Delay Discounting, Reinforcing Value of Food, and Components of Metabolic Health

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ABSTRACT

Background: According to the Centers for Disease Control and Prevention (CDC), over one-third of US adults are obese. In order to assess causes of and treatments for obesity, researchers have evaluated a number of processes underlying health-related behaviors, one of which is delay discounting. Delay discounting is a cognitive process that describes the phenomenon by which individuals discount the value of a future reward compared to the value of an immediate reward. Researchers have associated delay discounting with drug addiction, alcoholism, and cigarette smoking. More recently, delay discounting has been studied with regards to health-related behaviors, such as body weight management, food intake, glucose control, and physical activity. While a number of studies have concluded that obese individuals tend to be greater discounters, the relationship between delay discounting and various health-related behaviors beyond smoking and drug use remains unclear. The purpose of this study is to evaluate the relationship between delay discounting and diet quality, glucose tolerance, physical activity, and fasting vs. non-fasting conditions.

Methods: Sixty-five males (*n=20*) and females (*n=45*) were recruited for the present study. Participants completed two lab sessions: one under non-fasting conditions, and one under fasting conditions which involved measurements of body mass and composition, blood pressure, blood glucose, blood lipids, and health-related questionnaires. Delay discounting and food purchase tasks were completed at both visits. Participants were asked to complete a four-day food intake record and wear a physical activity monitor for four days.

Results: Lower rates of discounting were found in those who consumed more total vegetables, and lower food reinforcement was observed in those who spent less time sedentary and more time physically active, had greater dietary Restraint, and had a lower resting heart rate. There were no significant differences between discounting rates and food reinforcement across fasting and non-fasting conditions.

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ABSTRACT (General Audience)

Background: More than one-third of US adults are obese. Obesity brings with it a number of chronic health conditions as well as the financial burden of increased healthcare costs. There are a multitude of treatment methods for obesity, and researches have evaluated many aspects of behaviors that contribute to obesity. Decision-making processes are an important factor related to management of body weight as well as general health. One field of study concerned with decision-making is called behavioral economics, and it includes the concept of delay discounting. Delay discounting is a cognitive process by which individuals tend to discount the value of future rewards in favor of more immediate rewards. This behavior has been associated with drug use and addiction, alcoholism, and cigarette smoking, as well as a number of other psychological or social parameters. More recently, research has connected delay discounting with health-related factors such as body weight management, glucose control, physical activity, and diet quality. A number of studies have concluded that obese individuals tend to be greater discounters, meaning that they prefer immediate rewards rather than delaying gratification for future rewards, however the relationship between delay discounting and various health-related behaviors remains unclear. The purpose of this study is to evaluate the relationship between delay discounting and diet quality, glucose tolerance, physical activity, and fasting vs. non-fasting conditions.

Methods: Sixty-five males (*n=20*) and females (*n=45*) were recruited for the present study. Participants completed two lab sessions: one under non-fasting conditions, and one under fasting conditions which involved measurements of body mass and composition, blood pressure, blood glucose, blood lipids, and health-related questionnaires. Delay discounting and food purchase tasks were completed at both visits. Participants were asked to complete a four-day food intake record and wear a physical activity monitor for four days

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CHAPTER 1: Introduction

More than one-third of U.S. adults are obese, according to the Centers for Disease Control and Prevention (CDC).[1] Obesity is defined as a BMI $\geq$ 30 kg/m^2.[2] There are a number of chronic health conditions related to obesity, which include type-II diabetes, cardiovascular disease, stroke, and certain types of cancer.[3] These health conditions are some of the leading causes of death in the United States. Obesity also brings with it a financial burden, as evidenced by the annual medical costs for an obese person being $1429 greater than that of a normal weight person (BMI < 25 kg/m^2).[1] A meta-analysis performed by Kim and Basu at the National Bureau of Economic Research (2016) indicates that national annual medical costs attributable to obesity is over $149 billion.[4] In 2006, this cost was estimated to be $40 billion, demonstrating the vast increase in costs associated with obesity.[5] Overweight and obesity is also associated with increased number of sick days, short-term disability, and worker's compensation days.[6]

The Academy of Nutrition and Dietetics Position Paper on Obesity Treatment (2016) and the AHA/ACC/TOS Guideline for the Management of Overweight and Obesity in Adults (2013) list a plethora of treatment methods for achieving and maintaining weight loss in adults.[7,8] These methods range from those on the individual level, such as medication, surgery, and behavioral interventions, all the way to public policy level strategies, such as menu labeling and taxing of certain foods.[7,8] It is stated that the treatment of overweight and obesity in adults requires sustainable lifestyle changes at one or more of these levels in order to be successful. One method for obesity treatment is targeting individual decision-making regarding lifestyle-related behaviors.[7] People must make a multitude of decisions every day, many of which pertain to food and physical activity. The significance of these behaviors is that they are both modifiable risk factors to the development of obesity and chronic disease. Targeting the mechanisms by which individuals make food intake and physical activity decisions could be an effective way to accomplish sustainable behavior change.

One such process related to decision-making is delay discounting. Delay discounting is the behavioral economic concept that describes the phenomenon by which individuals discount the value of a future reward compared to the value of an immediate reward when presented with a decision between the two.[9] This cognitive process has been studied in regards to its association with drug addiction,[9-14] alcoholism,[15] and cigarette smoking,[16,17] as well as a number of other psychosocial parameters[18-20]. More recently, researchers have sought to determine whether relationships exist between delay discounting and health-related behaviors such as body weight management,[21-31] food intake,[32-36] glucose control,[37-39] and physical activity.[35,40-43] While some associations have been repeatedly produced in these studies, other relationships remain inconclusive. Studying the rewards decision-making process with relation to health behaviors could help professionals identify potential avenues for intervention and thus decrease the prevalence of obesity and chronic disease in U.S. adults.

CHAPTER 2: Review of the Literature

Delay Discounting

A cognitive process by which people make decisions about immediate versus future rewards is delay discounting. Delay discounting is defined by Kirby, Petry and Bickel (1999) as "the reduction in the present value of a future reward as the delay to that reward increases".[11] This means that the value of the delayed reward (also known as reinforcer) is "discounted" compared to that of an immediate reward.[9] The degree to which an individual discounts a delayed reinforcer is quantified by the steepness of discounting, such that a steeper rate refers to greater preference for immediate rewards. Rate of discounting has been determined using a number of questionnaires, which are designed to present the option of a smaller, more immediate reward vs. a larger, future reward at varying delays.

As previously mentioned, much of the research on delay discounting has been conducted in the field of drug addiction to determine the method by which addicts make decisions. Numerous studies have found that addicts, alcoholics, and cigarette smokers tend to discount future rewards in preference of immediate rewards. The same principle has been proven in other conditions such as ADHD and anxiety, which will be explained later in more detail. The purpose of this literature review is to assess whether there is evidence in the literature demonstrating similar discounting characteristics with relation to health-related factors, such as body mass, metabolic health, and lifestyle behaviors. If there is, it may suggest a role of delay discounting as a point of intervention for combatting the rise of obesity in the U.S.

Delay Discounting Research

In the context of delay discounting research, the most commonly examined reinforcer has been money. One such method for evaluating discounting patterns for money is the 27-item Monetary Choice Questionnaire.[44] Adjusting Amounts (AA) tasks present options in a similar fashion and systematically increase or decrease the value of the immediate reward.[45,46] Rather than money, some researchers have instead utilized other commodities of interest in discounting tasks. For example, Hendrickson, et al. (2015) successfully validated the use of a novel Food Choice Questionnaire (FCQ) against existing adjusting amounts tasks.[45] This new tool uses both food and money as reinforcers. The Food Purchase Task, which will be discussed later, was devised by Epstein and colleagues to assess the reinforcing value of food.[47] Drugs have also been incorporated as reinforcers in discounting tasks.[14,15]

Subjects' responses to the questionnaire, no matter what the reinforcer, are used to calculate the rate of discounting. Most studies have analyzed discounting using a hyperbolic function, assuming that the devaluation of delayed reinforcers is proportional to their delay.[9,48] Delay discounting experiments utilize a model similar to that of psychophysical experiments, where subjects are presented with a choice between a fixed larger, later reward and an adjusting immediate reward. The value of the immediate reward at which the subject considers the two rewards to be of equal worth is termed the "indifference point".[9] In other words, the indifference point is "the amount of money at which immediate rewards become preferred over the delayed reward".[33] This data can be utilized to create a curve when indifference points from varying delays are collected from the subject.[9] Rate of discounting can then be determined utilizing the indifference curve in a hyperbolic equation developed by Mazur (1987):

$$V = \frac{A}{(1 + kD)}$$

In this equation, "V is the present value of the delayed reward A at delay D and *k* is a free parameter that determines discount rate".[11,49] Thus *k* is the parameter of interest and represents the rate of discounting. The hyperbolic function is considered to be the superior method of analysis for delay discounting, as compared to an exponential function.[15,50] An alternative method to quantifying rate of discounting is by Area Under the Curve (AUC).[51] This combines measures of discounting obtained at different delays to calculate the area under the empirical discounting function. A smaller area under the curve represents steeper discounting.[51]

One of the first studies evaluating discounting of delayed rewards is popularly known as the "marshmallow test" and was performed by Mischel in 1958.[52] In this experiment, 4-year-old preschoolers were assessed on the amount of time they could wait for a larger delayed reward while resisting a smaller, immediate reward, both in the form of marshmallows.[53] Longitudinal data from this study indicates that those children who exhibited lower discounting of delayed rewards (i.e. highly valued future rewards) had more positive long term outcomes than their counterparts, including higher SAT scores, higher educational attainment, and less drug use in adulthood.[53,54]

Since the marshmallow study, delay discounting has been largely studied in the area of drug use and addiction. Researchers have analyzed the subjective value of money as well as other commodities in an effort to quantify the level of discounting in a number of drug-related populations. In 1999, Kirby, Petry, and Bickel found that opioid-dependent subjects discounted money at a rate almost two-times that of their control counterparts.[11] Higher discounting rates have also been observed in cocaine- and nicotine-dependent subjects compared to non-dependent controls.[12] Similar findings exist for cigarette users, as evidenced by a study conducted by Bickel, Odum, and Madden (1999).[16] The results of this study indicated that current smokers discounted the value of delayed money more than never-smokers and ex-smokers. While money has been most commonly used as a reinforcer in addiction research, some researchers have expanded to using the drug of choice. For example, Petry (2001) examined the level of discounting for both money and alcohol in present alcoholics, abstinent alcoholics, and controls who had no history of alcohol or drug abuse.[15] It was found that alcoholics discounted all rewards more steeply than the controls. Petry used similar research methods in a later study and discovered that drug abusers discounted money, health, and freedom at a higher rate than non-substance using controls.[13]

More recent studies have examined delay discounting with relation to other behavioral and personal factors. For example, in a study where participants were recruited through Amazon's Mechanical Turk, an "online labor market" in which researchers can post surveys for wide populations to complete for monetary compensation, those who exhibited higher ADHD scores tended to choose present rewards over future rewards in a delay discounting task.[18] Anxiety is another characteristic which has been examined in college students.[19] Those who were declared "High Trait Anxiety," scoring in the upper 25% of the distribution in Spielberger's State-Trait Anxiety Inventory, were significantly more impulsive (i.e. preferred more immediate choices) based on a delay discounting questionnaire.[19,55] The rate of discounting was found to predict future property crime in college students across a one- and two-year period, as evidenced by a three-year cohort study conducted by Lee, et al. (2017).[20] These studies all indicate that there is a correlation between behavior and discounting of delayed rewards. Those who are more present-minded appear to exhibit behaviors related to addiction, anxiety, and even crime.

