuming a preload of low-energy-dense soup in any form is a strategy that can be used to reduce energy intake in adults.
Another preload study by Cecil et al focused on the effects of preloads varying in energy content on the ability of young children to accurately compensate for the energy consumed in the preload. This study gave participants a high energy, low energy, or no energy preload prior to the lunch meal. The lunch meal was served 90 minutes after preload consumption. The results of this study showed that the children adjusted their energy intake at lunch after eating different preloads. When the children ate a high energy preload, they ate significantly less than they did when a low energy or no energy preload was consumed. Although the children did successfully compensate for the additional energy in the preload at the lunch meal, they failed to compensate over the course of an entire day. The results of this study suggest that a preload is only effective at reducing energy intake in the short term (e.g., at the subsequent meal).

The timing of a meal preload is another important factor to consider when using meal preloads to reduce subsequent intake. Booth et al provided glucose preloads to participants 20 minutes before lunch, immediately before lunch or after lunch. The results of this study showed that consuming the preload 20 minutes before lunch reduced food intake at lunch and subsequent meals compared to the control group. Preload consumption immediately before lunch also reduced food intake at lunch but not at subsequent meals for the remainder of the day. These researchers concluded that long-term satiating properties of a carbohydrate meal preload are most effective when consumed 20 minutes prior to a meal.
Macronutrient content of meal preloads may affect the overall effects of the preload on satiety, food intake and hormonal response. A study by Geliebter et al conducted experiments in rats and humans to determine the effects of isocaloric loads of protein, fat, carbohydrates and a mixture of macronutrients on subsequent energy intake.\textsuperscript{38} The study found no differences between food intakes after specific loads. Collectively, the study showed that caloric loads, regardless of macronutrient content, suppressed subsequent food intake more than the non-caloric control. Another study compared the effects of isocaloric, isovolumetric high fat or simple carbohydrate preload drinks.\textsuperscript{61} This study found that spontaneous meal requests after the preload took twice as long to occur after the high fat preload versus the simple carbohydrate preload. The results of this study suggest that high fat preloads have greater satiating effects than simple carbohydrate preloads. A study by Atsbury et al focused on the effect of preloads with varying amounts of protein on within energy intake in lean subjects.\textsuperscript{25} This study found that energy intake following the protein preload versus the water control was significantly lower. The study also found that the protein content of the preloads had a dose-response effect on subsequent energy intake.

A study by Kirkmeyer and Mattes explored the relative importance of a food’s macronutrient composition, energy value, energy density, fiber content, weight, volume, sensory properties and rheology on hunger and food intake.\textsuperscript{41} To do this, preloads of peanuts, peanut butter, almonds, chestnuts, chocolate, rice cakes, pickles, and/or no preload were consumed by participants in random order. Hunger was assessed over the feeding period. The results showed that hunger
ratings after the consumption of 500 kilocalories of peanuts, peanut butter, almonds, chestnuts and chocolate were significantly lower than the low energy preloads or no preload. This study concluded that energy content might be the primary determinant of a food’s impact on hunger.  

**Glycemic Index:**

Continuing with the assumption that glycemic response plays a large role in overall energy intake and satiety, a specific dietary factor of foods that may have an influence on body weight and food consumption is the glycemic index. Jenkins et al developed the glycemic index in 1981 as a tool to quantify the blood glucose response to a specific food. Any food that is rapidly digested and absorbed or metabolically converted into glucose has a high glycemic index. Foods with a high glycemic index tend to raise blood glucose levels more drastically than foods with a low glycemic index. As a result of the drastic rise in blood glucose levels, insulin levels spike. When insulin levels spike, people tend to experience increased cravings and overeating. Refined grain products are an example of foods that have a high glycemic index. The glycemic load is another way to determine the effect of carbohydrate consumption. The glycemic load used the glycemic index and the amount of carbohydrate being consumed to rank the overall carbohydrate content in foods.

Results from one glycemia study demonstrated that meals containing identical amounts of energy can have significantly different effects on metabolism, satiety, and subsequent food intake. This study used a crossover design with obese teenage boys as the participants. Participants consumed
identical test meals at breakfast and lunch with a low, medium, or high glycemic index. Plasma and serum blood levels were measured after breakfast and subsequent food intake was recorded for the 5 hour period after lunch. The results showed that voluntary energy intake after the high glycemic index meal was 53% higher than after the medium glycemic index meal and 81% higher after the low glycemic index meal. The high glycemic index meal also resulted in higher serum insulin levels and lower post-absorptive plasma glucose levels. Furthermore, overall satiety ratings were lower at every time point after the high glycemic index breakfast compared with the low and medium glycemic index meals. Overall, this study concluded that high glycemic index foods induce hormonal and metabolic changes that make the availability of metabolic fuels limited ultimately decreasing satiety over time and leading to overeating in obese subjects.\textsuperscript{34} A study found that children who consumed a lower glycemic index breakfast consumed more calories throughout the remainder of the day than children who consumed a higher glycemic index breakfast.\textsuperscript{62} However, this study also found that when children ate their next meal greater than 3 hours after breakfast, subsequent energy intake was not associated with glycemic index of the breakfast meal.

Other studies suggest that there is not a significant difference in energy intake after high versus low glycemic index foods. One study evaluated the effects of consuming high versus low glycemic index meals in thirty-nine healthy adults.\textsuperscript{63} The study found that there were no significant differences in plasma glucose or insulin responses, appetitive ratings, or food intake between
treatments. Another glycemic index study tested the effects of two high carbohydrate diets made up of low glycemic index food or high glycemic index food on post-prandial blood profile, appetite sensations, energy expenditure and energy intake.\textsuperscript{64} This study found that ratings of fullness were higher after the test meal that contained low glycemic index foods. However, subsequent energy intake was not different between treatments.

