ASSOCIATIONS OF SNACK FOOD GROUP CONSUMPTION AND PATTERNS WITH WEIGHT STATUS AND DIET QUALITY AMONG ADOLESCENTS 12-19 YEARS IN THE UNITED STATES

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ABSTRACT

Purpose: Snacking is an important component of dietary intake yet remains understudied, particularly among adolescents who consume 25% of their daily calories from snacks. Previous research provides evidence that adolescents with overweight (OW) and obesity (OB) consume larger and more frequent snacks than adolescents with normal weight (NW). The objective of this study was to compare the food group composition of snacks by weight status as well as to identify snacking patterns and predictors among adolescents in the United States (US).

Methods: Anthropometric, dietary, and demographic data from adolescents, 12-19 years old, in the 2005-2016 National Health and Nutrition Examination Survey were analyzed. The mean of the two days of dietary recall was used to measure dietary intake, which serves as a proxy for usual intake. Mean equivalents of the 37 food components present in individual snack foods reported by each adolescent across two days of intake were estimated using the Food Patterns Equivalents Database. Latent Class Analysis (LCA) was used to study the effect of mutually exclusive food component consumption groups. Multivariate logistic regression models were used to analyze membership in relation to dietary quality (Healthy Eating Index 2015 [HEI-2015] scores), weight status (BMI & BMI Z-score), selected snacking parameters (e.g., mean snack calories), and socio-demographic (e.g., race, gender) covariates.

Results: Adolescents with two days of reliable dietary recall data and complete anthropometrics were included in the descriptive analysis (n = 6423). Adolescents with NW consumed greater energy, vegetable, whole grains, refined grains, dairy, and solid fat from snacks than adolescents with OW and OB ($p < 0.05$). LCA identified two main snacking patterns. The "Heavy Snackers" pattern was associated with higher consumption of each food component, total energy and snacking energy while the "Light Snackers" pattern was associated with lower consumption each food component, total energy and snacking energy. After adjustment for energy misreporting, OW or OB classification did not significantly increase the odds of being in either class while being classified with NW decreased the odds of being in the "Heavy Snacker" class. In addition, increasing BMI z-score and HEI-2015 total score increased and decreased the odds of being in the "Heavy Snackers" class respectively. The strongest predictors of a "Heavy Snacker" pattern were male gender, non-Hispanic white race, lower dietary quality, and increased snacking parameters, while female gender, all races except non-Hispanic white, better dietary quality, and decreased snacking parameters were strong predictors of a "Light Snacker" pattern.

Conclusion: We can conclude that consuming less foods as snacks contributed positively to weight status and overall diet quality among US adolescents. Findings from this cross-sectional study remain consistent with snacking, diet quality, and weight status associations, but add to existing knowledge with the identification of snack consumption patterns. The dietary patterns derived may provide a useful basis for dietary interventions targeted at snacking among adolescents by recommending light snacking and low consumption of energy dense snack foods. Additional studies are needed to further understand what the main food pattern components are across gender and racial backgrounds and to confirm whether associations between snacking and weight status are due to food quality, quantity, or both.

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CHAPTER 1

INTRODUCTION

Obesity Among US Adolescents

Obesity rates are highly prevalent across all ages in the United States (US), but pediatric obesity has become a standalone public health priority, with one in five US children having overweight (OW) or obesity (OB); placing this group not only at an increased risk of diet-related co-morbidities and psychosocial consequences in their youth but later in life as well (Fryar, Carroll, & Ogden, 2018; Hales, Carroll, Fryar, & Ogden, 2017; Ogden et al., 2016). A child is classified as OB by a norm-referenced body mass index (BMI) when he or she is above the normal or healthy weight for his or her age, height, and gender, compared to the adult criterion-referenced BMI measure of OB. Children's BMI levels are expressed relative to their peers because their body composition varies as they age as well as between boys and girls (Daniels et al., 2005). Compared to other pediatric populations, adolescents 12 to 19 years old, have the highest OB prevalence and are more likely to remain OB as adults (Y. C. Wang, Orleans, & Gortmaker, 2012). As of 2016, the latest release of the NHANES data, the prevalence of overall pediatric OB was 18.5% affecting about 13.7 million children and adolescents in the US. The rate among the adolescent age group was 20.6%, which is higher than both the baseline percentage (17.9%) of adolescents with OB and the target rate (16.1%) for the 2020 national objective goal. The desired 10% improvement by 2020 is not expected to be met for this objective (Hales et al., 2017; U.S. Department of Health and Human

Services, Office of Disease Prevention and Health Promotion [HHS ODPHP], 2018). In fact, the nation's OB prevalence is expected to continue to rise until 2030 if no progress is made (Hruby & Hu, 2015). Additional national health objectives including prevention of inappropriate weight gain highlights the public health importance of pediatric OB. The adolescent age group is consistently farthest from reaching these objectives to reduce weight gain and improve diet quality (Wang et al., 2012; HHS ODPHP, 2018).

Individuals who have OW or OB are thus at an increased risk of chronic diseases such as diabetes, cardiovascular disease, and certain cancers; contributing to psychosocial and physical morbidity, mortality, and resulting economic burden in the U.S. (Daniels, 2009). OW and OB also confer increased burden of poorer mental health outcomes. According to the World Health Organization, childhood OB is associated with a reduced quality of life and an increased likelihood of teasing, bullying, and social isolation (Pizzi & Vroman, 2013). Results from a representative US population of children and adolescents found that having OB is linked with an increased odds of poor mental health (Tevie & Shaya, 2015). However, the relationship between social well-being, mental health, and childhood OB is multidirectional, as poor mental health can be a risk factor and a comorbidity due to physiological, psychological, and behavioral overlap, including dysregulation of serotonin, sedentary behavior, changes in eating patterns/appetite and sleep patterns, low self-esteem, and a negative self-image (Pizzi & Vroman, 2013). The OB trend has been fueled by a multitude of sociocultural shifts and accelerated by hereditary and behavioral risk factors, with the latter being largely modifiable (Njike et al., 2016). Since weight is influenced by energy consumption behaviors, diet and nutrition play an important role in the development, prevention, and treatment of these chronic diseases.

A large body of evidence has shown that that children with OW and OB are at a substantially increased risk of having OW in adulthood (Must & Strauss, 1999; Ward et al., 2017). Compared to other pediatric populations, adolescents 12 to 19 years old are more likely to remain OB as adults (Y. C. Wang et al., 2012). Clinical evidence suggests that metabolic abnormalities such as elevated blood pressure, glucose, and cholesterol levels, once observed only in adults, are emerging in children with OB (Cote, Harris, Panagiotopoulos, Sandor, & Devlin, 2013; Umer et al., 2017). The excess weight is thought to impact multiple physiologic processes and organs, further facilitating OB and chronic disease initiation or progression. Established biological mechanisms that link OB with disease can lead to orthopedic, endocrinal, gastroenterological, pulmonary, and neurological diseases that persist for a prolonged time and limit activities of daily living (Must & Strauss, 1999; Remington, Brownson, Wegner, 2016).

Dietary Patterns Among Adolescents

Adolescence is a transitional time period consisting of developmental, physical, and social changes that ultimately impact eating behaviors and nutritional health. This age group is undergoing rapid growth and has the highest demand for energy and nutrients of any time throughout the lifecycle (Daniels et al., 2005; Story, Neumark-Sztainer, & French, 2002). Adolescents are also navigating the choices surrounding independence, eating away from home, and peer acceptance. These changes impact food choice and behavior patterns in their present and future due to established habits that are more likely to be carried into adulthood e.g. snacking, skipping breakfast, and low intake of fruits and vegetables (Story et al., 2002). Intakes of fruits, vegetables, and milk typically decrease during adolescence while soft drink consumption increases, suggesting that diet quality declines from childhood to adolescence. These findings establish adolescents as prime candidates for early intervention and pose a unique opportunity to impact eating behaviors and food choices during this time (Story et al., 2002; D. Wang, van der Horst, Jacquier, & Eldridge, 2016).

Recommendations for healthy eating patterns are provided in the Dietary Guidelines for Americans according to age, gender, and level of physical activity taking into consideration three main factors, body weight maintenance, adequate nutrient consumption, and chronic disease risk reduction. Recommendations are designed to meet nutrient needs while staying within limits for overconsumed dietary components and not exceeding calorie requirements. Energy requirements are influenced by height and weight and have been established using Estimated Energy Requirements (EER) equations for three different levels of physical activity across various age and gender groups. Food group recommendations are based on the energy requirements and the assumption that all foods are consumed in nutrient-dense forms, lean or low-fat and prepared without added fats, sugars, refined starches, or salt. The food groups are identified in cup- and ounce-equivalents to identify the amounts of foods from each food group with similar nutritional content, due to varying forms and concentrations of foods within food groups (United States Department of Agriculture [USDA], 2020).

Energy needs vary substantially from 1,400 to 3,200 calories per day for older children and adolescents, with boys generally having higher calorie needs than girls. The energy requirements for adolescents with low physical activity, including only the physical activity of independent living, range from 1600 – 2400 calories per day. Based on those energy requirements and a healthy U.S.-style eating pattern, recommended amounts of food from each food group include: 2 to 3 cups of vegetables, 1 ½ to 2 cups of fruit, 3 to 4 oz-equivalents of whole grains, 2 to 4 oz-equivalents of refined grains, 3 cups of dairy, 5 to 6.5 oz-equivalents of protein, and 22 to 31 grams of oil. In addition, added sugar and saturated fats should be limited to less than 10% of daily calories, which is consistent for all age groups. For adolescents following this eating pattern, 8 – 15% of calories are left for consumption at their discretion i.e. consumption of added sugars, solid fats, alcohol, or more than the recommended amount of each food group. The Healthy U.S.-Style Pattern is the base USDA Food Pattern and is updated based on current food consumption and composition data (U.S. Department of Health and Human Services [HHS] and U.S. Department of Agriculture [USDA], 2015).

Average equivalent intakes of food pattern groups and other dietary components for age-gender groups collected from WWEIA data indicate whether individuals are close to meeting the Dietary Guidelines for Americans. According to food pattern consumption data reviewed in current dietary guidelines, adolescents are consuming well under the recommended daily equivalents for vegetables, fruit, and dairy while on target for total grains and protein foods (USDA, 2018a). Despite consuming the recommended amount of grains, a closer look reveals that adolescents do not consume recommended amounts of whole grains but exceed recommendations for refined grains. Furthermore, meat, poultry, and egg intake exceed weekly recommendations while seafood and nuts/seed consumption lag. Lastly, solid fat intake is about twice as much as oil intake which is just below recommended ranges (HHS and USDA, 2015). Mean total food pattern equivalent intakes as a percent of recommendations for adolescents with low physical activity from 2015-2016, WWEIA NHANES data can be found in Table 6.

Diet quality can be further assessed by the Healthy Eating Index 2015 (HEI-2015), a measure of dietary pattern changes and alignment with the Dietary Guidelines for Americans. An ideal overall HEI-2015 score of 100 reflects that the analyzed set of foods aligns with the Dietary Guidelines for Americans. Interpretation of scores remains a challenge due to variations in quality of food patterns for two diets with the same total scores. However, scores above 80 have been used as an indicator of a "good" diet, while scores below 51 indicate a "poor" diet, and between 51 and 80 reflect the need for dietary improvement (Al-Ibrahim & Jackson, 2019). The average HEI-2015 score for Americans is 59 out of 100, indicating that average diets of Americans do not align with the dietary guidelines. HEI-2015 scores vary by age group; in fact, children ages 6-17 had scores at 53 out of 100 which are lower than the population average ("HEI Scores for Americans | USDA-FNS," n.d.).

Despite shifts in dietary quality measures, nutrient intake and average usual intakes from food and beverages can also be good indicators of diet quality. National estimates of mean usual intakes for nutrients of concern from total food and beverage consumption by adolescents age 12-19 years in NHANES 2013 – 2016 can be found in Table 1. This compiled data reveals that adolescents do not consume enough dietary fiber, vitamin D, calcium, magnesium, and potassium but consume saturated fats, sodium, and sugar in excess, which is consistent with conclusions made from What We Eat in America data in the dietary guidelines (USDA, 2019). Lastly, to expose macronutrient concerns, estimated distributions of usual contributions of a specific nutrient to total energy intake are compared with age-specific recommended macronutrient distribution ranges. Protein consumption as a percent of energy is on the lower end of the Acceptable Macronutrient Distribution Range (10-30%), while carbohydrates (45-65%) and fat (25-35%) are on the higher end of the acceptable macronutrient distribution ranges.