Delay Discounting and Brain Function

Delay discounting falls within the realm of behavioral economics, which focuses on behaviors that function within a system of constraint. Research in this field evaluates the "conditions that influence the consumption of commodities".[9] Neuroeconomics combines behavioral economics and neuroscience to analyze brain reactivity during delay discounting tasks using functional magnetic resonance imaging (fMRI) or positron emission tomography (PET). An informative summary of this method is provided in a review by Bickel et al. (2007).[10] Scanning the brain during decision-making tasks allows researchers to identify the areas of the brain activated in various circumstances. Two brain systems of interest are the impulsive system and the executive system. The impulsive system involves brain areas including the amygdala, nucleus accumbens, ventral pallidum, and other related structures. It is responsible for some physiological and emotional responses. The executive system, on the other hand, lies in the prefrontal cortex and is involved in logical thought processes such as outcome expectations, working toward a goal, contemplation of future consequences, and social control. A theory known as the "competing neural systems hypothesis" poses that these systems are in constant competition during decision-making processes. It is theorized that a state of drug dependence might result from the impulsive system outweighing the functions of the executive system, thus allowing one's impulse to override logic.[10]

Just as many people exhibit impulsive behaviors with drugs, etc., impulsivity often plays a role in food choices. Therefore, it is understandable that this concept would translate to behaviors associated with weight gain and obesity. One study utilized fMRI reactivity in obese women while they completed delay discounting tasks to evaluate activation of the executive regions of the brain during these tasks.[27] Discounting tasks were classified as difficult or easy based on reaction time and the percentage of “now” choices, such that immediate and delayed choices had more similar subjective values in difficult trials than in easy ones. Difficult delay discounting tasks resulted in greater activation of executive function regions of the brain. Those participants who had *less* activation of these regions during difficult tasks had a greater rate of weight gain over the next 1.3-2.9 years. These results signify that the development and progression of obesity could be explained in part by poor functioning of the executive regions.[27] However, the authors note the possibility that obesity causes alterations in executive function, further increasing the risk for weight gain which might result in progression of neural adaptations, and so on in a “snowball effect”.[27,56,57]

Reinforcing Value of Food

Due to a heightened interest in the “obesogenic” environment, i.e. the constant presence of food cues promoting high fat and high sugar diets, a number of researchers have shifted focus toward food as a reinforcer.[47,58-61] Reinforcement is a key contributor to choice; when presented with multiple options, people will likely choose the one that is reinforcing in some way.[60] Thus, reinforcers play a key role in the development of many factors associated with lifestyle and behavior choices and can contribute to the development of unhealthy behaviors thought to contribute to obesity.[60] To assess the role and magnitude of food as a reinforcer, researchers have studied what is known as the reinforcing value of food.[60] This concept has been defined as “the motivation to obtain food, or how hard someone will work or how much time they will allocate to obtain food”.[60] It is described as the “relative reinforcing value” because the value of one choice is relative to the value of another available option, and is often abbreviated as RRV_{food}. Those people who find food highly reinforcing might be more likely to eat larger quantities of food, which could be a contribution to weight gain. Epstein, Dearing, and Roba (2010) developed the Food Purchase Task as a questionnaire-based approach to quantifying the relative reinforcing value of food and further analyze its association with health behaviors.[47] This questionnaire allows researchers to characterize participants' motivation for food with regards to the price they are willing to pay on an adjusting schedule.[47] The relative reinforcing value is estimated by observation of the crossover or switch point, which is the point at which the individual's preference switches from the most-preferred to the least-preferred choice.[59]

Food reinforcement differs across individuals and may influence the ability to maintain a healthy weight.[59] Evidence supports that obese adults and children tend to find food more reinforcing than their healthy-weight counterparts. For example, Saelens and Epstein (1996) asked eight obese and eight non-obese college students to rank four snack foods and four sedentary activities, separately, in order of preference.[61] Subjects then sampled a small amount of each food and performed each activity for a short time. Reinforcing value was assessed with a series of tasks in which subjects were able to earn points to trade for food or sedentary activity. It was observed that obese individuals found eating snack foods more reinforcing than engaging in sedentary activities.[61] Similar results were observed in children when Temple and colleagues assessed the relative reinforcing value of food with relation to body weight status and food intake.[62] Results from these studies indicate that there appears to be a positive relationship between the reinforcing value of food and energy intake.[61,62] In addition, overweight children find food to be more reinforcing than non-food alternatives. Their lean peers, on the other hand, find non-food alternatives to be more reinforcing than food.[62] One major challenge to combatting childhood obesity is finding alternatives that can compete with behaviors of eating and physical inactivity that contribute to excess weight gain.[60] In an effort to explain such phenomena and seek answers, researchers have further evaluated the role of food reinforcement and other behavioral factors with which it may interact.

Reinforcing Value of Food and Delay Discounting – Reinforcement Pathology

It is possible that discounting behaviors and food reinforcement interact to determine choices related to food. This interaction has been termed "reinforcement pathology."[60] For example, those people who find food highly reinforcing and cannot delay gratification are likely susceptible to developing unhealthy eating behaviors. Conversely, those who are able to delay gratification may be able to balance the high reinforcing value of food with self-control and stave off undesired weight gain.[60]

A number of studies have examined this interaction by administering both delay discounting tasks and food reinforcement tasks. Rollins et al. (2010) studied food intake of healthy, non-smoking, non-obese women with relation to relative reinforcing value of food, ad libitum energy intake, and delay discounting of money.[63] Results of this study indicated that those who exhibited higher discounting of money and greater relative reinforcing value of a personally-selected food consumed greater total energy in an ad libitum eating task. The same principle was observed but to a lesser degree of significance when rate of discounting was low. No significant relationship was observed between delay discounting and energy intake alone, but rather that discounting served as a moderator for the effect of relative reinforcing value of food. It is a potential limitation that this study included only non-obese females.[63] Another study with a similar design assessed the interaction of delay discounting, the Power of Food Scale (PFS), and ad libitum snack intake preceded by an oatmeal preload.[34,64] The PFS measures hedonic, or pleasure driven, hunger.[64] A bland oatmeal preload served the purpose of eliminating physical hunger, potentially providing a more accurate assessment of hedonic eating. It was found that among those with high PFS scores, greater discounting was related to a higher total energy intake in the eating task. The opposite pattern was observed in low PFS scorers, such that lower discounting was associated with higher energy intake. A significant interaction to predict food intake was not observed between PFS and delay discounting.[34]

Delay Discounting and Obesity

Perhaps the most cited study regarding body weight status and delay discounting was performed by Weller, et al. (2008) and involved healthy weight and obese individuals.[21] After having BMI measured in the lab and completing computerized discounting tasks, it was concluded that obese women showed greater delay discounting than healthy weight women. There was no significant difference between obese and healthy weight men.[21] Results from Ikeda, et al. (2010) demonstrated that BMI was positively associated with the degree of impatience assessed by questionnaire, and that females were significantly more impatient than males.[25] Likewise, a study in mice found that female mice were more impulsive than males under mild food restriction.[65] Additional research is required to confirm the gender effect of delay discounting.

A number of other studies have confirmed steeper discounting rates in obese individuals compared to their healthy weight counterparts.[26,28,30,33,66] In a community-based sample of healthy adults, BMI was positively associated with choosing a more immediate reward in delay discounting tasks.[26] Another study in adults found that both BMI and age were significantly associated with rate of discounting.[28] Price, et al. (2016) also observed that overweight and obese participants discounted significantly more than did the controls when evaluating money as a reward.[30] Similar results have been observed with other reinforcers, including food, money, and discount vouchers; obese participants chose smaller, sooner rewards more frequently compared to normal weight participants.[66] An interesting study in overweight and obese females utilized “preloading” (giving participants a bland meal) to remove hunger as a confounding variable in discounting tasks and intake of palatable foods.[33] While BMI was positively associated with greater palatable food intake in a taste-test task, BMI was not correlated with delay discounting. The results of this study suggest that hunger may be a significant determinant of response to a delay discounting task, however more work needs to be done to confirm this.[33]

Delay discounting research with regards to body mass has been conducted in the adolescent population as well. Using an adjusting-amounts task, Fields et al. (2013) discovered that overweight and obese adolescents discounted more than healthy-weight adolescents.[23] However, there was no significant difference between overweight and obese groups.[23] Another study in female adolescents assessed weight concern, or “preoccupation and dissatisfaction with one’s weight,” and BMI with relation to rate of discounting.[31] Steeper discounting was associated with greater weight concern and BMI. These findings suggest that obesity prevention and treatment efforts should acknowledge both impulsivity and weight concern among adolescents.[31] Use of prevention strategies early in life could prove to be a useful strategy for reducing adult overweight and obesity.

A number of studies utilized crowdsourcing methods such as Amazon Mechanical Turk to recruit large populations to complete discounting questionnaires. Bickel et al. (2014) recruited over 1000 participants and determined that obese people discounted more than non-obese people.[22] The authors suggest that future research should divide the obese population into smaller subgroups to study differences among them.[22] Another study using AMT assessed discounting rates, body mass, and "grit," which is a measure of one's perseverance for long-term goals.[24] Higher discounting of delayed rewards was observed in obese individuals and those with low grit scores. There was no difference between discounting in men and women in this study.[24] While such studies are able to attain a larger sample size, there are some limitations associated with online surveys. All data is collected via self-report, meaning that values such as height and weight may be inaccurate.