Overall, the glycemic effect of food is an important characteristic that can help individuals develop and maintain healthy blood glucose levels by balancing insulin response. Eating foods with a high glycemic index can cause a rapid glycemic response that sometimes results in overeating at subsequent meal times. Foods with a low glycemic index appear to improve overall glycemic control.

**Glucostatic Theory**

Numerous theories about the control of food intake and satiety have been proposed in past research.\textsuperscript{51} The aminostatic, thermostatic and lipostatic theories of food intake are all different theories from the past. The lipostatic theory proposes that the amount of stored fat directly affects food intake.\textsuperscript{51} The thermostatic theory proposes that the heat created by metabolic processes would either inhibit or initiate food intake to maintain a constant body temperature.\textsuperscript{51} The aminostatic theory proposes that excess or insufficient amounts of plasma amino acids are responsible for initiating or inhibiting food intake.\textsuperscript{51} Carlson et al was among the first researchers to publish a text about the theory behind glucose and satiety in 1916.\textsuperscript{28} Jean Mayer compiled Carlson’s ideas and his own research into the glucostatic theory.\textsuperscript{28} The glucostatic theory was developed over 50 years
ago in an attempt to identify the biochemical explanation for hunger, meal initiation and total energy intake. The glucostatic theory suggests that changes in blood glucose concentrations are detected by glucoreceptors in the brain and ultimately affect total energy intake. The theory further suggests that reduced glucose availability and utilization in the brain leads to feelings of hunger and meal initiation, whereas increased glucose availability and use in the same brain location leads to decreased feelings of hunger and termination of eating. Overall, the researcher behind this theory, proposed that “metabolic hypoglycemia” is the signal for food intake in humans.\textsuperscript{28} The theory was intended to explain the short-term control of hunger and food intake, the long-term regulation was thought to be influenced by lipostatic effects on body weight and energy balance.

The proposal of the glucostatic theory inspired researchers to test the hypotheses suggested in the theory. Bernstein and Grossman conducted an experimental test of the theory in 1955.\textsuperscript{29} The study was divided into two parts to test the effect of induced hyperglycemia (via IV fluids) on food intake and on the desire to eat. The food intake portion of the study was made up of 9 healthy adult males that completed food consumption tests. The satiety portion of the study included 12 healthy adult males. The results of this particular study did not support the proposed hypotheses included in the glucostatic theory. Consumption of food in participants that were hyperglycemic did not differ significantly from control days when saline treatments were given. In addition, the desire to eat was not significantly affected by the glucose treatment versus the saline treatment.
The small sample size of this study further motivated other researchers to investigate.

Other studies have been conducted to test the hypotheses of the glucostatic theory. However, the results of the studies were inconsistent, making it very difficult to formulate conclusions. After years of experimental research, researchers started to dismiss the glucostatic theory and focus on other hypotheses related to the mechanism of satiety and food intake. At this time, researchers focused their attention on the role of the hypothalamus on regulation of satiety and food intake and the role of hormones such as CCK on hunger and feeding habits.

Current researchers continue to conduct studies to identify the plausibility of the glucostatic theory. A review published in 2009 focused on the available research on the glucostatic theory. Overall, the review concluded that satiety and meal initiation are influenced by the overall pattern of blood glucose dynamics not merely by an increase or decrease in the amount of glucose in the blood.

**Satiety**

Satiety is the condition of being full which is achieved after eating when further eating is inhibited. Satiety can be measured by the duration of time between meals or the amount of food consumed at the next meal. One major obstacle to weight loss and the prevention of obesity is the feeling of hunger that is associated with negative energy balance when people restrict calories.
Due to the fact that satiety involves psychological, physiological, and metabolic components, it is difficult to accurately measure. In research, satiety is often measured using a visual analog scale or a simple category scale. These types of measurement tools can have methodological issues. Cardello et al created a simple, more quantitative tool to measure perceived hunger and fullness. These researchers developed the Satiety LabeledIntensity Magnitude scale (SLIM). This scale was compared to visual analog scales to test reliability. The SLIM scale produces data with ratio properties, enabling researchers to make statements about sensations of satiety such as “half as intense as other sensations”. This measurement tool is designed to measure perceived satiety responses over time, immediately before or after eating in the same individual to compare responses to different foods.

Research has shown inconsistent findings regarding the differences in the satiety effects of macronutrients. Some research suggests that proteins have the greatest satiating effect, carbohydrates next, and fats are the least satiating. Other researchers argue that the different macronutrients have equivalent effects on satiety. Another theory is that physical weight exerts an influence on appetite and satiety. One study by Porrini et al confirmed this theory. This study focused on determining the effect of weight, protein, fat, and timing of preloads on food intake. They did this by using two different foods, one rich in protein and one rich in fat. The foods were given at different times and in different forms in order to determine overall effects on satiety and eating. These researchers concluded that sensory characteristics of foods, such as weight and
volume, play an important role in controlling food intake and initiating feelings of satiety. Overall, they found that the weight and protein content of food are two important factors when trying to reduce food intake and increase satiety.

