Fall 2016

School Policy, Food and Physical Activity Environment, and Childhood Obesity

Ruicui Liu
Old Dominion University, liuruicui@gmail.com

SCHOOL POLICY, FOOD AND PHYSICAL ACTIVITY ENVIRONMENT, AND CHILDHOOD OBESITY

by

Ruicui Liu
B.A. July 2001, Renmin University of China, China
M.S. May 2008, Old Dominion University

A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

HEALTH SERVICES RESEARCH

OLD DOMINION UNIVERSITY
December 2016

Approved by:

Qi Zhang (Director)

George C. Maihafer (Member)

Holly D. Gaff (Member)

ABSTRACT

SCHOOL POLICY, FOOD AND PHYSICAL ACTIVITY ENVIRONMENT, AND CHILDHOOD OBESITY

Ruicui Liu
Old Dominion University, 2016
Director: Dr. Qi Zhang

The purpose of this study is to examine the effect of school food and physical activity environments on energy balance-related behaviors and Body Mass Index (BMI) and to simulate the effect of school-based nutrition and physical activity policies on childhood obesity prevention. Four models based on the Social Ecological Framework of childhood obesity were developed. Parameters of these models were calibrated and validated with empirical data derived from the Early Childhood Longitudinal Study – Kindergarten Class of 1998-99 and the 2003-2004 National Health and Nutrition Examination Study. The correlation between observed and simulated BMI was 0.85 for 5th grade children and 0.87 for 8th grade children, indicating the validity of the models. The results demonstrated (1) one occasion of sweet snack consumption in school each week may lead to a 0.027 unit increase in BMI among 5th grade children in 2 years and among 8th grade children in 3 years; (2) one occasion of salty snack consumption in school each week may lead to a 0.025 unit increase in BMI among 5th grade children in 2 years and among 8th grade children in 3 years; (3) one occasion of sugar-sweetened beverage consumption in school each week may lead to a 0.05 unit increase in BMI among 5th grade children in 2 years and a 0.06 unit increase in BMI among 8th grade children in 3 years; (4) one minute of physical activity in school each week may lead to a 0.0008 unit decrease in BMI among 5th grade children in 2 years and one physical education class each week may lead to a 0.05 unit decrease in BMI

among 8th grade children in 3 years. Comparison of simulated and observed data revealed that school-based policies targeting competitive food availability and physical activity opportunity in school had the potential to prevent childhood obesity. Moreover, prevention and interventions should be taken as early as the first few years of children's school life. A simulation modeling approach was useful in exploring the effect of environmental factors on childhood obesity and energy balance-related behaviors.

This dissertation is dedicated to my family: my husband, Jixie Zhang, son Ian, and daughter Lily.

ACKNOWLEDGEMENTS

This dissertation could not have been finished without the guidance and encouragement provided by my committee. I would like to express the deepest gratitude to Dr. Qi Zhang for his advice, support, valuable comments and suggestions. His contagious enthusiasm for research and the aspiration of preciseness he demonstrated has been a driving force through my doctoral training.

I want to express my gratitude to Dr. Holly Gaff for her important input and suggestions. Her insight and expertise in the Modeling and Simulation approach has inspired my interest in this technique. Dr. Holly's innovative teaching style also made the process of learning this new technique full of joy and fun.

I also appreciate Dr. George Maihafer for his persistent support. I have benefited greatly from the discussions with him regarding IRB. His guidance and comments were invaluable.

I would like to thank Dr. Deanne Shuman and Dr. Richardean Benjamin for giving precious advice about the topic and theoretical base of my research. Thanks also go out to my classmates for the innumerable discussions over lunch and coffee.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

CHAPTER Ⅰ

INTRODUCTION

Problem Statement

As students spend most of their waking time at school, school represents an important setting for children's health and human development. Numerous studies (Cullen, Watson, Zakeri, & Ralston, 2006; Masse, de Niet-Fitzgerald, Watts, Naylor, & Saewyc, 2014; Mullally et al., 2010; Taber, Chriqui, & Chaloupka, 2012; Wordell et al., 2012) suggested that the school food and physical activity (PA) environment, defined as all foods and PA opportunities made available to students, may play an important role in shaping children's body weight status. However, due to the complex interaction among the biological, psychological, sociocultural, and environmental factors influencing diet and PA—the two behaviors essential to body weight status—the current understanding of the effect of the school food and PA environment is limited (Hammond, 2009). Using a simulation modeling approach, this dissertation seeks to disentangle the influence of multiple risk factors and examine the effect of school food and PA environments on children's diet, PA level, and body weight status.

This study also attempts to test the effect of policies targeting the school food and PA environment on childhood obesity prevention. In order to tackle the escalating problem of obesity, a variety of policies, including those targeting school food and PA environments, have been developed and adopted during the last decade. For example, at the federal level, the Healthy, Hunger-Free Kids Act of 2010 (HHFKA 2010) authorizes the Department of Agriculture (USDA) to set nutritional standards for all foods regularly sold in school during school days (Let's Move, 2010). The HHFKA 2010 also set basic standards for local school wellness policies that all local education agencies were required to create and implement by the beginning of the 2006-2007 school year (Let's Move, 2010). The standards require local school districts to set goals for nutrition education and PA and to provide nutrition guidelines for all foods available on campus (Let's Move, 2010). However, local school districts still have flexibility to make their own school wellness policies based on their particular needs. A 2013 report from the Robert Wood Johnson Foundation found that there was a wide gap in the comprehensiveness and strength of local school wellness policies (Chriqui et al., 2013). Overall, there were only 46% of students in a district with a wellness policy that included all elements required by the Healthy, Hunger-Free Kids Act of 2010.