The adolescent population consumes the most total grams of sugar compared to any other age group and exceeds both sodium limits (USDA, 2019). Underconsumption of calcium, potassium, dietary fiber, and vitamin D is associated with health outcome concerns and therefore they are considered nutrients of public health concern (HHS and USDA, 2015). Food groups and nutrients consumed in excess may displace recommended foods and nutrients lacking in the diet that are important to overall health, ultimately contributing to OB (HHS and USDA, 2015). Existing literature shows that diets rich in minimally processed plant-based foods such as fruits, vegetables, and whole grains that are naturally high in fiber and low in saturated fat protect against the development of risk factors for several chronic diseases, including cancers, cardiovascular disease, OB, and type 2 diabetes (Fardet & Boirie, 2014).

Table 1. *Nutrients of Concern and Mean Usual Intakes from Total Food and Beverage Consumption for Adolescents Age 12-19 Years, WWEIA, NHANES 2013 – 2016*

Nutrients of Concern		Mean Usual Intake	
Nutrient	Range of recommended intake* (EAR/AI)**	Males	Females
Dietary Fiber (g)	25 – 31	16	13
Calcium (mg)	1300	1167	854
Potassium (mg)	4700	2546	1925
Magnesium (mg)	360 – 410	282	219
Vitamin D (mcg)	10	6	4
Sodium (mg)	1500 – 2300***	3888	2875
Saturated Fats(g)	-	31	23
Sugar (g)	-	133	101
Macronutrient	AMDR**** (% of energy)	Males	Females
Carbohydrate	45 - 65	51	52
Fat	25 - 35	34	34
Protein	10 – 30	16	15

NOTES: *Recommended intake ranges assume low activity level; **dietary reference intakes used to estimate the prevalence of inadequate nutrient intakes in a population group. EAR = estimated average requirement, the average daily nutrient intake level that is estimated to meet the requirements of half of healthy individuals in an age and gender group. AI = Adequate Intake, the recommended average daily intake level based on observed or experimentally determined estimates of nutrient intake by groups of apparently healthy people when an EAR cannot be derived (USDA, 2019); ***CDRR=Chronic Disease Risk Reduction intake level; ****AMDR=Acceptable Macronutrient Distribution Range
SOURCE: USDA, Agricultural Research Service, 2019. Usual Nutrient Intake from Food and Beverages, by Gender and Age, What We Eat in America, NHANES 2013-2016 Available http://www.ars.usda.gov/nea/bhnrc/fsrg; Range of recommended nutrient intake available at https://health.gov/dietaryguidelines/2015/guidelines/Appendix 7

Snacking Trends Among Adolescents

In the US, increased trends in snacking and eating occasions over the past few decades have coincided with an increase in the proportion of the population that has OW or OB particularly among children (Dunford & Popkin, 2018; Ogden et al., 2016). The snacking trend is evidenced by increases in the daily number of eating occasions and energy intake from snacking, as well as decreases in time between consecutive eating occasions; likely a result of an increased pace of life among all age groups over the years (Bellisle, 2014). What We Eat in America (WWEIA) data reveals that three meals a day are consumed by the majority of the U.S. population, with two to three snacks being most common amongst all ages (USDA, 2018b). However, 84% of children in the two to five age range follow this common eating pattern compared to only half of adolescents; most adolescents have two or more snacks regardless of consuming the traditional three meals (HHS and USDA, 2015). Twenty six percent of adolescents consumed one to two snacks per day in 2015 (USDA, 2018c).

A study on 37 years of snacking trends (1977-2014) among children in the US found that overall snacking behavior (per capita energy intake from snacks, number of snacks per day, and calorie intake per child) has increased for all socio-demographic groups, peaking during the 2003-2006 time period and trending downward from 2006-2014 (Dunford & Popkin, 2018). Over the 37 years, the largest increase in calorie intake was observed among non-Hispanic black adolescents and those in the lowest household income group (Dunford & Popkin, 2018). Furthermore, foods containing nutrients of concern were commonly consumed at these snacking occasions including SSBs, desserts, and salty snacks; fueling concerns about the quality of foods and beverages consumed as snacks and how snacking affects current energy intake and OB development in US children (Dunford & Popkin, 2018; Miller, Benelam, Stanner, & Buttriss, 2013).

Among the many diet-related factors that contribute to OB, snack and sugar sweetened beverage (SSB) consumption have become a considerable focus with 75% of added sugar consumption across age and gender groups in the US coming from these categories (HHS and USDA, 2015). A recent analysis of consumption of all SSBs found that during 2011–2014, 62.9% of youth consumed at least one SSB on a given day accounting for 9.3% and 9.7% of total daily calorie intake for boys and girls aged 12–19 years (Rosinger, Herrick, Gahche, & Park, 2017). This observation alone falls just under the 2015 Dietary Guidelines Advisory Committee recommendations to limit intake of added sugars to no more than 10% of energy. There has been a significant decrease in daily soda consumption since 2004 which suggests that interventions encouraging reduced consumption of soda are working, however, sugar sweetened sport drinks are increasing, and overall prevalence of daily soda consumption remains high especially among adolescents (Kit, Fakhouri, Park, Nielsen, & Ogden, 2013; Mesirow & Welsh, 2015).

Associations between SSB and increased risk of OB are likely due to excess calories, metabolic effects, and a failure to compensate for the consumption of liquid calories, resulting in an energy imbalance (Malik & Hu, 2015; Mesirow & Welsh, 2015). A failure to compensate for energy intake after snacking in general has also been observed, especially if snacking on an irregular basis (Gregori, Foltran, Ghidina, & Berchialla, 2011). Assuming energy imbalance underlies the childhood OB momentum, adolescents need the largest reductions in caloric intake to bridge that gap (Wang et al., 2012). Eating context can explain some of these findings in that some parents and teachers use snacks for reward and behavioral management as opposed to an emphasis of nutrition typically done at mealtime, which can lead to maladaptive eating patterns. Understanding contribution and context of snacks helps describe the full picture and influence the creation of tailored guidance (Loth et al., 2019; Turner, Chriqui, & Chaloupka, 2012).

Adolescents’ snack consumption comprises a quarter of their energy intake (Njike et al., 2016; Piernas & Popkin, 2010). The 2015–2016, NHANES data for adolescent boys and girls revealed that on a given day, the foods and beverages consumed during snack occasions contributed 21-22% of total daily energy, 31–34% of total sugar, and 21–23% of saturated fat intake across gender groups. However, energy contribution from these nutrients of concern, sugar and sodium, were at their lowest from the 10 years prior, suggesting a positive shift in snacking composition, but studies to examine snack composition are needed to elucidate these shifts (USDA, 2010a – 2018d). Substantial proportions of nutrient intake were provided by foods and beverages consumed at snack occasions for the following nutrients: fiber (19– 20%) although lowest among adolescents, vitamin C (26–28%), potassium (18–20%), calcium (19– 21%), and magnesium (22–25%). Smaller but notable contributions were provided by snacks to intakes of protein (11–13%), vitamin A (15–17%), vitamin B-6 (15–17%), folate (12–16%), vitamin D (14–18%), iron (15–17%), and zinc (13– 15%) (USDA, 2018d).

Impact of Snacking Definitions

Increased snacking trends and consumption of small more frequent meals is rendering it increasingly harder to distinguish a meal versus a snack. Studies have shown that individuals who classify their eating occasions as meals seem to choose more nutrient dense foods because labeling eating occasions can influence perception and ultimately food choice, satiety, and daily calorie intake (Hess, Jonnalagadda, & Slavin, 2016; Njike et al., 2016). Definition distinction might seem trivial, but in addition to influencing individual food selection, it can impact accuracy and interpretation of research. Snacking definitions influence the relationships between snacking behaviors and health outcomes. Development of dietary guidelines for healthy snacking recommendations are dependent on snacking definitions but development of a universally accepted definition remains a challenge due to advantages and disadvantages of current definitions described in the literature (Gregori et al., 2011; Johnson & Anderson, 2010).

Hess et al. (2016) has defined several terms in relation to snacking, the term "snack foods" refers to energy-dense, nutrient poor foods, the term "snack" refers to food consumption outside of regular meal times and the term "snacking" refers to the act of eating a snack, regardless of whether the food consumed was a typical "snack food" or not. Some studies are consistent with Hess et al. (2016) and define snacks as any food consumed beyond the traditional three meals a day, regardless of size, duration, or content, while others include self-reported name of eating occasion in addition to time of consumption (Bellisle, 2014). More conservative snack definitions combine food items consumed within 15 minutes, snack foods consumed within a meal as a meal, and recode missing meals and snacks according to clock time (Piernas & Popkin, 2010).

Hybrid definitions illustrate the complexity in interpreting research and developing an objective definition for snacking. Individual snacking definitions have their own limitations, for example, definitions that consider nutrient content alone are highly subjective and may include food items consumed during a traditional meal. Definitions based on time of consumption negate concerns resulting from nutrient content classification but are influenced by varying cultural and lifestyle eating patterns leading to misclassification of eating occasions. Snacks defined by maximum energy content and time intervals between consumption regardless of time of day are complex and remain highly variable. Self-designation is also highly subjective and susceptible to individual perception but widely used in national surveys and thus in the present study. Although also included in the definition for the present study, inclusion of beverages in definitions is controversial due to differences in satiety compared to foods (Johnson & Anderson, 2010).

Murakami and Livingstone (2016b), evaluated several different definitions in their studies on eating frequency and diet quality and their findings revealed the importance of eating occasion distinction when assessing dietary pattern impact on health. Snacks were separated by first defining an eating occasion as all foods eaten at one discrete time, excluding any episode less than 50 calories to avoid the inclusion of water only or miniscule quantities of food such as a piece of candy or a few nuts and then either designating by contribution to total energy intake, self-report name of eating occasion, or clock time. They found associations between meal frequency and better diet quality irrespective of meal definitions and varied associations between snack frequency and diet quality depending on the definition used. The snack definition based on energy intake was associated with better dietary quality, but definitions based on self-report and time had no associations. Further confirming variability in study conclusions, Gregori et al. (2010) took a meta-analytic approach to understanding the impact of snacking definitions and weight status, concluding that the probability of having OB is dependent on the chosen snack definition.

As evidenced in the reviewed articles, the lack of clarity confounds interpretation of the literature and results in variability in conclusions, further reducing the reliability of meta-analyses. A need for clear definitions has been consistently highlighted as a limitation in the literature and a barrier to evidence-based dietary recommendations for consumers (Johnson & Anderson, 2010; Miller et al., 2013). Universally accepted snack definitions remain an important gap in the government issued Dietary Guidelines for Americans (Hess et al., 2016). In the meantime, researchers on the subject acknowledge that attempts to explicitly define snacking do not always align with cultural or individual perceptions of what constitutes an eating occasion and recommend defining a strict definition of snacking in studies (Johnson & Anderson, 2010).

For many reasons, including complexities in measuring and defining snacking, current scientific literature is mixed on whether snacking has a positive or negative impact on overall health and body composition (Hess, Jonnalagadda, & Slavin, 2016; Johnson & Anderson, 2010). Snacking is perceived to have a range of proposed benefits around appetite, weight, and blood glucose management. The proposed benefits can be further influenced in either direction by food portion sizes and energy-density as well as social and psychological cues (Bellisle, 2014; Hess et al., 2016; Miller et al., 2013) Regular snacking may also help children and adolescents meet dietary recommendations and contribute to overall dietary quality by increasing opportunities for necessary food and nutrient consumption. However, habitual snacking without compensation can contribute to excess energy intake via energy-dense snack foods, sugary drinks, and fast foods often eaten as snacks, placing increased consideration on the nutritional quality of foods eaten between meals and overall health (Dunford & Popkin, 2018; Miller et al., 2013). Research assessing associations between snacking, weight status, and dietary quality among children and adolescents is summarized in Table 2.