Similar to the results of the above mentioned study, other research suggests that calories consumed in liquid form are not compensated for in the same way as a solid food with the same number of calories. This difference can be attributed to the physical differences between liquids and solids. Another factor may be the effect that mastication has on satiety response. Mastication activates receptors in the brain that affect satiety. It is important to consider the different characteristics of food that can affect overall satiety and eating habits.

Dietary fiber has been shown to enhance satiety because it adds bulk and weight to the diet. Meal-induced signs of satiety are present for both preabsorptive and postabsorptive states. Preabsorptive satiety mechanisms are the most essential in the induction and maintenance of satiety. This means that prolonging the intestinal phase of nutrient digestion and absorption will increase satiety and decrease energy intake. Consumption of sufficient amounts of dietary fiber can increase the viscosity of the gastrointestinal contents. This increase slows gastric emptying and small bowel transit time, interferes with the digestive enzymes, disrupts micelle formation and changes interaction of nutrients with the mucosal surface. These events cause slower fat and carbohydrate absorption, which lengthens the time in which these macronutrients can interact with preabsorptive mechanisms of satiety. There is increasing evidence to suggest that adequate intake of fiber has a positive effect on decreased energy intake and
satiety. One study investigated the effects of fiber on satiety. This study found that women who incorporated foods rich in viscous fibers into mixed low fat meals showed suppressed sensations of hunger and enhanced post-meal satiety.\(^{41}\)

A review by Cassady et al discussed the possibility that masticatory efficiency influences energy balance through changes in lipid availability.\(^{40}\) Increased chewing could free more lipids from nuts and ultimately increase the amount of energy available to the body. This would lead to positive energy balance. However, increased presence of lipids in the small intestine can result in increased secretions of hormones such as cholecystokinin (CCK), glucagon-like peptide-1 (GLP-1), and peptide YY.\(^{42}\) Higher concentrations of these hormones are related to greater feelings of satiety. Ultimately, the increased available energy from the increased presence of lipids might be counteracted by a stronger feeling of satiety.

**Satiety Signals: CCK, GLP-1, and Ghrelin:**

During food consumption, ingested foods are passed through the gastrointestinal tract and digested by the body. Ingested food is processed mechanically and chemically in order to produce absorbable nutrients. When the gastrointestinal tract contains nutrients, a variety of physiological responses are activated to aid in overall digestion. Certain satiety signals are highly involved in appetite regulation. These signals affect satiety levels after consuming certain foods by activating neurons in the brain. Ghrelin, GLP-1 and cholecystokinin are gastrointestinal hormones that have an impact on short-term satiety.\(^{42}\)
Ghrelin is an orexigenic peptide that is produced by endocrine cells located in the gastrointestinal tract. This peptide is primarily released in the stomach in response to feedback from the intestine or a postabsorptive site. Ghrelin greatly impacts food intake and metabolism.\textsuperscript{43} The main role of ghrelin is to participate in appetite stimulation and regulation of energy homeostasis. Plasma ghrelin levels change throughout the day in response to food intake. Unlike other gastrointestinal hormones, circulating ghrelin levels increase before meals and decrease when food is consumed. The secretion of ghrelin before meals is related to a cephalic response stimulated by the sympathetic nervous system.\textsuperscript{43}

Since ghrelin levels increase before a meal and stimulate hunger, the hormone plays an important role in short-term food intake and long-term weight maintenance. Cummings et al found that plasma ghrelin levels rose by 78\%, on average, 1-2 hours before the onset of a meal and decreased drastically within 1 hour after a meal.\textsuperscript{44} The researchers used previously published rodent studies to confirm their hypothesis that ghrelin acts as a physiological meal initiator. According to a critical review of literature, post-prandial ghrelin response is macronutrient specific in normal weight individuals.\textsuperscript{45} This review concluded that carbohydrates are the most effective macronutrient for ghrelin suppression. Proteins cause prolonged ghrelin suppression, increasing overall satiety. Fat appears to have minimal ghrelin-suppressing capacity.

Cholecystokinin (CCK) is located in secretory and neural tissues of the gastrointestinal tract. CCK is responsible for the rate of nutrient delivery from the
stomach to the small intestine. Basal plasma CCK concentrations are roughly 1 pm in most individuals and rise to 5-8 pM after eating. CCK levels increase gradually over the 10-30 minute timeframe following meal ingestion and then slowly fall. The levels can remain elevated for up to 5 hours after eating. Dietary consumption of fat and protein increase serum CCK greater than carbohydrates.\textsuperscript{46}

When CCK is released into the gastrointestinal tract, it has a variety of roles in the overall digestive process. Studies have shown that CCK has an effect on satiety and food intake.\textsuperscript{46} High levels of plasma CCK have been shown to cause increased satiety and decreased food intake. Gibbs et al were the first researchers to administer synthetic CCK to rats before a meal to observe the dose response.\textsuperscript{47} This study found that CCK reduced the size of the meal in a dose-dependent fashion. The mechanism responsible for satiety control by CCK involves the activation of vagal afferent fibers and slowed gastric emptying.

Glucagon-like peptide 1 (GLP-1) is another satiety signal that affects overall food intake. GLP-1 is a gastrointestinal hormone that is released from cells in the small intestine 5-30 minutes after food ingestion. GLP-1 is secreted in proportion to the number of calories consumed. As plasma levels of GLP-1 increase, post-prandial satiety also increases.\textsuperscript{48} One meta-analysis studying the effect of GLP-1 infusion in humans showed that participants reduced calorie intake by an average of 11.7%. This study also showed that calorie reduction is dose-dependent and does not differ between obese and normal weight individuals.\textsuperscript{49} The increased satiety produced by increased GLP-1 secretion is a result of the effects it has on the central nervous system and gastric emptying. In
addition to the effect that GLP-1 has on satiety, it also promotes insulin secretion at mealtimes. GLP-1 has been shown to increase the effectiveness of the steps of insulin biosynthesis. A 6 week study showed that a subcutaneous infusion of GLP-1 to participants with type 2 diabetes normalized glycosylated fructosamine and reduced HbA1c by 1.3%. In this study, the GLP-1 infusion also showed a reduction in body weight.

