PREDICTORS OF ACUTE DIETARY COMPENSATION AMONG SEDENTARY WOMEN AFTER FREE-LIVING MODERATE INTENSITY EXERCISE

by

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(Under the Direction of Michael Schmidt)

ABSTRACT

The purpose of these analyses was to identify individual characteristics that may predict changes in acute compensatory responses associated with exercise. Sedentary women's total day and 3-hour dietary intake for total calories (TOT), carbohydrate (CHO), protein (PRO), and fat (FAT) was evaluated on a selected exercise and non-exercise day during an 8-week walking intervention. Results indicated increased 3-hour dietary intake with exercise. Dietary restraint was positively associated with total day FAT ($r = 0.29$) compensation. Disinhibition was positively associated with 3–hour TOT ($r = 0.32$), CHO ($r = 0.29$), PRO ($r = 0.30$), and FAT ($r = 0.27$) compensation. Ability to delay gratification (food) was negatively associated with 3-hour PRO ($r = -0.52$) compensation. Acute compensatory responses to exercise did occur in free-living settings. Individual characteristics, such as dietary restraint and disinhibition, may make individuals more susceptible to compensate following exercise.

INDEX WORDS: acute compensation; psychological traits; eating behavior traits; compensatory responses; individual variability

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DEDICATION

I dedicate this thesis to the following individuals, all of whom have been by my side to support and encourage me through this process. The constant encouragement from these individuals has helped me to succeed in my endeavors and reach my full potential.

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CHAPTER 1

INTRODUCTION

Maintaining energy balance is important in order to prevent overweight and obesity. Energy balance maintenance requires an individual's energy intake to equal their energy expenditure. When this homeostasis occurs weight is kept constant among individuals [1]. If one of these factors (energy expenditure or energy intake) becomes more predominant than the other a negative or positive energy balance will result. A negative energy balance occurs when energy expenditure exceeds energy intake. This promotes weight loss in individuals and is the preferable and recommended energy balance status for individuals looking to lose weight [2, 3]. A positive energy balance occurs when energy intake exceeds expenditure [4]. This typically is an unfavorable energy balance status as it often results in weight gain and other negative health consequences.

A net positive energy balance is a contributing factor to the increase in overweight and obesity seen in the United States [5]. Currently two-thirds of men and women in the United States are overweight with 35% being classified as obese [6]. A major contributor to this increase in overweight and obesity over the last 30 years is the decrease in physical activity and subsequent increase in sedentary behavior. Currently in the United States, 32% of people report participating in no leisure time physical activity [7].

Moderate intensity exercise is recommended to help prevent overweight/obesity, and promote weight loss. Physical activity recommendations consist of 150 minutes of moderate intensity exercise per week or 75 minutes of vigorous intensity exercise per week or a combination of the two [8]. In the United States, less than 48% of the population meets this recommendation [7]. Individuals trying to lose weight are encouraged to achieve greater levels of physical activity consisting of approximately 300 minutes of moderate intensity activity or 150 minutes of vigorous intensity activity per week [8]. These higher levels of activity should result in the negative energy balance required to produce weight loss.

However, upon participation in an exercise program, weight loss does not always occur as predicted based on energy expenditure. When weight loss through exercise occurs in women, the average amount of weight lost is seen to only be approximately 30% of predicted weight loss [3]. Nevertheless, in some individuals there is no change in weight and in others an increase in weight occurs in response to the exercise program. The inability of exercise to produce the expected degree of weight loss is of concern since it is an integral component of most weight loss and weight management programs.

The implications of this lack of weight loss suggest that there are mediating factors occurring in individuals that are influencing energy balance and thus mitigating the amount of weight being lost. The less than expected weight loss among many individuals is believed to be attributed to behavioral compensatory responses. [3, 9, 10]. Behavioral compensatory responses are actions that an individual takes as a response to their participation in structured exercise. These responses may be adverse behaviors such as increasing energy intake or being less active during non-exercise periods or a combination of both. It is these changes in behavior that are suspected of being the greatest barrier to weight loss. Moreover, while changes in dietary intake and physical activity are both behavioral compensatory responses, dietary intake is 100% behavioral [5, 9]. It is therefore suggested that this component may be more influential in impeding weight loss through participation in an exercise intervention. Accordingly, it is important to fully understand the effects of exercise on dietary behaviors in individuals trying to lose or maintain body weight.

While both long and short term changes in compensatory responses to exercise are important to describe, the focus of this research project was restricted to acute compensatory responses. Following an acute bout of exercise, minimal to no compensatory responses in energy intake have been shown to occur [9-14]. While this suggests the potential for exercise to induce a negative energy balance in the short-term it should be noted that most of these studies have been conducted in laboratory settings and not in free-living conditions. The setting in which an individual eats can profoundly influence their dietary habits [15]. The controlled laboratory setting is not a “natural” setting for individuals and therefore may not reflect habitual eating habits that would occur in response to exercise. Moreover, laboratory settings often only have select food options that may not consists of choices preferable to the participants. It is therefore necessary to examine the compensatory behaviors that occur when there are no limits to the food choices that can be made with no observation of choices being made, the latter factor potentially being influenced by social desirability. It is in a free-living environment that natural behavioral responses to exercise can best be studied.

Existing research has primarily focused on group-level compensatory responses to exercise. Group analysis can mask inter-individual variations in changes in eating habits brought on by participation in exercise. Focusing on inter-individual variation is necessary to determine how individuals respond to acute exercise. By distinguishing those individuals who increase their energy intake after exercise from those individuals who do not increase their energy intake after exercise we can then go on to further ascertain the factors that may predispose individuals to compensate following an acute bout of exercise.

Personality traits of individuals may be one of these predisposing factors that can predict whether an individual is likely to compensate to exercise through an increase in energy intake [11, 16-18]. Numerous studies have looked at the eating behavior traits of dietary restraint and disinhibition [9, 11, 17, 18] and post-exercise energy intake. These studies have shown a negative [11, 14] association with dietary restraint and a positive [19] association with disinhibition and post-exercise energy intake following an acute bout of exercise. Other personality traits, particularly sensitivity to reward [5, 9, 18, 20, 21], impulsivity [18, 20, 21], and ability to delay gratification [18] may also play a role in compensatory behavior following an acute bout of moderate intensity exercise. However, the relationships between these personality traits and acute compensation have been incompletely characterized.

There may also be other non-personality related factors that can influence dietary intake following exercise. There is evidence that compensatory responses are greater among overweight and obese compared to lean women [22] . However, other studies have reported that lean women have a hyperphagic response to exercise whereas overweight/obese women do not [12, 19]. It is logical to assume that body composition would contribute to how one responds to an exercise session; however, the exact nature in which body composition contributes to eating habits after exercise remains unclear. In addition, exercise timing may be influential in the eating responses that take place following exercise. Only one study to date has looked at the time of day effect of an acute bout of exercise on energy intake in women and determined that time of day did not influence energy intake [23]; however, further study is warranted.

Among individuals seeking to maintain or lose weight, increasing energy intake after an acute bout of exercise can negate or reverse the negative energy balance induced by exercise. There are individuals that are clearly more at risk for this phenomenon than others, making the identification of predictors to compensation an important priority. This study will attempt to expand on the current research in acute compensatory responses to exercise and fill in current gaps in the literature regarding predictors of acute compensatory responses after an exercise session among free-living individuals.

Statement of the Problem

Due to the continual rise in overweight and obesity over the last 30 years, efforts to identify the factors contributing to an inability of individuals to lose or maintain weight has been of much importance. Recently, compensatory behavioral responses to exercise have become a prominent area of focus. These recent efforts attempt to quantify which behavioral variables contribute to the inability of individuals to maintain a negative energy balance following exercise. Evidence suggests that a change in eating behavior following exercise is an important component of this behavioral response [3, 9, 10]. Therefore, identification of individual traits that make persons more susceptible to partake in this compensatory response will help future efforts for individually tailored weight loss and weight management programs. Moreover, due to our contemporary obesogenic environment it is important to identify individuals prone to consume an increased amount of food from this environment. Compensatory dietary responses following exercise in the free-living environment has been under-studied. Furthermore, there is a need to better understand the extent to which psychological factors may influence eating behaviors following exercise performed in a free-living setting.

Statement of Purpose

The purpose of this study was to further the understanding of acute dietary compensatory responses following free-living exercise. Specifically, the goal was to examine the influence different eating behavior and psychological traits have on energy intake following exercise and how these responses are potentially influenced by body composition and timing of exercise during the day.

Specific Aims

Aim 1: To examine the associations between sensitivity to reward, impulsivity, and ability to delay gratification on acute dietary compensation following free-living exercise bouts in previously sedentary women.

Hypothesis 1: Women who show increased sensitivity to reward, increased impulsivity, and an inability to delay gratification will have greater dietary compensation.

Aim 2: To examine the associations between eating behavior traits (dietary restraint and disinhibition) on acute dietary compensation following free-living exercise in sedentary women.

Hypothesis 2: Women who have decreased dietary restraint and increased disinhibition will have greater dietary compensation.

Aim 3: To examine the extent to which body composition and exercise timing influence acute compensatory responses following free-living exercise in sedentary women.

Hypothesis 3: Women who are overweight and obese and women who perform exercise in the morning will have greater dietary compensation.

Delimitations

I. All subjects were sedentary, premenopausal 25-45 year old females living in and around Athens, Georgia.

II. All subjects had no physical limitations that prevented them from participating in moderate intensity activity.

III. All subjects had no pre-diagnosed mental health conditions.

IV. All subjects were not taking any medication that would alter their mood or eating habits.

Limitations

I. Use of the National Cancer Institute's ASA-24 program to quantify dietary intake could have resulted in errors in our measure of dietary compensation.

II. This study only compared acute behavioral compensatory responses for one exercise day and one non-exercise day for each subject. Looking at acute behavioral responses on several exercise and non-exercise days may be more beneficial in order to fully portray if and how an individual compensates to exercise.

III. Subjects acted as their own controls and therefore were not randomized into different experimental groups. Nor were the completion of an exercise day and a non-exercise day completed in a randomized manner.

IV. There could have been other environmental and social influences on eating behavior outside of exercise that may have influenced eating on the respective exercise and non-exercise day.

V. A minimum accelerometer vector magnitude cut point of 2,691 counts or above was used to establish a moderate intensity walking bout for all subjects. However, the relative intensity of an exercise bout is different across individuals and therefore not all subjects may have been walking at the same relative intensity. The relative intensity of the walking bout for each subject could potentially influence eating behavior responses following exercise.

Assumptions

I. All dietary recalls were completed honestly and as accurately as possible for food intake and portion sizes.

II. All psychological questionnaires were answered honestly and accurately.

III. The exercise and non-exercise days selected for analysis were representative of typical behavior.

Definition of Terms

<u>Delay of Gratification:</u> Individual’s ability to postpone immediate gratification and participate in behavior related to longer term outcomes [24].

<u>Dietary Compensation:</u> An increase in energy intake due to participation in exercise.

Dietary Restraint: Conscious reduction in energy intake in order to create a negative energy balance [16, 18, 25, 26].

Disinhibition: Individual's tendency towards overeating in the presence of external stimuli [25, 26].

Energy Balance: A measure of biological homeostasis determined through energy intake and energy expenditure.

Energy Intake: The total consumption of calories from food.

Energy Expenditure: The total amount of work done through contributions from three main components: basal metabolic rate, thermogenesis from food, and physical activity.

Impulsivity: The tendency to think, control, and plan insufficiently resulting in a maladaptive response [20, 27, 28].

Non-Exercise Activity Thermogenesis: Energy expenditure that comes from physical activity done outside of exercise as well as energy expenditure from activities of daily living, fidgeting, maintaining posture, and muscle contractions [9].

Sensitivity to Reward: Responses to conditioned and unconditioned rewarding stimuli [29].

CHAPTER 2

REVIEW OF LITERATURE

Energy balance is important for weight management with a negative energy balance promoting weight loss and a positive energy balance promoting weight gain over time. The factors that influence energy balance can be classified into two primary categories: biological and behavioral. Behavioral factors can further be broken down into energy intake and energy expenditure. Changes in these two behavioral factors can significantly influence the energy balance of a person. Energy expenditure can be increased through participation in physical activity and exercise and induce a negative energy balance if energy intake is held constant. However, increases in energy intake can minimize or entirely negate the induced caloric deficit. Dietary responses after exercise are variable among individuals and the individual characteristics making one susceptible to detrimental dietary responses post-exercise remains to be fully characterized. Evaluation of psychological traits may expose personality characteristics that predict how an individual will respond to exercise in terms of their eating behaviors. Furthermore, the influence of body composition and timing of exercise may modify the acute dietary behavioral responses.

Role of Energy Balance in Overweight and Obesity

Energy balance is modulated by the regulation of energy intake and energy expenditure. Energy expenditure is comprised of three main components: basal metabolic rate, thermic effect of food, and activity thermogenesis. Basal metabolic rate is an individual's energy that is expended in a resting state. Thermic effect of food is the increased energy that is expended due to the digestion of food and absorption and metabolism of ingested nutrients. Activity thermogenesis is the energy expended from physical activity and can be further divided into two components: exercise thermogenesis and non-exercise thermogenesis. In the typical adult, basal metabolic rate, thermic effect of food and activity thermogenesis account for 60%, 10-15%, and 25-30% of total energy expenditure, respectively [4]. Energy intake comprises everything that an individual consumes over the course of a day and is comprised of three major macronutrients: carbohydrate, protein, and fat [30]. To ensure maintenance of energy balance, energy intake must equal energy expenditure. When energy intake exceeds energy expenditure a positive energy balance ensues.

Continual maintenance of a positive energy balance promotes weight gain and the development of overweight and obesity in individuals. In our current society where overweight and obesity has become an epidemic, with two-thirds of individuals in the United States being classified as overweight or obese [7], it is important to identify the factors that are contributing to a persistent positive energy balance among a high proportion of individuals.

Factors Influencing a Positive Energy Balance

Both physiological and behavioral factors [9, 31, 32] can contribute to the development of a positive energy balance. Physiological factors that promote a positive energy balance include a decrease in basal metabolic rate [25, 31] as well as a decrease in thermogenesis from food [31]. Physiological factors promoting a positive energy balance are believed to be protective mechanisms to prevent starvation and continual, indefinite weight loss [9]. These responses ultimately resist any deliberate energy deficit efforts.

Behavioral factors have been shown to play a greater role in the formation of a positive energy balance. Behavioral factors include changes in energy expenditure and changes in energy intake [1, 3]. Behavioral changes in energy expenditure come from changes in exercise thermogenesis and non-exercise thermogenesis. Since physical activity is the largest source of individual variability in energy expenditure [1, 4, 33] the low levels of physical activity seen among the adult population today may strongly impact energy balance. Changes in energy intake can be pernicious to energy balance and potentially more potent. Changes in energy intake that promote a positive energy balance occur by either increasing the amount of food consumed or by consuming the same amount of food but more energy dense food.