Snacking and Weight Status Among Adolescents

A review of the literature has shown that the relationship between snacking and weight status is inconsistent and depends on a variety of factors including how snacks, dietary intake, and weight status are defined. In fact, Keast et al. concluded that snacking was associated with reduced risk of having OW and OB, finding inverse relations between snacking frequency and the percentage of energy from snacks with OW and OB prevalence. In addition, similar inverse relations were found between increased eating frequency, having OB, and metabolic disease risk in OW minority youth, despite increases in energy intake associated with increased eating frequency (House et al., 2015). Frequent snacking has been linked with increased energy consumption so it is logical to expect that it would also be associated with a higher risk of OB, but an assessment of the literature does not support this intuitive notion (Johnson & Anderson, 2010; N. I. Larson, Miller, Watts, Story, & Neumark-Sztainer, 2016). Several studies in a review of recent research confirm inconclusive results, with many finding a protective effect or no association between snacking and OB in adolescents and a smaller number of studies finding an increased risk of OB with snacking (Larson & Story, 2013). However, recent research found that after adjusting for misreporting in energy intake, increased snacking frequency was associated with increased risks of OW and abdominal OB in adolescents and children (Murakami & Livingstone, 2016b).

Tripicchio et al. (2019) looked at the association, among a nationally representative adolescent sample, of weight classification with three major variables: snack frequency, snack size, and snack energy density. The major finding was that adolescents' with OW and OB snack more often and consume larger snacks compared to adolescents' classified as normal weight (NW) but the study did not indicate whether OW and OB are eating different types of snacks. Another interesting finding from the study was that adolescents with OW and OB were not consuming more energy dense snacks compared to adolescents classified with NW (Tripicchio et al., 2019). A study done in the UK found that snacking frequency may be associated with higher or lower adiposity, with the direction of association being dependent on BMI status and snack food choice (O'Connor, Brage, Griffin, Wareham, & Forouhi, 2015). Therefore, understanding snack composition is important not only to guide recommendations, but also to understand adolescent choices around snack frequency and size.

Findings from Tripicchio et al. (2019) are consistent with associations between increased snacking frequency and increased risks of OW and OB in adolescents found by Murakami & Livingstone (2016b) and other reviews highlighting the gap in nutritional composition of snacks consumed by US adolescents (Larson et al., 2016). However, they are contradictory to findings from a previous study on snacking measures that found a direct relation between servings of energy dense snack foods and BMI among US adolescents (Larson et al., 2016). The relations between snacking and BMI were not consistent unless energy-dense foods were consumed. These contradictory findings and gaps highlighted by Trippichio et al. (2019) will be elucidated in the present study by discerning snacking patterns based on food group consumption and predicting membership based on snacking characteristics.

Snacking and Diet Quality Among Adolescents

A recent paper highlights similar findings pertaining to the contribution of snacking to 5-7-year-old children's overall diet quality. Loth et al. found that snacking contributed positively to children's diet quality, while previous research found that snacking contributed negatively to children's diet quality (Loth et al., 2019; Murakami, 2018). Other notable findings from Loth et al. include differences in snacking contribution to diet quality by gender and racial background, which is a gap identified by a review of the implications of snacking on weight status among children and adolescents (N. Larson & Story, 2013; Loth et al., 2019).

There is some suggestion that the association of snacking and weight status depends on the nutritional composition of foods and beverages consumed as snacks, with consumption of energy dense snack foods associated with OW and OB (Larson, Miller, Watts, Story, & Neumark-Sztainer, 2016; Njike et al., 2016; Vernarelli, Mitchell, Rolls, & Hartman, 2018). Furthermore, consumption of high-energy-dense snacks was found to contribute negatively to children's diet quality, and vice versa for nutritionally dense snacks (Murakami & Livingstone, 2016a). Dietary Guidelines for Americans currently recommend that adolescents consume nutrient-dense snacks to help them meet their nutritional requirements as opposed to energy-dense snacks due to their association with decreased diet quality (HHS and USDA, 2015). Energy density is a common factor across dietary patterns recommended for weight management (Smethers & Rolls, 2018). Finally, Llaurado et al. found that increased eating frequency throughout the day was associated with greater diet quality (Llauradó, Albar, Giralt, Solà, & Evans, 2016).

Findings from these studies suggest that, overall, snacking has the potential to increase diet quality but is dependent on the quality of the snacks consumed.

Explanations for these unclear findings include variation in study designs and methodological limitations such as intervention duration, timing, type of snack consumption, and potential bias in reporting dietary intake and restricted eating patterns (Johnson & Anderson, 2010; Njike et al., 2016). In order to address these limitations, this study will: a) utilize NHANES data b) account for reporting bias of food intake, c) use comprehensive snacking definitions, and d) examine the associations of snacking on OB using categorical weight classifications.

Specific Aims

The primary aim of this study is to examine intakes of various food groups consumed as snacks and snacking patterns by weight status (NW, OW, OB) from 2006-2016 in the US. The main research questions are as follows: "Do food group intakes from snacks (mean equivalents per food group) vary by adolescent weight classification (NW, OW, OB)?" and "How do snacking patterns differ by adolescent weight status (BMI and BMI Z-score) and overall diet quality, as measured by the HEI-2015?" We hypothesize that food group consumption will differ by weight classification, and that weight classification and total HEI-2015 score will predict food pattern membership.

To examine snacking pattern associations with weight status, dietary and demographic data from adolescents in the 2006-2016 NHANES will be analyzed. The food group intakes from snacks, as indicated in the USDA Food Patterns Equivalents Database, consumed by adolescents will be described. We will also examine snacking patterns by weight classification (BMI-for-age percentiles: NW <85th; OW ≥ 85th to <95th; OB ≥ 95th) as well as with HEI-2015 to assess impact on overall diet quality. Within the US, snacking has been shown to be influenced by race-ethnicity, household education, gender, and income groups; thus, these variables will be included as covariates in the analyses (Dunford & Popkin, 2018). This study will address the gap in what a nationally representative sample of adolescents consume as snacks in the United States.

Given shifts in eating patterns and the increase of pediatric OB over the past 30 to 40 years in the United States, it is important to consider how snacking behaviors contribute to elevated BMI during adolescence as snacking is an important component of dietary intervention to be addressed (Hruby & Hu, 2015; Larson & Story, 2013). This need is echoed across national platforms; Healthy People 2020 emphasizes the importance of preventing unhealthy weight gain as new and innovative policies and environmental interventions to support diet are implemented (HHS ODPHP, 2018). Adolescent snacking behavior can coexist with other lifestyle aspects to induce adverse effects on dietary intake and weight status (Story et al., 2002). Findings will also add to existing knowledge around the role of snacks in diet quality and body weight control, by using a nationally representative sample, which aids in comparison of results. Findings could provide new or confirm existing evidence of snacking patterns to inform behavioral recommendations and policies such as changes to the nutrition fact panel and ensuring that certain snacks are accessible in settings where adolescents and children spend the majority of their time. Clearly defined guidelines and policies based on consistent findings help enable the efforts of nutrition professionals working in industry, schools, and other community settings to better tackle the challenge of pediatric OB.

Table 2. *Research Assessing Associations between Snacking, Weight Status, and Dietary Quality among Children and Adolescents*

	Reference	Summary of Results
Snacking & Weight Status	Keast et al., 2010	Snacking was associated with reduced risk of being overweight and obese; inverse relations between snacking frequency and the percentage of energy from snacks with OW and OB prevalence.
	House et al., 2015	Inverse relations were found between increased eating frequency, obesity and metabolic disease risk in OW minority youth, despite increases in energy intake associated with increased eating frequency
	O'Connor et al., 2015	Snacking frequency may be associated with higher or lower adiposity, with the direction of association being dependent on BMI status and snack food choice
	Larson & Story, 2013	Several studies in a review of recent research confirm inconclusive results, with many finding a protective e□ect or no association between snacking and obesity in adolescents and a smaller number of studies finding an increased risk of obesity with snacking
	Murakami & Livingstone, 2016b	After adjusting for EI/EER, increased snacking frequency was associated with increased risks of OW and abdominal OB in adolescents and children
	Tripicchio et al., 2019	OW and OB adolescents' snack more often and consume larger snacks compared to NW adolescents. OW and OB adolescents are not consuming more energy dense snacks compared to NW adolescents
	Larson et al., 2016	Associations suggest that energy-dense foods contribute to OW in US adolescents. They found direct relation between servings of energy dense snack foods and BMI.
Snacking & Diet Quality	Loth et al., 2019	Snacking contributed positively to children's diet quality with differences in contribution by gender and racial background
	Murakami & Livingstone, 2016c	Meal frequency was associated with better diet quality, while the associations for snack frequency varied depending on the definition of snacks
	Murakami, 2018	Lower nutritional quality of meals, but not snacks, was associated with lower overall diet quality
	Murakami & Livingstone, 2016a	Consumption of high-energy-dense snacks was found to contribute negatively to children's diet quality, and vice versa for nutritionally dense snacks
	Llauradó, Albar, Giralt, Solà, & Evans, 2016	Increased eating frequency throughout the day was associated with greater diet quality

CHAPTER 2

METHODS

Study Design

The design of this study is secondary data analysis of cross-sectional data obtained from the National Health and Nutrition Examination Surveys (NHANES). NHANES is an ongoing, nationally representative study of the nutritional and health status of the civilian, non-institutionalized US population. It is managed by the National Center for Health Statistics (NCHS) which is part of the Center for Disease Control and Prevention (CDC) (National Center for Health Statistics, 2017). NHANES tracks health and nutritional status over time using interviews, physical examinations, and laboratory exams. NHANES data is collected in a continuous ongoing survey cycle with data being released in two-year cycles. NHANES uses a complex, multistage, probability sampling design with county as the primary sampling unit from which clusters of households and participants are randomly selected. Approximately 5,000 people are selected from 15 different counties and certain population subgroups are oversampled to increase the reliability and precision of health status indicator estimates for these groups, depending on public health trends (Zipf et al, 2013; Johnson, Dohrmann, Burt, & Mohadjer, 2014; Ahluwalia, Dwyer, Terry, Moshfegh, & Johnson, 2016).

A multi-stage, unequal probability of selection design was implemented to increase the number of participants for specific demographic groups. Overall, African Americans, Mexican Americans, low income persons, adolescents 12-19 years, and persons 60 years and older are oversampled in NHANES (NHANES 2005-2006

Overview, n.d.). As of 2007, all Hispanics were oversampled in addition to Mexican Americans, and pregnant women were no longer oversampled (NHANES 2007-2008 Overview, n.d.). Beginning with the 2011-2012 survey, Asian Americans were oversampled (NHANES 2011-2012 Overview, n.d.), which means by 2015, the target population was oversampled for Hispanic, non-Hispanic black, and non-Hispanic Asian persons. Non-Hispanic white and other people who fell below 185% of the poverty level and non-Hispanic white and other people who are 80 years and over were also oversampled. The cut-point for low-income oversampling was previously ≤ 130% and changed to ≤ 185% of the Health and Human Services poverty guidelines in 2015 (NHANES 2015-2016 Overview, n.d.). Sample weights are used to produce national, representative estimates. They incorporate the unequal probabilities of selection, as well as adjustments for non-participation by selected sample persons.

Procedure

A screener administers a short interview during home visits to determine if any persons in the home are eligible and obtain participation consent. Once participants are considered eligible, data are collected by trained study staff and participants complete an in-home interview where demographic and health-related information are collected about the household, followed by a medical examination and a 24-h recall for collection of food consumption data (Ballanton, Moshfegh, Baer, & Kretsch, 2006). A second 24-h recall is collected via phone ideally within 10 days after the initial 24-h recall to account for day-to-day variation. Both recalls make up the dietary intake element of the NHANES known as What We Eat in America (WWEIA), which is jointly administered by the USDA and National Center for Health Statistics (NCHS, 2017).

The USDA uses a 5-step Multiple-Pass Method for dietary interviews in which respondents receive cues to help them remember and describe foods they consumed in the 24 hours of the previous day. Originally, a paper version of the method was used but as of 2002, a computer-assisted version with standardized questions and response options was developed namely, the Automated Multiple-Pass Method (AMPM)(Ahluwalia, Dwyer, Terry, Moshfegh, & Johnson, 2016). The Computer-Assisted Personal Interview (CAPI) system is used to administer all interviews including the AMPM (National Health and Nutrition Examination Survey: Sample Design, 2011–2014, 2014). Dietary data are typically released about 6–9 months after the initial release of other NHANES component data corresponding to that cycle. This lag is because of the time spent checking the dietary data for quality and determining the nutrient composition for foods and beverages for all items reported in the survey (Ahluwalia et al., 2016).