**Summary**

In summary, obesity is a serious public health concern in the United States. Weight loss and weight maintenance can be very difficult for individuals to achieve. Research has been focused on obesity and weight management for many years. Small, sustained changes may be the most feasible strategy for obesity treatment and prevention. Meal preloading could be a potential small change to decrease energy intake and stabilize blood glucose and insulin levels. The literature shows mixed results on the effect of meal preloads on energy intake, hormones and satiety.
Chapter 3

METHODS

Participants and Methodology:

For this study, fifteen healthy, non-diabetic adults without any known peanut or tree nut allergies were recruited from a campus community. Written informed consents were obtained from all participants at the initial subject visit, and height and weight measurements were collected as well as general health information. Body weight was measured using a Tanita scale. Height was measured using a calibrated stadiometer. The study was approved by the Institutional Review Board (Appendix D).

The glycemia trial followed a randomized, 3x3 block crossover design. The day prior to testing participants refrained from vigorous activity and consumed a standard dinner meal followed by a 10 hour fast. Participants were also provided a Subway gift card to purchase a standard, high carbohydrate dinner meal the night prior to testing. The standard meal was a 6-inch Sweet Onion Chicken Teriyaki sandwich with a cookie and drink from Subway (Table 1). Participants were not instructed on a specific drink to consume. Alcohol and caffeine were also avoided the night prior to testing.

Participants reported to the test site early the next morning in the fasted state to complete one of three treatment meals: control (CON), peanut (NUT), or grain bar (BAR). The NUT group consumed 23 grams of peanuts and 6 oz water followed one hour later with a buttered bagel and juice. The BAR group consumed a whole grain snack bar and 6 oz water followed one hour later with a
buttered bagel and juice. For the control treatment, 6 oz of water was consumed one hour prior to the buttered bagel and juice meal. Test days were separated by a one week wash-out period.

Blood samples were collected via finger stick to measure blood glucose immediately before peanut/snack bar/control ingestion, immediately before bagel ingestion, and at 30 minute intervals for the 2 hour period after ingestion of the bagel meal. A calibrated OneTouch glucometer was used to determine capillary blood glucose. The same glucometer was used for each subject during the study. Venous blood draws were done to test insulin levels using radioimmunoassays. The venous blood draws occurred at three time points: pre-peanut/snack bar/control ingestion, pre-meal ingestion, and 30 minutes post-meal ingestion. All venous blood draws were done by an experienced phlebotomist.

Assessment of perceived satiety were measured at each treatment using a validated scale ranging from “greatest imaginable fullness” to “greatest imaginable hunger” (see appendix A). Satiety assessments were completed immediately before peanut/snack bar/control ingestion, immediately before bagel ingestion, and at 30 minute intervals for the 2 hour period after ingestion of the bagel meal. After the testing, participants were free to follow their normal routine. Each participant was instructed to record all food and beverages consumed for the rest of the day. The food logs were assessed using Food Processor to compare food intake among the different treatment groups.
Independent Variable:

The independent variables in this study were the peanuts, snack bar, and water, depending on the treatment group. The serving size for the peanuts was 23 grams. The portion of peanuts was isocaloric to the grain bar and contained 5 grams of carbohydrates, 11.6 grams of total fat and 5.5 grams of protein. The snack bar serving size was one whole bar. The bar contained 140 kcals, 27 grams of carbohydrates, 3 grams of total fat and 1 gram of protein. One 6 ounce serving of water was used as the control and given with each preload (Table 1).

Statistical Analysis:

The data were analyzed using PASW Statistics 19.0, (Predictive Analytics Software Statistics package, IBM, 2009). Incremental area-under-the-curve was calculated using the trapezoidal rule to represent 120 minute glucose response to meal ingestion and to determine if the treatments display different results. A multivariate general linear model for repeated measures was used to determine significant treatment effects. Time x treatment effects were assessed using the repeated-measures ANOVA test. All results are expressed as means ± SEM P<0.05 will be considered significant.

<table>
<thead>
<tr>
<th>Food Item</th>
<th>Amount</th>
<th>Kcal</th>
<th>CHO (g)</th>
<th>Total Fat (g)</th>
<th>Protein (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanuts</td>
<td>23 g (.82 oz)</td>
<td>140</td>
<td>5.0</td>
<td>11.6</td>
<td>5.5</td>
</tr>
<tr>
<td>Snack bar</td>
<td>1 bar</td>
<td>140</td>
<td>27</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>White bagel</td>
<td>1 whole</td>
<td>260</td>
<td>54</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Butter</td>
<td>14 g</td>
<td>100</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Juice</td>
<td>200 g</td>
<td>100</td>
<td>24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>6 oz</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sweet Onion Chicken Sandwich</td>
<td>6 inch</td>
<td>380</td>
<td>59</td>
<td>4.5</td>
<td>26</td>
</tr>
<tr>
<td>Subway Choc. Chip Cooke</td>
<td>1 whole</td>
<td>210</td>
<td>30</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Nutrient composition of food items used on treatment days.
Chapter 4

DATA AND RESULTS

Statistical analysis:
The data were analyzed using PASW Statistics 19.0, (Predictive Analytics SoftWare Statistics package, IBM, 2009). The data was normally distributed. Area-under-the-curve (AUC) and incremental AUC (iAUC) values were calculated using the trapezoidal rule. Time x treatment effects were assessed using the repeated-measures ANOVA test. All results are expressed as means ± SEM, and a $P$ value $\leq 0.05$ was considered significant.