Behavioral Compensatory Responses to Exercise

When the aforementioned responses occur as a result of the initiation of, or participation in, exercise they are termed compensatory responses because they contribute to attenuating or completely reversing the negative energy balance created by exercise. Biological factors that contribute to a positive energy balance after exercise can be termed automatic compensatory responses [9]. These responses are obligatory and inevitable, believed to be programmed so as to prevent a negative energy balance. On the other hand, behavioral factors that promote a positive energy balance after exercise are termed volitional compensatory responses [9]. These responses are facultative and are in one’s control. Behavioral (volitional) compensatory responses to exercise have been shown to be the greatest barrier to maintaining a negative energy balance following exercise [9, 28, 34]. The two most common behavioral compensatory responses to occur following exercise are a decrease in non-exercise activity thermogenesis (NEAT) and an increase in post-exercise energy intake [3, 9, 34].

NEAT, also referred to as spontaneous physical activity, is energy expenditure that comes from physical activity outside of exercise as well as energy expenditure from activities of daily living, fidgeting, maintaining posture, and muscle contractions [4, 9]. Evidence suggests that following exercise individuals partake in less physical activity outside of the exercise session as compared to a non-exercise day [3]. Stubbs et al. [35] showed that during a 7-day exercise intervention subjects progressively reduced their daily energy expenditure from day 1 to day 7. In a more acute study by Alahamdi et al. [36] overweight and obese men had 16% and 25% reduced NEAT on day 3 after moderate and high intensity exercise, respectively. However, since only the NEAT component of total energy expenditure is a behavioral construct it is believed to be the less influential of the behavioral compensatory responses.

When individuals increase their energy intake following exercise in order to make up for the energy they expended during the exercise session, this is deemed compensation. Increases in energy intake following exercise are considered to be more potent than changes in NEAT [9]. This is because energy intake is 100% behavioral [9], whereas energy expenditure from NEAT is only 40% behavioral [3]. It should be noted though that increases in energy intake following exercise can occur in a variety of ways: increased eating frequency, increased meal size, larger portions eaten, or consumption of more energy dense foods [9]. Importantly, the undoing of a negative energy balance through compensatory increases in energy intake can take mere minutes. For example, expending 600 calories through exercise would take at least 60 minutes but consumption of 600 calories of food can take 3-4 minutes [9].

Both acute and chronic compensatory responses to exercise are of contemporary research interest. Since behavioral regulation of energy balance is more tightly controlled in humans for periods of less than one week [32] behavioral compensatory responses to a single exercise session may present differently than to a longer exercise intervention.

Acute Dietary Compensation to Exercise

The majority of evidence from acute compensation studies suggest no to very minimal increase in acute energy intake following exercise [9-14, 23]. There are several studies however that have shown an increase in acute energy intake following an exercise bout ranging from approximately 80 – 470 kcal/day [37]. In an early study by Verger et al. [38] 13 college aged (20-25 years) men (n=8) and women (n=5) of normal weight (BMI 19.5 ± 1.7 kg/m^2 and 23.4 ± 1.5 kg/m^2 for men and women, respectively) participated in a 2 hour exercise session comprised of various athletic aerobic events. Subjects completed four exercise sessions with the delivery of a meal, consisting of two high-protein, one high-lipid, and two high carbohydrate foods, after exercise varying from immediately after to 30 minutes, 60 minutes or 120 minutes after. Following an exercise session, subjects ate approximately 470 kcals more during the meal following the exercise as compared to the meal at the same time on a non-exercise day. Moreover, in this study it was shown that the longer the meal was delayed following exercise the greater the energy intake during the meal, with subjects consuming the most calories when the meal was served two hours after exercise as compared to right after exercise. A study conducted in middle-aged (n= 36, 26 ± 7 years) sedentary, pre-menopausal females

(BMI 27 ± 3 kg/m^2) showed similar increases in energy intake following an exercise session [19]. Subjects participated in a control, non-exercise session and an exercise session consisting of 60 minutes of moderate intensity walking. Following each session subjects were taken to a cafeteria where they were allowed to eat ad-libitum and select from a wide variety of foods. Participant's immediate, post-exercise lunch meal was recorded for energy intake by researchers. In addition, subject's 12-hour energy intake (including lunch) was recorded through the use of food diaries. Following exercise, immediate post-exercise energy intake was approximately 80 calories greater than on the non-exercise day and 12 hour energy intake was approximately 133 calories greater than on the non-exercise day. Additional evidence shows that sedentary individuals do not have as much short-term control of food intake compared to active individuals [11, 20, 25, 39] and this may make them more at risk for acute compensation following exercise.

It should be noted that the majority of acute compensatory studies have been conducted in research laboratories with only select food options available for post-exercise dietary intake. In these laboratory studies, subjects are removed from their natural environment, which can result in subjects deviating from their usual eating behaviors. No studies were identified to have evaluated acute dietary compensation following exercise in a completely free-living situation. It is important to quantify how exercise performed in a free-living environment influences acute, post-exercise, ad-libitum food intake in a free-living setting. It is only through studies conducted in free-living environments that we can accurately determine how individual's compensatory responses deviate from controlled conditions [31, 40].

Individual Variability in Acute Dietary Compensatory Responses

The majority of studies that have looked at energy intake following exercise have looked at compensatory responses in terms of group means. Recent evidence suggests that it may be more informative to look at individual variability in compensatory responses to exercise [9, 11, 41]. Evaluating inter-individual variability in post-exercise energy intake responses may reveal insights into compensatory responses following exercise that are not evident with the group analysis.

Recently, two studies [41, 42] have explicitly looked at this issue of individual variability in acute compensatory responses. In Hopkins et al. [41] 16 sedentary, overweight and obese (BMI 29.6 ± 4.0 kg/m^2) females (39.3 ± 10.3 years) completed an exercise session consisting of cycling at 70% VO_{2max} for a duration that elicited an energy expenditure of 400 calories and a time-matched no exercise control session. Following exercise, variable responses in energy intake (−234.3 to 278.5 kcals) was seen among subjects with 56% of subjects having consumed the same amount or less after exercise and 38% having consumed more after exercise. The study by Unick et al. [42] had 19 sedentary, pre-menopausal, overweight and obese (BMI between 25 – 39.9 kg/m^2) women between the ages of 18 – 45 years complete 40 minutes of moderate intensity walking and a time matched rest condition. In 1-2 hours following each session, subjects were presented a buffet style meal in which they could eat ad-libitum. Following exercise, 58% of subjects had a lower energy intake compared to the non-exercise day and 42% of subjects had a higher energy intake. Conclusions from both studies suggested that individuals vary significantly in the direction and magnitude of acute dietary compensatory responses following exercise. These two aforementioned studies are seminal in highlighting the importance of inter-individual variability in acute exercise dietary compensation.

When individual compensatory responses are examined there are two distinct groups that form. These groups are termed “compensators” and “non-compensators”. The compensators are those individuals who increase their energy intake in response to exercise and the non-compensators are those who decrease or do not change their energy intake after exercise. Since few studies have closely looked at the individual variability in acute compensatory responses, further study is warranted to quantify this variability among individuals in a free-living setting.

Moreover, while the presence of individual variability in acute compensatory responses has been noted, the characteristics that contribute to an individual being a compensator or non-compensator have only begun to be studied. Further investigation into the psychological characteristics of individuals who are compensators versus non-compensators may shed light into what makes some individuals more susceptible to compensatory responses and what makes others resistant. Identifying these traits in an acute setting may be pertinent for success in long term goals such as weight loss or weight maintenance. It is speculated that those individuals who compensate early (in an acute setting) will likely compensate the most in a long-term exercise intervention [9]. Therefore, finding the predominant traits displayed by individuals who compensate to just an acute bout of exercise may help in the determination and identification of individuals potentially most susceptible to long term compensation.

Eating Behavior and Psychological Traits as Predictors of Acute Dietary Compensatory Responses

The obesogenic environment makes the amount and variety of food available ubiquitous. However, despite this level of food availability and the temptations in the food environment there are still individuals who remain lean. This suggests that the psychological traits a person does or does not possess may moderate how they interact with this food environment [28]. Only in the past two decades has evidence begun to emerge on the roles psychological and eating behavior traits play on food intake, and only even more recently have their roles in regards to compensatory responses with exercise begun to be evaluated. The role of dietary restraint and disinhibition on acute dietary compensation following exercise has been well studied; however; other personality traits such as sensitivity to reward, impulsivity, and ability to delay gratification have been identified to play an important role on food intake but their exact role in acute dietary compensatory responses has yet to be determined. Therefore, this direction of research shows promise in identifying possible psychological traits that may predict susceptibility to acute compensatory responses. The eating behavior and psychological traits described below have been shown to be steady and enduring influences on eating behavior and not susceptible to day-to-day changes [31, 43]. Therefore, these traits may be relevant for identifying those individuals at constant vulnerability to overeat and most susceptible to compensatory responses following exercise.

Dietary Restraint and Disinhibition

Dietary restraint, otherwise known as volitional inhibition, is the conscious reduction in energy intake in order to create a negative energy balance [16, 18, 25, 26]. This concept comes from the development of Restraint Theory, which postulates that eating behaviors are under cognitive rather than physiologic control [17, 44]. At one end of the spectrum there are unrestrained eaters who give little thought to the kind and amount of food that they eat. At the other end of the spectrum are restrained eaters who are constantly concerned with their food intake. It is plausible that where one falls on the restraint spectrum will influence their daily energy intake.

Dietary restraint has a strong influence on food intake in individuals. A high level of dietary restraint is associated with a decreased level of food consumption whereas a low restraint level is associated with overeating [17, 18]. Lawson et al. [26] showed that individuals of low dietary restraint are 4.1 times more likely to consume over 2,500 calories a day than individuals of high dietary restraint. In a study by Lauzon et al. [45] highly restrained middle age women were found to have a lower energy intake (9,678 ± 313 kJ/day) compared to medium (10,541 ± 351 kJ/day) and low restraint (10,513 ± 349 kJ/day) individuals. Studies conducted in a natural setting have shown that high levels of restraint result in less overeating among individuals [17].

An individual's cognitive approach to eating can be influential in their eating response following exercise [16]. Hill et al. [19] proposed that exercise would affect restrained versus unrestrained individuals differently. He postulated that restrained individuals would be less sensitive to exercise induced changes in hunger or appetite. These individuals would maintain a tighter control over their food intake and consequently would not consume as much food following exercise as unrestrained individuals. On the other hand, it has been postulated that for restrained individuals certain events may act as a disinhibitor and serve to release their tight control over their energy intake [46]; exercise could be a potential disinhibitor that may cause restrained individuals to break their restraint and overeat. Acute exercise studies in a laboratory setting have demonstrated that a single bout of exercise does not increase energy intake in restrained or unrestrained women [47-49]. The free-living food environment may present different temptations than a laboratory setting on eating behavior following exercise in restrained and unrestrained individuals and therefore this trait could present as a potential driver for compensatory behavior.

Restraint's role on energy intake is unfortunately not straight forward as its influences are moderated by body mass index (BMI) [1, 17, 18, 37]. Obese individuals tend to show low levels of dietary restraint compared to their normal weight counterparts [18]. Within the normal weight category, a positive association is seen between weight and restraint [17] whereas in the obese category, a negative association is seen between weight and restraint [17]. The Hill et al. [1] model of dietary restraint and body composition postulates that unrestrained lean individuals will have increased energy intake following exercise because they are theoretically more sensitive to changes in energy demands and more responsive to the physiological cues of hunger and satiety. Hill's model further postulates that unrestrained overweight/obese individuals will not increase energy intake after exercise because these individuals will not experience the same changes in hunger as their lean counterparts.

Disinhibition is defined as an individual's tendency towards overeating in the presence of external stimuli [25, 26, 43]. Disinhibition has been shown to be positively associated with BMI [43] and obesity [43, 50], suggesting that it influences eating behavior and dietary intake. Research from several studies has shown that this eating behavior trait is influential in food intake and is associated with a tendency towards eating high-fat and sweet foods [43]. Preload studies demonstrated that individuals with high levels of disinhibition ate more, independent of restraint status [43]. Furthermore, in two studies that did not administer a preload, similar responses were seen. Lawson et al. [26] showed that among 18 – 49 year old women, those who reported high levels of disinhibition had a frequency of overeating 2.5 times more than women with low levels of disinhibition (18.5 vs. 7.3 times over a 2 week period). Similarly, a study by Lauzon et al. [45] reported that middle–aged women with high disinhibition had a higher energy intake than women with low disinhibition (11,029 ± 357 kJ/day vs. 9,663 ± 363 kJ/day, $p < 0.05$).

After exercise, individuals with high levels of disinhibition are more likely to overcompensate than their counterparts [17, 43]. In a chronic exercise study by Keim et al. [51] subjects completed a 4 month exercise intervention. Subjects who were characterized as overeaters ate consistently more than undereaters on exercise days (2,536 kcals versus 1,353 kcals). Those who overate during the exercise intervention where also characterized as having high disinhibition. In a more acute exercise study by Visona and George [19], subjects completed one bout of exercise with immediate and 12 hour energy intake observed following exercise. Subjects with high disinhibition had greater absolute energy intake 12 hours after exercise completion compared to their counterparts (1496 ± 445 vs. 1246 ± 224 kcals).

While associations between dietary restraint and disinhibition with compensatory responses have been rather well studied, the associations between these eating behavior traits and macronutrient intake changes following exercise have not been well characterized. With regard to general macronutrient intake, Lauzon et al. [45] showed that females with higher dietary restraint had a greater protein intake and adults with higher disinhibition had a greater percent of their energy intake from fat than their counterparts. Another study by Kiem et al. [51] supports this notion by showing that among overweight women those with high disinhibition scores had a diet proportionally higher in fat. While these studies did not explicitly look at changes in macronutrient intake following exercise they present groundwork for possible acute exercise influences on macronutrient responses among women.

Sensitivity to Reward

Sensitivity to reward is defined as responses to conditioned and unconditioned rewarding stimuli [29]. This personality trait is related to the Behavioral Approach System (BAS) first defined by Gray in 1976. The BAS system is a reward system that responds to incentives by activating behavior to obtain specific rewards [21]. Greater trait sensitivity to reward reflects a greater activation of the BAS system and thus results in an increase in appetitive motivation [21]. Sensitivity to reward presents itself on a spectrum with the low end of the spectrum being anhedonia and the high end of the spectrum being hedonia. Anhedonia is characterized by a diminished ability to experience pleasure from natural or expected rewards whereas hedonia is characterized as an enhanced ability to experience pleasure from natural rewards [52].

Sensitivity to reward is rooted in the mesolimbic dopamine (DA) pathway. This pathway plays a vital role in appetitive and consummatory motivated behaviors [52]. The DA system plays a vital role in eating and survival and is influenced by the amount of dopamine released, the density of receptors, and the swiftness of dopamine transport back to the cell [53]. Evidence shows that individuals differ in the availability of dopamine and the functioning of the DA pathway [52, 53]. This suggests that individual differences in appetitive responses can be expected as a result of the individual differences in the functioning of the DA pathway.