Participants/Study Size

Data from 2005-2016 were analyzed in this study. An individual can be classified as a non-respondent to any of the portions of the survey. Over the 12-year time period, there was 3.7% Mobile Examination Center (MEC) non-response and an additional 7.9% of the sample persons did not complete the dietary portion. A total of 60,936 individuals participated in the at-home interview, of which 58,660 completed MEC interviews and 54,043 completed at least one dietary recall (NHANES 2013-2014, n.d., & NHANES 2015-2016 Overview, n.d.). Adolescents with less than two days of dietary data were excluded. Of the 8179 adolescent participants with dietary data, 1020 participants were excluded due to having only one dietary recall. Adjustments made for survey non-response do not account for item non-response, but the dietary recall status variable included in the NHANES individual food files and total nutrient files indicates whether a survey participant's response to the dietary recall section was accurate and complete. All relevant variables associated with the 24-h dietary recall data contained a value, therefore none of the records during this time period were deemed unreliable. In addition, 212 adolescents did not have a self-identified snacking occasion and were excluded so as to not skew average dietary variables with their zero values. Given the eligibility criteria, 6974 adolescent participants remained in the full analytic sample from 2005-2016.

Measures

Data Sources

Individual data regarding participant health history, dietary status, and background came from six NHANES datasets: Individual Food File – Day One, Individual Food File – Day Two, Total Nutrient File – Day One, Total Nutrient File – Day Two, Examination, and Demographic files. In addition, the Food and Nutrient Database for Dietary Studies (FNDDS) datasets were used in conjunction with the NHANES datasets to characterize food components. See flowchart of data construction in Appendix A. The measures included in this study are described below.

Demographics

The following self-identified characteristics were assessed in this study: age (years), gender (male, female), race/ethnicity (non-Hispanic white, Hispanic/Mexican American, non-Hispanic black, other/multi-racial/non-Hispanic Asian), and Head of household (HH) [Education level, and Income]. The gender variable was used to create a dichotomous variable where 0 is for “male” and 1 is for ‘female”. The race variables were used to create a categorical race variable with four levels, “Non-Hispanic white” = 0, “Non-Hispanic Black” = 1, “Mexican American/other Hispanic” =2 and “Other/Multi-Racial/Asian” = 3. Head of household education level was recoded as a 2-level categorical variable where 0 combined categories “less than 9th grade” and “9-11th grade including 12th grade with no diploma” and 1 was “high school graduate/GED or equivalent”, and “college graduate or above”. In addition, the annual household income variable was recoded as a dichotomous variable where 0 was less than $20,000 and 1 was equal to or greater than $20,000.

Examination - Weight Status

According to the Anthropometry Procedures Manual 2016, standing height was measured in centimeters (cm) using a stadiometer and weight was measured in kg using a digital scale, both by trained staff in the MEC. If the stadiometer failed, measuring tape was approved for use. If the digital scale malfunctioned, two portable scales were approved for use. Weight results are viewable in kilograms (kg) and pounds and height results are viewable in English and metric units (CDC, 2016). Height and weight collected in the MEC were used to calculate the BMI. Date of birth and gender were used to derive age-and-gender specific BMI-percentiles (BMI%) using the CDC growth charts. The "agd" package in R was used to reference the CDC growth charts and derive adolescent BMI for each participant. The classifications include normal weight (NW) <85th percentile, overweight (OW) ≥85th to <95th percentile, and obesity (OB) ≥95th percentile.

Dietary Intake

Adolescents self-reported dietary intake was collected using the USDA AMPM (Blanton, Moshfegh, Baer, & Kretsch, 2006; Ahluwalia et al., 2016). Participants were also provided three-dimensional models and/or USDA's Food Model Booklet to estimate food amounts. Participants self-identified eating occasions using a pre-determined list (e.g., "breakfast"). The mean of the two days of dietary intake was used to construct all dietary variables, which serves as a proxy for usual intake and is consistent with current literature (Murakami & Livingstone, 2016a).

Snacking Definition

Due to the self-report nature of NHANES data, snack occasions were participant defined. For this study, snacking occasions were selected based on eating occasions identified by participants as "snacks," "beverages", or "extended consumption," as well as the Spanish equivalents "*merienda*", "*bebida*", "*bocadillo*", "*tentempie*", and "*entre comida*" to capture the general definition of snacking that refers to eating in between meals. This expanded definition is consistent with recent research (Tripicchio et al., 2019).

Food Group Components

The FNDDS is a database of foods, their nutrient values, and weights for typical food portions that serves as a complement to WWEIA dietary data to code the food intake and calculate nutrient intakes (Raper et al., 2004; Ahuja, Moshfegh, Holden, & Harris, 2013). Also included among the FNDDS datasets is the Food Patterns Equivalents Database (FPED) which converts the foods and beverages in the FNDDS to the 37 USDA Food Patterns components (Raper et al., 2004). Each participants' snacking occasions from the two WWEIA dietary recalls were broken down into the USDA Food Pattern components using the corresponding FPED files for each year and day of data collection. Eleven food component groups were selected to derive the dietary patterns including: Total Fruit (cup eq.), Total Vegetables (cup eq.), Beans and Peas (cup eq.), Total Whole Grains (oz. eq.), Total Refined Grains (oz. eq.), Total Protein Foods: excludes legumes (oz. eq.), Total Dairy (cup eq.), Oils, Solid Fats, Added Sugars, and Alcoholic Drinks.

Summary statistics for average mean equivalents of selected food component groups of the analytic sample were assessed. Given that mean equivalents in some food groups were very small, they were dichotomized above and below the median of average consumption to distinguish high and low consumption as a categorical variable of each food component. In some cases, the median mean equivalent was zero creating a group equal to zero and above zero. The median splits are shown in Table 3. Finally, the analytic dataset was reformatted to run the Latent Class analysis in Mplus using the "MplusAutomation" package in R (Hallquist & Wiley, 2018).

Table 3. *Food Intake Patterns and Median Mean-Equivalents for Adolescents Age 12-19 Years, WWEIA, NHANES 2005 – 2016*

Food Intake Patterns		Group Count	
Food/component	Median Mean-Equivalent	< Median	≥ Median
Fruits (cups)	0.02	3480	3494
Vegetables (cups)	0.00*	4440	2534
Legumes (cups)	0.00*	6810	164
Whole Grains (oz-eq)	0.00*	5033	1941
Refined Grains (oz-eq)	0.68	3487	3487
Dairy (cups)	0.12	3489	3485
Protein foods (oz-eq)	0.02	3415	3559
Oils (grams)	2.34	3486	3488
Solid Fats (grams)	5.21	3487	3487
Added Sugars (tsp)	5.08	3487	3487
Alcoholic Beverages	0.00*	6773	201

NOTES: *Food components with a median of zero were split into groups equal to zero and greater than zero
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted; FPED 2005 - 2016, Day 1 & 2

Healthy Eating Index

HEI is a summary measure of dietary quality designed to measure how well diet quality corresponded with the Dietary Guidelines for Americans. It is a scoring metric of dietary quality independent of actual amounts; components are assessed on a density basis (amounts per 1,000 calories) due to the variations in dietary recommendations. HEI is also useful for evaluating the quality of any set of foods such as the US food supply as a whole or within a community, but does not reflect other dietary guideline recommendations such as physical activity, body weight, and food safety (Krebs-Smith et al., 2018). HEI-2015 consists of 13 categories: whole fruit, total fruit, whole grains, dairy, total protein foods, seafood and plant proteins, greens and beans, total vegetables, fatty acids, refined grains, sodium, saturated fat, and added sugars. The categories capture the balance among food groups, subgroups, and dietary elements that are encouraged and discouraged, known as adequacy and moderation components. Total Nutrient files including FPED components across both days of dietary recall intake data were used to calculate average daily energy intake and HEI-2015 component scores. High scores for the adequacy components reflect higher intakes that meet or exceed the standards but for the moderation components, reflect desirable lower intakes. All 13 component scores are summed together for each individual for a maximum of 100 points: the higher the score, the higher the diet quality (Krebs-Smith et al., 2018). The HEI-2015 SAS macro was translated into R syntax and used to calculate the HEI-2015 score for each participant in the analytic sample.

Dietary Reporting Accuracy

To assess dietary reporting accuracy, particularly misreporting of energy intake, the ratio of reported energy intake to estimated energy requirements (EI:EER) was used as a covariate in the analysis as opposed to removing improbable cases which would result in selection bias (Murakami & Livingstone, 2016a; Tripicchio et al., 2019). EER was calculated using Dietary Reference Intake equations based on age, gender, height, weight, and physical activity level as well as assuming a "low active" level of physical activity (≥1.4 to <1.6) for all adolescents (Murakami & Livingstone, 2016b; IOM, 2015; Belcher et al., 2010; Trumbo, Schlicker, Yates, & Poos, 2002). Dietary weights were also used to adjust for dietary nonresponse and food intake that varies by day of the week (Murakami & Livingstone, 2016b). Dietary weights were constructed by adjusting the

MEC sample weights. The dietary weights are more variable than the MEC weights, and the sample sizes are smaller, resulting in larger estimated standard errors compared to similar estimates based on MEC weights. Only adolescents with two days of recall were analyzed in this study, therefore the two-day dietary weights were used, which further adjust for the additional non-response and the proportion of weekend-weekday combinations of Day 1 and Day 2 recalls. The dietary weights used in this study were transformed by taking the two-day weights and multiplying by 1/6 to create a 12-year weight (CDC, 2020; Heeringa, West, & Berglund, 2017).

Analyses/Statistical Methods

Statistical analyses were performed using R 3.6.1 and Mplus Version 8.3. Main dietary outcomes included average mean equivalents of selected food component groups and latent class membership, which was derived as a two-part process. First, membership was classified in a latent class model (to be described subsequently) and then recoded to zero or one to create a dichotomous variable that was regressed on several predictors. Main independent variables include one categorical (weight group) and two continuous (BMI Z-score and HEI-2015 score) variables. Additional dietary predictors included mean snack calories, mean snack calories as a percent of mean total energy intake, mean snack frequency (number of snacking occasions), mean snack size (calories per snacking occasions), and mean snack energy density (calories per gram (g) per snack occasion).

Descriptive statistics were performed and presented as means (± standard errors) for continuous variables and counts/percentages for categorical variables. Latent classes were created to determine what predicts membership in the classes and how membership differs by selected covariates. Mutually exclusive dietary patterns were first derived from selected food components during only snacking occasions using latent class analysis (LCA). LCA models with 1 to 8 classes were fit including weights as well as adjustment for average total daily energy as a covariate. Total daily energy was transformed to total kilocalories (kcal) by dividing total calories by 1000 for a consistent scale. Model fit was compared using the Bayesian information criterion (BIC), with the lowest value preferred. An entropy value close to 1.0 also indicates good model fit. Use of the "MplusAutomation" package in R enabled pulling nested output from the Mplus files for comparison of summary statistics (Hallquist & Wiley, 2018).

Latent class membership was merged with the analytic dataset to create the regression analytic dataset. The regression analytic dataset included a subset of the full analytic sample due to item nonresponse for predictor variables and non-participation in the MEC portion (N=6423). This dataset was turned into a survey design object in R, in which sample weights were used to control for oversampling as well as to account for the unequal probability of sampling and survey nonresponse, strata were used to account for design effects of stratified sampling, and cluster was used to specify primary sampling unit.

Several multivariable logistic regression models were run using the survey design object. For all tests, $p < 0.05$ was considered significant. The final models regressed latent class membership on weight group, controlling for age, gender, race, HH education, and Annual Family Income; latent class membership on BMI z-score, controlling for age, gender, race, HH education, and Annual Family Income; latent class membership on HEI-2015 total-score, controlling for age, gender, race, HH education, and Annual Family Income; and latent class membership on mean snack calories, controlling for mean snack calories as a percent of total energy intake, mean snack frequency, mean snack size, and mean snack energy density. The models were run with and without EI:EER due to possible confounding and varying strengths of association evidenced in current literature.