Delay Discounting and % Body Fat

While the previous studies provide fairly consistent results that BMI is positively associated with rate of discounting, there are some limitations to using BMI as an indicator of weight status. BMI does not account for body composition and can be an inaccurate predictor of health status in some populations.[67] Unlike BMI, percent body fat takes into account individual differences in adiposity. In adolescents, Lu et al. (2014) measured percent body fat by Bioelectrical Impedance Analysis (BIA) and compared with delay discounting measures. Greater percent body fat was associated with greater delay discounting in girls.[29] Rasmussen et al. (2010) also used BIA to determine percent body fat in adults, and utilized both food and money as reinforcers in the delay discounting tasks. Percent body fat was predictive of discounting for food as a reward, but not for money.[68] Similar results were observed by Hendrickson (2013) in a comparable population, where higher percent body fat was associated with more impulsive choice for food, but not for money.[69]

Delay Discounting and Food Intake

Habitual food intake and diet quality have been examined in a limited number of studies. Garza, et al. (2016) found that greater discounting was positively associated with fast food consumption.[36] A study in overweight and obese women by Appelhans, et al. (2012) found that delay discounting was not significantly associated with the percent of food items consumed away-from-home, ready-to-eat, or home-prepared, as assessed by weighed food records.[32] However, there was a significant positive correlation between discounting and greater energy intake for foods that were ready-to-eat and away-from-home, but not in those that were home-prepared.[32] In an effort to associate the relationship between diet quality and delay discounting, Garza, et al. (2013) evaluated diet with regards consumption of fruit/vegetable, fat/cholesterol, milk/dairy, and sugar-sweetened beverages using the Food Behavior Checklist.[35,70] Those with greater diet scores (i.e. better diet quality) exhibited high value of the future in discounting tasks.[35] In individuals with diagnosed eating disorders, steeper discounting has been observed in those with bulimia nervosa and binge eating disorder, while those with anorexia nervosa tend to exhibit lower rates of discounting.[71-73] Delay discounting could be an underlying factor in the eating behaviors associated with these disorders.[71]

Delay Discounting and Glucose Control

Several studies have examined delay discounting in diabetic populations.[74,75] Lebeau et al, (2016) compared HbA1c in type-II diabetic patients with discounting tasks derived from a preliminary study, and assessed both gain and loss discounting using money as a reinforcer.[74] There was a significant positive correlation between delay discounting for gains and HbA1c, meaning that people with poorer glycemic control exhibited steeper discounting. These results were determined after adjusting for possible confounding variables, including socio-demographic, clinical, and psychological data. This study was limited by its cross-sectional data set which did not include observation of patients over time or patients of varying population sectors.[74] Similar results were observed in adolescents with type-I diabetes, where delay discounting was positively associated with HbA1c.[75]

Other research has examined the effects of acutely fluctuating blood glucose on decision-making.[37,38] Wang and Dvorak (2010) based their hypotheses on principles of evolutionary psychology in which humans' present- or future- mindedness is highly dependent on the body-energy budget, or how much glucose is available.[37] They predicted that when the body-energy budget status quo is in positive balance, humans will be more future oriented. The basis for this future-mindedness lies in the primal concern for reproduction. Conversely, when the body-energy budget is decreasing or negative, humans would value present rewards in an effort to promote survival. In this study, blood glucose was measured immediately before the completion of discounting tasks on two occasions: once before ingestion of a drink that contained sugar or artificial sweetener, and once after. There was a decrease in future discounting after participants consumed a drink containing sugar, and an increase in future discounting in those who consumed the drink containing artificial sweetener. It can be concluded that the preference for future or present rewards was influenced by changing blood glucose levels.[37] Wang and colleagues have studied these effects more recently and found comparable results.[38] In one study it was concluded that the change in discounting before and after a drink was likely due to reduction in hunger/appetite, rather than reduction in thirst. Another study indicated that ingestion of glucose, but not water or another form of sugar, reduced delay discounting.[38]

Delay Discounting and Physical Activity

In a recent study by Mørkbak, et al. (2017), self-management and health outcomes were assessed in diabetic individuals with relation to time preference.[39] Rather than using delay discounting tasks, this study utilized the Discrete Choice Experiment, which, like discounting tasks, assesses the value of future rewards by presenting two choices available at varying delays. Results indicated that present bias was associated with both age-at-onset and year-of-debut of diabetes. Moreover, after controlling for year-of-debut and socioeconomic characteristics including gender, income, and education, there was a significant correlation between age-at-onset $\leq$ 48 years and present bias. This means that those who were diagnosed with diabetes at a younger age exhibited more present bias. Other lifestyle factors associated with present bias were physical inactivity, obesity, and diabetes illiteracy. These results support the hypothesis that present-bias serves as a driver for poorer self-management of diabetes. It is important to understand the mechanisms behind poor self-management in an effort to create effective interventions in prevention or treatment of diabetes.[39]

It is of special consideration that the previous study examined physical activity habits with relation to time preference and health outcomes.[39] The importance of physical activity in health is widely known, with its contributions to weight loss and all the associated benefits, as well as reduction in the risk of many chronic diseases.[67] Being physically active can improve muscular strength, balance, endurance, mental health, cognitive function, and metabolic health.[67] Yet, only 21% of Americans meet the 2008 Physical Activity Guidelines, according to 2014 CDC data.[76] Only a handful of studies have assessed the association between physical activity and discounting of delayed rewards. In one such study by Garza, et al. (2013), it was observed that those who prefer long-term rewards reported higher levels of physical activity.[35] Research in older adults demonstrated that those who exercised exhibited lower rates of discounting.[40] Physical activity in this study was assessed in terms of frequency and duration using validated questionnaires.[40]

A unique study assessed discounting as a function of time engaged in physical activity; this research sought to determine the magnitude of cost that people perceived non-exercise physical activities to be.[42] The levels of activity in the discounting tasks included walking, standing in line, and waiting while sitting. Results indicated that steeper discounting was positively associated with more physically demanding activities.[42] Some research has focused on physical activity as an intervention to manipulate discounting characteristics. In rats, it was observed that physical activity reduced the sensitivity to reinforcement amount and delay, with statistical significance being robust and consistent over 12 consecutive days of testing.[43] Two human studies were performed by Sofis, et al. (2017) to determine the effects of a physical activity intervention on discounting behaviors.[41] The first study utilized accelerometers (Fitbit Charge HR) and the Monetary Choice questionnaire as measures. After meeting three times per week during baseline to complete the MCQ, and during treatment to complete the MCQ and coach-led exercise, there was a decrease in discounting. However, it was unclear whether physical activity was responsible for this effect. The second study assessed habitual physical activity using the International Physical Activity Questionnaire (IPAQ). Participants attended sessions three times per week during baseline to complete the MCQ, and during treatment to complete the MCQ and partner physical activity. Results of this experiment indicated that delay discounting decreased from baseline to treatment, and discounting levels were maintained over a one-month follow-up period. However, the decrease in discounting after the onset of treatment was only observed in those whose physical activity increased with treatment (i.e. those who were less physically active before participating). These results confirm the hypothesis that physical activity intervention would decrease levels of delay discounting.[41]

Differing results in the two experiments could be explained by a number of factors. Activity in the second experiment was not coach-led. The second experiment utilized varied start dates that occurred in winter and spring, as opposed to a standard start date in the summer in the first experiment. Furthermore, exercise treatment in experiment two was not completed simultaneously with coaches, and the sample size was larger.[41]

While physical activity has been associated with lower rates of discounting in a number of studies, activity levels were only assessed via self-report rather than measured by accelerometry. Those experiments that did utilize accelerometry were focused on the role of physical activity as an intervention rather than an association.[41] While this data is useful, there is lacking evidence in the literature that discounting rates and physical activity are associated in the general population. Understanding this association could provide evidence for cognitive mechanisms behind the development of obesity and chronic disease, and serve as a viable point of intervention.

Interventions

Interventions have been tested under the hypothesis that reducing delay discounting would in turn reduce present-biased behaviors, such as drug use or overeating.[17,69,77] Stein, et al. (2016) utilized episodic future thinking (EFT) as an intervention, a process by which participants imagine positive life events in the future.[17] This proved effective to reduce delay discounting and cigarette smoking in current smokers.[17] Previously, Daniel et al. (2013) found that EFT resulted in lower delay discounting and ad libitum food intake in overweight or obese women, compared to controls that did not undergo EFT exercises.[77] Another approach to reducing discounting is mindfulness training. Hendrickson and Rasmussen (2013) employed mindful eating training that involved recording observations during an eating task such as how the food felt, smelled, and tasted.[69] Participants in the intervention group completed this training between delay discounting sessions. Results indicated that discounting was significantly lower in the mindful eating group during the second session, with no significant difference existing in the control group.[69]

Conclusion

With more than one-third of US adults being obese and the known complications associated with obesity, it is of great importance to determine the mechanisms by which individuals make decisions regarding diet and physical activity.[1] Delay discounting, the process by which individuals discount future rewards in favor of more immediate rewards, is one cognitive process that has been studied in the context of these behavioral decisions as well as others.[9] Evidence has demonstrated associations between discounting behaviors and drug use and addiction, ADHD, anxiety, and crime.[10-13,15,16,18-20] There are fairly conclusive results concerning the positive correlation between delay discounting and obesity, however evidence regarding some health-related behaviors associated with obesity remains inconclusive.

Only a few studies, to our knowledge, have associated physical activity habits with discounting, and physical activity data was acquired through self-report.[35,40] Other research related to physical activity has examined its ability to reduce discounting, and one study found this intervention to be successful in humans while another found it successful in rats.[41,43] No studies have directly measured physical activity in an effort to determine its relationship to delay discounting. Food intake studies have examined whether hunger affects discounting behaviors.[33,34] These results indicate that, after “eliminating” hunger with a standard meal, those who exhibit steeper discounting eat more food in an eating task.[33,34] However, this evidence is limited and more research is needed to conclude whether hunger is a significant determinant of discounting. Dietary habits that have been examined include the amount of foods consumed at home versus those consumed away from home, as measured by food intake records.[32] There is not conclusive evidence indicating whether diet quality is related to rates of discounting.[35] There is some evidence of a positive association between discounting and HbA1c, meaning that higher discounters tend to have poorer glycemic control.[74,75] No research has examined glucose tolerance and correlated these results with discounting measures, to our knowledge. We seek to fill the gaps in the literature by comparing rates of discounting with health-related factors in a broad population.

CHAPTER 3: Specific Aims

1. To determine the relationship between diet quality, assessed by the Healthy Eating Index 2015, and rate of discounting.
    a. *Hypothesis: Individuals with poorer diet quality, as evidenced by lower HEI-2015 scores, will exhibit steeper rates of discounting.*
2. To determine the relationship between glucose tolerance and rate of discounting.
    a. *Hypothesis: Those with lower glucose tolerance will show higher rates of discounting.*
3. To determine the relationship between physical activity level measured by accelerometry and rate of discounting.
    a. *Hypothesis: Individuals who engage in less physical activity will exhibit higher rates of discounting.*
4. To determine whether fasting or non-fasting conditions are a significant determinant of rate of discounting.
    a. *Hypothesis: Discounting rates will be greater under fasting conditions compared to non-fasting conditions.*

CHAPTER 4: Delay Discounting, Reinforcing Value of Food, and Components of Metabolic Health

Abstract

Background: Delay discounting describes the phenomenon by which individuals discount the value of a future reward in favor an immediate reward. Researchers have associated delay discounting with drug addiction, alcoholism, and cigarette smoking, and, more recently, with health-related factors such as body weight management, food intake, glucose control, and physical activity. While a number of studies have concluded that obese individuals tend to be greater discounters, the relationship between delay discounting and various health-related behaviors beyond smoking and drug use remains unclear. The purpose of this study is to evaluate the relationship between delay discounting and diet quality, glucose tolerance, and physical activity and to assess the effect of fasting vs. non-fasting conditions on discounting behaviors.

Methods: Sixty-five males (*n=20*) and females (*n=45*) were recruited for the present study. Participants completed two lab sessions: one under non-fasting conditions, and one under fasting conditions which involved measurements of body mass and composition, blood pressure, blood glucose, blood lipids, and health-related questionnaires. Delay discounting and food purchase tasks were completed at both visits. Participants were asked to complete a four-day food intake record and wear a physical activity monitor for four days.