Sensitivity to rewards has been shown to be prominent in addictive behaviors such as alcohol, drugs, and nicotine [54, 55]. Recent evidence suggests that there are biobehavioral parallels between overeating and other addictive behaviors [28, 53, 55, 56]. This insinuates that even natural rewards such as food can stimulate the reward system in ways analogous to other addictive behaviors. If individuals find food rewarding they are more likely to engage in behaviors, such as overeating, that give them this pleasurable outcome (35).

Empirical evidence demonstrates that the extreme ends of sensitivity to reward (anhedonia and hedonia) commonly present themselves in eating disorder patients. Individuals who suffer from anorexia nervosa show low levels of sensitivity to reward compared to healthy controls while individuals who suffer from binge eating disorders display high levels of sensitivity to reward [57]. Consequently the hedonic aspects of food may play an important role in appetite and contribute to eating behaviors. This notion has been further evaluated among healthy populations with self-report measures of sensitivity to reward positively associated with overeating [27, 55, 56] and BMI [29, 58].

In a study by Davis et al. [55], 25- 45 year old women with higher sensitivity to reward as measured by the collapsed BAS scale had greater overeating episodes. Moreover, a study conducted by Guerrieri et al. [27] showed that in a varied food environment (such as the current obesogenic environment) sensitivity to reward influenced calorie intake to a greater extent than in a monotonous food environment, further emphasizing the role this personality trait may play in regulating energy intake.

While evidence shows that sensitivity to reward is linked to food intake, no studies were identified that characterized the relationship between varying levels of sensitivity to reward and food intake responses to an acute bout of exercise. Finlayson et al. [59] attempted to identify this relationship by observing the association between exercise and hedonic preferences for foods. Following an acute bout of exercise, subjects who compensated by increasing energy intake had increased hedonic preference for a range of foods. Exercise's role on reward driven eating is mixed and physical activity's role in modulating hedonic responses to food remains incompletely characterized [13]. Some speculate that exercise serves to buffer reward driven eating while others have suggested that acute exercise may have an enhancing effect on reward driven eating [11]. Since reward plays an important role in eating and changes in hedonic preferences for food could contribute to increased energy intake, identification of the role sensitivity to reward plays in acute compensatory responses following exercise can provide insight into those individuals more susceptible to overeat following exercise.

Impulsivity

Impulsivity is regarded as a multidimensional [18, 20, 28, 60, 61] construct that can be loosely defined as the tendency to think, control, and plan insufficiently [20, 27, 28], resulting in a maladaptive response. Impulsivity is an umbrella term that can be categorized into three main operationalisms: 1) sensitivity to reward, 2) insufficient response inhibition, and 3) self-reported trait impulsivity [28]. The complexity of impulsivity can make it difficult to distinguish its role in eating behaviors. When impulsivity is operationalized in terms of response inhibition it becomes more clearly defined as the inability to inhibit a predominant response [28]. The system controlling response inhibition operates based on the executive control model described by Logan & Cowan [62]. In this model interaction of the executive and subordinate systems occur with the executive system forming intentions and the subordinate system carrying out the actions. However, the subordinate system's ability to carry out intentions is dependent on the executive system. Therefore, when intentions change the executive system in individuals can inhibit the carrying out of certain prior intentions by the subordinate system. Individual variation in the ability of the executive system to inhibit the subordinate system results in varying levels of impulsivity among individuals.

Moreover, impulse control and eating habits may be predisposed to the innate eating habits of earlier century Homo sapiens. Prior to the development of an obesogenic society, food was a natural reinforcer that, when available, promoted eating even in the absence of physiologic need in order to store energy in the body for when food may later be scarce [28, 63, 64]. This prepotent response (to eat palatable food whenever it's available) has become a liability, as it is no longer a necessity for survival. Unfortunately, the engrained nature of this response and today's current food environment puts individuals who are unable to effectively inhibit the behavior at high risk for increased consumption of palatable, energy dense foods.

Impulsivity has been reported to be a strong predictor of food intake [18]. Individuals with high trait impulsivity are at risk for responding to appetitive stimuli because they are more sensitive to external cues and therefore more vulnerable to the obesogenic environment [56, 64]. Empirical evidence confirms that high levels of impulsivity are associated with overeating [20, 21, 28, 56, 65] and a greater preference for energy dense foods [28, 50]. Additionally, high-impulse individuals have a harder time resisting food [20] and stopping eating once they have started [50] compared to low impulse individuals.

In a general population study conducted by Davis, Strachan, and Berkson [52] normal weight, overweight, and obese women were evaluated for their level of impulsivity and food intake. Within each weight category, the women with higher impulsivity scores had greater overeating and greater consumption of energy dense foods. Overall, impulsivity was demonstrated to be positively related to BMI. Other studies looking specifically at response inhibition in individuals show that individuals who are poorer at inhibiting responses (i.e. more impulsive) generally present with greater BMI than individuals who are better at inhibiting responses (less impulsive) [27, 66]. Nederkoon et al. [66] and Geurrieri et al. [27] examined normal weight and overweight/obese children and showed that the overweight/obese children had significantly greater difficulty inhibiting prepotent responses compared to the normal weight, control children. A study in adult women [65] correspondingly showed obese women to have greater difficulties in response inhibition compared to their lean counterparts.

The aforementioned studies only showed a link between impulsivity, overeating, and obesity and not causality. To determine whether or not impulsivity causes overeating a study was conducted by Guerrieri et al. [20] in which impulsivity was manipulated in order to determine causality between impulsivity and overeating. Impulsivity was induced in the subjects via a cognitive priming method and a behavioral priming method. Both methods of inducing impulsivity resulted in overeating in subjects compared to the inhibition of impulsivity trial. This study is seminal in highlighting the implications of increased impulsivity in individuals. Evidence surrounding impulsivity shows that this personality trait has significant influence on proneness for overeating. Therefore, it is highly plausible that this trait will be influential on eating behavior following exercise.

Ability to Delay Gratification

Ability to delay gratification is defined as an individual's ability to postpone immediate gratification and participate in behavior related to longer term outcomes [24]. This psychological trait is most often described in terms of delayed discounting. Delayed discounting is a behavioral paradigm that measures the devaluation of a reward over time and the level to which a person chooses smaller, more immediate rewards over larger, more delayed rewards [18, 50, 63]. A prominent study by Mischel et al. [67] showed the range of individual variability in ability to delay gratification and the long-term stability of this trait to predict eating behavior over a decade later, suggesting that this trait may be significant in its influence on food intake in individuals.

Recent evidence has shown delayed discounting to be an important factor in eating behavior [18, 24]. Individuals are often forced to choose between the immediate pleasures of desirable, energy dense foods or longer-term rewards such as weight maintenance or weight loss [18]. Studies show that low discounting (i.e. valuing the long term reward) is associated with healthier eating, less weight gain [18], and an ability to resist highly palatable, energy dense foods [68]. Enhanced discounting is concomitant with increased difficulty resisting highly palatable foods and therefore presents itself as a doorway to obesity [24, 68]. A study completed by Rollins et al. [68] showed that in non-obese women, energy intake of palatable food could be predicted by the level of delay discounting the women exhibited. The women who had higher levels of delay discounting had a greater consumption of palatable, energy dense food and therefore a greater energy intake. Similar results were observed by Appelhans et al. [69] in an overweight/obese population. Overweight/obese women who more steeply discounted future reward were shown to have a greater increase in palatable, energy dense food consumption and thus greater total energy intake as compared to overweight and obese women who less steeply discounted future rewards.

Based on the evidence from recent studies around the ability to delay gratification and energy intake, it can be postulated that this psychological trait may influence energy intake after acute exercise. Women who have an inability to discount future rewards may be more susceptible to increasing their energy intake following exercise.

Body Composition as a Potential Modifier to Acute Dietary Compensatory Responses

Dietary intake following exercise is modulated by body composition [25, 51]. However, there is contradictory evidence on the role body composition plays in dietary intake following a bout of exercise. Some speculate that, following a bout of exercise lean individuals will have a hyperphagic response to exercise in order to defend their body fat stores [11]. For example, in a study by Kissileff et al. [70] subjects completed both a moderate and vigorous bout of exercise on a cycle ergometer and then were given a yogurt shake to consume. Following the moderate bout of exercise, lean women had a greater increase in energy intake from the yogurt shake compared to the non-exercise control condition. The obese women, conversely, had a decrease in energy intake following both the moderate and vigorous intensity exercise as compared to the non-exercise control condition.

On the other hand, others speculate that following a bout of exercise obese individuals will increase their energy intake to a greater extent than their lean counterparts. In a study by George and Morganstein [22], 25- 45 year old sedentary, female subjects performed an hour of moderate intensity walking and then were allowed to eat an ad libitum meal thirty minutes following exercise. Overweight/obese women had a significantly larger change in energy intake following exercise than did the lean women. The overweight/obese women also had a greater percentage of their intake from fat than did the lean women.

There is still much debate around the specific influence of body composition on post-exercise energy intake. In general, obese individuals tend to have a higher energy intake relative to body weight than lean individuals [22, 30, 71]. Furthermore, overweight and obese adults are shown to be more impulsive [28, 65], have a greater sensitivity to reward [18, 28, 29], more steeply discount future rewards [72], and have less dietary restraint [17, 18] compared to their lean counter parts. This suggests that obese individuals may be more prone to overeat following exercise than lean individuals.

Exercise Timing as a Potential Modifier to Acute Dietary Compensatory Responses

The timing of energy intake can significantly influence the amount of food consumed. Extensive research by John De Castro [15, 73] has revealed that in modern western society energy intake increases across the day with the largest meal occurring in the evening. Furthermore, as the day progresses the time interval between the eating sessions decreases. This pattern of eating often results in most individuals experiencing less satiety at the end of the day making them more vulnerable to greater caloric intake during this time.

Due to the influence time of day has on everyday eating behavior it is plausible that timing of exercise may influence eating behaviors after exercise. However, to date, only one study was identified to have explicitly tested this phenomenon in women. In a study by Maraki et al. [23], 12 normal-weight (21.6 ± 1.6 kg/m^2), 18- 45 year old female subjects partook in a one-hour aerobic exercise class on two separate days, one occurring in the morning and one occurring in the evening. Energy intake was measured using 24-hour food diaries filled out by the subjects on each exercise day and assessed for whole day energy intake. There were no significant differences between whole day absolute energy intake and relative energy intake between the morning exercise class and the evening exercise class. This suggests that time of day of exercise does not influence subsequent energy intake. However, one study is not sufficient to definitively make this claim and therefore further study is warranted in order to firmly establish how timing of exercise influences dietary compensation.

Overall Summary

Acute dietary compensation following exercise in free-living settings is relatively understudied. Since exercise and eating are habitually completed in natural environments it is imperative to identify the acute compensatory responses that occur among individuals in free-living, rather than laboratory, settings. Furthermore, the characteristics that make an individual susceptible to compensatory dietary behaviors have not yet been fully explored. Several psychological traits that have been observed to play a prominent role in food intake may also be influential in predicting dietary compensatory responses following exercise; however, these studies have not yet been conducted. Additional research is also needed to better understand how body composition and the timing of exercise influence dietary responses to exercise participation.

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CHAPTER 3

PREDICTORS OF ACUTE DIETARY COMPENSATION AMONG SEDENTARY WOMEN AFTER FREE-LIVING MODERATE INTENSITY EXERCISE[1]

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Abstract

OBJECTIVE: Psychological characteristics may provide insight into susceptibility to compensatory responses. The aim of this study was to identify individual characteristics that may predict changes in acute energy intake associated with exercise participation. DESIGN AND METHODS: Previously sedentary women's (n = 57, 36.2 ± 6.36 years) total day and 3-hour dietary intake were evaluated on a selected exercise and non-exercise day during an 8-week walking intervention. Participation in walking bouts ≥ 30 minutes was measured via accelerometer. Dietary intake was assessed for total calories (TOT), carbohydrate (CHO), protein (PRO), and fat (FAT). RESULTS: 3-hour TOT (569.51 vs. 400.83 kcals) and CHO (239.95 vs. 207.04 kcals) were significantly increased with exercise. Dietary restraint was positively associated with total day FAT (r = 0.29) compensation. Disinhibition was positively associated with 3-hour TOT (r = 0.32), CHO (r = 0.29), PRO (r = 0.30), and FAT (r = 0.27) compensation. Ability to delay gratification (food) was negatively associated with 3-hour PRO (r = -0.52) compensation. CONCLUSIONS: Acute compensatory responses to exercise did occur in free-living settings. Individual characteristics such as dietary restraint, disinhibition, and ability to delay gratification may make individuals more susceptible to compensate following exercise.

Introduction

A prolonged positive energy balance can lead to overweight and obesity. Moderate intensity exercise is a recommended strategy to prevent weight gain and promote weight loss [1]. However, upon starting an exercise program, variable responses in weight loss occur with women – on average - losing only 30% of their predicted weight loss [2]. This less than predicted weight loss suggests that there are factors mitigating exercise's ability to promote weight loss in individuals. Behavioral compensatory responses, in particular increased energy intake, are alleged to be a key barrier to weight loss from exercise [2-4]. Therefore it is necessary to understand the effects exercise has on dietary compensation in individuals. Several studies have examined energy intake following an exercise bout [3-8] and observed minimal to no acute compensatory responses in energy intake. However, all of these studies have been conducted in laboratory settings rather than free-living environments. Extensive research by De Castro [9, 10] suggests that the setting in which an individual eats can profoundly influence their eating habits. Therefore it is necessary to examine the compensatory behaviors that occur in the natural obesogenic environment.

Existing evidence [11, 12] indicates that there is significant inter-individual variability in acute compensatory responses to exercise. However, little is known about the individual characteristics that may predispose select individuals to compensatory behavior following an acute bout of exercise. Eating behavior traits may predict whether or not an individual is likely to compensate to exercise through an increase in energy intake [6, 13-15]. Several studies have looked at dietary restraint and disinhibition [3, 6, 14-16] and have reported a negative [6, 8] association with dietary restraint and a positive

[16] association with disinhibition and post-exercise energy intake. Other psychological characteristics, particularly sensitivity to reward [3, 15, 17-19], impulsivity [15, 17, 18], and ability to delay gratification [15] have also been observed to influence food intake and therefore may contribute to compensatory behavior following an acute bout of exercise.

Non-personality related factors such as body composition [7, 20] and exercise timing [21] may also influence an individual's acute compensatory response to exercise. However, the role these factors play remains incompletely characterized. There is evidence that acute compensatory responses are greater among overweight and obese compared to lean women [20]. However, other studies have reported that lean women have a hyperphagic response to exercise whereas overweight/obese women do not [7, 16]. Only one study has examined the time of day effects of an acute bout of exercise on energy intake in women [21]. While no time of day effects were observed, further study is necessary.

The purpose of these analyses was to determine the extent to which eating behavior traits, psychological characteristics, body composition, and exercise timing influence total day and 3-hour dietary compensation among sedentary women after an acute bout of exercise. A better understanding of the role these factors may play in determining post-exercise energy intake is needed to better understand the factors driving individual differences in compensatory behavior following exercise.