Results:
Study recruitment and completion took place between May and August 2011. A total of fifteen individuals completed this study. Thirteen of the participants were females (28.4±2.9 y; BMI, 23.1±0.9 kg/m$^2$) (Table 1). Fasting glucose and insulin concentrations were below the cut-off for prediabetes (<5.55 mmol/L) and insulin resistance (<20µU/mL) for all participants (Table 2). All 15 individuals successfully completed the study. However, only 10 out of 15 participants completed diet records for each visit. Descriptive statistics did not differ significantly by gender (Table 2). There were no correlations between descriptors and fasting glucose, fasting insulin, or satiety at baseline.

Glucose values were normally distributed. Fasting glucose concentrations did not differ by treatment (range: 88.1±1.7 to 89.2±1.4 mg/dL). Glucose curves varied between treatments ($p=0.023$). Blood glucose was significantly higher one hour after ingestion of the grain bar compared to the peanut and control
treatments (p<.001). At 30 minutes after the bagel meal, the control glucose was significantly higher than for the peanut or grain bar (p=.048). Glucose did not differ significantly between groups at the remaining times (p=.676, .073, .733 and .973 at pretest, 60 min. post bagel meal, 90 min. post bagel meal and 120 min post bagel meal, respectively) (Fig. 1). However, at 60 minutes post bagel meal, glucose after the peanut preload was elevated higher than the grain bar preload. During the 180 minute time period, the iAUC for glucose did not vary significantly between preload treatments (p=.749) (Fig. 2).

Fasting serum insulin concentrations did not significantly differ by treatment (range: 5-16 µU/mL). However, insulin did vary significantly between treatments (p<.001). The insulin change one hour after grain bar consumption was significantly higher than after the peanut or control at the same time point (p<.001). The change in insulin one hour after peanut consumption was significantly higher than for the control treatment (p=.002) (Fig. 3).

Overall satiety, expressed as the 180 minute incremental AUC, differed significantly between treatment (p=.001) (Fig. 4). Perceived satiety ratings showed a significant interaction between treatments (p=.002). One hour after preload consumption, peanut and bar consumption was associated with greater satiety than the water control (p<.001). At 30 minutes post bagel meal, the grain bar was associated with greater satiety versus the water control (p=.049). The bar was also associated with greater satiety versus peanut and control at 60 and 90 minutes post bagel meal (p=.003 and .034, respectively). At 120 minutes post
bagel meal, the final satiety measurement, the bar was still associated with greater satiety than the peanuts ($p=.023$) (Fig. 5).

The complete food records (all three visits) received from ten of the participants showed that total energy intake, including test meal, on treatment days did not differ significantly between treatments ($p=.233$). However, the mean energy intake for the control group was 1879 kcals, compared to 1772 and 1756 kcals for the peanut and grain bar preload, respectively (Fig. 6)(Table 3).
At time 0, the test meal was consumed, which was exactly one hour after ingestion of the control treatment (water) or the peanut or grain bar treatment, each consumed with water. *P* values for repeated measures ANOVA interaction factor for postprandial glycemia (0.023) and for the 180 min incremental area-under-curve (0.749). At time 0, mean glucose for grain bar intervention is significantly greater than that for peanut or control (*p*<0.001); at time 30, mean glucose for control is significantly greater than that for peanut or grain bar (*p*≤0.048).

**Table 2.** Descriptive characteristics of participants (n=15)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>2F/13M</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>28.4±2.9</td>
<td>(20-58)</td>
</tr>
<tr>
<td>Height, in</td>
<td>66.6±.97</td>
<td>(61-75)</td>
</tr>
<tr>
<td>Weight, lbs</td>
<td>146.3±7.5</td>
<td>(118-234)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>23.1±0.9</td>
<td>(18-31)</td>
</tr>
<tr>
<td>Serum fasting glucose, mmol/L</td>
<td>4.9±0.1</td>
<td>(4.3-5.3)</td>
</tr>
<tr>
<td>Serum fasting insulin, uM</td>
<td>10.2±0.8</td>
<td>(5-16)</td>
</tr>
</tbody>
</table>

Data represent mean±SE; range in parentheses. Glucose and insulin concentrations were averaged from 3 fasting samples and not correlated to age, weight, or body mass index.

**Figure 1. Incremental serum glucose (mg/dL) over time (minutes).** At time 0 the test meal was consumed, which was exactly one hour after ingestion of the control treatment (water) or the peanut or grain bar treatment, each consumed with water. *P* values for repeated measures ANOVA interaction factor for postprandial glycemia (0.023) and for the 180 min incremental area-under-curve (0.749). At time 0, mean glucose for grain bar intervention is significantly greater than that for peanut or control (*p*<0.001); at time 30, mean glucose for control is significantly greater than that for peanut or grain bar (*p*≤0.048).