Results: Lower rates of discounting were found in those who consumed more total vegetables, and lower food reinforcement was observed in those who spent less time sedentary and more time physically active, had greater dietary Restraint, and had a lower resting heart rate. There were no significant differences between discounting rates and food reinforcement across fasting and non-fasting conditions.

Introduction

More than one-third of U.S. adults are obese (BMI $\geq$ 30 kg/m^2), according to the Centers for Disease Control and Prevention (CDC).[1,2] Obesity brings with it a number of chronic health conditions as well as the financial burden of increased healthcare costs, number of sick days, time on short-term disability, and worker's compensation days.[1,3,4,6] The Academy of Nutrition and Dietetics as well as a joint effort by the American Heart Association, American College of Cardiology, and The Obesity Society identify a wide variety of methods for weight loss and maintenance.[7,8] One such method is targeting behavioral factors such as decision-making processes to identify causes of obesity and potential treatments.[7]

In the field of behavioral economics, delay discounting is a decision-making process by which individuals tend to discount the value of a future reward in favor of an immediate reward.[9] This cognitive process has been widely studied in regards to its association with drug addiction[9-14], alcoholism[15], and cigarette smoking[16,17], as well as a number of other psychosocial parameters.[18-20]

In recent years, delay discounting research has been conducted with regards to health-related factors and behaviors. A number of studies have associated steeper discounting (i.e. more value placed on immediate rewards than delayed rewards) with body weight management[21-31], food intake[32-36], glucose control[37-39], and physical activity.[35,40-43] Another relevant concept to the processes by which individuals make health-related decisions is the reinforcing value of food, broadly defined as an individual's motivation to obtain food.[60] Similar to delay discounting research, evidence supports that obese adults and children tend to exhibit greater reinforcing value of food than healthy-weight individuals.[61,62]

The purpose of this study is to determine if delay discounting and reinforcing value of food are associated with health-related factors and behaviors contributing to metabolic health and whether the two interact to influence these elements. Presence of these associations could shed light on behavioral factors leading to obesity and its related comorbidities and identify potential avenues for intervention. Unique attributes of this study compared to related literature include measurement of physical activity with accelerometry, dietary quality assessment using the Healthy Eating Index, measurement of glucose tolerance, as well as collection of other health parameters related to metabolism. Assessment of these health-related measures will contribute a unique perspective to the growing body of literature concerned with the role of delay discounting in health.

Research Design & Methods

Participants

Males and females of various racial and ethnic backgrounds were recruited for the present study. Eligibility criteria included ages 18-65 years and BMI of 20-40 kg/m^2. Subjects were excluded if they were taking any medications or supplements that could influence any of the study variables. All subjects were required to be weight stable, meaning that they had not lost or gained 5 pounds in the past 6 months or were not actively trying to lose or gain weight. Females were excluded if they were pregnant or trying to become pregnant.

Subjects were recruited via advertisement, which included emails and posted fliers. Subjects signed an informed consent document prior to participation. This study was conducted under the approval of the Virginia Tech Institutional Review Board.

Study Design

The present study consisted of two visits to the lab, both of which took place in the morning. One visit followed an overnight fast and the other followed the subjects' normal breakfast routine. It was recorded whether participants' normal breakfast routine prior to the respective study session consisted of fasting or consuming food or beverage. During the fasting visit, measurements included height, weight, % body fat, blood pressure, glucose tolerance, blood lipids, and complete blood count. Delay discounting questionnaires were completed at both visits. The purpose of this design was to examine the level of delay discounting related to food and activity under fasting and non-fasting conditions. The order of the visits was randomized. Informed consent and questionnaires regarding health-related behaviors were completed during the first visit, regardless of randomization. Participants were asked to wear a physical activity monitor for four days and to keep a four-day food intake record between study sessions (three weekdays and one weekend day). Figure 1 depicts the study design and measures.

Measures

Pregnancy Test

Females were asked to collect 2-3 teaspoons of urine for a pregnancy test. A positive result precluded participation due to exposure to radiation associated with Dual-Energy X-Ray Abosorptiometry (DEXA).

Body Mass and Composition

Body weight and height were measured using a standard digital scale with a standard stadiometer (Scale-Tronix, Inc.) in light clothing without shoes. Body mass index (BMI) was calculated in kg/m^2. Dual-Energy X-Ray absorptiometry (DEXA) was measured in light clothing to determine percent lean body mass and fat-free mass in all subjects.

Blood Pressure

Blood pressure and heart rate were measured under quiet, comfortable lab conditions using an automated blood pressure monitor (Colin Press-Mate) after a seated rest period of 5-10 minutes.

Blood Draw and Oral Glucose Tolerance Test

A fasting blood draw was collected via venipuncture into vacutainer tubes. Blood collected at baseline was used to assess glucose, lipids, and cholesterol. After the baseline blood draw, subjects were then provided with a 75-gram glucose beverage (Fisher HealthCare 75 Sun-Dex). A small amount of blood was collected before and two hours after consumption of the beverage.

Blood glucose was analyzed using a YSI (Yellow Springs Instruments) in the lab. Total cholesterol, HDL, LDL, VLDL, LDL:HDL, Total cholesterol:HDL, and triglycerides were measured by Solstas Lab Partners, Inc. (Roanoke, VA) using the timed-endpoint method. Complete Blood Count was also measured by Solstas Lab Partners, Inc., using an automated cell counter.

Food Intake

Subjects were asked to complete a 4-day food intake record in order to calculate the Healthy Eating Index 2015 (HEI-2015) score for each individual. Dietary analysis was performed using the Nutrition Data System for Research (NDSR) software, version 2014, developed by the Nutrition Coordinating Center (NCC) at the University of Minnesota, Minneapolis, MN.

The HEI-2015 is used to describe overall diet quality based on intake of food components divided into 13 categories. Components are grouped by “Adequacy” or “Moderation,” the scoring of which are based on recommendations from the 2015-2020 Dietary Guidelines for Americans. Food components in the “Adequacy” group include Total Fruits, Whole Fruits, Total Vegetables, Greens and Beans, Whole Grains, Dairy, Total Protein Foods, Seafood and Plant Proteins, and Fatty Acids. Those in the “Moderation” group include Refined Grains, Sodium, Added Sugars, and Saturated Fats.[78] For each component of the HEI, higher scores indicate closer compliance with the 2015-2020 Dietary Guidelines for Americans, which aim to emphasize variety of food groups, nutrient density, and improving dietary choices.[78,79] In the “Adequacy” category, consuming more of the respective foods results in a higher score, whereas consuming more foods in the “Moderation” category results in a lower score. Collectively, a total HEI score closer to the maximum of 100 points indicates better diet quality. The HEI scoring method is density-based, meaning that scores for each component are standardized on a per-1000-calorie basis, aside from fatty acids, which is scored based on the ratio of unsaturated to saturated fatty acids. Therefore, the HEI is independent of individual energy needs based on age, sex, activity level, etc.[78,79]

Previous versions of the HEI, including HEI-2010 and HEI-2005, are validated, reliable measures of diet quality based on compliance with the DGAs.[80] HEI-2015 differs from previous editions in that “Empty Calories” has been replaced with “Added Sugars and Saturated Fats,” and legumes are now counted in four components (Total Protein Foods, Seafood and Plant Proteins, Total Vegetables, and Greens and Beans)."[78]

Diet records were assessed for underreporting of food intake, since this is a common issue related to self-reported food intake. Participants' estimated resting energy requirements were calculated using the Mifflin-St. Jeor equation, and then used to calculate the percent of estimated energy requirements consumed on average over the four-day recording period.[81] Participants who reported consuming $< 80\%$ of their estimated resting energy needs were excluded from analyses involving dietary assessment.[82]

Three Factor Eating Questionnaire (TFEQ)

Subjects were asked to complete the Three-Factor Eating Questionnaire, which assesses cognitive control of eating behavior (Restraint), disinhibition of control (Disinhibition), and susceptibility to hunger (Hunger). Dietary Restraint refers to the tendency of an individual to control food intake in an effort to prevent weight gain or promote weight loss.[83,84] Disinhibition refers to "the tendency to eat because palatable foods are available, because others are eating or because of emotional distress," and Hunger "describes the intensity with which hunger sensations are perceived and the extent to which such sensations evoke eating."[85] The purpose of administering this questionnaire was to gain further insight into psychological factors affecting food-related decision-making which could impact the health outcomes measured in this study.[86] Chi square analysis was performed to determine the presence of significant associations between measures of the TFEQ and discounting and reinforcing value of food.

Physical Activity Assessment via Accelerometer

Subjects were asked to wear a physical activity monitor (Actigraph GT3X) during waking hours for four days. Actilife software, version 6 (2011), was used to compute the following data for each participant: time spent in sedentary, time spent in light physical activity, time spent in moderate physical activity, time spent in vigorous physical activity, time spent in very vigorous physical activity, time spent in Moderate-to-Vigorous physical activity (MVPA), percent time spent in each of the aforementioned categories, as well as total steps taken. The category "MVPA" indicates Moderate-to-Vigorous Physical Activity and refers to the amount of time spent above the "moderate" cut point level.[87]

Intensities were determined using Freedson Adult (1998) cut points in 60-second epochs.[88-90] Cut points classify intensities by the number of counts per minute. Counts are determined using frequencies and intensities of raw accelerometer values, the algorithm for which is proprietary to ActiGraph. Table 1 shows the number of counts per minute that constitute each intensity.[89]

Table 1: Freedson Adult (1998) Cut Points in Actilife Software	
Sedentary	0-99 CPM
Light	100-1951 CPM
Moderate	1952-5724 CPM
Vigorous	5725-9498 CPM
Very Vigorous	$\geq$ 9499 CPM[90]
MVPA	$\geq$ 1952 CPM[87]

Infection/Inflammation Questionnaire

Subjects were asked to complete a questionnaire about any recent illness or infection within the past month to assess current health status with regards to health behavior-related decision-making.