CHAPTER 3

RESULTS

Sample Characteristics

Participant characteristics are described in Table 4. Overall, 3229 adolescents were male and 3194 were female, 50.3% and 49.7% respectively, during the 2005-2016 survey cycles. The average age was 15.5 (se=0.05) which is consistent across weight groups. A total of 1774 (27.6%) adolescents self-identified as non-Hispanic white, 1799 (28%) non-Hispanic black, 2190 (34.1%) Mexican American/Hispanic, and 660 (10.3%) as Other/Multi-racial/non-Hispanic asian. In addition, 51% of the sample had a head of household with more than high school education (n=3275) and 49% with less than a high school education (n=3148). 84.7% of head of households also had an annual income greater than or equal to $20,000 (n=5439) while 15.3% had less than $20,000 annual income (n=984). The mean BMI was 24 (se=0.15). The percentage of adolescents classified in each weight group was 3814 (59.4%) NW, 1122 (17.5%) OW, and 1487 (23.1%) OB.

Table 4. *2005-2016 Socio-Demographic & Anthropometric Characteristics of Study Participants N=6423*

Respondent Characteristics	N =	Unweighted %
Gender		
Male	3229	50.3%
Female	3194	49.7%
Race		
Non-Hispanic White	1774	27.6%
Non-Hispanic Black	1799	28.0%

Table 4. (*continued*)		
Respondent Characteristics	N =	Unweighted %
Mexican-American/Hispanic	2190	34.1%
Other/Multi-Racial/Non-Hispanic Asian	660	10.3%
Head of Household Marital Status		
Married/ Living with partner	4055	63.1%
Widowed	188	2.9%
Divorced/ Separated	1049	16.3%
Never Married	807	12.6%
Head of Household Education		
High school or less	3275	49%
More than high school	3148	51%
Annual Family Income		
< $20,000	984	15.3%
≥ $20,000	5439	84.7%
Weight Status		
Normal Weight	3814	59.4%
Overweight	1122	17.5%
Obese	1487	23.1%
SOURCE: Demographic Files, NHANES 2005-2016		

Unadjusted dietary characteristics of participants are described in Table 5. Average daily snacking energy intake among adolescents in this study was 478 calories and average total daily energy intake was 2085 calories; snacking accounted for 23% of the day's total intake on average. When energy intake was compared with EER, 25.6% of adolescents showed some degree of overreporting and 74.4% of adolescents showed some degree of underreporting their energy intake. Higher levels of the energy ratio (EI:EER >1) indicate overreporting and lower values (EI:EER <1) indicate under-reporting. On average, adolescents were classified as underreporting their energy intake (EI:EER = 0.824) which was true across weight categories with adolescents in the OB category underreporting energy intake the most (NW = 0.915, OW = 0.751, OB = 0.624). Additional snacking parameters include mean snack frequency (3.434 snacks/day), mean snack size (137 calories/snacks) and mean snack energy density (1.783 calories/g/day). Lastly, the average total HEI-2015 score among adolescents was 47.2, with little variation across weight groups (NW = 47.3, OW = 46.5, OB = 47.3).

Table 5. *2005-2016 Unadjusted Dietary Characteristics of Study Participants N=6423*

Mean Respondent Characteristics	Overall; N = 6423		NW; N = 3814		OW; N = 1122		OB; N = 1487	
	Mean	SE**	Mean	SE**	Mean	SE**	Mean	SE**
Total Energy Intake (calories)	2085	17	2168	26	1992	32	1924	27
EI:EER*	0.82	0.01	0.91	0.01	0.75	0.01	0.62	0.01
Snack Energy Intake (calories)	478	10	517	14	427	17	406	16
Snack Energy Intake as % of Total Energy	0.22	0.00	0.23	0.00	0.21	0.01	0.20	0.01
Snack Frequency (occasion/person/day)	3.43	0.05	3.62	0.06	3.19	0.08	3.09	0.07
Snack Size (calories/occasion)	137	3	145	5	125	4	125	4
Snack Energy Density (calories/g/occasion)	1.78	0.02	1.88	0.03	1.68	0.05	1.59	0.05
HEI-2015 Total Score	47.17	0.26	47.30	0.34	46.50	0.49	47.30	0.54

NOTES: Findings in this table were weighted but unadjusted for misreporting of energy intake; *the ratio of reported energy intake to estimated energy requirements used to assess misreporting of energy intake; **Standard errors represent weighted standard deviations; NW = Normal Weight, OW = Overweight, OB = Obese
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted; FPED 2005 - 2016, Day 1 & 2

Average mean equivalents per food group from snacks are shown in Table 6 along with most recent data from overall consumption as well as the recommended intakes for comparison. The main food components of U.S. adolescent snacks, as evidenced by average mean equivalents are fruits (0.35 cup; se=0.016), refined grains (1.13 oz.; se= 0.034), protein (0.49 oz.; se=0.026), dairy (0.40 cup; se=0.015), oils (5.17

g; se=0.165), solid fats (8.76 g; se=0.251) and added sugars (7.98 tsp; se=0.261). The main food components were similarly consumed across weight groups with adolescents classified with NW consuming slightly higher averages in each category. Average mean equivalents per food group by weight group are shown in Table 7. Differences across weight groups in consumption were statistically significant for total calories, vegetables, whole grains, refined grains, dairy, and solid fat intake ($p < 0.05$). Adolescents classified with NW consumed greater amounts of total calories, vegetables, whole grains, refined grains, dairy, and solid fats, while adolescents with OB consumed the lowest amounts respectively, except for vegetables, in which adolescents with OW consumed the lowest amounts.

Table 6. *Food Component Patterns and Mean Intakes (Total and from Snacks) as a Percent of Recommendations for Adolescents Age 12-19 Years, WWEIA, NHANES*

Food Intake Patterns		Mean Intakes* as Percent of Recommendations			
Food/component	Range of Recommended Intake**	Total (2015-2016)	Snacks-NW; N = 3814	Snacks-OW; N = 1122	Snacks-OB; N = 1487
Calories, total	1600 – 2400	85 - 127 %	90 - 135 %	83 - 125 %	80 - 120 %
Fruits (cups)	1.5 - 2.0	44 - 59 %	18 - 24 %	16 - 22 %	15 - 20 %
Vegetables/Legumes (cups)	2.0 - 3.0	36 - 55 %	5 - 7 %	3 - 5 %	4 - 6 %
Whole Grains (oz-eq)	3.0 - 4.0	22 - 29 %	5 - 6 %	4 - 5 %	3 - 4 %
Refined Grains (oz-eq)	2.0 - 4.0	161 - 323 %	31 - 63 %	25 - 49 %	23 - 46 %
Dairy (cups)	3.0	63%	14%	12%	11%
Protein foods (oz-eq)	5.0 - 6.5	74 - 96 %	8 -11 %	7 - 10 %	5 - 7 %
Oils (grams)	22.0 - 31.0	84 - 118 %	18 - 25 %	16 - 22 %	14 - 20 %
Solid Fats (grams)	< 10% of calories***	14 - 20 %	4 - 5 %	3 - 4 %	3 - 4 %

Table 6. (*continued*)

Added Sugars (grams)	< 10% of calories***	13 - 19 %	6 - 9%	5 - 8 %	5 - 8 %
Alcoholic Beverages (grams of ethanol)	< 10% of calories***	0%	0%	0%	0%

NOTES: *mean intakes are averages of male/female adolescents age 12-19 years and mean snack intake data is from the present study; **Min-Max recommended intake ranges assume low activity level according to Healthy U.S.-Style Pattern; ***Solid fats, added sugars, and alcoholic beverages shown as percent of recommended calories and converted to calories per gram via FPED methodology. 8 - 15 % of calories are left for consumption of added sugars, added refined starches, solid fats, alcohol, or to eat more than the recommended amount of food in a food group.
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted; FPED 2005 - 2016, Day 1 & 2; Food Intake Patterns available at https://health.gov/dietaryguidelines/2015/guidelines/Appendix 3; FPED methodology and total mean intakes available at www.ars.usda.gov/nea/bhnrc/fsrg

Table 7. *Food Component Patterns and Mean Intakes (from Snacks) by Weight Group among Adolescents Age 12-19 Years, WWEIA, NHANES 2005 – 2016*

Food Intake Patterns	Mean Intake						Mean Comparison		
Food/component	NW; N = 3814		OW; N = 1122		OB; N = 1487				
	Mean	SE	Mean	SE	Mean	SE	Mean difference	t-value	p-value
Energy, total (kcal)	2.17	0.03	1.99	0.03	1.92	0.03	-0.18	-4.06	**<0.001**
Fruits (cups)	0.37	0.02	0.32	0.03	0.31	0.02	-0.04	-1.23	0.22
Vegetables (cups)	0.14	0.01	0.10	0.01	0.12	0.01	-0.04	-2.64	**0.01**
Legumes (cups)	0.01	0.01	0.00	0.00	0.00	0.00	-0.01	-1.07	0.29
Whole Grains (oz-eq)	0.18	0.01	0.14	0.02	0.12	0.01	-0.04	-2.03	**0.05**
Refined Grains (oz-eq)	1.25	0.05	0.99	0.05	0.92	0.06	-0.27	-4.06	**<0.001**
Dairy (cups)	0.43	0.02	0.35	0.03	0.35	0.04	-0.07	-2.03	**0.05**
Protein foods (oz-eq)	0.55	0.03	0.48	0.07	0.33	0.03	-0.07	-0.91	0.37
Oils (grams)	5.56	0.22	4.87	0.34	4.29	0.30	-0.69	-1.68	0.10
Solid Fats (grams)	9.69	0.37	7.66	0.30	6.96	0.43	-2.04	-4.85	**<0.001**
Added Sugars (tsp)	8.45	0.38	7.32	0.44	7.15	0.39	-1.14	-1.90	0.06
Alcoholic Beverages (no. of drinks)	0.07	0.02	0.03	0.01	0.07	0.02	-0.03	-1.52	0.13

NOTES: Boldface indicates significantly different, $p < 0.05$
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted

Latent Class Analysis: Snacking Patterns

Food patterns were derived with the full sample (N=6974) and participant consumption of each selected food component was categorized by median splits. A two-class solution was selected based on the entropy value of 0.760 and a significant drop in BIC value (79649) from the one class model to the two-class model, shown in the plot of all BIC values (see Figure 1). The first snacking pattern, class one, labeled "Heavy Snackers" is characterized by adolescents who eat above the median mean eq. of every food group (Fruits, Refined Grains, Dairy, Protein, Oils, Solid Fats, and Added Sugars) except Vegetables, Legumes, Whole Grains, and Alcoholic Drinks. The second snacking pattern, class two, labeled "Light Snackers," was represented by adolescents who eat below the median mean eq. of each food group. Furthermore, adolescents in class one were about equally likely to consume above or below the median mean equivalents of vegetables. Consuming above the median mean equivalent for each food group was associated with increased odds of being in class one, all p-values were statistically significant. Latent class probabilities and odds ratios are shown in Tables 8 - 9.

Adolescents consuming less calories were more likely to be in the "Light Snackers" group and less likely to be in the "Heavy Snackers" group. An increase in calorie consumption resulted in an increased odds of being in the first class by a factor of 3.317 which means adolescents consuming more calories are 232% more likely to be in the "Heavy Snackers" pattern ($p < 0.001$). Assigning adolescents' to their most likely latent class membership resulted in 3460 or 49.6% in the "Heavy Snackers" class.