**Figure 2. Incremental AUC for serum glucose for the 3 hour (mg/dL) (mean ±SE).**
Figure 3. Incremental serum insulin (µU/mL) over time (minutes). Insulin differed significantly between treatments (p<.001). At time 0 the test meal was consumed, one hour after preload or control consumption. The insulin change at time 0 for the grain bar was significantly higher than for the peanut or control (p<.001). At the same time point, the change in insulin after peanut consumption was significantly higher than for the control (p=.002).

Figure 4. Incremental AUC for satiety (mm) (mean ±SE). The 180 minute AUC for satiety was significantly greater for the bar versus the peanut and control (p=.001).
Figure 5. Perceived satiety (mm) over time (minutes). At time 0 the test meal was consumed, which was exactly one hour after ingestion of the control treatment (water) or the peanut or grain bar treatments, each consumed with water. There was a significant interaction between treatments (p=0.002, repeated measures ANOVA). Both peanut and grain bar consumption were associated with greater satiety than control treatment after one hour (Time 0) (p<0.001). Grain bar consumption was associated with greater satiety versus control at 30 min (p=0.049), and grain bar consumption was associated with greater satiety versus peanut and control at 60 and 90 min (p<0.040). At 120 min, grain bar consumption remained more satiating than peanut consumption (p=0.023). The 180 min AUC for satiety was significantly greater for grain bar versus peanut and control (p=0.001).

Figure 6: 24-hour energy consumed on treatment day (kcals, including test meal). No significant difference between treatment groups (p=.233). Energy intake for control treatment was higher than both peanut and bar treatments.
Table 3. Mean energy intake (including treatment meal) for treatment day (mean±std. error)

<table>
<thead>
<tr>
<th></th>
<th>Energy (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut</td>
<td>1772±149</td>
</tr>
<tr>
<td>Bar</td>
<td>1756±144</td>
</tr>
<tr>
<td>Control (water)</td>
<td>1879±209</td>
</tr>
</tbody>
</table>
Chapter 5: DISCUSSION AND CONCLUSION

Discussion: In this randomized, crossover study, meal preloading was shown to have an impact on satiety by both subjective and objective measures. When participants were asked to subjectively assess hunger using a validated visual analog scale, hunger was significantly decreased when the individual received one of the preloads versus the control. Participants used food logs to record food intake for the remainder of the day after the trial. Calculating total energy intake provided objective data showing that individuals had lower energy intake when a preload was consumed compared to the control (water). The results of this preload study are consistent with other studies that tested the effects of meal preloading on satiety and energy intake.\textsuperscript{25,26} Rolls et al conducted a preload study using a crossover, repeated measures design comparing preloads with different macronutrient profiles to a control treatment (no preload).\textsuperscript{65} This study found that when a yogurt preload was given to normal-weight males and obese females, subsequent energy intake at the lunch meal was significantly less than when the participants received no preload. Atsbury et al investigated the effect of consuming different amounts of whey protein preloads on appetite and energy intake using a randomized, crossover design.\textsuperscript{25} The study found that energy intake following the control (flavored water) preload was significantly higher than caloric preloads regardless of the amount of kilocalories in the preload. Overall, these studies and the study discussed in this paper conclude that incorporating a
caloric preload prior to a meal will increase overall satiety and decrease subsequent energy intake, regardless of the macronutrient content of the preload.

Although increased satiety resulted from consumption of both preloads (high fat and high carbohydrate), this study found that satiety was significantly higher at certain time points when the grain bar preload was consumed compared to the peanut preload. Other preload studies have found a variety of different results when comparing the effects of high carbohydrate versus high fat foods on overall satiety. One study by Rolls et al compared the effects of carbohydrate and fat preloads on eating behaviors in obese and lean humans. The results of this study showed that the high-fat preloads suppressed subsequent intake less than the high-carbohydrate preloads. Another study by Blundell et al reported similar effects of fat versus carbohydrate foods on satiety. Blundell et al conducted experiments in lean subjects that showed that providing a 362 kcal carbohydrate supplement at breakfast suppressed appetite 90 minutes later. In the same study, the 362 kcal fat supplement at breakfast had no significant impact on overall satiety at any measured time point. The same researchers conducted an experiment in obese subjects to further assess the satiety effects of fat. This study allowed participants to eat a range of either high fat or high carbohydrate foods. The obese subjects ate twice as much from the fat items than from the carbohydrate items. Blundell et al used this data to conclude that fat has a weak impact on overall satiety. Although the results of this study imply that carbohydrate preloads may be the optimal choice to increase overall satiety, future
trials are needed to determine whether macronutrients have a different impact on overall satiety.

The results of this study support the ideas addressed by John Meyer in the glucostatic theory.28 As previously mentioned, the glucostatic theory suggests that glucose uptake and utilization are vital components of hunger control, satiety and regulation of overall energy balance. John Meyer suggested that foods with a high glycemic index appear to attenuate subsequent glycemia. In the current study, mean glucose was significantly lower 30 minutes post meal after grain bar preload consumption compared to the peanut preload (Fig. 1). Ultimately, the final blood measurement at 120 minutes after meal consumption showed that blood glucose levels were similar for the peanut and grain bar preload. In addition, insulin measurements for the grain bar and peanut preload did not peak differently at 30 minutes post meal. The insulin results displayed in this study show that although the whole grain bar is a high carbohydrate food, insulin levels did not ultimately increase more than for the low carbohydrate peanut preload. To summarize, the high carbohydrate preload did not increase subsequent glycemia or insulinemia in this trial, supporting the glucostatic theory.