Efforts have been made to assess the efficacy of these policies. However, results from these studies are mixed. Many of them used change in body weight as a study outcome, but school food and PA environments do not directly cause changes in body weight. Changes in body weight may take longer than the study period to be measurable. In addition, the school food and PA environment are two of many factors influencing changes in body weight. Genetics, age, and the food and PA environment in other settings are all related to a change in body weight. In fact, policies targeting the school food and PA environment are usually implemented as part of a comprehensive obesity prevention strategy that simultaneously targets children's knowledge, attitudes, and behaviors as well as their social, cultural, and physical environments in all settings. It is thus very challenging to isolate the effects of the policies targeting school food and PA environments with empirical studies.

This study uses a simulation modeling approach to overcome these limitations. This approach promotes understanding of a complex system such as obesity through developing a systematic model to simulate the empirical environment (Sokolowski & Banks, 2010). It can also help policy makers to explore the effects of new policies without disrupting the ongoing operation of an existing real-world system. In a simulation model, time can be adjusted to allow for a speed-up or slow-down of the functioning of the system. In addition, by altering the simulation inputs, this approach can help answer “what if” questions (Banks, Carson, Nelson, & Nicol, n.d.). With the use of a simulation model, this dissertation tries to demonstrate the need for school-based nutrition and PA policies by quantifying the effect of school-based nutrition and PA policies on childhood obesity prevention.

Purpose of the Study

Aim 1**:** To explore the influence of the school food and PA environment on children’s energy balance-related behaviors (eating behaviors and PA level).

Aim 2**:** To examine the impact of the school food and PA environment on children’s weight gain.

Aim 3: To simulate the effect of school-based nutrition and PA policies on childhood obesity prevention.

Background

Obesity is defined as a body mass index (BMI) of 30 or higher for adults and in the 95 percentile or higher for children of the same age and gender (Centers for Disease Control and Prevention [CDC], 2014a; Barlow & the Expert Committee, 2007). BMI can be calculated as weight (kg)/height^2 (m) or weight (lb)/height^2 (in) x 703 (CDC, 2014a). Currently, 36.5% of adults in the U.S. are obese, and the prevalence of obesity among 2- to 19-year-old children was 17% in 2011-2014 (Ogden, Carroll, Fryar, & Flegal, 2015).

Obesity is a major risk factor for many serious chronic diseases and health conditions. Adult obesity is associated with increased risk of cardiovascular disease, including coronary heart disease (CHD), stroke, and peripheral vascular disease (World Health Organization [WHO], 2000). Obesity is a predisposing factor for many cardiovascular risk factors, such as hypertension, high cholesterol level, and impaired glucose tolerance (WHO, 2000). Being overweight (BMI equal to or greater than 25 but less than 30) and obese contribute to a 14%-20% cancer-related mortality. Moreover, the prevalence of type 2 diabetes is 3 to 7 times higher in those who are obese than in normal-weight adults (American Cancer Society, 2011; Rogers & Still, n.d.).

The health consequences of childhood obesity are more profound. Childhood obesity is very likely to persist into adulthood, with all the associated health risks. The immediate health consequences of childhood obesity include insulin resistance, high cholesterol, high blood pressure, bone and joint problems, and psychological problems (CDC, 2015a).

The obesity epidemic causes substantial medical costs. Trasande and colleagues estimated in 2009 that the total obesity-associated hospitalization cost for children and youth ages 2–19 reached $237.6 million in 2005. According to a report by Wang, McPherson, Marsh, Gortmaker, and Brown (2011), medical costs for treatment of the preventable diseases caused by obesity will increase by $48-66 billion per year in the U.S. It is imperative to take actions to halt the epidemic of obesity among both adults and children.

Obesity is preventable. Compared to treatment, prevention is more cost-effective (Kesten, Griffiths, & Cameron, 2011). The WHO recommends that obesity during childhood could be prevented through population-based initiatives, in particular through school and community-based programs (WHO, 2012). Because schools provide an established infrastructure and continuous, intensive contact with children, the Institute of Medicine (IOM) also recommends that schools should be a national focal point for obesity prevention (IOM, 2012).

Significance

This dissertation addresses a highly significant public health problem in the U.S.: the childhood obesity epidemic. Over the past decades, numerous school-based programs and interventions aimed at controlling this epidemic have been implemented. However, most of these interventions have focused on behavior education. Programs targeting the school food and PA environment were sparse. Furthermore, due to the short duration of these interventions, knowledge about their long-term effect on weight gain was limited

(Kelishadi & Azizi-Soleiman, 2014). Using data from a national longitudinal study, this dissertation examines the effect of the school food and PA environment, in terms of the availability of alternative foods and the opportunity for PA, on children's eating behaviors, PA level, and weight gain. To my knowledge, it is the first study that systematically evaluates the effect of the school food and PA environment on BMI using simulation models. It will expand our understanding about the mechanism through which the food and PA environment influences body weight and thus give insights into school-based policies that seek to curb the escalating prevalence of childhood obesity in the U.S.