Materials and Methods

Study Design and Subjects

These analyses were conducted using data collected as part of an 8-week walking intervention among 130 sedentary, premenopausal women aged 25-45 years living in Athens – Clarke County and the surrounding areas (Project PACE). Women were recruited through email listservs to University of Georgia faculty, staff, and graduate students and through advertisements placed in the Athens-Clarke County Flagpole magazine and the University of Georgia Columns newspaper. Potential participants were excluded if they were menopausal, pregnant, lactating or attempting to become pregnant, too active (defined as partaking in 30 minutes or more of physical activity on two or more days of the week), had any orthopedic limitations that prevented them from participating in moderate intensity exercise, had any diagnosed mental health conditions, or were taking any medication that could alter their mood or appetite (Appendix A). The current analyses were conducted among a subset of 57 women who completed a 24-hour dietary recall on at least one exercise day and one non-exercise day during the 8-week intervention (Appendix B). The exercise day was defined as a minimum 30 minute walking bout as identified by accelerometer. The study was approved by the University of Georgia Institutional Review Board. All subjects provided written informed consent prior to participation in the study.

Protocol

The Project PACE study was conducted in 5 waves from September 2012 to November 2013. At baseline subjects height and weight were taken, both verbal and written instructions were provided to the subjects on proper wear of the ActiGraph

GT3X+ accelerometers and proper completion of the National Cancer Institute's ASA-24 dietary recall program, and a battery of psychological assessments was completed.

During the baseline week, subjects wore the accelerometer during all waking hours and partook in their normal daily activities. In addition, subjects completed 24-hour diet recalls on three randomly assigned days (two weekdays and one weekend day). During the following eight weeks subjects again wore the accelerometer during all waking hours and completed six randomly assigned 24-hour dietary recalls (three during weeks 1-4 and three during weeks 5-8). During these eight weeks subjects were instructed to complete at least 150 minutes of moderate intensity walking per week in minimum walking bouts of no less than 10 minutes duration.

Anthropometric Data

Body weight was measured to the nearest 0.1 kg using a digital scale (Tanita, Model WB-110A, Tokyo, Japan) with subjects wearing no shoes and light clothing. Stature was measured to the nearest 0.1 cm using a digital stadiometer without shoes (Secca, Model 222, Hanover MD). Body Mass Index (BMI) was calculated from these measures by dividing the subject's weight (kg) by their height (m) squared.

Physical Activity

Physical activity was assessed using the ActiGraph GT3X+ accelerometer (Actigraph, Pensacola, FL). The ActiGraph GT3X+ is a tri-axial accelerometer that measures frequency, intensity, and duration of free-living acceleration in three planes (vertical, anterior-posterior, medial-lateral) [22]. The Actigraph GT3X+ has been demonstrated to have good relative validity for steps and energy expenditure ($r = 0.82$, $p < 0.01$) at moderate intensity levels [23].

Subjects wore the accelerometer on an elastic belt around their waist on their right side in line with their mid-thigh. The accelerometer was worn during all waking hours for the entire nine weeks of the Project PACE study. Moderate intensity walking activity was determined using a threshold accelerometer vector magnitude count of 2,691 [24] or above and walking bout length was determined as the amount of time (in minutes) the accelerometer vector magnitude counts remained at or above this moderate intensity level.

Dietary Intake

Dietary intake was measured using the National Cancer Institutes (NCI) Automated Self-Administered 24-hour Recall (ASA-24) program. This free online program replicates the format and structure of an interview-administered 24-hour recall. The NCI ASA-24 program instructed subjects to enter in everything they ate and drank from midnight to midnight the previous day and guided the respondents through a step-by-step process for entering in each individual food and drink item they consumed as well as the portion sizes for each item.

The NCI ASA-24 program was constructed based on the U.S. Department of Agriculture's Multiple Pass Method (MPM) [25]. The MPM is a 5-step dietary interview system in which multiple passes through the 24-hour time period are made. The 5 steps of MPM include a quick list, forgotten foods list, time and occasion, detail and review, and final probe [26]. During each of these passes memory cues as well as standardized wording is used to help a respondent recall all of the food they ate. The MPM has been validated and has been demonstrated to be accurate in the estimation of total calorie and protein intake [26, 27].

For this analysis, total day and 3-hour post-exercise total calories, carbohydrate, protein, and fat intake for the identified exercise and non-exercise day were used. On the exercise day, 3-hour dietary intake was determined by using the subjects walking bout end time as the start time of the 3-hour period. Everything consumed by the subject from the end of the walking bout extending 3 hours was summed together to provide 3-hour intake. On the non-exercise day, 3-hour intake was measured using the same times established on the exercise day. Total day intake was calculated as the sum of everything consumed on the selected exercise and non-exercise day. All macronutrient data were converted from grams to calories using the conversion factor of 1 gram equals 4 calories for carbohydrate and protein and 1 gram equals 9 calories for fat.

Identification of Exercise and Non-Exercise Days

A representative exercise and non-exercise day were selected using the physical activity and dietary data collected during the Project PACE exercise intervention period. The exercise day was defined as a day in which both a 24-hour diet recall and a minimum 30-minute moderate intensity walking bout were completed. When there were multiple occurrences of an exercise day for a subject the first exercise day was used. If on the chosen exercise day more than one bout of moderate intensity walking was performed then the walking bout of the longest duration was selected. The non-exercise day was defined as a day in which subjects completed a 24-hour diet recall only. When there were multiple non-exercise days, the day closest in time to the chosen exercise day was used.

Dietary Compensation

For these analyses dietary compensation was defined as the difference in dietary intake between the identified exercise and non-exercise day for each subject and was calculated using the total calorie, carbohydrate, protein, and fat intake measured by the NCI ASA-24 diet recall program. Absolute total day and 3-hour dietary compensation was calculated as the difference in total calorie and macronutrient intake between the exercise day and non-exercise day (Ex EI – Non-Ex EI). In addition, total day dietary compensation expressed as a percentage of change was calculated using the following equation: (((Total Day Ex EI – Total Day Non-Ex EI) / Total Day Non-Ex EI) *100).

Psychological Assessment Protocol

Subjects completed all psychological assessments during the Project PACE initial baseline visit. These assessments included the Three Factor Eating Questionnaire Revised 18-item Version, the Sensitivity to Punishment and Sensitivity to Reward Questionnaire, the Go/No Go Task, the Delay Discounting Task for Money, the Monetary Choice Questionnaire, and the Delay Discounting Task for Food. Each assessment is described below.

Three Factor Eating Questionnaire Revised 18-Item Version

The Three Factor Eating Questionnaire Revised 18-item Version (TFEQ-R18) measures current eating behaviors and is comprised of three subscales measuring cognitive restraint, disinhibition, and emotional eating [28]. 18 items are scored on a 4-point scale and summed for each of the three subscales. The raw subscale scores are then converted to a 0-100 scale. Higher scores indicate greater cognitive restraint, disinhibition, or emotional eating. The TFEQ-R18 has good internal consistency with alphas of 0.84, 0.83, and 0.87 for cognitive restraint, disinhibition, and emotional eating respectively [28]. In addition, this questionnaire has been demonstrated to be valid in obese [29], non-obese [30], and general [28] populations.

Sensitivity to Punishment and Sensitivity to Reward Questionnaire

The Sensitivity to Reward Scale of the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) measures general appetitive motivation around a variety of contexts with items on this scale relating to specific rewards [31]. The Sensitivity to Reward Scale consisted of 24 “yes” or “no” questions with “yes” scores receiving one point and “no” scores receiving zero points. A summary score was acquired by summing all of the “yes” answers for this scale. The Sensitivity to Reward Scale shows good construct validity and acceptable internal consistency with an alpha of 0.75 for females [31].

Go/No Go Task

The Go/No Go Task determines a respondent’s level of impulsivity through a measure of behavioral inhibition. This task was run using the EPrime™ software (Psychology Software Tools, Pittsburgh, PA) and presented respondents with a series of “Go” cues (about 80% of the time) in which they were to respond to as quickly as possible and interspersed “No Go” cues (about 20% of the time) in which they were to inhibit their response [32]. The regularity of the Go cues creates a prepotent tendency to respond that then must be inhibited by respondents when the No Go cue is shown, which allows for a measure of the individual’s ability to inhibit a prepotent response. For this study, respondents were presented with a Go signal (a white “X”) or a No Go signal (a white “K”) on the screen for a brief period of time. Respondents were instructed to press the X key as quickly as possible if the Go signal appeared on the screen. Errors of commission were calculated for the task and represent the frequency in which a response was not inhibited when it should have been (i.e. the X key was pressed when the K was shown).

Delay Discounting Task for Money and Monetary Choice Questionnaire

The Delay Discounting Task for Money and the Monetary Choice Questionnaire determine a respondent's ability to delay gratification to a reward. The task assesses preferences for smaller immediate rewards compared to larger delayed rewards [33]. For this task dichotomous items were presented to subjects and a choice had to be made between a monetary option that is immediate and available and another monetary option that is larger but delayed. The monetary options ranged from $1 to $100 and the delays ranged from one day to one year. For the Monetary Choice Questionnaire, hyperbolic temporal discounting functions, expressed as k values, at three different levels of magnitude (small $25-$35, medium $50-$60, and large $75-$85) were estimated for individuals using the approach by Kirby et al. [34]. For the Delay Discounting Task for Money the indifference point, which represents the amount of immediate money deemed equal to the larger delayed reward [33], was calculated. Upon further analysis, the three k values from the Monetary Choice Questionnaire and the indifference point from the Delay Discounting Task for Money were highly correlated ($r = 0.77 – 0.85$, $p < 0.01$) and therefore a principal component analysis was run to reduce the four values into one representative value of delayed discounting for money.

To help improve the validity of this measure subjects were told that they could receive one of their actual choices on the task. Subjects were informed that at the end of the questionnaire they would roll a die and if a six was rolled then they would choose a poker chip which corresponded to a question number and that they would earn the money reward that they answered for that question.

Delay Discounting Task for Food

The Delay Discounting Task for Food presents subjects with a list of snack foods and asks respondents to pick their favorite item. The task then goes on to ask the respondent if they would prefer to have one 100-calorie portion of that snack food now or two 100-calorie portions at a later delayed time. Delays ranged from one day, one week, two weeks, three weeks, one month, two months, three months, six months, or one year. Respondent's impulsive choice ratio (the number of times they chose the one 100-calorie portion option divided by total number of questions) was calculated for this task.

Statistical Analyses

Statistical analysis was performed using SPSS, Version 21.0 (Armonk, NY). The data were inspected for normality and outliers. One subject was excluded from final analyses due to physiologically implausible dietary intake values. Demographic variables are reported as means ± standard deviations (SD) for continuous variables and percentages for categorical variables. Spearman correlations were calculated to assess the bivariable associations between each eating behavior and psychological trait and total day and 3-hour total calories and macronutrient compensation. Regression diagnostics were performed to identify any potentially influential subjects prior to running regression analyses. Simple linear regression was used to evaluate the predictive association of each eating behavior and psychological trait as well as BMI on each acute dietary compensation measure. All predictor variables were then entered into a multiple linear regression model and a backward stepwise approach was used to identify the independent and mutually adjusted predictive association of each predictor variable on total day and 3-hour total calories and macronutrient compensation. Analysis of variance was conducted to compare BMI and exercise timing to total day and 3-hour total calories and macronutrient compensation. An alpha level of 0.05 was used to determine significance.

Results

Subject Characteristics

These analyses had 57 middle-aged, premenopausal, female subjects. Subjects characteristics are presented in Table 3.1.The majority of subjects were Caucasian with the remaining identifying themselves as African American, Hispanic, and Other. Participants fell into all BMI classes with 31.6% normal-weight, 26.3% overweight and 42.1% obese. With regards to exercise timing 12.3% of women were morning exercisers, 31.6% afternoon exercisers, and 56.1% evening exercisers.

Mean Energy Intake and Dietary Compensation

Mean total day and 3-hour energy intake for total calories and macronutrients are reported in Table 3.2. There was no difference in total day energy intake between the exercise and non-exercise day. However, significant differences were observed for 3-hour total calorie ($\Delta = 168.68 \pm 603.11$, $p = 0.04$) and carbohydrate ($\Delta = 89.03 \pm 254.81$, $p = 0.01$) intake on the exercise day as compared to the non-exercise day. Mean total day dietary compensation for total calories, carbohydrate, protein, and fat was 30.82 ± 670.47, 57.31 ± 376.86, -1.59 ± 150.19, and -3.20 ± 362.39 kcals, respectively. Mean 3-hour dietary compensation for total calories, carbohydrate, protein, and fat was 168.68 ± 603.11, 89.03 ± 254.81, 21.92 ± 110.77, and 48.91 ± 290.42 kcals, respectively.

Individual Variation in Dietary Compensation

Examination of the individual variation in dietary compensation resulted in varying magnitude and direction of responses among subjects. Individual variation is depicted in Figure 3.1 for total day total calories compensation and Figure 3.2 for 3-hour total calories compensation. Total day dietary compensation for total calories ranged from -1832.45 to 1663.70 kcals and for carbohydrate, protein, and fat ranged from -785.62 to 1214.10, -272.54 to 345.94, and -872.65 to 640.82 kcals, respectively. 3-hour dietary compensation for total calories ranged from -1216.64 to 1367.10 kcals and for carbohydrate, protein, and fat ranged from -402.42 to 718.96, -285.61 to 255.70, and -883.10 to 733.03 kcals, respectively. For total day total calorie compensation 40.4% of subjects were seen to be compensators, 28.1% were non-compensators, and 31.6% had no change. A total day total calorie change greater than ± 0.5 SD (± 300 kcals) was used to identify individuals as compensators or non-compensators. For 3-hour total calories compensation 63.2% of subjects were seen to be compensators, 28.1% non-compensators, and 28.1% no change. A 3-hour total calorie change greater than ± 0.5 SD (± 240 kcals) was used to identify individuals as compensators or non-compensators.

Associations Between Eating Behavior and Psychological Traits and Acute Dietary Compensation

Spearman correlations (r) between eating behavior and psychological traits with total day and 3-hour dietary compensation are reported in Table 3.3. A significant, positive association was found between dietary restraint and total day fat compensation ($r = 0.29$, $p = 0.04$). Dietary restraint also trended towards significance for total day total calories ($p = 0.06$) compensation. Disinhibition was found to be significantly, positively associated with 3-hour total calories ($r = 0.32$, $p = 0.02$), carbohydrate ($r = 0.29$, $p = 0.03$), protein ($r = 0.30$, $p = 0.03$), and fat ($r = 0.27$, $p = 0.05$) compensation. A significant, negative association was seen between ability to delay gratification (food), as measured by level of discounting for food, and 3-hour protein ($r = -0.52$, $p = 0.01$) compensation. In addition, ability to delay gratification (food) trended towards significance for total day total calories ($r = -0.37$, $p = 0.07$) compensation. Sensitivity to reward trended towards significance for 3-hour total calories ($p = 0.06$), carbohydrate ($p = 0.05$), and fat ($p = 0.06$) compensation. Similar correlations were observed for total day percent change diet variables and eating behavior and psychological traits (Appendix C). Impulsivity and ability to delay gratification ($), as measured by level of discounting for money, were not related to total day and 3-hour acute dietary compensation. Inter-correlations between various predictor variables were examined and are reported in Appendix D.