The effects that meal preloading has on satiety and energy intake can be applied to Hill’s small change approach to obesity prevention and management.20 Consuming a small snack prior to consuming a meal is a behavior change that can easily be incorporated by most individuals. According to the results of this study and other similar preload studies, this small behavior change could decrease daily energy intake by approximately 100 kcals/day, increase satiety, and improve
overall glycemic control. The results of this study suggest that the macronutrient profile of a preload does affect satiety and subsequent energy intake. However, preloads in general appear to decrease subsequent energy intake and satiety.

America on the Move, a nonprofit organization, has conducted research that supports the idea that small changes can decrease weight gain and eventually lead to weight loss. This organization suggests that decreasing daily energy intake by 100 kcals will substantially affect overall health and weight status. In the current study, preloads decreased subsequent intake by greater than 100 kilocalories compared to the control. Incorporating healthy meal preloads into a food routine could potentially be an easy, non-restrictive weight loss and/or weight management tool.

**Limitations/Delimitations:**

This study has some limitations. Firstly, the sample size was small compared to other similar studies. Another limitation of the study was the completion of food logs after each visit. Only 10 of the participants turned in a food log after each visit (total of 3 logs). In addition to not receiving three food logs for each participant, research has shown that food logs lack accuracy for determining energy intake. Johnson et al found that in a large survey, 15% of adults were found to be “low-energy” reporters when completing food logs. Lastly, the participants in this study were all healthy, normal weight individuals. The small sample size and similarity of participants makes it impossible to generalize the results to other groups of individuals.
**Strengths:**

This study also has certain strengths. The crossover design of this study allowed each participant to act as his/her own control, reducing the influence of confounding variables. In addition, each participant was provided a gift card to consume a high carbohydrate meal for dinner the night before each treatment. The standardized, high carbohydrate meal allowed participants to replace carbohydrate stores prior to testing reducing the variability in individual carbohydrate stores prior to test days.

**Future Studies:**

In order to determine the specific effects of different macronutrient preloads it will be necessary to conduct additional research. Future studies would benefit from analyzing hormones that are affected by food intake such as GLP-1, ghrelin and CCK. It would also be beneficial to use qualitative research to determine if qualities of the food, such as texture, taste, and smell, have any effect on satiety ratings and subsequent hunger. Determining the physical effect of mastication on subsequent food intake is another area for future research. Limited data exists to determine whether liquid and solid foods differ in their effects on food intake and weight.

**Conclusion:**

In conclusion, data from this randomized controlled trial suggests that the grain bar and peanut preload increased satiety greater than the water preload. Grain bar consumption 1 hour prior to the test meal was associated with greater perceived satiety at 60, 90, and 120 minutes post bagel meal as compared to the
peanut and/or control treatments. Both glucose and insulin concentrations were significantly higher 1 hour after the grain bar was consumed compared to the peanut or control preload. However, the incremental area-under-the-curve for glucose for the 180 minute trial period was not significantly different between treatments, suggesting that grain bar consumption initiated immediate blood glucose and blood insulin response that did not continue after the test meal was consumed. The results of this study suggest that consuming a preload of peanuts 1 hour prior to a carbohydrate-rich meal will not result in reduced 2 hour post-prandial glycemia and insulinemia and increased satiety as compared to an isocaloric grain bar treatment, which was the original hypothesis of the study. The results also suggest that meal preloading may be a potential small change that will aide in weight loss and/or weight maintenance. Further research needs to be done to determine the most effective meal preload strategy.
REFERENCES


68. Johnson, R. (2002). Dietary Intake—How Do We Measure What People Are Really Eating?. *Obesity; 10*:63S-68S.
APPENDIX A

SATIETY SCALE
PRELOAD TRIAL

INTRODUCTION
The purposes of this form are (1) to provide you with information that may affect your decision as to whether or not to participate in this research study, and (2) to record your consent if you choose to be involved in this study.

RESEARCHERS
Dr. Carol Johnston, a Nutrition professor at Arizona State University Polytechnic Campus, and Katie Fleming, nutrition graduate student, have requested your participation in a research study.

STUDY PURPOSE
The purpose of the research is to examine how peanut and whole grain bar consumption one hour prior to the ingestion of a buttered bagel and juice meal affect blood glucose and satiety levels.

DESCRIPTION OF RESEARCH STUDY
You have indicated to us that you are 21-60 years of age, generally healthy, and non-diabetic. This study will initially involve the completion of a brief health history questionnaire to demonstrate the absence of medical conditions that may impact the study. Your weight, height, and waist circumference will be measured at this time. This first meeting will take <45 minutes. This research study includes three trial days, each consisting of 6 finger sticks and 3 blood draws from an arm vein. The each trial will last approximately 4 hours each and are spaced one week apart.

The day prior to testing you will need to avoid caffeine and alcohol and refrain from moderate to vigorous activity, and you will consume a standardized dinner meal at night (a sub sandwich, cookie, and drink). The following morning, you will report to the test site in a rested (no moderate to intense exercise for 24 hr) and fasted (no food or drink except water for 12 hours beginning at the completion of the dinner meal) condition. Blood samples will be collected from an arm vein and using a finger stick prick. You will then consume the preload (peanuts or whole grain bar), wait one hour, and then consume a meal composed of a bagel, butter, and juice drink. Immediately prior to and at 30, 60, 90, and 120 minutes after you consume the test meal, finger sticks will be performed. Blood samples will also be collected from an arm vein immediately prior to and at 30 minutes post meal consumption. Blood samples will be analyzed for glucose and insulin. The amount of blood drawn from an arm vein is less than 2 teaspoons per draw. During the 2-hour post-meal period when data are being collected, you may read, work on a computer, or move about the room; however, you will be asked to refrain from consuming additional food and beverages (except water). Each time blood is collected, you will be asked to record feelings of satiety on a scale of -100 to 100. Once the trial is completed, you will be asked to record all food and beverages consumed the remainder of the day.