This dissertation develops new research methodology for childhood obesity research. It uses an innovative simulation modeling approach to examine the influence of school environmental factors on energy balance-related behaviors and weight gain. The use of a simulation model is appropriate when the problem under study is embedded in a complex system and involves a variety of factors at multiple levels. Childhood obesity is a complex system where the body weight of a child is influenced by a variety of biological, behavioral, environmental, and sociocultural factors. These factors interact with one another simultaneously. A simulation model can be used to depict the complex interactions between these factors, "thereby helping to understand the 'big picture' rather than considering pieces of the system [of childhood obesity] in isolation" (Levy et al., 2011, p. 380). Moreover, because this approach considers multiple factors at different levels simultaneously, it can be used to estimate the synthesized effect of these factors on children's body weight.

A simulation model can also be used to foresee the effect of various policy options by making assumptions in regard to the availability of resources, the strength of the policies, and an individual's reaction to new policies. Simulation modeling approaches have been increasingly used in health service research in various settings, such as emergency rooms, clinics, and public health departments. With the assistance of the M&S approach, this dissertation evaluates the effect of school-based nutrition and PA policies on childhood obesity prevention. The results of the study provide insights into future policy development.

Theoretical Framework

The Social Ecological Model (SEM) is used to guide the present study. SEM is a theory-based model for understanding the multiple and interacting personal and environmental determinants of health behaviors (McLeroy, Steckler, Bibeau, & Glanz, 1988). According to SEM, health behaviors are influenced by factors nested at the individual, interpersonal, community, organizational, and public policy levels (Figure 1). Influences on health behaviors interact across these different levels. Table 1 lists the factors at each level of the SEM that impact an individual's body weight.

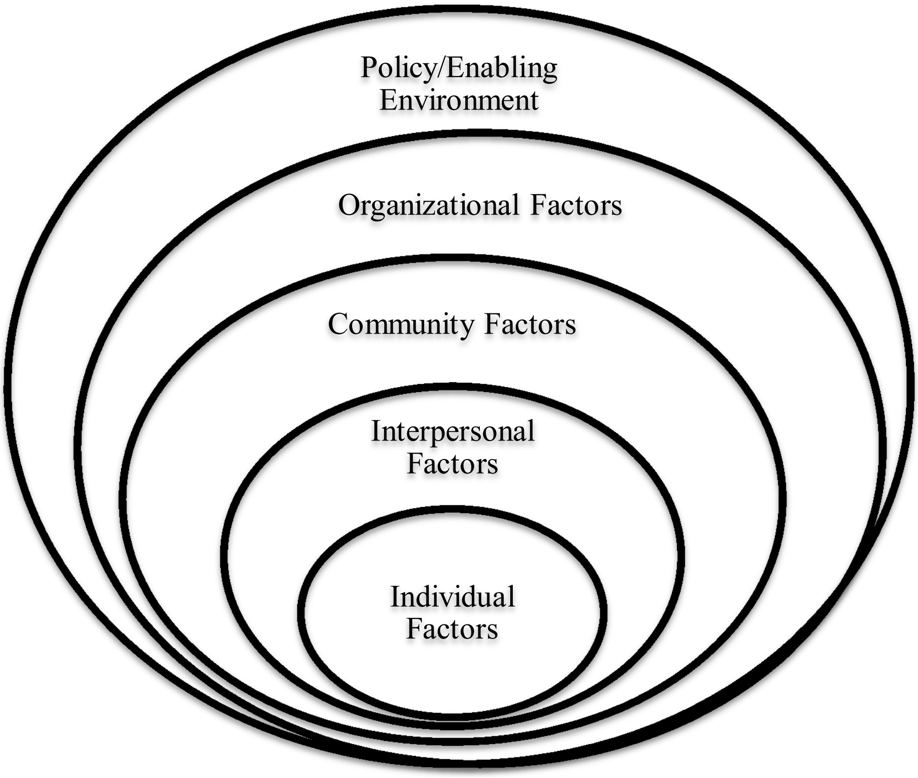

Figure 1. The Social Ecological Model (SEM).