Eating Behavior and Psychological Traits as Predictors of Acute Dietary Compensation

Standardized β are reported in Table 3.4 for total day dietary compensation and Table 3.5 for 3-hour dietary compensation. Regression diagnostics were conducted and potential influential subjects were identified. Regression analyses were then run without these influential subjects for comparison. Regression results, with potential influential subjects removed, revealed no differences in standardized β except for the predictor variable disinhibition in which standardized β were slightly stronger. Due to the minimal changes in standardized β values, all subjects were included in the final regression models.

Using simple linear regression, dietary restraint was a significant predictor of total day total calories compensation. Increased dietary restraint of one standard deviation was associated with a 0.33 standard deviation increase in total calorie compensation, which corresponds to approximately 221.26 kcals. In multiple linear regression analysis dietary restraint remained an independent predictor of total day total calorie compensation with a one standard deviation increase in restraint corresponding to a 0.30 standard deviation increase in total calorie compensation (approximately 201.14 kcals). For 3-hour total calories compensation, simple linear regression showed disinhibition to be a significant predictor. A one standard deviation increase in disinhibition is associated with a 0.27 standard deviation increase in 3-hour total calories compensation, which approximates 162.84 kcals. When examined with multiple linear regression analysis, both disinhibition and dietary restraint were independent predictors of 3-hour total calories compensation. When both variables are included in the prediction model the regression coefficient for dietary restraint approximately doubles and for disinhibition is increased 0.10 standard deviations.

There were no significant predictors of total day carbohydrate compensation. For 3-hour carbohydrate compensation, simple linear regression revealed that both disinhibition and sensitivity to reward are positive, significant predictors. However, when examined in the multiple linear regression model, disinhibition remained a positive independent predictor and dietary restraint became an independent predictor for 3-hour carbohydrate compensation. When entered into the multiple linear regression model the regression coefficient for dietary restraint doubled and the regression coefficient for disinhibition increased almost 0.10 standard deviations.

BMI, through simple linear regression, was identified to be a significant predictor of total day protein compensation. In the multiple linear regression model, BMI remained a significant independent predictor along with dietary restraint on total day protein compensation. Significant predictors of 3- hour protein compensation are BMI and disinhibition. However, when entered into the multiple linear regression model only disinhibition remained an independent predictor of 3-hour protein compensation.

For total day fat compensation, simple linear regression showed dietary restraint as a significant predictor. In multiple regression analysis, dietary restraint remained an independent predictor of total day fat compensation. There were determined to be no significant predictors of 3-hour fat compensation.

Relationship between BMI and Acute Dietary Compensation

While no significant relationship was observed between BMI category and total day and 3-hour dietary compensation there do appear to be some difference among the BMI categories. Normal weight subjects had the greatest increase in total day total calories and carbohydrate compensation with exercise while obese women had the greatest increase in total day protein and fat compensation upon exercise participation. For 3-hour compensation, normal weight and obese women has similarly large increases in total calorie intake after exercise. In addition, normal weight women had the greatest increase in carbohydrate compensation following exercise whereas obese women again had the greatest protein and fat compensation following exercise. Overweight women had very minimal changes in compensation with exercise. Mean total day and 3-hour dietary compensation for each group is reported in Table 3.6.

Relationship between Exercise Timing and Acute Dietary Compensation

No significant relationship was found between exercise timing and total day and 3-hour dietary compensation. Despite these indifferences, total day total calories and carbohydrate compensation was greatest for the women who exercised in the morning whereas protein compensation was greatest for evening exercisers and fat compensation was greatest for afternoon exercisers. Interestingly, morning exercisers had a decreased 3-hour post-exercise energy intake for total calories and macronutrients as compared to their non-exercise day. In contrast, afternoon and evening exercisers had an increased 3-hour energy intake as compared to their non-exercise day. Mean total day and 3-hour dietary compensation for each group is reported in Table 3.7.

Discussion

These analyses examined the relationships among eating behavior traits, psychological characteristics, body composition, and exercise timing on total day and 3-hour post-exercise dietary compensation as well as individual variability in acute dietary compensation among sedentary, premenopausal women. Contrary to most literature on acute compensatory responses to exercise [3-8] these analyses showed a significant increase in mean 3-hour post-exercise total calorie and carbohydrate intake. Acute compensatory responses seen here could be attributable to the free-living setting in which the study was conducted. Unlike most laboratory studies, subjects were able to complete their exercise and consume foods in their habitual environment and at their own convenience. The nature of this design may have allowed for detection of acute compensatory responses that cannot be identified in a laboratory setting because of the tightly regulated constraints in which exercise and eating are performed. Furthermore, acute compensatory responses could have resulted because of the temptations of the obesogenic food environment, which can be easily avoided in a laboratory setting, where a predetermined test meal occurs, but are much harder to resist in a free-living setting. Acute compensatory responses seen in this study could also be attributable to the 3-hour time window in which energy intake data was assessed. In most acute studies compensatory responses are measured 30 minutes to one hour after exercise. This may not be long enough to detect significant changes in acute energy intake post-exercise. Parallel with existing research [11, 12], our results exhibited varying magnitude and direction of acute compensatory responses to exercise. This suggests that there are select individuals that are more susceptible to acute dietary compensation following exercise while others remain resistant. Identification of individual characteristics that enhance susceptibility for compensation could be key to identifying those persons most at risk to increase their energy intake after exercise.

Examination of various eating behavior and psychological traits and their role on acute dietary compensation revealed that disinhibition was a consistent predictor of 3-hour dietary compensation. Individuals with increased disinhibition reported having greater post-exercise energy intake for total calories and macronutrients than individuals with lower levels of disinhibition. This is consistent with other acute exercise studies [16, 35] as well as existing evidence for the role of disinhibition on general eating behaviors [14, 36]. Individuals who present with greater levels of disinhibition are more likely to have a loss of control over eating and thus overeat. Furthermore, these individuals also are more likely to engage in opportunistic eating. Exercise may provide an opportunity to eat and therefore individuals with greater disinhibition are taking advantage of this opportunity and eating after exercise. Since these individuals are also prone to have a loss of control of eating once they start their opportunistic eating they may be overeating in these circumstances. This trait did not appear to influence total day compensatory responses however suggesting it has greater implications for immediate, short-term energy balance.

In addition, dietary restraint was positively associated with total day total calorie and fat intake. This contrasts some evidence [6, 8, 35, 37, 38], which suggests that those with increased restraint do not have increased energy intake after exercise because they tightly regulate and control their energy intake. Others postulate [39] that for restrained individuals certain events may be a disinhibitor and make them release their tight control over their energy intake and exercise may be one of these disinhibitors. Results from these analyses suggest that in a free-living setting exercise may cause restrained sedentary women to break their tight control and increase their total day energy intake, primarily through an increase in fat intake.

Examination of psychological characteristics, specifically sensitivity to reward, impulsivity, and ability to delay gratification interestingly showed that an individual's ability to delay gratification (as examined through food discounting) was negatively associated with acute dietary compensation. Statistically significant associations were seen for 3-hour protein compensation. Surprisingly, this suggests that individuals who show an inability to delay gratification are less likely to have increased acute dietary compensation after exercise as compared to individuals who are able to delay gratification. The reason for this relationship remains unclear and warrants further examination. In addition, sensitivity to reward might also influence an individual's likelihood for 3-hour post-exercise dietary compensation. Although not significant, sensitivity to reward was positively associated with 3-hour energy intake. While some speculate that exercise serves as a buffer to reward driven eating, these analyses support the contrasting opinion that acute exercise enhances the effect on reward driven eating [6]. However, since these results did not achieve statistical significance the exact role sensitivity to reward plays on acute dietary compensation remains ambiguous. The psychological characteristics of impulsivity and ability to delay gratification (as examined through monetary discounting) did not appear to have any influence on acute dietary compensation during either the total day or 3–hour time period. However it should be noted that there are other dimensions of impulsivity, such as trait impulsivity, that should be examined before discounting this trait.

Other non-personality related factors, BMI and exercise timing, were examined for their influence on acute compensatory responses. Although not statistically significant, the data suggest a U-shape relationship between BMI and acute compensatory responses with normal-weight and obese individuals having greater compensation than overweight individuals. This U-shape relationship is a phenomenon that could be a result of hyperphagic responses [7, 16] in the normal-weight women in order to defend body fat stores [6] and an inability of the obese women to properly preserve a negative energy balance initiated by exercise. The inability of obese individuals to preserve their negative energy balance may be attributed to increased hunger following exercise or may be due to the propensity of this group to overeat in general.

Exercise timing results interestingly showed that women who exercise in the morning have increased total day total calorie intake however this is not attributed to an increase in 3-hour post-exercise intake. Morning exercisers had a decrease in 3-hour total calorie and macronutrient intake following exercise suggesting that these women are increasing their energy intake at another time-point during the day (i.e. later in the afternoon or evening). Afternoon and evening exercisers had increased 3-hour post-exercise energy intake but had much less of a total day increase in energy intake as compared to the morning exercise group. It may be that exercising at these later time points allows for less opportunity to increase consumption later on in the day and therefore results in less change in total day consumption.

This study is novel because it observed acute compensatory responses in a free-living environment. Individual's completed exercise and eating in free-living settings, which allowed them to be exposed to the temptations of the obesogenic environment. In addition, these analyses explored associations between acute dietary compensation and a number of novel psychological characteristics and identified several factors, which may be useful in identifying individuals susceptible to compensatory diet responses to exercise. However, It should be noted that these analyses only looked specifically at exercise's role on changes in eating behavior and therefore did not attempt to quantify other environmental and social factors that could have influenced changes in eating behaviors. It is possible that the changes in eating behavior seen in this study were not influenced entirely by exercise alone but also by other factors known to impact eating behaviors. In addition, acute behavioral compensatory responses were compared on only one exercise day and one non-exercise day for each subject. Looking at acute compensatory responses on several separate exercise and non-exercise days may be more beneficial in order to fully portray if and how an individual acutely compensates to exercise. Furthermore, reporting of dietary intake was completed through an online 24-hour self-administered recall program. It was assumed that participants honestly and accurately input all of their foods and portion sizes. This however, may have resulted in underreporting of energy intake.

In conclusion, the present analyses suggest that in free-living settings acute, 3-hour post-exercise dietary compensation does occur among sedentary, pre-menopausal women. Examination of various eating behavior traits and psychological characteristics revealed that dietary restraint and disinhibition may play an influential role on acute dietary compensatory responses to exercise. Identification of these traits as “red flags” can help to distinguish those individuals who may be most susceptible to increasing their energy intake upon participation in exercise. This will help future efforts around individually tailored weight loss and weight management programs.

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Table 3.1: Subject Characteristics

	N	Mean ± SD
Age (years)	57	36.2± 6.36
BMI (kg/m^2)	57	30.16 ± 7.36
Race*		
Caucasian		49 (86)
African American		6 (10.5)
Hispanic		1 (1.8)
Other		1 (1.8)
PA Bout (min)	57	48.19 ± 16.67
PA Total Day (min)	57	52.47 ± 22.01
Dietary Restraint	53	56.89 ± 18.78
Disinhibition	54	38.27 ± 20.57
Sensitivity to Reward	49	7.73 ± 3.74
Impulsivity	56	0.29 ± 0.21
Ability to Delay Gratification ($)	57	0.03 ± 0.04
Ability to Delay Gratification (food)	25	0.91 ± 0.15

* Reported as N (%)

Table 3.2: Mean Energy Intake from ASA-24

	Exercise Day	Non-Exercise Day	p*
Total Day Intake			
Total Calories	1785.88 ± 554.97	1755.05 ± 596.95	0.73
Carbohydrate	848.21 ± 287.23	790.90 ± 285.38	0.26
Protein	275.09 ± 123.69	276.68 ± 118.10	0.94
Fat	665.09 ± 291.07	668.29 ± 293.52	0.95
3-Hour Intake			
Total Calories	569.51 ± 467.60	400.83 ± 472.61	0.04
Carbohydrate	239.95 ± 207.04	150.92 ± 168.24	0.01
Protein	87.81 ± 93.98	65.88 ± 87.69	0.14
Fat	213.76 ± 209.40	164.85 ± 226.38	0.21

All data reported in kcals (mean ± SD)

* Paired t-test

Table 3.3: Spearman Correlations between Eating Behavior & Psychological Traits and Total Day, 3-Hour Dietary Compensation

	Dietary Restraint	Disinhibition	Sensitivity to Reward	Impulsivity	Ability to Delay Gratification ($)	Ability to Delay Gratification (food)
Total Day						
Δ Total Calories	0.26	0.06	0.17	-0.14	0.05	-0.37
Δ Carbohydrate	0.09	0.02	0.21	-0.10	0.13	-0.11
Δ Protein	0.24	-0.03	-0.06	-0.17	-0.03	-0.23
Δ Fat	0.29*	0.03	0.16	-0.05	-0.03	-0.18
3-Hour						
Δ Total Calories	0.10	0.32*	0.27	0.14	0.03	-0.33
Δ Carbohydrate	0.03	0.29*	0.28	0.19	0.10	-0.23
Δ Protein	-0.09	0.30*	0.07	0.10	0.09	-0.52**
Δ Fat	0.15	0.27*	0.27	0.18	0.02	-0.31

* $p < 0.05$, ** $p < 0.01$

Table 3.4: Predictors of Total Day Dietary Compensation

	Δ Total Calories			
	Univariable (n=57)*		Multivariable (n=46)	
Predictor Variable	Std β	p	Std β	p
Dietary Restraint	0.33	0.02	0.30	0.04
Disinhibition	0.07	0.63	NS	-
Sensitivity to Reward	0.17	0.24	NS	-
Impulsivity	-0.11	0.40	NS	-
Ability to Delay Gratification	-0.02	0.86	NS	-
Body Mass Index	0.01	0.96	NS	-
	Δ Carbohydrate			
	Std β	p	Std β	p
Dietary Restraint	0.13	0.34	NS	-
Disinhibition	0.02	0.88	NS	-
Sensitivity to Reward	0.20	0.18	NS	-
Impulsivity	-0.11	0.41	NS	-
Ability to Delay Gratification	0.04	0.79	NS	-
Body Mass Index	-0.12	0.36	NS	-
	Δ Protein			
	Std β	p	Std β	p
Dietary Restraint	0.23	0.09	0.26	0.06
Disinhibition	0.05	0.71	NS	-
Sensitivity to Reward	-0.05	0.72	NS	-
Impulsivity	-0.18	0.19	NS	-
Ability to Delay Gratification	0.00	0.98	NS	-
Body Mass Index	0.31	0.02	0.37	0.01
	Δ Fat			
	Std β	p	Std β	p
Dietary Restraint	0.30	0.03	0.28	0.09
Disinhibition	0.04	0.77	NS	-
Sensitivity to Reward	0.17	0.22	NS	-
Impulsivity	0.01	0.92	NS	-
Ability to Delay Gratification	-0.03	0.85	NS	-
Body Mass Index	0.01	0.95	NS	-