On the days between trials, you can consume your normal diet and physical activity patterns. If you deviate from your routine diet, or if you begin taking medications, at any time between experiments, you are to notify the investigators of the study. The three trials will take place at the ASU nutrition department in the Health Science Center at the Polytechnic Campus. Study meals and foods will be provided at no charge. Up to 100 subjects will participate in this study.

RISKS
The experimental diets are composed of foods and drinks currently available for purchase and consumption (peanuts, whole grain bar, bagel, butter, and juice). If you have an allergy to any of these foods, you cannot participate in this trial. The trained investigator will be performing finger sticks under standard and sterile conditions. Venous blood will be collected by a research nurse. Temporary bruising of the skin or a feeling of faintness is possible.

BENEFITS
This study will provide information regarding the usefulness of meal preloads for controlling blood glucose concentrations and satiety levels following a meal.

NEW INFORMATION
If the researchers find new information during the study that would reasonably change your decision about participating, then they will provide this information to you.
CONFIDENTIALITY
All information obtained in this study is strictly confidential unless disclosure is required by law. The results of this research study may be used in reports, presentations, and publications, but your name or identity will not be revealed. In order to maintain confidentiality of your records, the investigators will use only subject codes on all data collected. Any papers with identifiers (screening materials and consents) will be securely housed in her locked ASU office with access limited to study personnel.

WITHDRAWAL PRIVILEGE
You may withdraw from the study at any time for any reason without penalty or prejudice toward you. Your decision will not affect you in any manner.

COSTS AND PAYMENTS
During the experimental periods, you will be provided with free food and beverages. You will also receive three $25 gift certificates to Target during the study.

COMPENSATION FOR ILLNESS AND INJURY
If you agree to participate in this study, then your consent does not waive any of your legal rights. However, in the event of harm, injury, or illness arising from this study, neither Arizona State University nor the researchers are able to give you any money, insurance coverage, free medical care, or any compensation for such injury. Major injury is not likely but if necessary, a call to 911 will be placed.

VOLUNTARY CONSENT
Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Carol Johnston; 6650 E. Williams Field Rd., Mesa, AZ 85212 (carol.johnston@asu.edu, 480-727-1713) or by Kaitie Fleming, graduate student (kaitie.fleming@asu.edu).

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Research Compliance Office, at 480-965-0788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to you.

Your signature below indicates that you consent to participate in the above study.

Subject’s Signature _________________________ Printed Name ___________________________

Contact Phone number __________________________ Email __________________________

SIGNATURE: __________________________

INVESTIGATOR’S STATEMENT
"I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided the subject/participant a copy of this signed consent document."

Signature of Investigator ____________________________ Date ____________________________
APPENDIX C

PARTICIPANT INSTRUCTIONS
Preload Study Instructions
Thank you for participating in this study. This sheet contains some important information regarding the study. Please feel free to email/call me if you have any questions. (email: krflemin@asu.edu, phone: 406-490-3316)

Day Prior to the Study
- Refrain from consuming any caffeine.
- Do not engage in any intense physical exercise.
- Eat a Subway dinner (gift card provided)
  - 6 inch/foot long Sweet Onion Chicken Teriyaki Sandwich with a cookie and a drink.
- Refrain from eating 10 hours prior to your scheduled visit.

Day of your Appointment
- Report to the testing facility fasted for your scheduled appointment.
- All appointments will be held in the Health Sciences Building, room 1449, Polytechnic Campus.

After your Appointment
- Record all foods eaten for the remainder of the day.

Study Appointments
Appt. 1: ________________________________
Appt. 2: ________________________________
Appt. 3: ________________________________
APPENDIX D

IRB APPROVAL
To: Carol Johnston  
HSC

From: Mark Roose, Chair  
Soc Beh IRB

Date: 06/24/2011

Committee Action: Amendment to Approved Protocol

Approval Date: 05/24/2011

Review Type: Expedited F12

IRB Protocol #: 1101005933

Study Title: Complementary Foods for Suppression of Appetite and/or Glycemia in the Postprandial State

Expiration Date: 01/30/2012

The amendment to the above-referenced protocol has been APPROVED following Expedited Review by the Institutional Review Board. This approval does not replace any departmental or office approvals that may be required. It is the Principal Investigator’s responsibility to obtain review and continued approval of ongoing research before the expiration noted above. Please allow sufficient time for reapproval. Research activity of any sort may not continue beyond the expiration date without committee approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported as research data. If you do not wish continued approval, please notify the Committee of the study termination.

This approval by the Soc Beh IRB does not replace or supersede any departmental or oversight committee review that may be required by institutional policy.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Soc Beh IRB immediately. If necessary, a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Soc Beh IRB. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.
APPENDIX E
VISIT TIMELINE
• 7:00 AM-Satiety/Blood
• 7:15 AM-Preload + water
• 8:00 AM-Satiety/Blood
• 8:15 AM-Bagel, butter, juice
• 8:45 AM-Satiety/Blood
• 9:15 AM-Satiety/Blood (finger)
• 9:45 AM-Satiety/Blood (finger)
• 10:15 AM-Satiety/Blood (finger)