Table 1
The SEM of Obesity

SEM Level	Factors
Individual	Genetics, age, gender Knowledge, attitudes, behavior related to diet and physical activity Socioeconomic status
Interpersonal	Food choice and physical activity habits reinforced in family and social networks, including family, friends, peers, co-workers, and religious networks
Community	Access to and affordability of healthy food and physical activity facilities, such as the walkability of neighborhoods and density of grocery stores
Organizational	Food options and physical activity opportunities in schools and workplaces

Table 1 (continued)

SEM Level	Factors
Public policy	Social norms regarding diet, physical activity, and body weight. Local, state, national, and global laws and policies pertaining to zoning, dietary guidelines, food marketing, nutrition labeling, taxes and subsidies, and school meal programs

Note. Adapted from McLeroy, Steckler, Bibeau, & Glanz (1988)

Based on the SEM, Egger and Swinburn (1997) proposed a model to explain the origins of obesity. In this model, the cause of weight gain, energy balance, is expressed as equilibrium in fat storage. There are three main influences on equilibrium in fat storage — biological, behavioral, and environmental, mediated by the difference between energy intake and energy expenditure and moderated by physiological adjustment. The biological influences include age, sex, hormonal factors, and genetics, all of which are unchangeable. The behavioral influences include habits, emotions, attitudes, beliefs, and cognitions. Behavioral factors are also influenced by biological and environmental factors. The environmental influences include the macro environment that determines the prevalence of obesity in a population and the micro environment that determines an individual's obesity status. Examples of micro environments include settings such as homes, neighborhoods, and schools, while macro environments refer to industries, services, or supporting infrastructures that influence the eating behaviors and PA level of a population (Swinburn, Egger, & Raza, 1999). The environments can further be categorized into four types: physical, economic, political, or sociocultural. Table 2 provides a brief description for each of the four types of environments in school that can influence a child's diet and PA level.

Table 2

A Description of the Physical, Economic, Political, or Sociocultural Environments That Influence Children's Diet and Physical Activity in School

Type	Description
Physical	Availability of healthy foods Restriction of unhealthy foods Accessibility to physical activity facilities Time designated for physical activity
Economic	The price of healthy and unhealthy food The cost related to physical activity in school
Political	The rules related to nutrition and health education, food accessibility, nutritional standards, and physical activity
Sociocultural	The attitudes, beliefs, and values related to food and physical activity of school students and staff

Note. Adapted from Swinburn, Egger, & Raza (1999)

The ecological model of obesity proposed by Egger and Swinburn (1997, p. 477) suggested a paradigm shift from "the traditional view of obesity as a personal disorder that requires treatment." It placed obesity in an ecological context where obesity was the result of the "obesogenic" environment and thus understanding, measuring, and altering the "obesogenic" environment would be critical to containing the current obesity epidemic.

The relationship between energy balance-related behaviors and environment was elaborated later by the EnRG framework (the Environmental Research framework for weight Gain prevention) (Kremers et al., 2006). The EnRG framework postulates energy balance-related behaviors as the result of direct and indirect influences of the environment. The direct influence reflects the automatic and unconscious influence that an environment has on behaviors. The indirect influence of the environment involves the mediating role of behavior-specific cognitions and the moderating effect of specific personal and behavioral factors, including demographic factors, personality, involvement, habit strength, and engagement in clustered behaviors (Kremers et al., 2006).

Definition

For the purpose of this dissertation the following terms are defined as:

1. School food and physical activity environment: all foods and PA opportunities in schools made available to students.
2. Competitive food: foods and beverages sold outside the federally reimbursable school meal programs and competing with regulated school meals, including a la carte items available in school cafeterias, as well as foods and beverages sold in vending machines and school stores and at school activities (Food Research and Action Center, 2010). Competitive foods in this study are categorized into 3 groups: sweet snacks, salty snacks, and sugar-sweetened beverages.
3. Sweet snacks: candy, ice cream, cookies, cakes, brownies, and other sweets.
4. Salty snacks: potato chips, corn chips (for example, Fritos, Doritos), Cheetos, pretzels, popcorn, crackers, or other salty snack foods.

5. Sugar-sweetened beverages (SSB): any drink that has added sugar, high fructose corn syrup, or sucrose (table sugar), including soft drinks (soda or pop), fruit drinks that are not 100% fruit juice, sports drinks, coffee and tea drinks, energy drinks, and sweetened milk or milk alternatives (CDC, 2010).
6. Energy intake: the total amount of energy absorbed through food intake each day.
7. Physical activity: exercise, leisure-time activity, or sports that make an individual sweat and breathe hard and last at least 20 minutes.

Research Questions and Hypotheses

The present study seeks to answer the following research questions:

1. Does the availability of competitive foods in school influence children's eating behaviors?

   Hypothesis 1: Availability of competitive foods in school was associated with increased consumption of competitive foods in schools.

   Hypothesis 2: Higher consumption of competitive foods in school was associated with increased energy intake.
2. Do more PA opportunities in school influence children's overall PA level?

   Hypothesis 3: More PA opportunities in school were associated with a higher PA level.
3. Do school and PA environments influence weight gain?

   Hypothesis 4: Higher availability of competitive foods in school was associated with more weight gain among children.

Hypothesis 5: More PA opportunities in school were associated with less weight gain among children.

4. To what extent does the school food and PA environment influence children's weight gain?
5. What is the effect of school-based nutrition and PA policies on childhood obesity prevention?

   Hypothesis 6: Policies that limit the availability of competitive foods in schools are capable of preventing childhood obesity.

   Hypothesis 7**:** Policies that increase PA opportunities in schools are capable of preventing childhood obesity.