*Subject number varies depending on predictor variable: dietary restraint n=53; disinhibition n=54; sensitivity to reward n=49; impulsivity n=56; ability to delay gratification n=57

Std β: regression coefficient with the x and y variables in standard deviation units

Univariable Model: Simple linear regression model in which each predictor variable was evaluated against each dietary compensation measure

Multivariable Model: Multiple linear regression model in which all predictor variables were put in and removed in a backward, stepwise fashion; alpha set at $p \leq 0.10$ for inclusion in final models

Table 3.5: Predictors of 3-Hour Dietary Compensation

	Δ Total Calories			
	Univariable (n=57)*		Multivariable (n=46)	
Predictor Variable	Std β	p	Std β	p
Dietary Restraint	0.15	0.28	0.28	0.06
Disinhibition	0.27	0.05	0.37	0.01
Sensitivity to Reward	0.27	0.06	NS	-
Impulsivity	0.13	0.35	NS	-
Ability to Delay Gratification	0.09	0.50	NS	-
Body Mass Index	0.06	0.65	NS	-
	Δ Carbohydrate			
	Std β	p	Std β	p
Dietary Restraint	0.12	0.39	0.25	0.09
Disinhibition	0.30	0.03	0.36	0.02
Sensitivity to Reward	0.30	0.03	NS	-
Impulsivity	0.11	0.41	NS	-
Ability to Delay Gratification	0.12	0.43	NS	-
Body Mass Index	-0.06	0.66	NS	-
	Δ Protein			
	Std β	p	Std β	p
Dietary Restraint	-0.01	0.97	NS	-
Disinhibition	0.28	0.04	0.34	0.02
Sensitivity to Reward	0.08	0.61	NS	-
Impulsivity	0.10	0.45	NS	-
Ability to Delay Gratification	0.11	0.40	NS	-
Body Mass Index	0.28	0.03	NS	-
	Δ Fat			
	Std β	p	Std β	p
Dietary Restraint	0.16	0.24	NS	-
Disinhibition	0.18	0.21	NS	-
Sensitivity to Reward	0.25	0.09	NS	-
Impulsivity	0.19	0.16	NS	-
Ability to Delay Gratification	0.14	0.30	NS	-
Body Mass Index	0.06	0.65	NS	-

*Subject number varies depending on predictor variable: dietary restraint n=53; disinhibition n=54; sensitivity to reward n=49; impulsivity n=56; ability to delay gratification n=57

Std β: regression coefficient with the x and y variables in standard deviation units

Univariable Model: Simple linear regression model in which each predictor variable was evaluated against each dietary compensation measure

Multivariable Model: Multiple linear regression model in which all predictor variables were put in and removed in a backward, stepwise fashion; alpha set at $p \leq 0.10$ for inclusion in final models

Table 3.6: Body Mass Index and Total Day, 3-Hour Dietary Compensation

	Normal Weight (n=18)	Overweight (n=15)	Obese (n= 24)	p*
Total Day				
Δ Total Calories	65.72 ± 861.80	-9.40 ± 589.79	29.79 ± 576.02	0.95
Δ Carbohydrate	135.50 ± 487.67	69.44 ± 301.25	-8.90 ± 324.52	0.47
Δ Protein	-25.95 ± 172.04	-45.69 ± 111.99	44.25 ± 146.59	0.14
Δ Fat	-12.50 ± 431.86	-28.74 ± 334.33	19.74 ± 335.88	0.92
3-Hour				
Δ Total Calories	218.21 ± 747.12	25.14 ± 578.03	221.24 ± 501.45	0.57
Δ Carbohydrate	176.69 ± 303.47	8.39 ± 244.08	73.70 ± 207.99	0.16
Δ Protein	-2.77 ± 149.04	0.11 ± 53.43	54.06 ± 99.25	0.18
Δ Fat	71.25 ± 338.74	-49.00 ± 273.23	93.33 ± 257.69	0.31

All data reported in kcals (mean ± SD)
* ANOVA used to asses differences between BMI categories

Table 3.7: Exercise Timing and Total Day, 3-Hour Dietary Compensation

	Morning (n=7)	Afternoon (n=18)	Evening (n=32)	p*
Total Day				
Δ Total Calories	121.65 ± 365.12	46.29 ± 737.41	2.26 ± 696.56	0.91
Δ Carbohydrate	168.36 ± 215.52	76.38 ± 375.56	22.30 ± 407.38	0.64
Δ Protein	-23.83 ± 103.21	-24.92 ± 156.37	16.40 ± 156.58	0.60
Δ Fat	-12.10 ± 327.87	25.60 ± 335.06	-17.45 ± 392.62	0.92
3-Hour				
Δ Total Calories	-164.17 ± 340.64	280.22 ± 649.80	178.74 ± 608.88	0.26
Δ Carbohydrate	-23.77 ± 198.87	143.71 ± 235.23	82.95 ± 273.21	0.34
Δ Protein	-26.87 ± 64.16	18.40 ± 111.14	34.57 ± 117.83	0.42
Δ Fat	-112.77 ± 149.27	90.52 ± 262.40	60.88 ± 321.30	0.28

Morning (0:00 - 10:59), Afternoon (11:00 - 16:59), Evening (16:00 - 24:00)

All values reported in kcals (mean ± SD)

* ANOVA used to assess differences between exercise timing groups

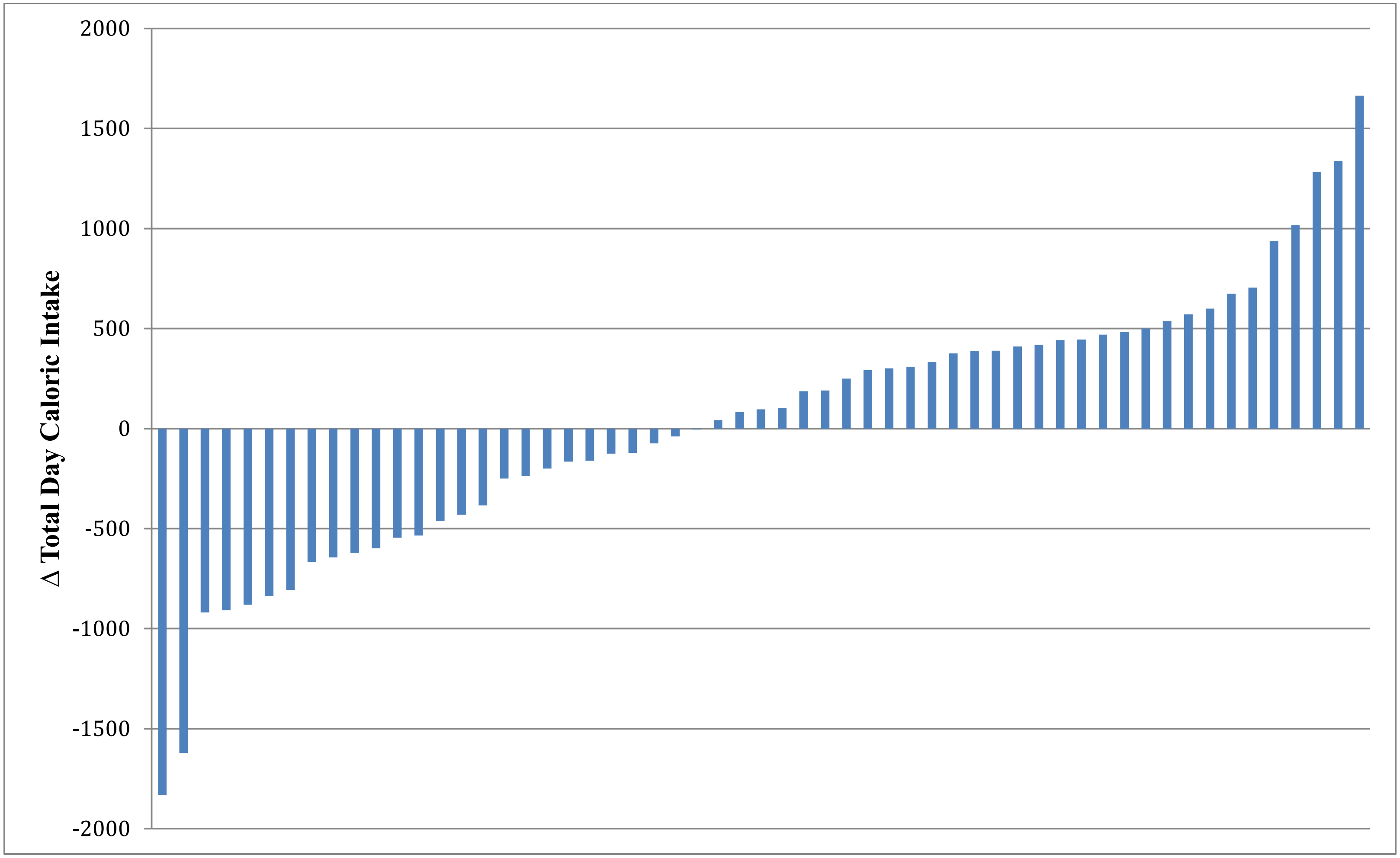

Figure 3.1: Individual Differences in Total Day Caloric Compensation

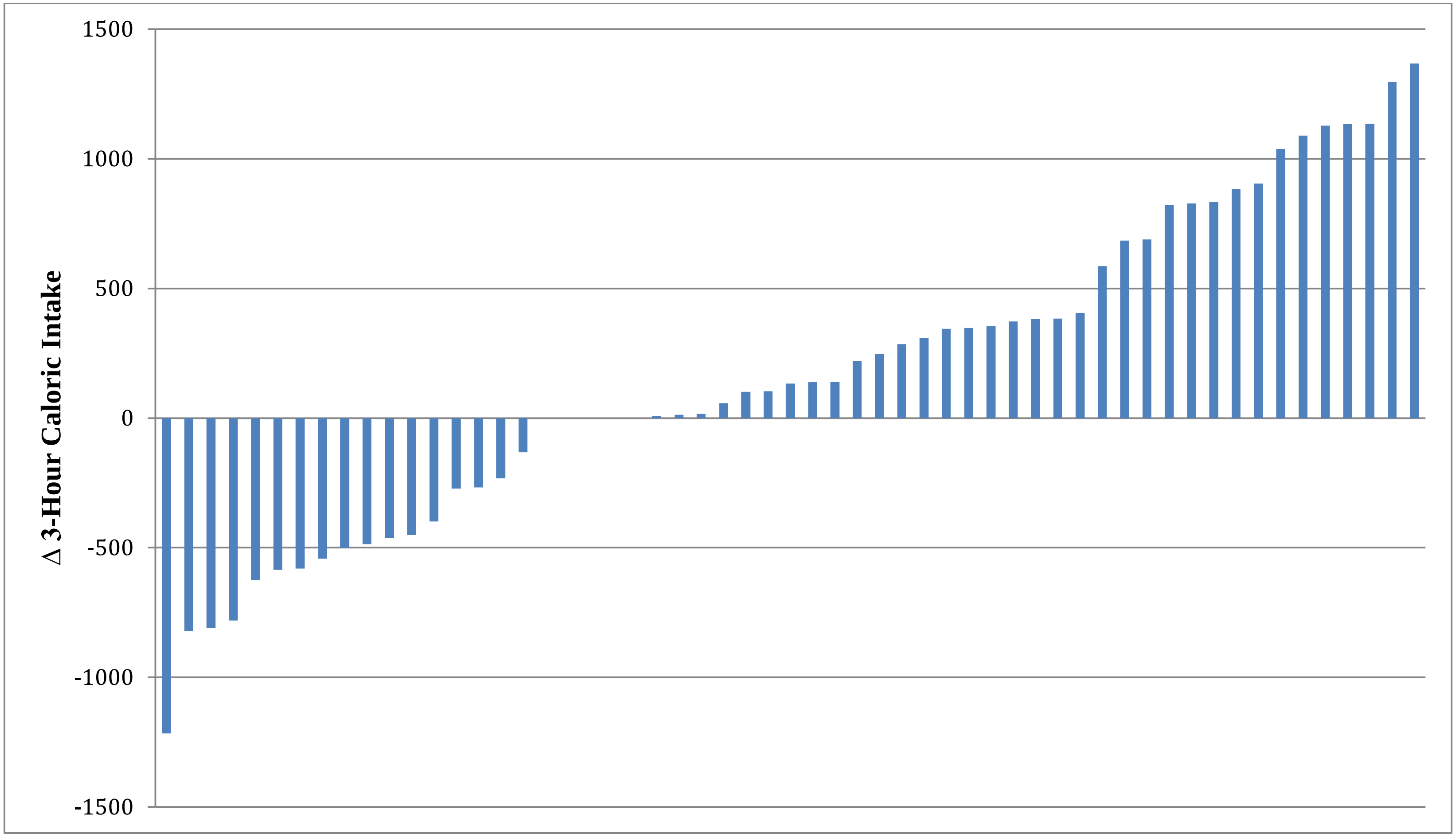

Figure 3.2: Individual Differences in 3-Hour Caloric Compensation

CHAPTER 4

DISCUSSION

Due to the high prevalence of overweight and obesity in the United States, an effort to identify the factors contributing to an inability of individuals to lose or maintain weight is of significant importance. Recently, compensatory behavioral responses to exercise have become a prominent area of focus. Research in this area has attempted to quantify which behavioral variables contribute to an inability of individuals to maintain a negative energy balance following exercise. Evidence suggests that a change in eating behavior following exercise is an important component of this behavioral response [1-3]. Therefore, identification of individual traits that make persons more susceptible to partake in this behavioral compensatory response will help future efforts around individually tailored weight loss and weight management programs. The purpose of these analyses was to further the understanding of acute compensatory responses in free-living settings following a bout of exercise and to identify any individual traits that predict these responses. Eating behavior traits, psychological characteristics, body composition, and exercise timing were examined to determine the association of each with energy intake following exercise.

Fifty-seven sedentary, premenopausal women from Athens-Clarke County and surrounding areas were examined for their dietary intake on a selected exercise and non-exercise day. For these subjects an exercise day was defined as a day in which the subject completed a minimum of a thirty minute moderate intensity walking bout. Subject's dietary intake was measured for both total day intake and 3-hour post exercise energy intake for total calories, carbohydrate, protein, and fat.

Overall, mean 3-hour energy intake for total calories and macronutrients was increased on the exercise day. A statistically significant increase occurred for 3-hour total calories and carbohydrate intake. These results contrast with most acute dietary compensation studies [2-7], which indicate no acute compensatory response to exercise. Acute compensatory responses in this study could be attributable to the free-living setting in which the study was conducted. Unlike most laboratory studies, subjects were able to complete their exercise and consume foods in their habitual environment at their own convenience. The nature of this design may have allowed for detection of acute compensatory responses that cannot be identified in a laboratory setting because of the tightly regulated constraints in which exercise and eating are performed. Furthermore, acute compensatory responses could have resulted because of the temptations of the obesogenic food environment, which can be easily avoided in a laboratory setting, where a predetermined test meal occurs, but are much harder to resist in a free-living setting. Another factor that could have attributed to the incidence of compensatory response in this study may be the 3-hour time window in which energy intake data was assessed. In most acute studies compensatory responses are measured thirty minutes to one hour after exercise. This may not be long enough to detect significant changes in acute energy intake post-exercise. Verger et al. [8] demonstrated that two hours post-exercise was when subjects consumed the largest amount of food. By examining food intake within a three-hour time window we may have identified a delayed acute compensatory responses that is missed by immediate post-exercise intake studies.