Table 8. *LCA Class Probabilities*

Food/component	Latent Class 1			Latent Class 2		
	< Median	≥ Median	SE	< Median	≥ Median	SE
Fruit	0.45	0.56	0.02	0.61	0.39	0.02
Vegetables	0.51	0.49	0.02	0.81	0.19	0.01
Legumes	0.97	0.03	0.01	1.00	0.00	0.00
Whole Grains	0.60	0.40	0.02	0.82	0.18	0.01
Refined Grains	0.22	0.78	0.02	0.82	0.18	0.02
Dairy	0.23	0.77	0.02	0.74	0.26	0.02
Protein	0.24	0.76	0.02	0.76	0.24	0.02
Oils	0.27	0.73	0.02	0.72	0.29	0.02
Solid Fats	0.14	0.86	0.02	0.82	0.18	0.02
Added Sugars	0.25	0.76	0.02	0.75	0.25	0.02
Alcoholic Drinks	0.97	0.03	0.01	0.97	0.03	0.01

NOTES: all food components were statistically significant ($p < 0.05$)
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted; FPED 2005 - 2016, Day 1 & 2

Table 9. *LCA Odds Ratio Results*

Food/component	Latent Class 1 Compared to Latent Class 2		
	OR	SE	p-value
Fruit	1.92	0.18	**<0.001**
Vegetables	4.15	0.51	**<0.001**
Legumes	7.10	2.94	**0.04**
Whole Grains	2.96	0.33	**<0.001**
Refined Grains	15.44	2.06	**<0.001**
Dairy	9.43	1.23	**<0.001**
Protein	10.08	1.27	**<0.001**
Oils	6.70	0.90	**<0.001**
Solid Fats	28.02	5.05	**<0.001**
Added Sugars	9.29	1.12	**<0.001**
Alcoholic Drinks	1.11	0.29	0.69

NOTES: boldface indicates significantly different, $p < 0.05$
SOURCE: What We Eat in America, NHANES 2005-2016, Day 1 & 2 dietary intake data, weighted; FPED 2005 - 2016, Day 1 & 2

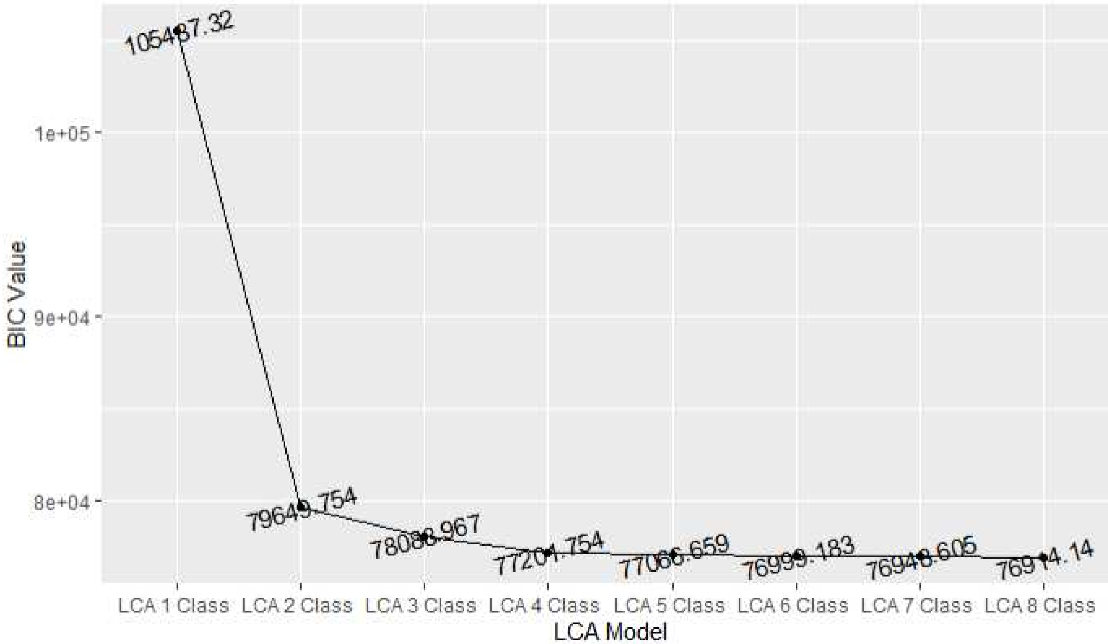

Figure 1. Plot of LCA BIC values to visualize model fit

Regression Model Results

The multivariable logistic regression modeling results are presented in Tables 10 - 13. Significant differences in demographic and health indicators were observed across the two snacking patterns. The final models include adjustment for energy intake misreporting and result in changes in estimates compared to models without energy intake adjustment (results shown in Appendices A – D). With a change in reference group (heavy versus light snackers), the estimates of either pattern were exact opposite and significant predictors remained the same. Results for Light Snackers as the reference group are not shown and results for Heavy Snackers as the reference group are described as follows.

Adolescents classified with NW have a decreased odds of being in the "Heavy Snackers" class by a factor of 0.12 or 88% ($t = -5.252$, $p < 0.001$). Adolescents with OW classification have a decreased odds of being in the "Heavy Snackers" class by a factor of 0.92 (not statistically significant; $t = -0.847$, $p > 0.05$) while adolescents with OB classification have an increased odds of being in the "Heavy Snackers" class by a factor of 1.22, which is also not statistically significant ($t = 1.784$, $p < 0.1$). Significant covariates included gender, race, and EI:EER. Being female decreased the odds of being in the "Heavy Snackers" class by a factor of 0.62 or 38% ($p < 0.001$). Identifying as non-Hispanic black resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.79 or 21% ($p < 0.05$). Identifying as Mexican/Hispanic resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.81 or 19% ($p < 0.05$). Identifying as non-Hispanic Asian, multi-racial or "other" race resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.65 or 35% ($p < 0.05$). Lastly for a one unit increase in EI:EER, which would indicate increased overreporting of energy intake, the odds of being in the "Heavy Snackers" class increased by a factor of 27.46 ($p < 0.001$).

When examining BMI z-score, a one unit increase resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.11 or 11% ($t = 2.443$, $p < 0.05$). Again, being female decreased the odds of being in the "Heavy Snackers" class by a factor of 0.61 or 39% ($p < 0.001$). Identifying as non-Hispanic black resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.79 or 21% ($p < 0.05$). Identifying as Mexican/Hispanic resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.81 or 19% ($p < 0.05$). Identifying as non-

Hispanic Asian, multi-racial or "other" race resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.67 or 33% ($p < 0.05$). As EI:EER increases by one unit, which indicates increased energy intake overreporting, the odds of being in the “Heavy Snackers” class increased by a factor of 29.99 ($p < 0.001$).

A one unit increase in total HEI-2015 resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.99 or 1% ($t = -3.091$, $p < 0.01$).When the HEI-2015 score is zero, holding all variables constant, the odds of being in the “Heavy Snackers” class decreases by a factor of 0.23 or 77 % ($p < 0.001$). Although unlikely that a diet would score as low as zero, HEI-2015 was designed to include zero and can represent very low consumption of encouraged components and very high consumption of discouraged components. Being female decreased the odds of being in the “Heavy Snackers” class by a factor of 0.63 or 37% ($p < 0.001$). Identifying as non-Hispanic black resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.79 or 21% ($p < 0.05$). Identifying as Mexican/Hispanic resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.85 or 15% but was not statistically significant. Identifying as non-Hispanic Asian, multi-racial or "other" race resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.66 or 34% ($p < 0.05$). As EI:EER increases by one unit, which indicates increased energy intake overreporting, the odds of being in the “Heavy Snackers” class increased by a factor of 24.44 ($p < 0.001$).

The model with class membership regressed on all snacking parameters indicates that a one unit increase in average snacking calories resulted in an increase in the odds of being in the “Heavy Snackers” class by a factor of 1.01 or 1% ($p < 0.001$). A one unit increase in average snacking calories as a percentage of average daily calories, resulted in an increase in odds by a factor of 2.34, but was not significant. A one unit increase in mean snack frequency resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.23 or 23% ($p < 0.05$). A one unit increase in mean snack size resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.99 or 1% ($p < 0.001$). A one unit increase in snack energy density resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.87 or 87% ($p < 0.001$). Female gender is associated with a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.70 ($p < 0.01$). As EI:EER increases by one unit, which indicates increased energy intake overreporting, the odds of being in the "Heavy Snackers" class increased by a factor of 6.13 ($p < 0.001$).

For final models in Table 10 - 12, the McFadden's pseudo-R^2 indicates that the predictors account for 14% of the variance in class membership. For the final model in Table 13, the McFadden's pseudo-R^2 indicates that the predictors account for 53% of the variance in class membership, suggesting that snacking parameters as predictors of snacking patterns account for more of the variability in predicting "Heavy Snacker" class membership.

Table 10. *Associations of BMI Category with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	0.12	0.05 – 0.26	**<0.001**
Overweight	0.92	0.76 – 1.12	0.399
Obese	1.22	0.98 – 1.52	0.078
Age	0.99	0.95 – 1.03	0.569
Gender (female)	0.62	0.51 – 0.75	**<0.001**
Race (Non-Hispanic Black)	0.79	0.63 – 0.97	**0.031**
Race (Mexican American/Hispanic)	0.81	0.66 – 0.99	**0.042**
Race (Other/Multi-Racial/non-Hispanic Asian)	0.65	0.46 – 0.92	**0.016**
HH Education	1.13	0.91 – 1.39	0.283
Annual Family Income	0.93	0.74 – 1.18	0.555
EI:EER	27.46	18.75 – 40.21	**<0.001**
Observations	6423		
Pseudo-R^2	0.141		

Table 11. *Associations of BMI Z-Score with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	0.10	0.05 – 0.23	**<0.001**
BMI Z-Score	1.11	1.02 – 1.21	**0.017**
Age	0.99	0.96 – 1.03	0.658
Gender (female)	0.61	0.50 – 0.75	**<0.001**
Race (Non-Hispanic Black)	0.79	0.64 – 0.98	**0.036**
Race (Mexican American/Hispanic)	0.81	0.66 – 0.98	**0.038**

Table 11. (*continued*)

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Race (Other/Multi-Racial/non-Hispanic Asian)	0.67	0.47 – 0.94	**0.023**
HH Education	1.12	0.90 – 1.38	0.312
Annual Family Income	0.93	0.74 – 1.17	0.532
EI:EER	29.99	20.44 – 44.00	**<0.001**
Observations	6423		
Pseudo-R^2	0.141		

Table 12. *Associations of HEI-2015 Total Score with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	0.23	0.10 – 0.50	**<0.001**
HEI2015 Total Score	0.99	0.98 – 1.00	**0.003**
Age	0.99	0.95 – 1.02	0.480
Gender (female)	0.63	0.52 – 0.77	**<0.001**
Race (Non-Hispanic Black)	0.79	0.64 – 0.98	**0.033**
Race (Mexican American/Hispanic)	0.85	0.70 – 1.05	0.132
Race (Other/Multi-Racial/non-Hispanic Asian)	0.66	0.47 – 0.93	**0.020**
HH Education	1.14	0.92 – 1.41	0.227
Annual Family Income	0.93	0.74 – 1.17	0.535
EI:EER	24.44	17.20 – 34.74	**<0.001**
Observations	6423		
Pseudo-R^2	0.142		

Table 13. *Associations of Snacking Parameters with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	0.00	0.00 – 0.01	**<0.001**
Mean Snacking Calories	1.01	1.01 – 1.01	**<0.001**
Mean Snack Calories/Mean Daily Calories	2.34	0.04 – 156.20	0.692
Mean Snack Frequency	1.23	1.03 – 1.46	**0.022**
Mean Snack Size	0.99	0.99 – 1.00	**<0.001**
Mean Snack Energy Density	1.87	1.63 – 2.15	**<0.001**
Gender (Female)	0.70	0.55 – 0.90	**0.006**
HH Education	1.13	0.83 – 1.52	0.441
EI:EER	6.13	2.43 – 15.47	**<0.001**
Observations	6423		
Pseudo-R^2	0.532		

CHAPTER 4

DISCUSSION

The objective of this study was to examine food groups and food group patterns consumed by adolescents as snacks between 2005-2016. This was accomplished by creating snacking patterns with intakes of various food groups and predicting membership in these patterns using weight status and dietary quality indicators. The main food components of snacks for all adolescents regardless of weight status included: fruits, refined grains, protein, dairy, oils, solid fats, and added sugars which are consistent with recent findings that snacking is a significant source of fruit, dairy, and refined grains as well as a poor contributor for vegetables (Loth et al., 2019). However, many of the main food components did not differ across weight groups, but statistically significant differences were found for consumption of vegetables, whole grains, refined grains, dairy, and solid fats. Significant differences were consistent in that adolescents classified with NW consumed greater amounts, while adolescents with OB consumed the lowest amounts apart from the vegetables food group, in which adolescents with OW consumed the lowest amounts.