In summary**,** the main goal of this study is to examine the effect of school food and PA environments and policies on children's energy balance-related behaviors and weight gain. The results of this study give insights into effective obesity prevention policies targeting the school environment. The following chapter provides an overview of the existing literature on the problem of childhood obesity in the U.S., energy balance-related behaviors, U.S. children's diet and PA levels, the obesogenic environment, and the school food and PA environment and policies in the U.S. Simulation modeling approaches and their application in obesity studies are covered as well.

CHAPTER II

LITERATURE REVIEW

The Problem of Childhood Obesity

Results from the National Health and Nutrition Examination Survey (NHANES) indicated that 16.9% of 2- to 19-year-old children were obese in the U.S. in 2011-2012 (Ogden et al., 2014). The prevalence of obesity among children increases with age. For example, in 2011-2012 the prevalence of obesity among 2- to 5-year-olds, 6- to 11-year-olds, and 12- to 19-year-olds was 8.4%, 17.7%, and 20.5%, respectively (Ogden, Carroll, Kit, & Flegal, 2014).

The prevalence of obesity among children and adolescents also varies with their race/ethnicity and their household socioeconomic status. Hispanics have the highest (22.4%) obesity prevalence, followed by non-Hispanic blacks (20.2%), then non-Hispanic whites (14.1%). Asian children and adolescents have the lowest prevalence of obesity (8.6%) (Ogden et al., 2014). Socioeconomic status was inversely related to obesity prevalence in non-Hispanic whites but not among non-Hispanic blacks or Mexican-Americans (Wang, 2011).

Obesity prevalence among children and adolescents in the U.S. has almost tripled over the last three decades (Ogden & Carroll, 2010). Recent evidence showed that the rapid growth of childhood obesity had slowed down and might have leveled during the last decade (Ogden, Carroll, & Flegal, 2008). There is a wide gap in the obesity trend among different age and socioeconomic status groups. For example, the prevalence of obesity among children aged 2 to 5 years decreased significantly from 13.9% in 2003-2004 to 8.4% in 2011-2012 whereas the prevalence of obesity remained stable for children aged 6 to 19 years (Ogden et al., 2014). Another study found that the prevalence of obesity among high-socioeconomic status adolescents has decreased in recent years, whereas the prevalence of obesity among their low-socioeconomic-status peers has continued to increase (Frederick, Snellman, & Putnam, 2014).

Obesity Prevention and Energy Balance-Related Behaviors

Simply put, obesity is an accumulation of energy imbalance where energy intake exceeds energy expenditure over a considerable time. The fundamental principle of energy balance can be displayed as the following equation (WHO, 2000):

Energy balance (changes in energy stores) = energy intake – energy expenditure

The fundamental principle of energy balance implies that obesity is preventable. Energy balance can be achieved through modifying the major variable factors that influence energy intake and energy expenditure.

Energy intake. Humans take in energy from consumed foods and drinks in the form of macronutrients such as protein, carbohydrate, and fat. As listed in Table 3, these macronutrients have distinctive characteristics that strongly influence their ability to bring eating to an end, ability to suppress hunger, energy density, storage capacity in body, and the extent to which they contribute to daily energy intake.

Due to their high water and fiber content and relatively low energy density, fruits and vegetables (F&V) are believed to have potential benefits in preventing obesity.

However, results from previous studies on the association between F&V consumption and BMI are mixed. The majority of the literature, including cross-sectional and prospective studies, found that higher intake of F&V was associated with reduced risk of long-term weight gain among adults (Bes-Rastrollo, Martínez-González, Sánchez-Villegas, Arrillaga, & Martínez, 2006; Vioque, Weinbrenner, Castelló, Asensio, & Garcia, 2008). However, in a study that consisted of 8,203 girls and 6,715 boys, Field, Gillman, Rosner, Rockett, and Colditz (2003) found there was no relation between intake of fruits, fruit juices, or vegetables and weight change. In a recent review of randomized controlled trials that evaluated the effect of increased F&V intake on body weight, Kaiser et al. (2014) concluded that increasing F&V consumption alone would not prevent obesity; this approach must be combined with efforts to reduce energy intake from other energy sources.

Table 3
Summary of the Characteristics of Protein, Carbohydrate, and Fat

Characteristics	Protein	Carbohydrate	Fat
Ability to bring eating to an end	High	Intermediate	Low
Ability to suppress hunger	High	High	Low
Energy density	Low	Low	High
Storage capacity in body	Low	Low	High
Contribution to daily energy intake	High	High	High

Note. Adapted from WHO (2000)

As opposed to F&V, junk foods are foods that are "heavily processed, highly palatable, and hyper-energetic and are often deprived of the vitamins and essential nutrients found in whole unprocessed foods" (Bayol, Farrington, & Stickland, 2007, p. 843). Because junk foods usually contain more energy and have a higher level of fat, increased consumption of junk food worldwide is considered a driving force behind the global obesity epidemic. Johnson, Mander, Jones, Emmett, and Jebb (2008) assessed the diet patterns of 1,203 children who participated in the Avon Longitudinal Study of Parents and Children and found that an energy-dense, low-fiber, high-fat diet was associated with higher fat mass and excess adiposity in childhood. Although not all fast foods are junk foods, the majority of fast foods sold at fast food outlets often have higher energy density than foods prepared at home (Rennie, Johnson, & Jebb, 2005). Increased consumption of fast food will contribute to excess energy intake. Although the cross-sectional studies that examined the effect of fast food consumption reported inconsistent results, the majority of the studies documented a positive association between fast food consumption and increased risk of obesity (Rosenheck, 2008). Moreover, almost all prospective cohort studies confirmed that increased fast food consumption led to excessive BMI growth (Rosenheck, 2008).