In agreement with prior research [9, 10], significant individual variability in compensatory responses was observed among subjects with varying magnitudes and directions of diet compensation responses occurring. In a comparable study [9] sedentary, pre-menopausal overweight and obese women completed 40 minutes of supervised moderate intensity walking and then were given access to a university cafeteria in which they were allowed to eat ad-libitum. Approximately 58% of women had a lower energy intake on the exercise day as compared to the non-exercise day and 42% of subjects had a higher energy intake as compared to their non-exercise day. In concordance with prior research, results from these analyses support that there are select individuals more susceptible to dietary compensation following exercise while others remain resistant. Therefore, it is imperative to identify what individual characteristics are contributing to this susceptibility.

In an attempt to identify some of these individual characteristics, this study examined the role of eating behavior traits, dietary restraint and disinhibition, on acute dietary compensation. Disinhibition appeared to be a consistent predictor of 3-hour dietary compensation. Increased disinhibition was associated with increased 3-hour total calories, carbohydrate, protein, and fat intake following exercise. This is consistent with other acute exercise studies [11, 12] as well as existing evidence for the role of disinhibition on general eating behaviors [13, 14] Individuals who present with greater levels of disinhibition are more likely to have a loss of control over eating and thus overeat. Furthermore, these individuals also are more likely to engage in opportunistic eating. Exercise may provide an opportunity to eat and therefore individuals with greater disinhibition are taking advantage of this opportunity and eating after exercise. Since these individuals are also prone to have a loss of control of eating once they start their opportunistic eating they may be overeating in these circumstances. This trait did not appear to influence total day compensatory responses however suggesting it has greater implications for immediate, short-term energy balance.

Increased restraint was associated with an increase in total day total calories and fat consumption on the exercise day. This contrasts with existing research [4, 7, 12, 15, 16], which indicates that individuals with increased dietary restraint have no change or a decreased energy intake after exercise because they tightly regulate and control their energy intake. However, it has been postulated that for restrained individuals certain events may act as a disinhibitor and serve to release their tight control over their energy intake [17]. Exercise may be one of these disinhibitors. The results of these analyses propose that in free-living settings exercise may cause restrained sedentary women to break their tight control and increase their total day energy intake, primarily through an increase in fat intake. Another explanation suggested by some [15, 18] could be that exercise increases the perceived pleasantness of food which may then lead restrained individuals to increase their energy intake.

Independent comparisons of dietary restraint and disinhibition in these analyses suggest that higher restraint is influential in total day intake while higher disinhibition is influential in short-term post-exercise energy intake. While not examined together for these analyses, the negative implications on energy balance for individuals with both high restraint and high disinhibition should be further considered.

Other psychological characteristics that may plausibly influence acute compensatory responses, specifically sensitivity to reward, impulsivity, and ability to delay gratification were explored. Existing research identifies these psychological characteristics as important factors in general eating behavior [19-23]. However, no studies were identified which have directly examined the role these characteristics play in acute dietary compensation. Results of these analyses indicate that an individual's sensitivity to reward may influence their likelihood for 3-hour post-exercise dietary compensation. Although not statistically significant, sensitivity to reward was positively associated with 3-hour energy intake. Increased post-exercise energy intake in individuals with increased sensitivity to reward could have occurred because subjects felt that by partaking in an exercise bout they earned the right to increase their intake or treat themselves to more energy dense foods for their achievements. However, since these results did not reach statistical significance the role sensitivity to reward plays on acute dietary compensation remains undetermined and is worthy of further investigation.

In this study, the ability to delay gratification was measured two different ways: 1) using subject's level of discounting for monetary rewards and 2) using subject's level of discounting for food rewards. Discounting for money has been demonstrated to be associated with general eating behavior and increased energy intake [19, 20, 24, 25]. The results of these analyses insinuate, however, that delay discounting for money may not be the best measure to predict acute compensatory responses to exercise among individuals as no statistically significant relationships were observed. Recent evidence has indicated that individuals discount primary reinforcers, such as food, more steeply than conditioned reinforcers (i.e., money) [26]. Studies have reported that an individuals level of discounting for food is associated with percent body fat [27], with those individuals having higher body fat more steeply discounting food than their leaner counterparts.

Results of these analyses reveal that an individual’s level of discounting for food is negatively associated with their acute dietary compensation. This implies that individuals who prefer the immediate food reward (i.e. have less self- control) will be less likely to compensate to exercise through an increase in energy intake. These results are surprising as impulsivity and preference for immediate gratification have been shown to be associated with increased energy intake in general [19, 20, 28, 29]. Since discounting for food has yet to be extensively examined in relationship to dietary compensation post acute exercise, explanations for this relationship remains unclear. Future research around acute compensatory behavior should consider examining an individual’s level of discounting for food as a potential predictive variable rather than their level of discounting for money.

The psychological characteristic of impulsivity did not appear to have any influence on acute dietary compensation during both the total day and 3–hour time periods. It should be noted however that impulsivity is a multidimensional construct [19, 28, 30-32] and even though this behavioral measure of impulsivity did not show any associations to acute compensatory behavior other dimensions of impulsivity may. Further evaluation of other measures of impulsivity, such as self-reported trait impulsivity, should be done to fully identify this psychological trait’s role in acute dietary compensatory behavior.

Non-personality related factors, BMI and exercise timing, were also examined for their potential influence on acute compensatory responses to exercise. While non-significant differences were observed between BMI categories, the results suggest a U-shape relationship between exercise and total calorie compensation with normal-weight and obese individuals having greater compensation than overweight individuals. Increased dietary intake in the normal-weight women could be resulting from a hyperphagic response [5, 11] occurring in the normal-weight women in order to defend body fat stores [4]. The increased energy intake observed in the obese women could be due to the use of food as a reward mechanism for participation in and completion of an exercise bout. The exact reason as to why overweight women may be less prone to increased energy intake with exercise remains unclear.

Exercise timing results demonstrated no significant between group differences in acute dietary compensation. Interestingly, the results do reveal that women who exercise in the morning have the largest increase in total day total calorie compensation however this is not attributed to an increase in 3-hour post-exercise energy intake. Women who exercised in the morning had a decreased 3-hour total calorie, carbohydrate, protein, and fat energy intake following exercise as compared to their non-exercise day. This suggests that these women are increasing their energy intake at another time-point during the day (i.e. later in the afternoon or the evening) and it is this later in the day increase in energy intake that is contributing to their overall total day increase. In contrast, afternoon and evening exercisers had an increased 3-hour post-exercise energy intake. Despite this increased 3-hour intake both groups had much less of a total day compensation as compared to the morning exercisers. Moreover, total day total calorie compensation was next highest in the afternoon exercisers and practically unchanged in the evening exercisers. It may be that exercising at later time-points allows for less opportunity to increase consumption later on in the day and therefore results in less change in total day compensation.

Strengths

1. This study was novel because it observed acute compensatory responses in a free-living environment. This study allowed subjects to perform both exercise and dietary behaviors in free-living settings thus allowing them to be exposed to the temptations present in the obesogenic environment. Most acute compensation studies to date have been conducted in laboratory environments. In this environment both the exercise sessions and the subsequent dietary intake are observed by researchers. Furthermore, the laboratory setting generally only presents subjects with certain foods available to be consumed and subjects must choose from those options. Both the observation of eating and the limited variety of food could influence eating behaviors and lead individuals to eat differently then they normally would after exercise. In addition, the limited variety of food available in the laboratory means subjects are not exposed to the temptations of the obesogenic food environment (in particular the fast food environment). Therefore, this method of experimentation may be missing an essential element influencing dietary compensation after exercise. The free-living setting allows individuals to consume whatever they want, whenever they want, and how often they want without being observed. This natural setting allows for individuals innate compensatory responses to be fully expressed.
2. Most prior compensation studies have only examined changes in total calorie intake as a result of exercise. Our study extended the knowledge base by also examining changes in the macronutrients carbohydrate, protein, and fat. By examining these macronutrients this study provided a more detailed look at acute

compensatory responses and attempted to identify factors contributing to total calorie compensatory responses.

3. The 24-hour dietary recalls for this study were completed at random time points. Subjects were not informed ahead of time what days they would be completing their diet recalls. Since the subjects were unaware of the days of their recalls they were more likely to eat as they usually do and not alter their food intake on recall days.
4. This study considered a number of novel psychological traits that have yet to be explored in the context of acute dietary compensation. Several factors were identified that may be useful in identifying individuals susceptible to compensatory diet responses to exercise.
5. To date, only one study has looked at the influence exercise timing has on acute compensatory responses in women. Our study adds to the limited literature on the role that exercise timing plays in acute dietary compensation among sedentary women.

Limitations

1. Errors in the measure of dietary compensation could have resulted from the use of the NCI ASA-24 program. Since this program is self-administered it is assumed that subjects are honestly and accurately inputting all foods and portion sizes correctly. However, as with most methods of dietary recall, it is possible that underreporting of food could have occurred and the reported energy intakes for total calories and macronutrients may be less than the actual energy intakes for total calories and macronutrients.

2. This study looked specifically at exercise's impact on eating behavior and did not attempt to quantify other environmental and social factors that could have influenced changes in eating behavior. It is possible that the changes in eating behavior seen in this study were due to other factors known to influence eating behavior among individuals such as whom a meal is eaten with, how many people are present at a meal, where a meal is eaten, and if technology is being utilized during the meal.
3. This study only compared acute behavioral compensatory responses for one exercise day and one non-exercise day for each subject. Assessing acute behavioral responses on several separate exercise and non-exercise days may be needed to fully portray if and how an individual acutely compensates to exercise.
4. A minimum accelerometer vector magnitude cut point of 2,691 counts and above was used to establish moderate intensity for identification of walking bouts for all subjects. However, the relative intensity of an exercise bout may be different across individuals walking at the same speed. Therefore, not all subjects may have been walking at the same relative intensity, which could have influenced the eating behavior response following exercise.

Conclusions

The present study suggests that in free-living settings acute, 3-hour post-exercise dietary compensation does occur among sedentary, pre-menopausal women. Examination of various dietary behavior traits and psychological characteristics revealed that dietary restraint and disinhibition might play an influential role on acute dietary compensatory responses to exercise. While sensitivity to reward, impulsivity, and ability to delay gratification appeared to be non-influential in acute dietary compensation these traits should not be completely discounted, as further research is warranted to fully quantify their relationship with acute dietary compensation. Identification of the aforementioned traits as “red flags” can help to distinguish those individuals who may be most susceptible to increasing their energy intake upon participation in exercise. This will help future efforts around individually tailored weight loss and weight management programs.