Delay Discounting

Delay discounting was measured using the Adjusting Amount and Adjusting Delay tasks. These are computerized tasks which were completed in the lab. The Adjusting Amount and Adjusting Delay tasks pose questions in an effort to determine the monetary equivalent of an immediately available commodity presented at varying delays. Included in the tasks, subjects completed delay discounting tasks, in which they were asked to choose between a smaller, immediate reward and a larger, delayed reward (e.g., $50 now or $100 in 6 months; 2 servings of favorite food now or $20 in 2 days?). Prior to completing these tasks, subjects chose their favorite food and sedentary activity from a standard list, and the chosen commodities were utilized in the questionnaires. For any tasks involving non-monetary commodities (e.g., food or activity), subjects first completed a task to determine the subjective equivalence value between the non-delayed, non-monetary commodity and non-delayed money. This equivalence value is needed to arrange the following delay discounting tasks and interpret their measures. Discounting rate was determined using the hyperbolic function devised by Mazur (1987):[49]

$$V = \frac{A}{(1 + kD)}$$

Discounting rates were assessed for non-systematic responses by the algorithm devised by Johnson and Bickel (2008).[91] It has been observed that participants sometimes respond in a way that seems “haphazard” rather than systematic, for reasons that might include misunderstanding of the task, inattentiveness due to experimental conditions, desire to respond in a “socially desirable” manner, among others. Based on the Johnson and Bickel (2008) algorithm, participants were excluded if 1) any indifference point (starting with the second delay) was greater than the preceding one by > 20% of the larger later rewards, in this case $200, or if 2) the last indifference point was not at least $100 less than the first indifference point.[91,92] In addition, nonlinear R^2 derived from indifference points was used to assess within-subject variability of responses.[91] Data were analyzed before and after exclusion of non-systematic responders. Visual inspection of the data revealed that excluding those individuals altered major outcomes and thus non-systematic responders were excluded from all final analyses.[92]

Reinforcing Value of Food

Subjects also completed hypothetical food purchase tasks. This involves reporting the number of servings of food that they would like to purchase and consume over a pre-defined period of 30 minutes. In some tasks, only one type of food was available across increasing prices, whereas other tasks presented a second food choice available at a constant price. Prior to completing the task, participants were asked to choose their favorite snack food from a standard list. Each participant was presented with a to-scale picture of one serving of the chosen snack food to use for reference throughout the task.

Using subjects' responses, demand intensity and elasticity were calculated as characteristics of reinforcing value of food. Demand intensity describes how much an individual would choose to consume if the item were free or at a minimal price.[93,94] Demand elasticity is the slope of the demand curve, a figure which describes the amount of food consumed as a function of price. As such, an elasticity <1 is classified as inelastic and represents less responsiveness of consumption to changing price. An elastic curve then has an elasticity >1 and represents greater responsiveness of consumption to changing price. Generally, consumption becomes more elastic (responsive) at higher prices, meaning that at a higher price range (relative to the food), consumption is more responsive to a change in price.[94]

Demand intensity and elasticity are calculated using the modified exponential equation by Koffarnus, et al. (2015):

$$Q = Q_0 * 10^{k(e^{-\alpha Q_0 C} - 1)}$$

In this equation, Q is the quantity of food purchased, Q_0 is the quantity of food purchased when the commodity is free and represents demand intensity, *k* is the average range of consumption across participants, α represents demand elasticity, and C equals price.[95]

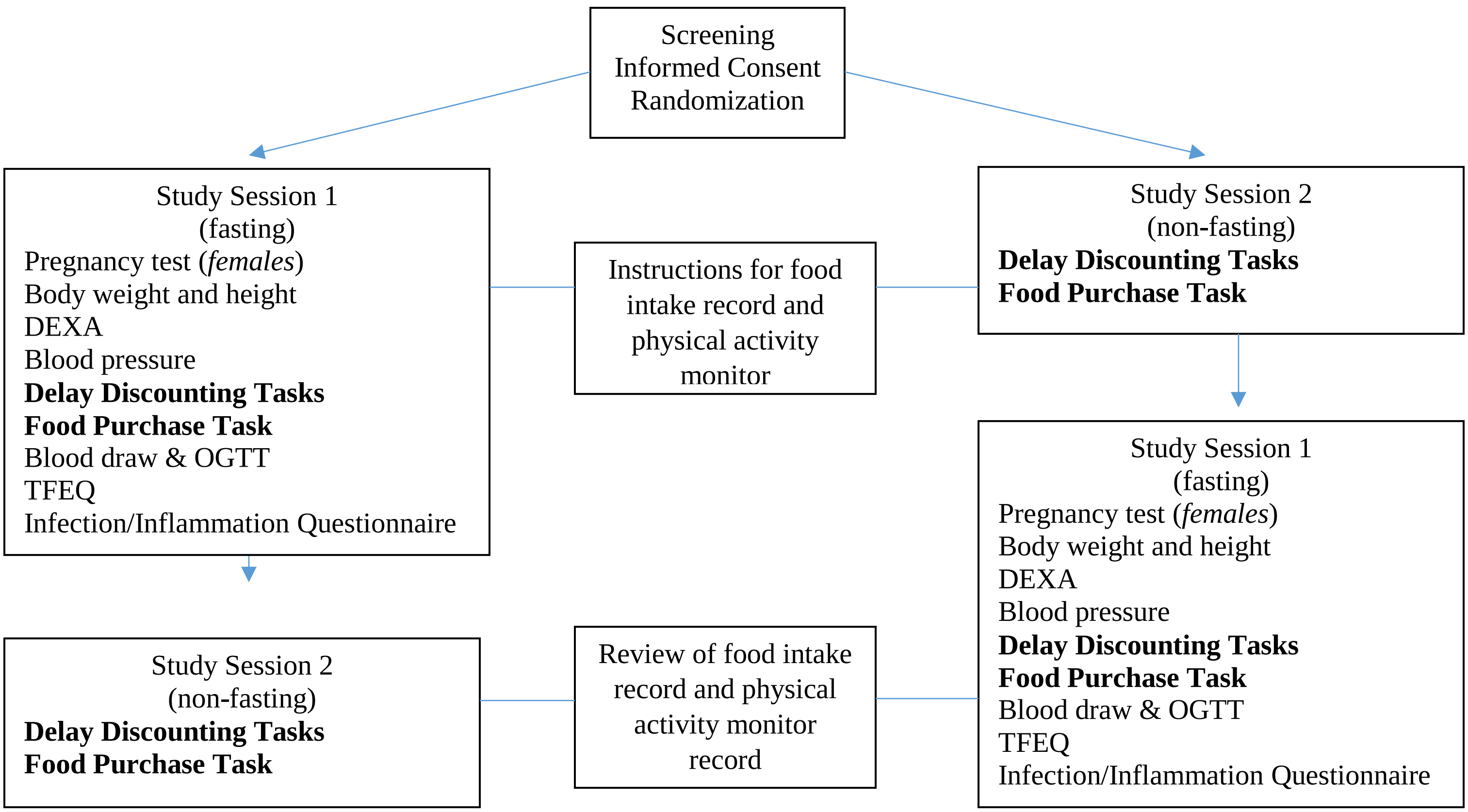

Figure 1: Study Design and Measures

Statistical Analysis

Statistical analysis was performed using SPSS statistical software version 25 (IBM, Armonk, NY, USA, 2017). Descriptive statistics were calculated for all study measures and evaluated for normality. Data are presented as mean ± SD. Outliers were calculated for the primary outcome measures of delay discounting and food reinforcement using the Outlier Labeling Rule devised by Hoaglin, Iglewicz, and Tukey (1986, 1987).[96-98] Upper and lower bounds were calculated by multiplying the interquartile range by 2.2; any data points outside of this range were excluded from analysis.[98] Independent samples t-tests were run to determine significant differences between means for males and females for all study measures. Paired samples t-tests were used to determine significant differences between means for fasting and non-fasting measures of delay discounting and food reinforcement. Correlational analysis was performed to determine the presence of a relationship between discounting and other study measures using Pearson's correlations. Significance for all analyses was assessed at the $\alpha=0.05$ level unless otherwise indicated. Further analysis of correlations was performed to control for familywise error associated with multiple comparisons using Holm's sequential procedure, a modification of the Bonferroni correction.[99]

Median splits were performed for measures of delay discounting and food reinforcement in order to categorize participants as exhibiting "high" or "low" discounting or reinforcing value of food relative to the study population. Using the median-split data, Pearson's chi-square analysis was used to identify association between delay discounting and food reinforcement, with significance determined at the level of $\alpha=0.05$. Effect size was determined using phi, such that a value of 0.1 represented a small, 0.3 a medium effect, and 0.5 a large effect.[100,101]

Similarly, median splits and chi square analysis were performed to assess for association between measures of the TFEQ and discounting and food reinforcement.

Results

Participant Characteristics

Sixty-five males (*n=20*) and females (*n=45*) participated in the present study. After exclusion for non-systematic discounting and one drop-out, the final *n* was 60, consisting of 42 females and 18 males.

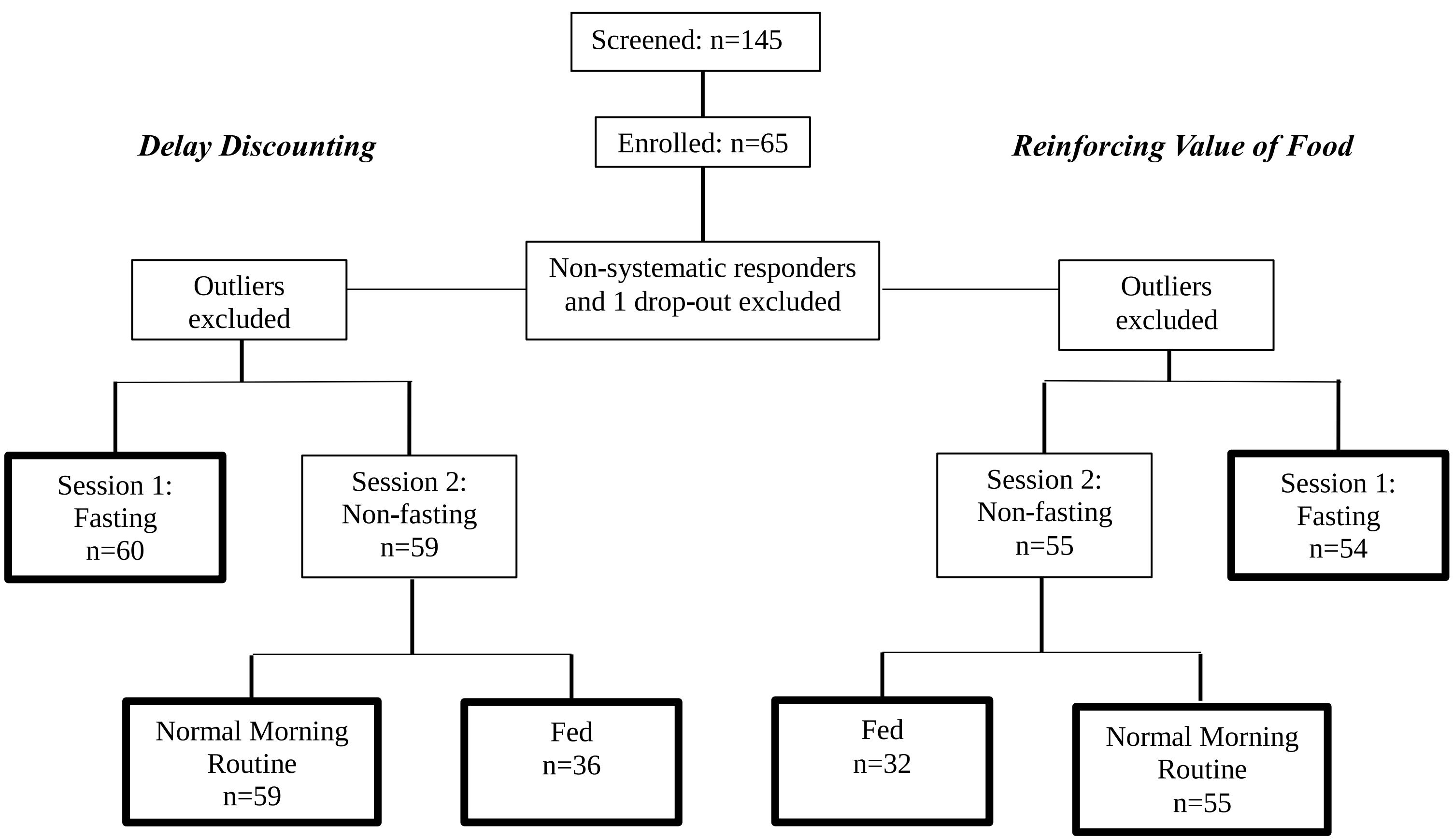

Figure 2: Participant Flow Diagram

Participant characteristics including body mass and composition, blood glucose, blood lipids, and blood pressure are presented in Table 2. Females had significantly higher % body fat than males (p=0.00001). Heart rate was significantly higher in females than in males (p=0.020), however there were no sex differences for blood pressure. Females also had significantly higher total cholesterol (p=0.006) and HDL (p=0.034) than males. There were no sex differences observed for blood glucose, LDL, VLDL, LDL:HDL, Total-C:HDL, or triglycerides.