Sugar-sweetened beverages (SSB) are a type of junk food. The CDC defines SSBs as any drink that has added sugar, high fructose corn syrup, or sucrose (table sugar), including soft drinks (soda or pop), fruit drinks, sports drinks, coffee and tea drinks, energy drinks, and sweetened milk or milk alternatives (CDC, 2010). SSBs are sweetened to increase palatability and consumption and thus will lead to excessive energy intake. Malik, Schulze, and Hu (2006) conducted a systematic review on a cross-sectional, prospective cohort and experimental studies of the relation between SSBs and the risk of weight gain. Findings from large cross-sectional studies, prospective cohort studies with long periods of follow-up, randomized controlled trials, and intervention studies all strongly articulated a positive association between greater intakes of SSBs and obesity in both children and adults. Therefore, the CDC (2010) recommended adults and children to consume more healthful beverages, such as water, low-fat/non-fat milk, and 100% juice, in place of SSBs.

Energy expenditure. Energy expenditure consists of the amount of energy needed to sustain body functions at rest, to digest food (the thermic effect of food), and to conduct PA. The necessary amount of energy for the body at rest is determined by body mass; the thermic effect of food depends mostly upon the food consumed; therefore, PA is the most variable component of energy expenditure. PA is basically determined by the time spent on the activity and the intensity of the activity (Hill, Wyatt, & Peters, 2012).

Studies on the association of PA and BMI have produced inconsistent results. This inconsistency is partially due to the complexity of PA and the difficulty in measuring PA. Nevertheless, in studies that used objective methods to measure PA, a negative association between PA and BMI was observed (Chan, Spangler, Valcour, & Tudor-Locke, 2003; Schulz & Schoeller, 1994). Ness et al. (2007) objectively measured the PA level of 5,500 12-year-old children enrolled in a longitudinal study and found a strong graded inverse association between PA and obesity; moreover, the graded inverse association was more prominent for moderate and vigorous PA. For children and adolescents, research found that greater sports participation was associated with less fat mass (Wijtzes et al., 2014). At the other end of PA, a sedentary behavior such as television viewing is considered a predictive factor of obesity for children and adolescents. The International Study of Asthma and Allergies in Children, Phase 3, found that worldwide increased television viewing hours were positively associated with BMI in both adolescents and children, with an apparent dose response effect (Braithwaite et al., 2013). Besides the frequency and length of time spent in PA, the intensity is also important. In theory, the intensity of PA impacts the extent to which macronutrients such as fat and carbohydrate contribute to energy metabolism (WHO, 2000). Fat is better oxidized with multiple bouts of intense exertion (WHO, 2000). In practice, Ruiz et al. (2006) carried out a cross-sectional study of 780 9-10-year-old children from Sweden and Estonia to examine the associations of PA intensity and fatness in children. The study found that lower body fat was significantly associated with more vigorous PA, but not with moderate or total PA. The 2008 Physical Activity Guidelines for Americans (U.S. Department of Health and Human Services [HHS], 2008) recommended that children and adolescents should participate in 60 minutes or more of PA each day, and vigorous-intensity PA should be included at least 3 days per week.

U.S. Children's Diet and Physical Activity

Data from NHANES showed that in the U.S. the average energy intake was 2,100 kilocalories for boys and 1,755 kilocalories for girls in 2009-2010 (Ervin & Ogden, 2013). U.S. children's average energy intake has decreased for most of the age groups during 1999-2000 to 2009-2010 (Ervin & Ogden, 2013).

Compared to 10 years ago, among children aged 2-19 in 2009-1010, the percentage of energy intake from protein increased, and the percentage of energy intake from carbohydrate decreased slightly. For a boy, the percentage of energy intake from protein increased from 13.5% to 14.7%, and the percentage of energy intake from carbohydrate decreased from 55% to 54.3%. For a girl, the percentage of energy intake from protein increased from 13.4% to 14.3%, and the percentage of energy intake from carbohydrate decreased from 55.8% to 54.5%. There was little change in the percentage of energy intake obtained from fat. Both boys and girls acquired one-third of their energy intake from fat (Ervin & Ogden, 2013).

The U.S. Department of Health and Human Services (HHS) and the U.S. Department of Agriculture jointly publish the *Dietary Guideline for Americans* every 5 years, providing authoritative dietary advice for American children and adults. The most recent edition, *The 2015-2020 Dietary Guidelines for Americans,* recommended increasing consumption of vegetables, fruit, grains, fat-free or low-fat dairy, and a variety of protein foods, while limiting the intake of sodium, saturated fats, and added sugars (HHS, 2015).