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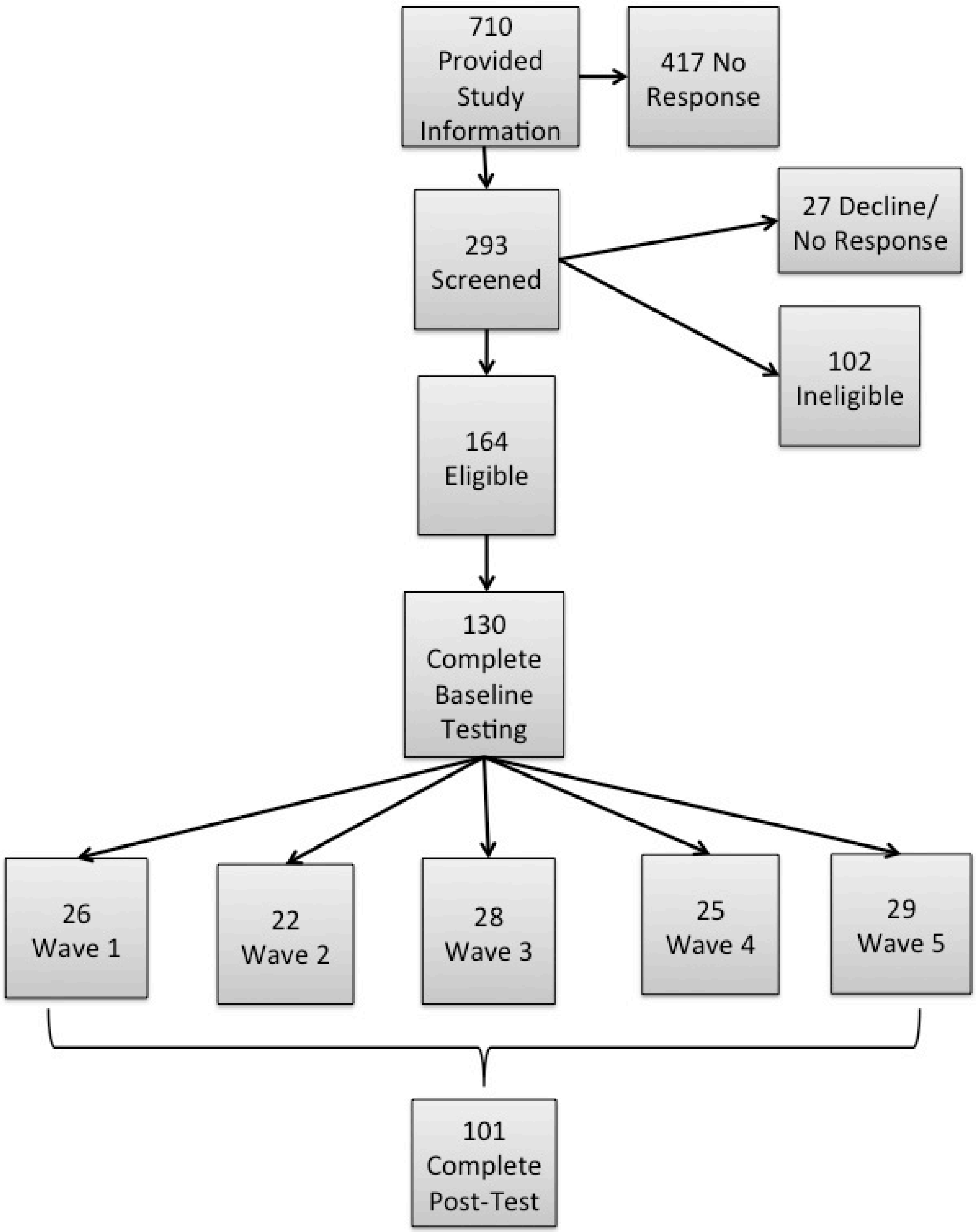
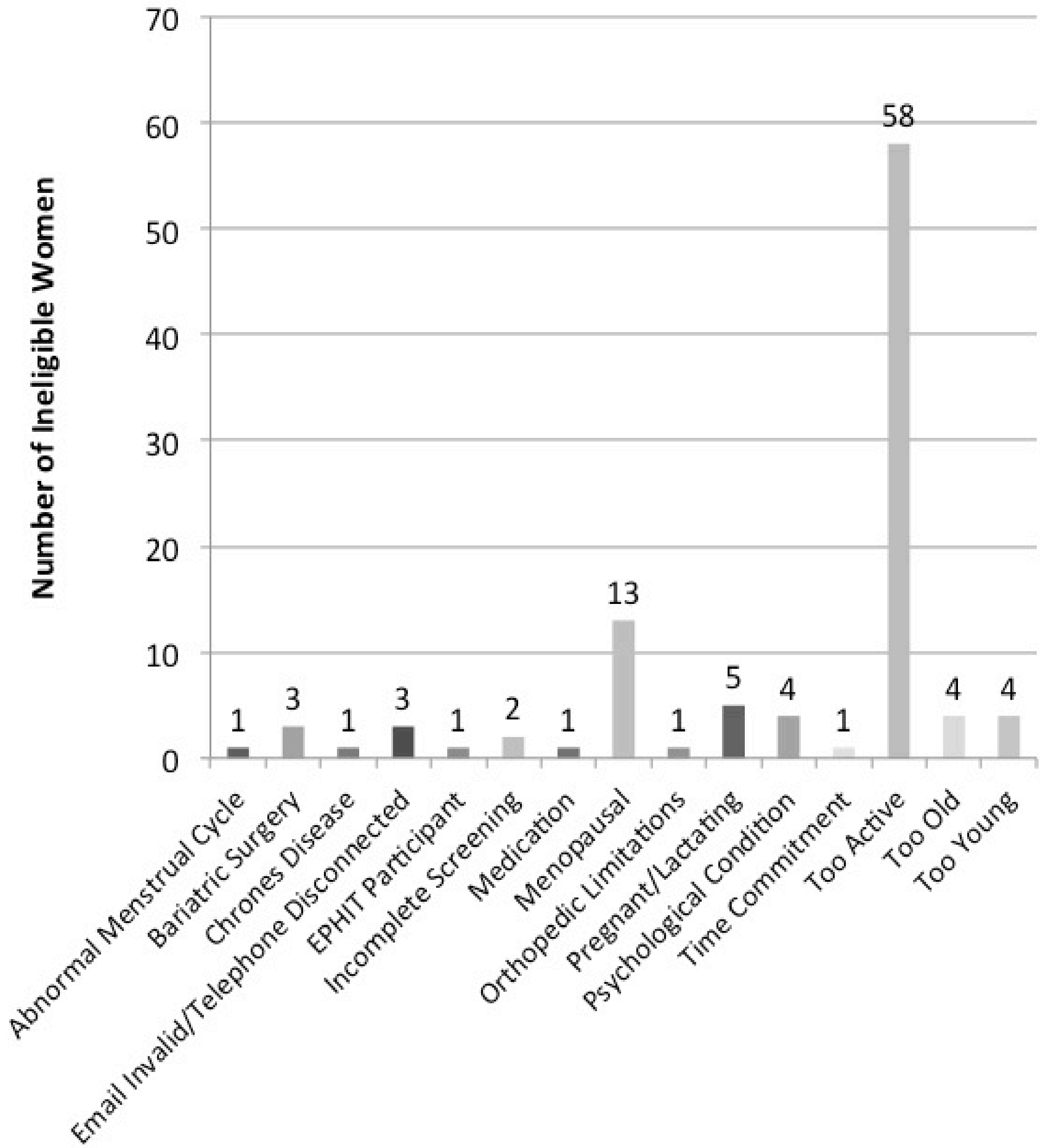
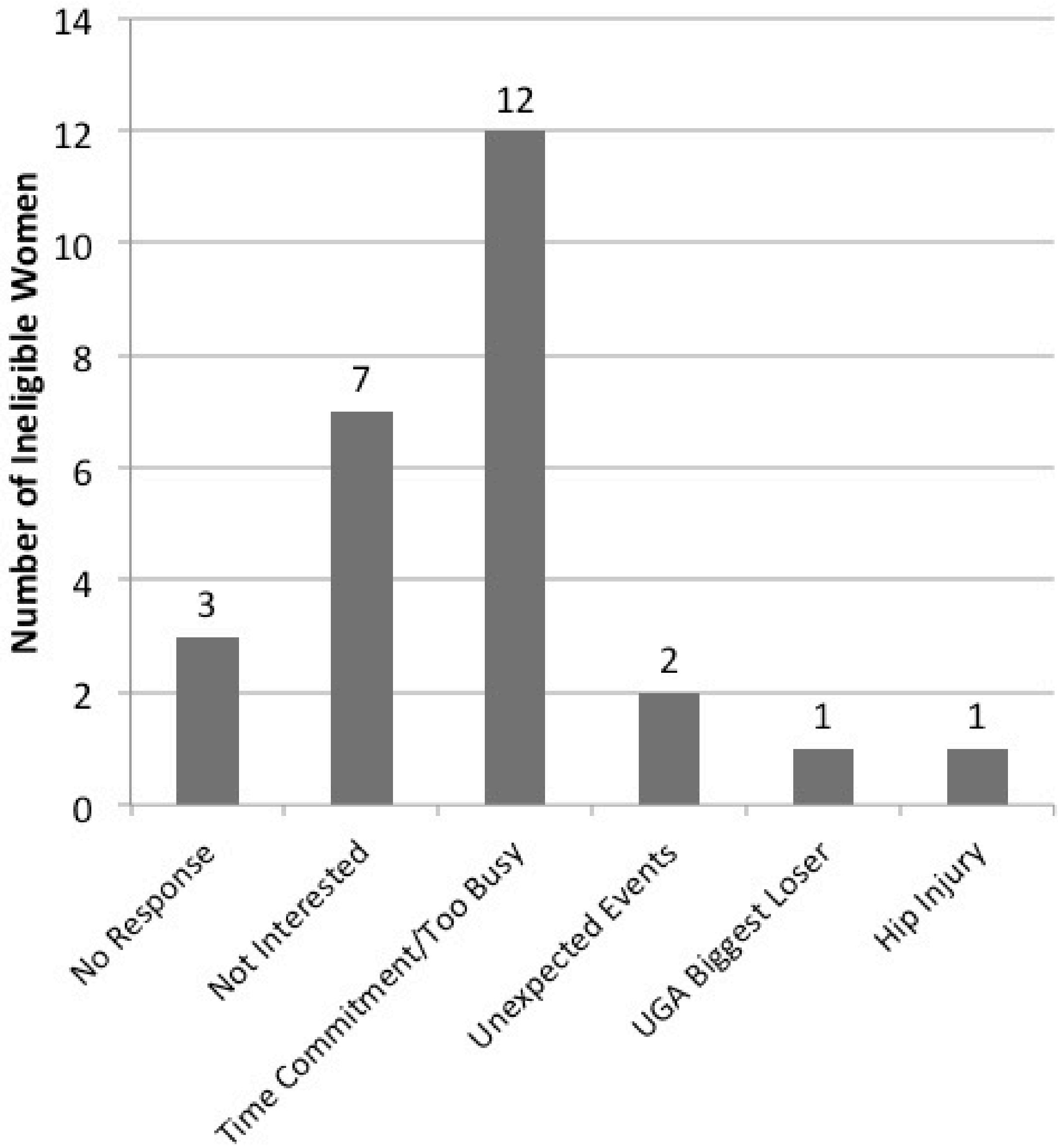
APPENDIX A

Project Pace Enrollment Flow And Ineligibility Breakdown



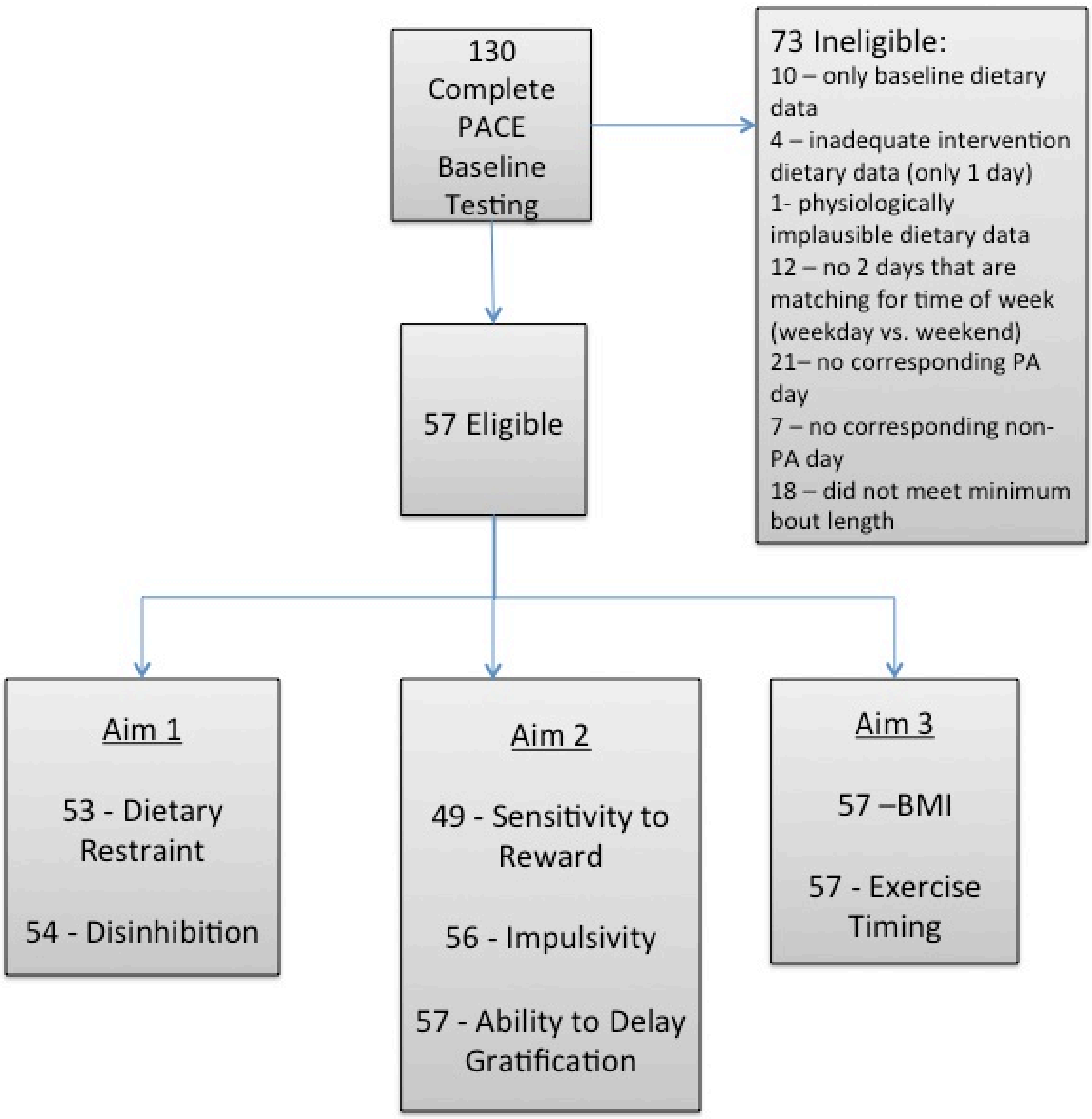

Number of Ineligible Women
70
60
50
40
30
20
10
0
58
13
1
3
1
3
1
2
1
1
5
4
1
4
4
Abnormal Menstrual Cycle
Bariatric Surgery
Chrones Disease
Email Invalid/Telephone Disconnected
EPHIT Participant
Incomplete Screening
Medication
Menopausal
Orthopedic Limitations
Pregnant/Lactating
Psychological Condition
Time Commitment
Too Active
Too Old
Too Young



14
12
10
8
6
4
2
0
Number of Ineligible Women
3
7
12
2
1
1
No Response
Not Interested
Time Commitment/Too Busy
Unexpected Events
UGA Biggest Loser
Hip Injury

APPENDIX B

Thesis Subject Flow And Ineligibility Breakdown



APPENDIX C

Total Day Percent Change Results Tables

<u>Table I:</u> Spearman Correlations between Eating Behavior & Psychological Traits and Total Day Percent Change Dietary Compensation

	Dietary Restraint	Disinhibition	Sensitivity to Reward	Impulsivity	Ability to Delay Gratification ($)	Ability to Delay Gratification (food)
<u>Total Day (%)</u>						
Δ Total Calories	0.30*	0.50	0.14	-0.18	0.03	-0.31
Δ Carbohydrate	0.12	0.00	0.20	-0.13	0.12	-0.16
Δ Protein	0.21	0.04	-0.10	-0.15	-0.07	-0.22
Δ Fat	0.32*	0.03	0.11	-0.07	-0.06	-0.18

* $p < 0.05$

Table II: Body Mass Index and Total Day Percent Change Dietary Compensation

	Normal Weight (n= 18)	Overweight (n=15)	Obese (n= 24)	p*
Total Day (%)				
Δ Total Calories	18.00 ± 64.90	7.63 ± 39.27	10.49 ± 36.96	0.81
Δ Carbohydrate	50.42 ± 107.61	21.23 ± 53.92	8.01 ± 46.65	0.18
Δ Protein	20.54 ± 95.55	-11.45 ± 39.25	30.95 ± 66.01	0.20
Δ Fat	12.32 ± 65.46	9.68 ± 59.94	24.19 ± 65.03	0.74

* ANOVA used to identify between group differences

Table III: Exercise Timing and Total Day Percent Change Dietary Compensation

	Morning (n = 7)	Afternoon (n = 18)	Evening (n = 32)	p*
Total Day (%)				
Δ Total Calories	19.75 ± 39.59	14.90 ± 46.37	8.84 ± 50.40	0.83
Δ Carbohydrate	37.60 ± 44.71	40.70 ± 96.98	13.20 ± 63.38	0.41
Δ Protein	0.15 ± 41.23	9.70 ± 71.30	23.91 ± 78.89	0.66
Δ Fat	25.96 ± 77.74	13.39 ± 52.88	16.40 ± 66.77	0.91

Morning (0:00 - 10:59), Afternoon (11:00 - 16:59), Evening (16:00 - 24:00)
* ANOVA used to identify between group differences

APPENDIX D

Bivariate Correlation Matrix between Predictor Variables

	Dietary Restraint	Disinhibition	Sensitivity to Reward	Impulsivity	Ability to Delay Gratification ($)	Ability to Delay Gratification (Food)	BMI
Dietary Restraint		-0.23	0.01	-0.20	-0.13	-0.39	-0.12
Disinhibition			0.36*	0.05	-0.01	0.09	0.23
Sensitivity to Reward				-0.07	0.16	0.11	0.00
Impulsivity					-0.17	-0.13	-0.03
Ability to Delay Gratification ($)						0.28	0.05
Ability to Delay Gratification (Food)							0.07
BMI							

* $p < 0.05$