Table 2: Descriptive Characteristics				
Parameter	**Mean ± SD**	**Male** (mean±SD)	**Female** (mean±SD)	**M/F p-value**
Age (*years*) (n=60)	29 ± 9	27 ± 8	30 ± 10	0.291
Body Mass and Composition (n=60)				
BMI *(kg/m²)*	25.1 ± 4.1	25.9 ± 4.1	24.8 ± 4.1	0.337
% BF	29.7 ± 10.4	21.4 ± 8.7	33.3 ± 8.9*	0.00001*
Blood Pressure and Heart Rate (n=60)				
Systolic *(mmHg)*	114 ± 10	116 ± 10	113 ± 10	0.259
Diastolic *(mmHg)*	62 ± 8	60 ± 7	63 ± 8	0.308
Heart Rate *(bpm)*	66 ± 9	62 ± 8	68 ± 9*	0.020*
Blood Glucose (n=59)				
OGTT min 0 *(mg/dL)*	86.53 ± 10.58	90.32 ± 13.86	84.87 ± 8.46	0.068
OGTT min 120 *(mg/dL)*	93.81 ± 25.98	91.00 ± 39.16	95.04 ± 17.94	0.587
Blood Lipids (n=58)				
Total Cholesterol *(mg/dL)*	173 ± 33	155 ± 26	180 ± 33*	0.006*
HDL *(mg/dL)*	62 ± 18	55 ± 14	66 ± 19*	0.034*
LDL *(mg/dL)*	93 ± 29	84 ± 26	97 ± 30	0.135
VLDL *(mg/dL)*	17 ± 9	16 ± 8	18 ± 10	0.428
LDL:HDL	1.6 ± 0.8	1.7 ± 0.7	1.6 ± 0.8	0.969
Total-C:HDL	3.0 ± 1.0	3.0 ± 0.8	3.0 ± 1.0	0.911
Triglyceride *(mg/dL)*	86 ± 46	78 ± 39	89 ± 49	0.429

**=significant difference*

Food Intake

Dietary analysis results are presented in Table 3. Three participants were excluded from analysis of dietary assessment on the basis of reporting consumption of < 80% of their estimated resting energy requirements, suggesting possible underreporting.[82] Males consumed significantly more calories per day than females (p=0.00003), as well as greater % of calories from protein (p=0.032).

Table 3: Dietary Analysis				
Parameter (n=57)	**Mean ± SD**	**Male (mean ± SD)**	**Female (mean ± SD)**	**M/F p-value**
Energy (kcals)	2168 ± 705	2756 ± 757*	1938 ± 537	0.00003*
% Carbohydrates	43.8 ± 7.1	42.0 ± 5.8	44.6 ± 7.5	0.217
% Protein	17.9 ± 5.1	20.2 ± 4.7*	17.0 ± 5.0	0.032*
% Fat	34.4 ± 5.8	33.3 ± 7.0	34.8 ± 5.3	0.409
Fiber (g)	26.4 ± 21.5	36.6 ± 36.1	22.4 ± 10.2	0.140

**=significant difference*

Average HEI-2015 scores are presented in Table 4. Again, for each component as well as the Total Score, scoring closer to the maximum possible points indicates closer compliance with the Dietary Guidelines for Americans.[78] Males scored significantly higher in the Total Protein Foods component (p=0.025). No sex differences were observed for other components or the Total HEI score.

Table 4: HEI-2015 Scores					
Component (n=57)	**Mean ± SD**	**Male (mean ± SD)**	**Female (mean±SD)**	**Max Possible Score[78]**	**M/F p-value**
Adequacy	37.0 ± 8.4	36.6 ± 7.9	37.2 ± 8.7	60	0.828
Total Fruit	2.8 ± 1.5	2.5 ± 1.6	2.9 ± 1.5	5	0.364
Whole Fruit	3.9 ± 1.5	3.7 ± 1.8	4.0 ± 1.3	5	0.618
Whole Grain	5.1 ± 3.7	5.6 ± 3.9	4.9 ± 3.7	10	0.531
Total Vegetable	3.5 ± 1.3	3.0 ± 1.1	3.6 ± 1.3	5	0.057
Total Protein Foods	4.7 ± 0.7	4.9 ± 0.3*	4.6 ± 0.8	5	**0.025***
Greens and Beans	2.7 ± 2.0	2.1 ± 1.7	3.0 ± 2.1	5	0.165
Dairy	5.7 ± 3.0	5.1 ± 3.1	5.9 ± 3.0	10	0.353
Seafood and Plant Protein	3.8 ± 1.8	3.6 ± 1.9	3.8 ± 1.8	5	0.683
Fatty Acid	4.9 ± 3.3	6.0 ± 2.8	4.5 ± 3.4	10	0.110
Moderation	27.4 ± 6.2	29.6 ± 6.4	26.6 ± 6.0	40	0.101
Refined Grain	7.6 ± 2.8	8.0 ± 2.9	7.5 ± 2.9	10	0.521
Added Sugar	8.8 ± 1.6	9.0 ± 1.4	8.7 ± 1.6	10	0.588
Sodium	5.4 ± 3.1	5.8 ± 3.5	5.3 ± 3.0	10	0.570
Saturated Fatty Acids	5.6 ± 3.0	6.8 ± 2.8	5.1 ± 3.0	10	0.061
Total	**64.5 ± 12.7**	66.2 ± 11.6	63.8 ± 13.2	100	0.516

**=significant difference*

Three-Factor Eating Questionnaire (n=59)

Scores for the Three-Factor Eating Questionnaire are presented in Table 5. For each component, a higher score indicates greater tendency to exhibit the respective characteristic related to eating behaviors.[83] There were no significant differences in scores based on gender.

Table 5: TFEQ Scores

Parameter	**Mean ± SD**	**Male** (mean±SD)	**Female** (mean±SD)	**Max Possible Score**[83]	**M/F p-value**
Restraint	8.9 ± 3.6	9.4 ± 4.5	8.7 ± 3.2	21	0.536
Disinhibition	6.8 ± 3.3	6.1 ± 2.3	7.0 ± 3.6	16	0.245
Hunger	6.4 ± 3.1	5.9 ± 3.3	6.6 ± 3.1	14	0.490

Physical Activity

Physical activity data are presented in Table 6. Males spent significantly more minutes in moderate activity (p=0.001) as well as MVPA (p=0.00004), which produced significant differences in % time spent in moderate activity (p=0.001) and MVPA (p=0.0001). Males achieved significantly more steps per day than females (p=0.027). It is also of note that males wore the monitor for significantly more minutes per day than females (p=0.006).

Table 6: Physical Activity measured by Accelerometry				
Average minutes per day (n=58)				
Intensity	**Mean ± SD**	**Male** (mean±SD)	**Female** (mean±SD)	**M/F p-value**
Sedentary	573 ± 118	584 ± 129	568 ± 114	0.631
Light	232 ± 79	248 ± 89	225 ± 74.8	0.314
Moderate	42 ± 24	62 ± 30*	33 ± 15	0.001*
Vigorous	5 ± 10	7 ± 11	4 ± 9	0.448
Very Vigorous	0.9 ± 3	2 ± 4	0.6 ± 2	0.353
MVPA	48 ± 29	70 ± 35*	38 ± 20	0.00004*
Average % of total time				
Sedentary	67.1 ± 9.3	64.5 ± 10.9	68.3 ± 8.4	0.156
Light	27.3 ± 8.7	27.8 ± 10.4	27.1 ± 8.0	0.775
Moderate	4.9 ± 2.5	6.8 ± 2.8*	4.0 ± 1.8	0.001*
Vigorous	0.6 ± 1.0	0.7 ± 1.0	0.5 ± 1.0	0.603
Very Vigorous	0.1 ± 0.3	0.2 ± 0.5	0.07 ± 0.2	0.292
MVPA	5.6 ± 2.9	7.7 ± 3.2*	4.6 ± 2.2	0.0001*
Average per day				
Steps	8408 ± 3564	10,283 ± 4514*	7565 ± 2708	0.006*
Time monitor worn (minutes)	853 ± 114	902 ± 88*	831 ± 119	0.027*

**=significant difference*

Delay Discounting

Delay discounting data are presented in Table 7. There were no significant differences between males and females in discounting rates measured under fasting, Normal Routine, or fed conditions. Paired t-tests revealed that there were no significant differences between discounting rates measured by the Adjusting Delay task under fasted vs. normal routine conditions (p=0.541) or fasted vs. fed conditions (p=0.398). Similarly, there were no significant differences in discounting rates measured by the Adjusting Amount task under fasted vs. normal routine conditions (p=0.186) or fasted vs. fed conditions (p=0.757).

Table 7: Delay Discounting Rates				
Parameter	**Mean ± SD**	**Male** (mean±SD)	**Female** (mean±SD)	**M/F p-value**
Fasting (n=60)				
(ln(*k*)) Adjusting Delay	-6.31 ± 1.42	-6.25 ± 1.33	-6.33 ± 1.47	0.838
(ln(*k*)) Adjusting Amount	-6.92 ± 1.61	-6.70 ± 1.37	-7.02 ± 1.71	0.482
Normal Routine (n=59)				
(ln(*k*)) Adjusting Delay	-6.27 ± 1.42	-6.21 ± 1.26	-6.29 ± 1.50	0.836
(ln(*k*)) Adjusting Amount	-7.18 ± 1.49	-6.89 ± 1.37	-7.31 ± 1.55	0.327
Fed (n=36)				
(ln(*k*)) Adjusting Delay	-6.24 ± 1.56	-6.29 ± 1.27	-6.22 ± 1.71	0.891
(ln(*k*)) Adjusting Amount	-7.04 ± 1.65	-6.89 ± 1.62	-7.11 ± 1.69	0.711

Delay Discounting - Correlations

After controlling for familywise error associated with multiple comparisons, Adjusting Amount discounting measured under Normal Routine conditions was significantly associated with HEI Total Vegetable score (r = -0.401; p=0.032).