F&Vs benefit children's health in many ways. Kim et al. (2014) analyzed children's 24-hour dietary recalls based on NHANES 2003-2010 and estimated the trends of F&V intake among children. They found that, on average, children's total fruit intake per 1000 calories increased 3% per year from 2003-2004 to 2009-2010. This trend was mostly attributable to the increased consumption of whole fruit (12% per year) and the decreased consumption of fruit juice (5% per year). The total vegetable intake per 1,000 calories remained unchanged over that period. Neither the vegetable intake nor the fruit intake met the consumption goals set by *The Healthy People 2020* for U.S. children.

Grains, whole grains in particular, are associated with healthy body weight because they have lower energy density but provide a feeling of fullness. Also using dietary data derived from the NHANES, Albertson and colleagues (2016) found that on average U.S. children consumed 0.74 whole grain ounce equivalents (oz eq)/day in 2011-2012; while over 70% of children met the daily intake recommendation for total grain, less than 1% of children met the whole grain recommendation in 2011-2012.

In 2007-2008, about 95% of U.S. children reported ever drinking milk during the past 30 days. Among these children, 20.2% reported low-fat milk, 45.4% reported two-percent milk, and 32.4% reported whole milk as the type of milk usually consumed (Kit, Carroll, & Ogden, 2011). Lasater, Piernas, and Popkin (2011) studied beverage patterns and trends among school-aged children in the U.S. between 1989 and 2008 and observed a decline in total milk consumption, coupled with a substantial increase in the consumption of certain SSBs, such as fruit drinks and sodas, high-fat, high-sugar milk, and sports drinks.

Ervin, Kit, Carroll & Ogden (2012) found that a substantial percentage (16%) of calories in the diet of U.S. children and adolescents between 2005 and 2008 came from added sugar. However, inconsistent with previous research that suggested that SSBs were the leading source of added sugar intake for children, the results of this study demonstrated that more of the added sugar calories came from foods as opposed to beverages.

Data from the Youth Risk Behavior Surveillance showed that only 17% of 9th -12th grade students reported that they were physically active at least 60 minutes per day (CDC, 2009). In 2013 only 29% of high school students attended physical education classes (PE) on each school day (CDC, 2014b). The percentage of 12th grade students who attended PE classes was even lower. In 2013, only 38% of 12th grade students attended PE classes weekly (CDC, 2014b).

The Obesogenic Environment

Energy balance-related behaviors are not a result of personal choices, but largely caused by the surrounding "obesogenic" environment. An "obesogenic" environment "promotes gaining weight and is not conducive to weight loss" (Swinburn et al., 1999). A large number of studies have been conducted to examine the contributing factors of physical environment to obesity. It is now recognized that the availability of healthy or junk foods near the home and workplace is related to food choice. For example, the presence of a large grocery store or having supermarkets near the workplace or home, greater in-store F&V availability, and a greater variety of F&Vs in stores all contribute to greater consumption of F&V, especially in metropolitan areas (Bodor, Rice, Farly, Swalm

& Rose, 2010; Bodor, Rose, Farley, Swalm, & Scott, 2008; Caldwell, Kobayashi, Dubow, & Wytinck, 2008; Izumi, Zenk, Schulz, Mentz, & Wilson, 2011; Michimi & Wimb, 2010;Thornton, Lamb, & Ball 2013; Zenk et al., 2009). On the other hand, living in close proximity to fast food outlets and an increased density of neighborhood fast food outlets was associated with lower F&V consumption and higher risk of obesity (Kruger, Greenberg, Murphy, DiFazio, & Youra, 2014; Li, Harmer, Cardinal, Bosworth, & Johnson-Shelton, 2009). The number of fast-food outlets in the U.S. has rapidly increased over the past decades. According to a 2008 report, there were a total of 248,400 units of fast-food restaurants in the U.S., and the value of fast-food sales reached $179 million in 2007 (as cited in Christian & Gereffi, 2010). The average yearly growth in the value of fast food sales was 5% from 2002 to 2007 (as cited in Christian & Gereffi, 2010). Furthermore, the relatively low price of junk foods has made access and consumption of these foods much easier. For example, the relatively lower cost of low-fat items in restaurants led to a significant increase in the sales of these items (Horgen & Brownell, 2002). Worldwide, studies showed that raising the price of SSBs through adding tax not only resulted in a lower demand for SSBs but also led to a higher demand for alternative beverages such as milk and fruit juice, and thus decreased risks of obesity (Cabrera Escobar, Veerman, Tollman, Bertram, & Hofman, 2013). Figure 2 shows the price change for selected foods and beverages in the U.S. during 1980-2010. Fresh F&Vs raced far ahead of other food groups in the increase of their price.

Similarly, living in an environment that provides settings and facilities for diverse

PA for children and families promotes PA (Oluyomi et al., 2014). Interventions including constructing more walking paths, sidewalks, and playgrounds may increase PA as well (Gustat, Rice, Parker, Becket, & Farley, 2012).