Compared to recommendations, average consumption of vegetables, whole grains, dairy, and protein from snacks was low across weight groups while consumption of solid fat and added sugar are high, falling just under recommendations. Solid fats and added sugars are nutrients of concern and consumption from snacks alone appear to meet half if not all of the recommendation. Adolescents following eating patterns described in the dietary guidelines are left with 8 – 15% of calories for discretionary consumption and intakes of nutrients of concern are equivalent to that gap suggesting that discretionary calories are not being used to consume additional recommended foods and nutrients. Alcoholic drink consumption was low across weight groups as expected since adolescents are not of legal drinking age. While the difference in consumption was not significant, number of alcoholic drinks consumed was highest among adolescents with OB and lowest for those with OW.

Based on consumption above or below the median of each food component, two snacking patterns were identified in this study of adolescent snacking composition. The "Heavy Snackers" pattern was associated with higher consumption of each food component and total daily energy, while the "Light Snackers" pattern was associated with lower consumption of each food component and total daily energy despite controlling for total energy intake. When examining individual food groups, consuming vegetables was equally likely and consuming below the median number of alcoholic drinks, legumes, and whole grains was more likely among adolescents in both snacking patterns. These findings are supported by descriptive observations that consumption of each food group was consistently low across weight status.

We also examined the patterns of snack food intake by weight group, BMI z-score, HEI-2015 total score, and several snacking parameters with multiple multivariable logistic regression analyses. We can conclude that increasing BMI category, OW or OB classification, does not significantly increase the odds of being in either class while adolescents classified with NW are significantly less likely to be in the "Heavy Snackers" class compared to adolescents with OW or OB. In addition, a one unit increase in BMI z-score, indicating an adolescent with OW or OB, increased the odds of being in the

"Heavy Snackers" class while a one unit increase in HEI-2015 total score decreased the odds of being in the "Heavy Snackers" class. These results suggest that being classified with an OW or OB BMI does not significantly predict a snacking pattern with overall higher food group consumption or total daily energy intake among adolescents.

Overall, significant demographic covariates included gender, race, and head of household education. Females and all other races besides non-Hispanic white were consistently less likely to be in the "Heavy Snackers" class, both of which remained true in models with and without adjustment for EI:EER. Consuming more foods as snacks was not associated with better diet quality. Therefore, results from the present study contradict findings from Loth and colleagues (2019) who evaluated snacking contribution to dietary intake among racially diverse boys and girls. They found that snacking positively impacted daily dietary quality more so for boys than girls as well as among Native American, Hispanic, and white adolescents while dietary quality of African American adolescent diets was not impacted by snacks (Loth et al., 2019). Also, in the present study, HH education, annual income, and age had no statistically significant impact in any of the models.

When class membership was regressed on snacking characteristics, findings suggested that adolescents in the "Heavy Snacker" class were consuming higher average snacking calories in addition to higher total energy intake. Increased mean snacking calories, snacking frequency, and snack energy density predicted a heavier snacking pattern which was expected, while increased mean snack size resulted in a decrease in the odds of being in the "Heavy Snackers" class. This finding suggests that the "Heavy Snackers" are snacking more frequently and consuming more calories, but when they do snack they are consuming less calories per occasion. Findings from the present study remain consistent with similar conclusions from a USDA data brief on Snacking Patterns of U.S. Adolescents in 2005-2006 which found that snacking more frequently was associated with increased total calorie intake but not BMI (Sebastian, Goldman, & Wilkinson Enns, 2010). However, NW associations in this study align with weight management recommendations to increase intake of low energy dense foods (Poole, Hart, Jelalian, & Raynor, 2016; Smethers & Rolls, 2018)**.** Conclusions from the present study also support findings from Tripicchio et al. (2019) who found that adolescents with OW or OB may be snacking more frequently, but contradict their findings that larger snacks and a lower consumption of energy dense snacks were associated with having OW or OB weight status.

Notable discrepancies exist between descriptive and analytical findings. According to weighted dietary characteristics of the sample by weight status, adolescents classified with NW had higher average snacking characteristics (e.g., 3.6 snacks/day, 517 snack calories, and 1.88 calories/g/occasion) than those with OW or OB, but were less likely to be in the heavy snacking class predicted by higher snacking characteristics (e.g., increased snack frequency, snack calories, and snack energy density). Adolescents in the NW category also consumed slightly higher mean-equivalents of each food group compared to adolescents in the other weight status categories, while less likely to be in the "Heavy Snackers" class consuming above the median of each food component. These adolescents were more likely to overreport their energy intake which might explain the conflicting results. Another explanation is that the descriptive and analytic results were not comparable because the descriptive food component consumption was not adjusted for energy misreporting, as done in the LCA and logistic regression models.

A strength of this study is that individualized measures of EER as a ratio to assess misreporting of EI in a representative sample of US adolescents were used as shown in Murakami (2018). The ratio of EI to EER was included as a covariate in all final logistic regression models and proved to be an analytically significant confounder in this study. The associations observed were influenced by misreporting of EI as evidenced by a change in the results before and after adjustment for EI misreporting. For all models, as EI:EER increases, which would indicate overreporting of energy intake, adolescents are also less likely to be in the "Light Snackers" class indicating that adolescents assignment to snacking patterns was impacted by under and overreporting of energy intake. The gold standard for obtaining unbiased information on energy requirements is the doubly labelled water technique but is expensive and impractical. However, the Dietary Reference Intake equations used in this study have been developed based on that technique and are considered an accurate proxy (IOM, 2005). The calculation of EER assumed a "low active" level of physical activity for all adolescents which was deemed accurate based on data from NHANES and current literature (Murakami & Livingstone, 2016a-d).

Limitations/Future Directions

Causality cannot be inferred from this study due to the cross-sectional design. Additional studies are needed to further understand what the main food pattern components are in order to determine whether associations between snacking and food group intakes are due to healthier food choices or simply consuming more. Understanding this difference will allow for appropriate improvement of recommendations. Snacking is an approachable area for behavior change and modifications to snacking habits in adolescents can encourage consumption of diets consistent with national recommendations later in life. If we can identify types of foods or a particular snacking pattern associated with health outcomes, then we can ultimately create better guidelines. It is important to understand eating pattern and weight relationships as OB continues to impact quality of life and burden the healthcare system.

Nutrition recommendations have shifted from a focus on nutrients and are increasingly provided to the general public in terms of foods and lifestyle changes. An individual's eating pattern is characterized by the combination of foods and beverages that make up their dietary intake, but further represents what they habitually consume and how those dietary components synergistically impact their health negatively or positively. Eating patterns that follow dietary guidelines have been associated with a lower risk of mortality, which has led to studies evaluating associations between various eating patterns and diet related health outcomes such as weight status (Sebastian, Cleveland, & Goldman, 2008). Snacking, a form of frequent eating, is one aspect of eating patterns that has received considerable attention. As described, some studies have shown that eating patterns inclusive of snacking may have a positive impact on healthy diet and weight maintenance, while other studies indicate that snacking can displace nutrient consumption with discretionary calories and negatively impact diet and weight status (Sebastian et al., 2010). The observations in the present study are consistent with mixed associations of snacking on body weight and health outcomes.

Adolescent snacking pattern associations have not been analyzed with latent class mixture models in this way; thus, this study took a novel approach at examining the consumption and composition of foods that make up snacking patterns. However, interpretation of the patterns was a challenge and may have been impacted by several limitations in the LCA methodology for this study. The food components were not directly comparable, since patterns differed in total snacking energy and total daily energy intake and daily energy intake differences were not effectively removed in the LCA. Since total energy was not effectively controlled for, controlling for average snacking calories or 'as a percentage of total or snacking calories' in the LCA may have been a more appropriate adjustment. Furthermore, looking at models without food groups that were consistently consumed in lower amounts across weight groups, such as alcoholic drinks, may allow for clearer patterns of the food groups consumed in higher amounts across weight groups. Lastly, the average mean-equivalents of each food component from snacking occasions were not on a standard scale making it difficult to derive useful latent profiles. Presenting average food group intake as calories from each food group or as a percent of snacking energy could help food group comparison and might be an important next step. The use of median split groups based on consumption to create categories rather than continuous mean consumption of each food component was a limitation. Rather than categorizing consumption via median splits, creating a binary variable of either "consumed – yes" or "consumed – no" may simplify interpretation of snack consumption patterns. Exploring other ways of expressing the variables for LCA and ease of comparison remains an important future direction for the present study.

Future directions also include using current Dietary Guidelines and MyPlate recommendations to express the average food components as a percentage of daily total portions of each recommended food group. Previous USDA research has been done assessing the effect of snacking on the likelihood of meeting the USDA's MyPyramid recommendations which implemented the key recommendations of the 2005 Dietary Guidelines for Americans (Sebastian et al., 2010). They found that snacks contributed to about one third of the MyPyramid groups, one fourth of discretionary calories, one third of added sugars, and one fifth of solid fats. There is a need to continue evaluating the impact of snacking in the context of accepted food guidance to be able to draw sound conclusions and comparisons as well as see how guidance translates to the public.

Dietary measures are highly susceptible to random and systematic measurement errors, given the variability in individual eating patterns. Therefore, a major limitation is reporting/recall bias due to adolescents self-reported data and dietary intake underreporting. Foods consumed during snacking occasions compared to main meals are more likely to be forgotten or excluded leading to underreported energy intake, which is common among adolescents, especially among those in higher BMI categories (Sebastian et al., 2010). Adolescents with OW and OB tend to underreport dietary intake as well as restrict eating patterns in the form of dieting or irregular meal consumption while those with NW tend to overreport energy intake (Murakami & Livingstone, 2016d). NHANES participants are also made aware that questions will be asked about what they eat therefore facilitating self-reporting bias. These types of bias may distort true independent relationships or create false relationships between dietary behaviors and intakes. However, the gold standard 5-step AMPM used to collect dietary intake was designed specifically to address this misreporting and enhance accurate data collection through questions and memory aids while reducing respondent burden (Ahluwalia et al., 2016).

The AMPM is the method of choice for quantifying "actual" intakes in national surveys because it relies on short-term memory, leaves less opportunity for participants to alter eating behavior, and does not require a high level of literacy; thus, it can be used with diverse populations. 24-h recalls are less-biased and burdensome than other dietary intake methods that rely on perceived intakes and long-term memory. Measurement error is also reduced by trained staff obtaining the dietary recalls via the standardized AMPM (Ahluwalia et al., 2016).

The use of nationally representative data, with consideration of oversampling and appropriately applied sampling weights, makes the findings more generalizable and comparable with other literature, which is a strength of this study. However, given the varied definitions of what is considered a snack in the literature, comparison of this study with others assessing the impacts of snacking could present a challenge. Self-identified snacking occasion designations were used in this study, while other studies have used time of day, types, or amounts of foods consumed to define a snacking occasion. Future research would benefit from the application of a universally accepted definition of snacking that ideally separates solid foods and liquids (Johnson & Anderson, 2010). Additional limitations in the existing literature include parental reporting of adolescent intake, combining OW and OB classifications as well as eating occasion outcomes, all of which limit the ability to estimate true independent associations of snacking on weight status (Keast, Nicklas, & O'Neil, 2010; Murakami & Livingstone, 2016b). However, a strength of NHANES is that adolescents do not need parental consent to participate.

Limitations exist in understanding health outcomes when a behavior is considered in isolation, findings from this cross-sectional study did not take into consideration the social, behavioral, or environmental factors that may influence snack choices, all of which are important factors for developing targeted interventions for adolescents. One important behavior is exercise, which is thought to influence post-exercise consumption of snacks and thereby counteract benefits of physical activity in some cases (Dimmock, Guelfi, West, Masih, & Jackson, 2015). Exercise was taken into consideration in the calculation of EER in this study. A low activity level was assumed for all adolescents based on NHANES data that adolescents spend fewer minutes per day in moderate to vigorous activity and are less active than younger children (Belcher et al., 2010). NHANES data lacks robust measures of physical activity, therefore additional measures of exercise were not included in this study (Ahluwalia et al., 2016).