Table 8: Significant Delay Discounting Correlations (*r*)						
	Adjusting Delay			**Adjusting Amount**		
Parameter	**Fasted**	**Normal Routine**	**Fed**	**Fasted**	**Normal Routine**	**Fed**
HEI total vegetable					-0.401 (p=0.032)	

Reinforcing Value of Food

Demand intensity and elasticity data are displayed in Table 9. There were no significant differences between males and females for measures of reinforcing value of food. Paired t-tests revealed no significant differences in demand intensity under fasting vs. Normal Routine conditions (p=0.108) or fasting vs. fed conditions (p=0.227). There were also no significant differences observed in demand elasticity under fasting vs. Normal Routine conditions (p=0.091) or fasting vs. fed conditions (p=0.386).

Table 9: Demand Intensity and Elasticity				
Parameter	**Mean ± SD**	**Male** (mean±SD)	**Female** (mean±SD)	**M/F p-value**
Fasting (n=54)				
Square root(demand intensity)	2.08 ± 0.73	1.93 ± 0.79	2.13 ± 0.72	0.391
Log(demand elasticity)	-1.27 ± 0.39	-1.18 ± 0.36	1.30 ± 0.40	0.334
Normal Routine (n=55)				
Square root(demand intensity)	2.01 ± 0.62	2.10 ± 0.76	1.97 ± 0.58	0.509
Log(demand elasticity)	-1.19 ± 0.39	-1.14 ± 0.41	-1.21 ± 0.39	0.551
Fed (n=32)				
Square root(demand intensity)	1.96 ± 0.62	2.21 ± 0.87	1.87 ± 0.49	0.287
Log(demand elasticity)	-1.16 ± 0.36	-1.00 ± 0.35	-1.22 ± 0.35	0.114

Reinforcing Value of Food - Correlations

Minutes and % time spent sedentary were significantly positively correlated with demand intensity across all feeding conditions. Demand intensity under Normal Routine conditions was negatively associated with % time spent in light activity (r = -0.341; p=0.048). Demand intensity under fed conditions was negatively associated with dietary Restraint (r = -0.484; p=0.015). A negative association existed between demand elasticity measured under fasting conditions and heart rate (r = -0.344; p=0.033). Demand elasticity under fed conditions was positively associated with % time spent in MVPA (i.e. a negative association with food reinforcement) (r = 0.351; p=0.049).

Table 10: Significant Reinforcing Value of Food Correlations (*r*)						
	Demand Intensity			**Demand Elasticity**		
Parameter	**Fasted**	**Normal Routine**	**Fed**	**Fasted**	**Normal Routine**	**Fed**
Heart Rate				-0.344 (p=0.033)		
Restraint			-0.484 (p=0.015)			
Sedentary Minutes	0.300 (p=0.03)	0.420 (p=0.004)	0.450 (p=0.02)			
% Sedentary	0.368 (p=0.014)	0.336 (p=0.014)	0.400 (p=0.023)			
% Light		-0.341 (p=0.048)				
% MVPA						0.351 (p=0.049)

Interaction of Delay Discounting and Reinforcing Value of Food

Pearson's correlations and chi square analysis revealed a number of significant interactions between measures of delay discounting and measures of food reinforcement, presented in Tables 11 and 12. Demand intensity measured under fasting conditions was positively associated with fasting Adjusting Amount discounting (r = 0.274; p=0.045). Fasting Demand Intensity was negatively associated with fasting Adjusting Delay discounting (r = -0.280; p=0.04) and fasting Adjusting Amount discounting (r = -0.274; p=0.045).

Chi square analysis of measures taken in the fasted state displayed a significant interaction between delay discounting measured by Adjusting Delay and food reinforcement measured by demand elasticity (p=0.028) with a medium effect size (Figure 3). Under Normal Routine conditions, a significant interaction existed between delay discounting measured by Adjusting Amount and food reinforcement measured by Demand Intensity (p=0.002) (Figure 4). Likewise, the same relationship existed in the fed state (p=0.033) (Figure 5).

Table 11: Significant Correlations Between Delay Discounting and Reinforcing Value of Food (*r*)		
Delay Discounting Measure	Fasting Demand Intensity	Fasting Demand Elasticity
Fasting Adjusting Delay		-0.280 (p=0.04)
Fasting Adjusting Amount	0.274 (p=0.045)	-0.274 (p=0.045)

Table 12: Chi Square Analysis of Delay Discounting and Reinforcing Value of Food			
Pair	**Pearson's Chi Square (df=1)**	**Asymptotic Significance (2-sided)**	**Phi (effect size)**
Fasting (n=54)			
AD / DI	1.200	0.273	0.149
AD / DE	4.800	0.028*	-0.298
AA / DI	1.862	0.172	0.186
AA / DE	3.650	0.056	-0.260
Normal Routine (n=54)			
AD / DI	1.985	0.159	0.192
AD / DE	3.650	0.056	-0.260
AA / DI	9.308	0.002*	0.415
AA / DE	1.862	0.172	-0.186
Fed (n=32)			
AD / DI	2.000	0.157	0.250
AD / DE	2.000	0.157	-0.250
AA / DI	4.571	0.033*	0.378
AA / DE	0.508	0.476	-0.126

**=significant at 0.05 level*

(AD=adjusting amount; AA=adjusting delay; DI=demand intensity; DE=demand elasticity)

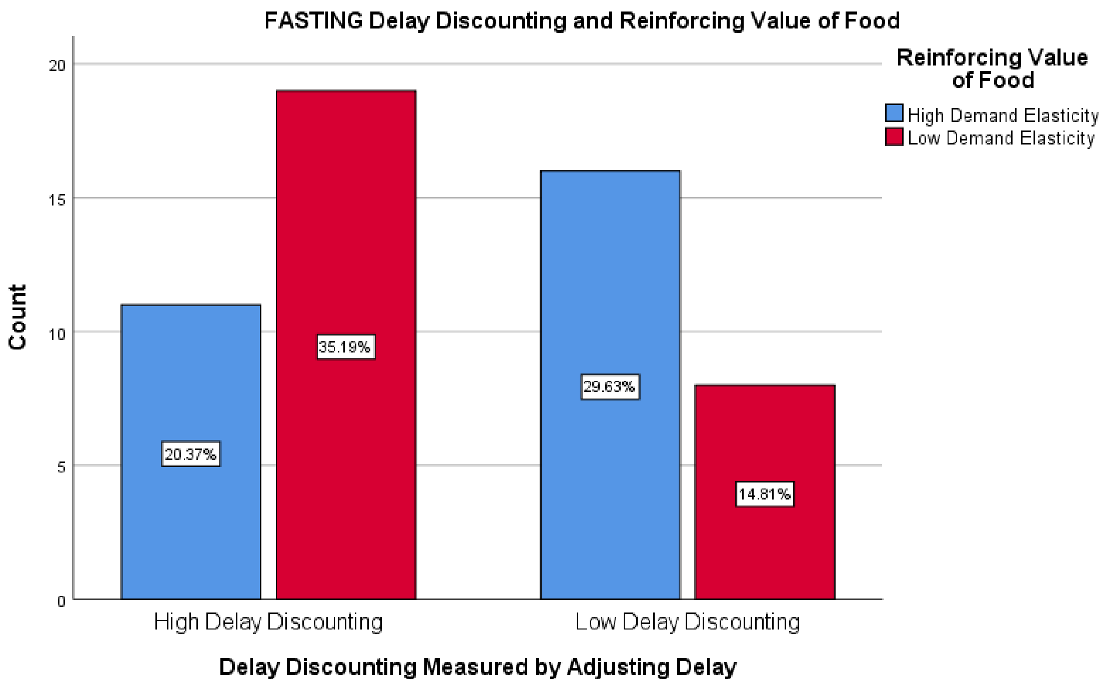

Figure 3: Chi square analysis of fasting delay discounting and demand elasticity

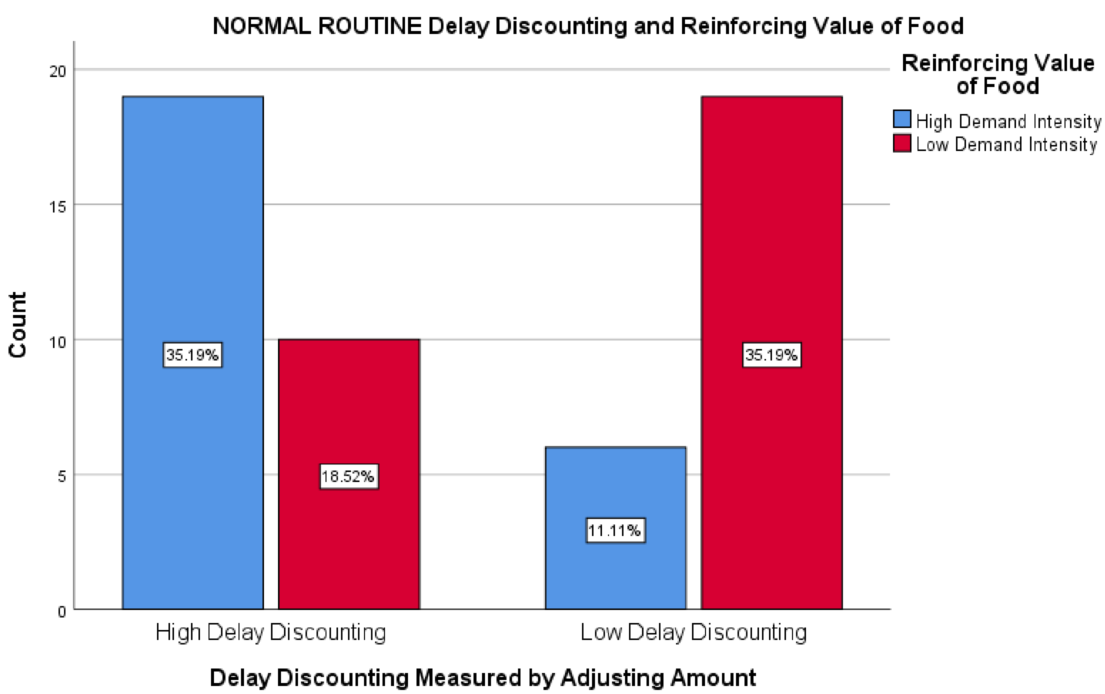

Figure 4: Chi square analysis of Normal Routine delay discounting and demand intensity

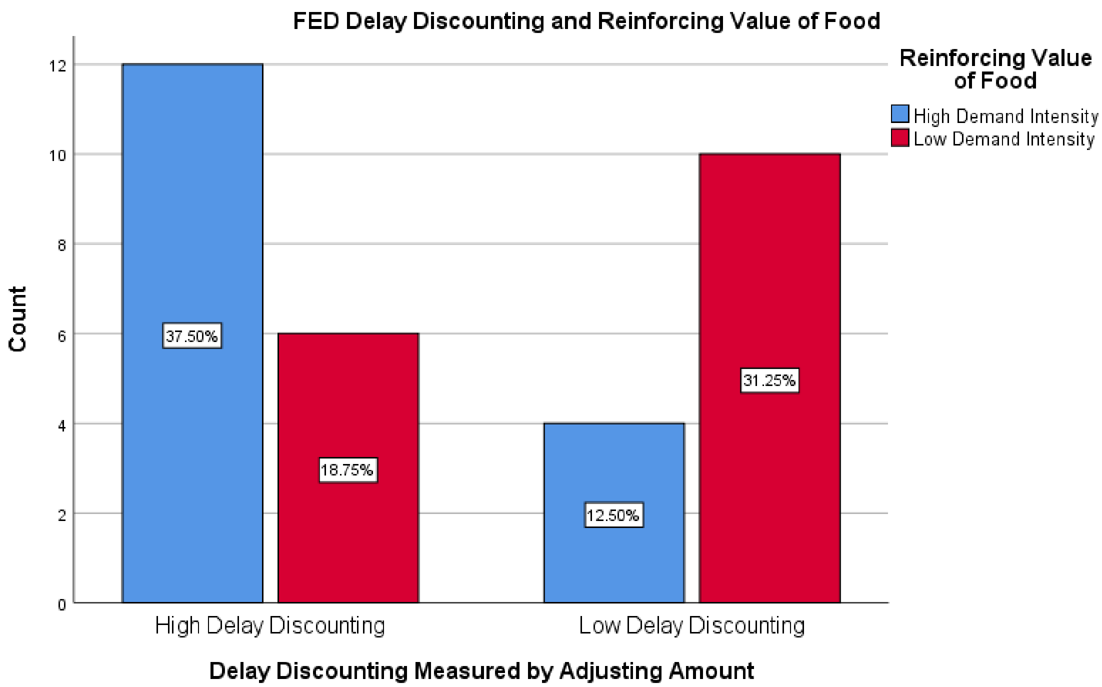

Figure 5: Chi square analysis of fed delay discounting and demand intensity

Interaction of Delay Discounting, Reinforcing Value of Food, and Components of the TFEQ

Chi square analysis revealed that Disinhibition was significantly associated with demand intensity measured under Normal Routine conditions (p=0.037) with a medium effect size (phi= -0.284), such that high Demand Intensity was associated with low Disinhibition. No other significant associations were observed.

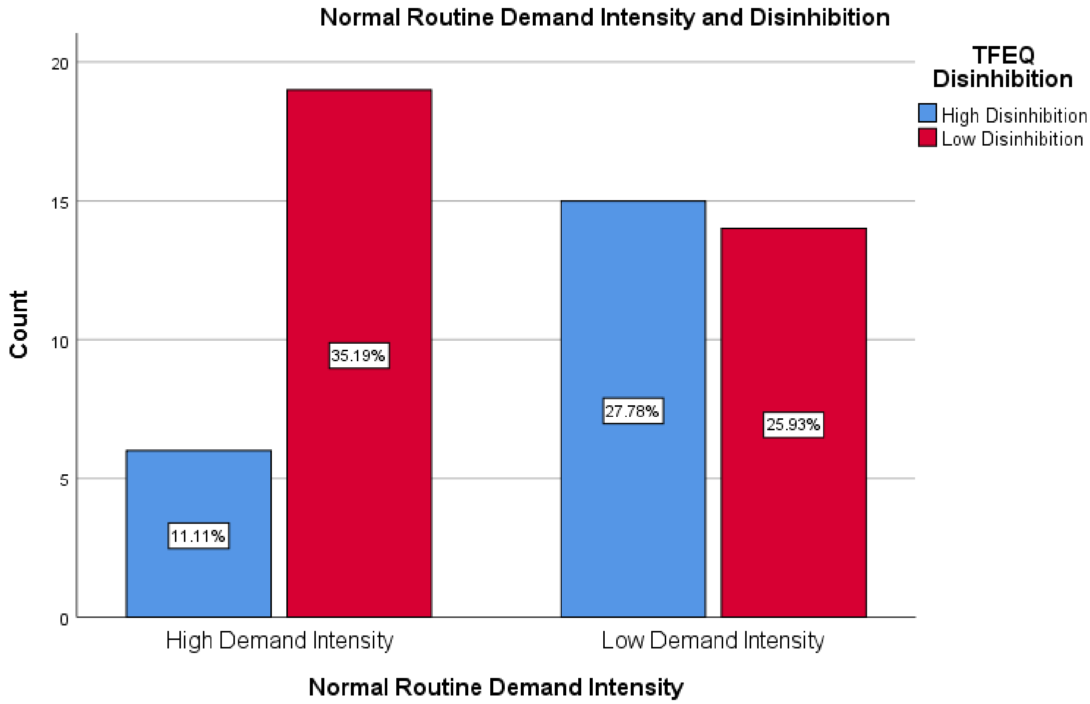

Figure 6: Chi square analysis of Normal Routine Demand Intensity and Disinhibition (TFEQ)

Discussion

The purpose of this study was to examine the association between delay discounting and reinforcing value of food and parameters of metabolic health, including diet quality, physical activity, blood glucose and lipids, and body composition. The major findings suggest lower rates of discounting in those who consumed greater total vegetables, and lower reinforcing value of food in those who spent less time sedentary and more time in light and moderate-to-vigorous physical activity, had greater dietary Restraint, and had a lower resting heart rate. These findings suggest that delay discounting and reinforcing value of food could contribute to factors associated with metabolic health. There were no significant differences between delay discounting and food reinforcement under fasting vs. non-fasting conditions.

Previous research correlated higher HbA1c with steeper discounting in diabetic participants, but direct measurement of glucose tolerance in the present study found no significant correlations with delay discounting.[74,75] These data suggest a potential effect of testing in a diabetic population, however results of the present study could have been limited by homogeneity of the sample population, with mean fasting and minute 120 glucose both being "normal".[102]

In general, participants displayed blood lipids that correspond with recommendations from the National Heart, Lung, and Blood Institute, The Mayo Clinic, as well as the "normal" values provided by Solstas Lab Partners, Inc.[103,104] Females exhibited significantly higher HDL, which is to be expected as the "healthy" level of HDL is higher for women than for men.[103] This factor likely contributed to females also displaying significantly higher total cholesterol.

Participants in the current study had better diet quality when compared to NHANES 2003-2004 data.[80] In the present study, higher scores in the Total Vegetables component were associated with lower rates of discounting and lower food reinforcement. It is of note that this association was observed across all feeding conditions within both measures of delay discounting. Garza, et al. (2013) found that better diet scores were associated with higher value of the future (i.e. lower discounting), however the association between delay discounting and reinforcing value of food and overall diet quality remains inconclusive based on the results of the present study [35,70] Additionally, the study by Garza, et al. (2013) used the Food Behavior Checklist as a measurement of diet quality, whereas the present study used the Healthy Eating Index.[35,70] Use of the Healthy Eating Index to associate diet quality with delay discounting is a unique approach in the field that, if utilized by other delay discounting researchers, could allow for more consistent comparison of diet quality across related studies. In addition to diet quality, significant negative correlations between the Restraint component of the TFEQ and demand intensity suggest those who find food more reinforcing tend to exhibit less conscious effort to control food intake.[83,85,86] This suggests a contribution of food reinforcement to an individual's desire or ability to control food consumption. Chi square analysis revealed that Disinhibition was significantly associated with demand intensity, suggesting that higher food reinforcement could be related to an individual's desire to eat because food is available, other people are eating, or due to emotional stress.[85]

Greater time spent sedentary was associated with greater reinforcing value of food, while greater time spent being physically active was associated with lower reinforcing value of food. These results support the notion that those who are more physically active find food less reinforcing and may thus have a better ability to maintain a healthy weight. Previous studies using self-report habitual physical activity found a negative association with discounting, however the results of the present study do not indicate any correlation.[35,40]

Correlations and chi square analysis suggest the presence of reinforcement pathology, or the interaction between delay discounting behaviors and reinforcing value of food.[60] It is of important note that correlations between delay discounting and demand intensity and elasticity were only observed in the measures taken under fasting conditions. These results could indicate an effect of fasting or non-fasting state on participants' responses to produce evidence of reinforcement pathology, however further research on this topic is warranted. Similarly, different results of chi square analysis were observed under the feeding conditions analyzed, such that a significant interaction was observed between delay discounting and demand intensity under Normal Routine and fed conditions, but not under fasting conditions. Rather, under fasting conditions there was a significant interaction between delay discounting and demand elasticity.

As such, further research may be necessary to determine effect of feeding state as well as differences in measures of discounting and food reinforcement to describe reinforcement pathology in more detail.

Differences in correlations across the three conditions of feeding (fasting, Normal Routine, and fed) also suggest possible differences in responses to discounting tasks and food purchase tasks under these conditions, however paired t-tests revealed no significant differences in the mean response values for these parameters. Previous literature has evaluated this principle by administering delay discounting tasks after “pre-loading” participants with a standard meal in an effort to eliminate hunger as a determinant of discounting.[33] Others have provided participants with sugary drinks or control drinks to observe the effect of changing blood glucose on discounting behaviors.[37,38] It is of note that the present study did not involve standard feeding before tasks completed in the Fed state, but rather participants consumed whatever they wanted before coming to the lab. Based on previous literature, there may be different effects on discounting behaviors based on type of sugar ingested.[38] Future studies may consider providing standard meals to assess discounting in the fed state to eliminate the effect of variance of foods consumed before completing the tasks.

This study has a number of strengths and limitations. One strength is measurement of physical activity levels with accelerometers; to our knowledge, no related studies to date have measured physical activity using accelerometry but rather by using methods of self-report. Another strength is characterization of diet quality using the HEI-2015. Use of this standardized method allows for comparison to population norms as well as comparison across studies that also use the HEI. A unique attribute of this study was measurement of delay discounting and food reinforcement under both fasting and non-fasting conditions, allowing for analysis to determine differences among responses based on feeding condition. Finally, the multitude of measures taken in this study provide a wealth of information related to metabolic health and health-related behaviors in order to determine relationships to delay discounting and reinforcing value of food.

Some limitations include the self-report nature of the food intake records, however underreporting was accounted for by excluding individuals who consumed < 80% of estimated energy needs. Self-report of times that the physical activity monitor was worn was another potential limitation, as this information was used to extract data from the monitors. Participants were instructed to wear the monitor during waking hours, meaning that sedentary time during sleep (day or night) was not recorded. However, previous studies have utilized similar wear patterns.[105] As a general limitation, the study population had low variability of many study measures and future research could benefit from recruiting a larger, more diverse sample.

Conclusions

Lower rates of discounting were found in those who consume more total vegetables as measured by the HEI-2015, and lower food reinforcement was observed in those who spent less time sedentary and more time physically active, had greater dietary Restraint, and had a lower resting heart rate. Contrary to our hypothesis, there were no significant differences between discounting rates and food reinforcement across fasting and non-fasting conditions. However, varying correlations across these conditions could indicate some difference in responses, and thus the effect of fasting and non-fasting conditions should be further evaluated with regards to delay discounting and food reinforcement. The results of this study imply that individuals who are more physically active and consume more vegetables tend to value future rewards and do not find food to be highly reinforcing, qualities which could contribute to improved body weight management and better metabolic health over time.

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