The inclusion of pregnant adolescent girls may present a limitation as their snacking patterns may differ compared to their non-pregnant peers. However, there were only 41 confirmed pregnancies among the full analytic sample, so this is unlikely to have a large impact on overall snacking patterns. Also, the ratio of family income to poverty was not used due to higher item non-response, but annual family income is an acceptable proxy for socioeconomic status. Finally, although models were adjusted for several potential confounders, some of the findings in the study may have occurred by chance as residual confounding could not be ruled out.

Conclusion

In conclusion, adolescent snacking patterns and weight status associations were varied in the present study. After adjustment for EI:EER, adolescents with a higher BMI z-score were more likely to snack frequently and consume more of each food group as well as total calories. Adolescents classified with NW or with a higher HEI-2015 score were less likely to consume more of each food group as well as higher total calories after adjustment for EI:EER. Thus, this study has further contributed to the literature the finding that energy misreporting and dietary intake definitions significantly confound associations regarding snack patterns and weight status among adolescents.

We can conclude that consuming less foods as snacks contributed positively to weight status and overall diet quality among US adolescents as indicated by higher HEI-2015 scores. The strongest predictors of a "Heavy Snacker" pattern were male gender, non-Hispanic white race, lower dietary quality, and increased snacking parameters, while female gender, all races except non-Hispanic white, better dietary quality, and decreased snacking parameters were strong predictors of a "Light Snacker" pattern**.** Findings from this cross-sectional study remain consistent with snacking, diet quality, and weight status associations, but add to existing knowledge with the identification of snack consumption patterns. The dietary patterns derived may provide a useful basis for dietary interventions targeted at snacking among adolescents by recommending light snacking and low consumption of energy dense snack foods. Since gender and race appear to be associated with snacking patterns and impact diet quality, future research with a focus on consumption and composition snacking pattern differences between boys and girls across racial backgrounds will be valuable for creating salient guidance.

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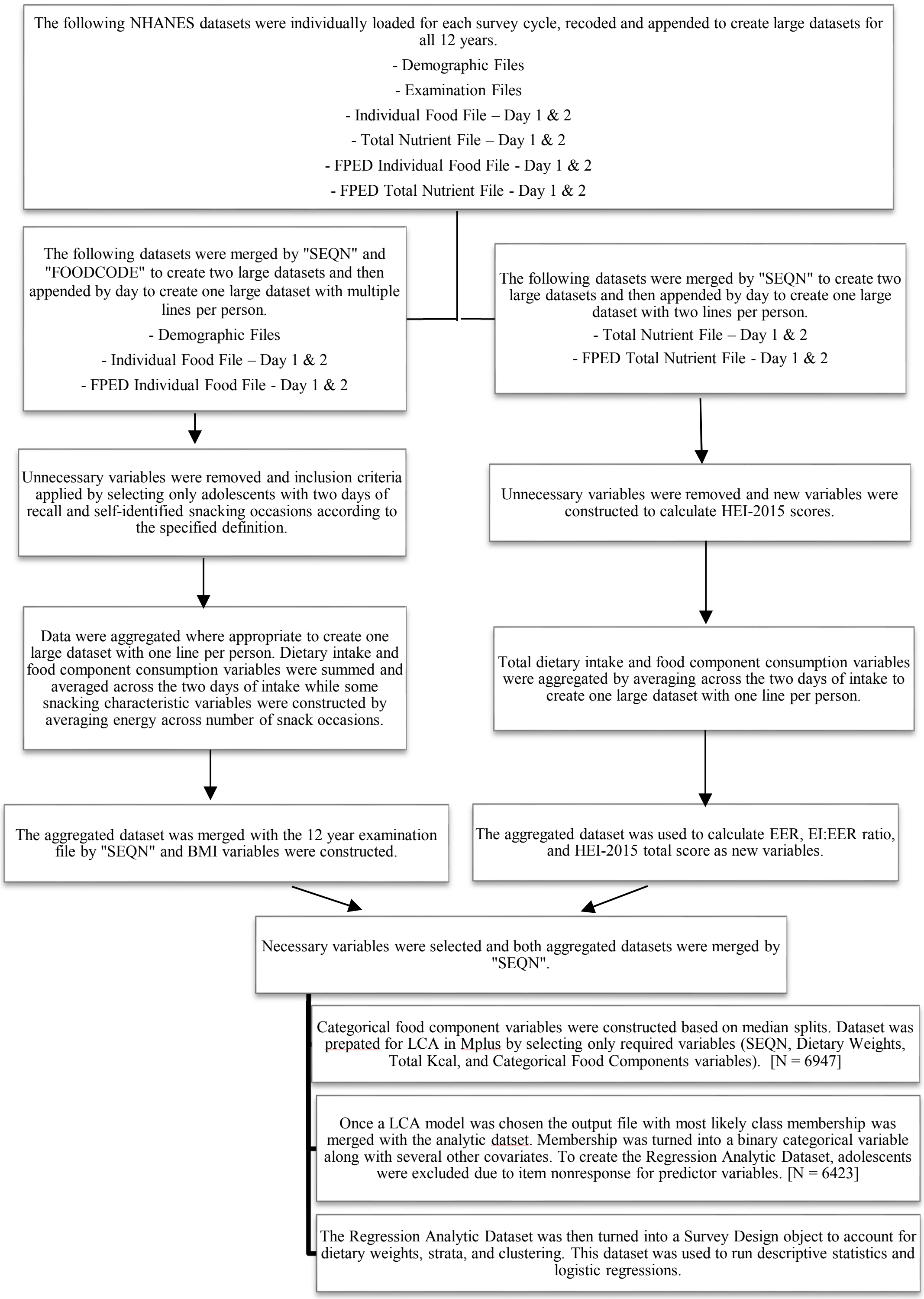
APPENDIX A

DATASET CREATION FLOWCHART



APPENDIX B

BMI CATEGORY ASSOCIATIONS WITH CLASS MEMBERSHIP

Regression results minus adjustment for energy intake are as follows, adolescents classified with OW or OB had a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.60 or 40% and 0.53 or 47%, respectively ($p < 0.001$). The odds of being in the "Heavy Snackers" class among adolescents classified with NW increased by a factor of 1.68 or 68%, although this association was not significant ($p > 0.1$). Significant covariates included gender and head of household education. Being female resulted in decreased odds of being in the "Heavy Snackers" class by a factor of 0.70 or 30% ($p < 0.001$). Head of household education beyond high school resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.24 or 24% ($p < 0.05$).

Table 14. *Unadjusted Associations of BMI Category with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	1.68	0.84 – 3.37	0.148
Overweight	0.60	0.50 – 0.72	**<0.001**
Obese	0.53	0.43 – 0.66	**<0.001**
Age	1.00	0.96 – 1.03	0.905
Gender (female)	0.70	0.59 – 0.85	**<0.001**
Race (Non-Hispanic Black)	0.86	0.71 – 1.04	0.118
Race (Mexican American/Hispanic)	0.93	0.79 – 1.11	0.430

Table 14. (*continued*)

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Race (Other/Multi-Racial/non-Hispanic Asian)	0.72	0.51 – 1.00	0.051
HH Education	1.24	1.01 – 1.52	**0.044**
Annual Family Income	0.88	0.71 – 1.09	0.243
Observations	6423		
Pseudo-R^2	0.022		

APPENDIX C

BMI Z-SCORE ASSOCIATIONS WITH CLASS MEMBERSHIP

Regression results minus adjustment for energy intake are as follows. A one unit increase in BMI z-score decreased the odds of being in the “Heavy Snackers” class by a factor of 0.77 or 33% ($p < 0.001$). Being female decreased the odds of being in the “Heavy Snackers” class by factor of 0.71 or 29% ($p < 0.001$). Identifying as non-Hispanic asian, multi-racial or "other” race resulted in a decrease in the odds of being in the “Heavy Snackers” class by a factor of 0.68 or 32% ($p < 0.05$). The other races were associated with a decrease in the odds of being in the “Heavy Snackers” class but were not statistically significant. Lastly, HH education level beyond high school resulted in an increase in the odds of being in the “Heavy Snackers” class by a factor of 1.25 or 25% ($p < 0.05$).

Table 15. *Unadjusted Associations of BMI Z-Score with “Heavy Snacker” Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	1.69	0.85 – 3.34	0.138
BMI Z-Score	0.77	0.71 – 0.84	**<0.001**
Age	0.99	0.96 – 1.03	0.773
Gender (female)	0.71	0.59 – 0.85	**<0.001**
Race (Non-Hispanic Black)	0.85	0.71 – 1.04	0.113
Race (Mexican American/Hispanic)	0.93	0.78 – 1.10	0.401

Table 15. (*continued*)

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Race (Other/Multi-Racial/non-Hispanic Asian)	0.68	0.49 – 0.95	**0.027**
HH Education	1.25	1.02 – 1.53	**0.037**
Annual Family Income	0.88	0.71 – 1.09	0.230
Observations	6423		
Pseudo-R^2	0.022		

APPENDIX D

HEI-2015 SCORE ASSOCIATIONS WITH CLASS MEMBERSHIP

Regression results minus adjustment for energy intake are as follows. A one unit increase in HEI-2015 score decreased the odds of being in the "Heavy Snackers" class by a factor of 0.99 or 1% ($p < 0.001$). When the HEI-2015 score is zero, holding all other variables constant, the odds of being in the "Heavy Snacker" class increased by a factor of 2.38 ($p < 0.05$). Being female decreased the odds of being in the "Heavy Snackers" class by factor of 0.73 or 37% ($p < 0.001$). All race categories are associated with a decrease in the odds of being in the "Heavy Snackers" class except for Mexican/Hispanic but are not statistically significant. Lastly, HH education level beyond high school results in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.31 or a 31% ($p < 0.01$).

Table 16. *Unadjusted Associations of HEI-2015 Total Score with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	2.38	1.19 – 4.76	**0.016**
HEI2015 Total Score	0.99	0.98 – 0.99	**<0.001**
Age	1.00	0.96 – 1.03	0.938
Gender (female)	0.73	0.61 – 0.89	**0.002**
Race (Non-Hispanic Black)	0.92	0.76 – 1.11	0.383
Race (Mexican American/Hispanic)	1.00	0.84 – 1.20	0.973

Table 16. (*continued*)

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Race (Other/Multi-Racial/non-Hispanic Asian)	0.76	0.55 – 1.06	0.111
HH Education	1.31	1.08 – 1.60	**0.009**
Annual Family Income	0.89	0.72 – 1.10	0.288
Observations	6423		
Pseudo-R^2	0.013		

APPENDIX E

SNACKING PARAMETER ASSOCIATIONS WITH CLASS MEMBERSHIP

Model results for membership regressed on all snacking parameters minus EI:EER indicate that a one unit increase in average snacking calories results in an increase in the odds of being in the "Heavy Snacker" class by a factor of 1.01 or 1% ($p < 0.001$). A one unit increase in average snacking calories as a percentage of average daily calories, resulted in a decrease in the odds by a factor of 0.02 ($p < 0.001$). A one unit increase in mean snack frequency resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.23 or 23% ($p < 0.05$). A one unit increase in mean snack size resulted in a decrease in the odds of being in the "Heavy Snackers" class by a factor of 0.99 or a 1% decrease ($p < 0.01$). A one unit increase in snack energy density resulted in an increase in the odds of being in the "Heavy Snackers" class by a factor of 1.93 or 93% ($p < 0.001$). Female gender and HH education were not significant.

Table 17. *Unadjusted Associations of Snacking Parameters with "Heavy Snacker" Class Membership*

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Intercept	0.01	0.01 – 0.02	**<0.001**
Mean Snacking Calories	1.01	1.01 – 1.01	**<0.001**
Mean Snack Calories/Mean Daily Calories	0.02	0.00 – 0.13	**<0.001**
Mean Snack Frequency	1.23	1.02 – 1.48	**0.030**
Mean Snack Size	0.99	0.99 – 1.00	**0.002**

Table 17. (*continued*)

Predictors	*Odds Ratios*	*Conf. Int (95%)*	*P-Value*
Mean Snack Energy Density	1.93	1.68 – 2.22	**<0.001**
Gender (Female)	0.94	0.77 – 1.16	0.595
HH Education	1.13	0.84 – 1.51	0.420
Observations	6423		
Pseudo-R^2	0.524		