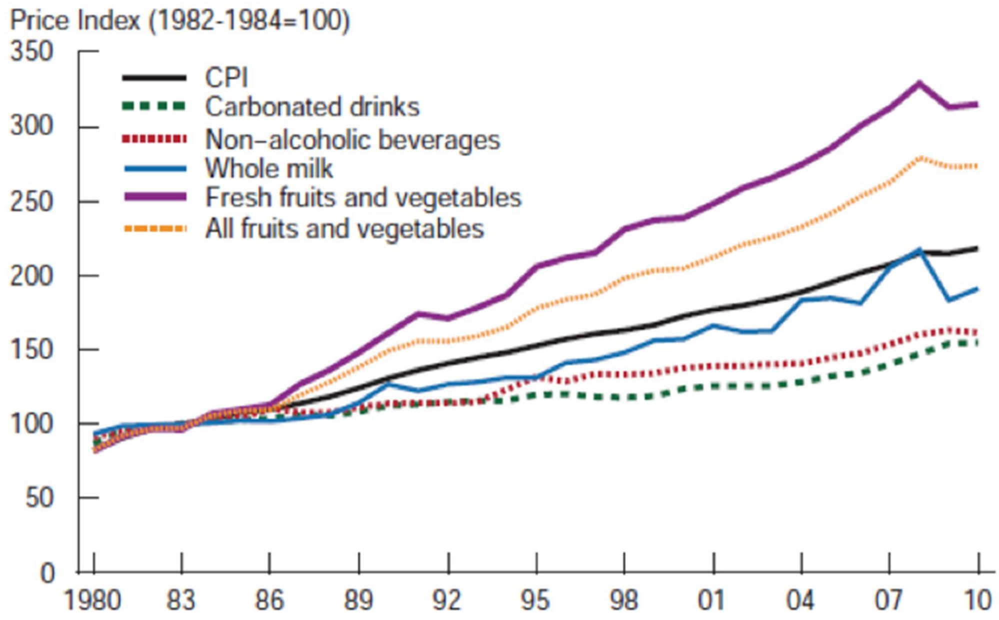

Figure 2. Price indices for selected foods and beverages in the U.S., 1980-2010. Source: Wiggins, Keats & Han (2015)

School Food and Physical Activity Environment for U.S. Children

School represents an important setting for U.S. children and adolescents. There were 49.5 million children and adolescents enrolled in public and 5.3 million enrolled in private elementary and secondary schools in 2010-2011 (National Center for Education Statistics [NCES], 2016). Children and adolescents spend a significant amount of their waking time at school. For example, an average American child spends about 1,300 hours in classrooms in a school year (Juster, Ono, & Stafford, 2004).

The school food environment could have a substantial impact on children's and adolescents' dietary behavior because it was estimated that about 19 to 50 percent of the total energy that a child or adolescent takes in on a school day comes from school foods (Gleason & Suitor, 2001). School foods mainly come from two sources: the National School Breakfast/Lunch Program and competitive foods sold outside of that program.

National School Breakfast/ Lunch Program. The National School Lunch Program (NSLP) was initiated in 1946 to respond to one of the prominent public health problems at that time, nutritional deficiencies among young men (as cited in Story, Nanney, & Schwartz, 2009). NSLP is now running in over 100,000 public and non-profit private schools and child care institutions. In 2012, over 31.6 million children and adolescents bought their lunch from the NSLP (USDA, 2013a). The National School Breakfast Program (SBP) was first introduced in 1966. Its primary goal was to provide funding for schools to serve breakfasts to children who had to travel a great distance to school (USDA, 2013b). The program has been extended several times, and its intent has been modified as "be[ing] made available in all schools where it is needed to provide adequate nutrition for children in attendance" (USDA, 2013b). In 2012 more than 12.9 million students received their breakfast from the program every day (USDA, 2013b).

Schools that take part in the NSLP/NSBP receive subsidies from the U.S. Department of Agriculture (USDA) in the form of a cash reimbursement for each meal served (USDA, 2013a, 2013b). In return, schools must provide reduced-price and free lunches and breakfasts to qualified children. All lunches and breakfasts provided by NSLP/NSBP must meet federally defined meal patterns and nutrition standards (USDA, 2013a, 2013b).

Current NSLP/NSBP meal pattern and nutrition standards are based on *Dietary Guidelines for Americans 2010*. The key features of current NSLP/NSBP nutrition standards include increasing the availability of fruits, vegetables, and whole grains in school meal menus, setting specific calorie limits for different age groups of children, and reducing sodium content in school meals (USDA, 2013a, 2013b).

Competitive foods. Competitive foods are foods and beverages sold outside the federally reimbursable school meal programs and competing with regulated school meals, including a la carte items available in school cafeterias, as well as foods and beverages sold in vending machines, school stores and at school activities (Food Research and Action Center, 2010). Competitive foods sold in schools before school year 2014 were not required to meet any nutritional standards. The Institute of Medicine (IOM) recommended in 2007 that federally reimbursable school meal programs should be the main source of nutrition at schools; if competitive foods were available, they should consist only of fruits, vegetables, whole grains, and nonfat milk and dairy products. However, the IOM recommendations are not federally mandated standards, and compliance with the recommendation is totally voluntary. As a result, competitive foods sold at schools are still mainly SSBs and snacks that are high in fat, sodium, and sugar.

Studies on the effect of competitive foods on children's nutrition status have consistently documented that increased availability of competitive foods would lead to higher daily calorie and fat intake. Moreover, easy access to competitive foods was associated with less consumption of F&Vs and milk (Cullen & Zakeri, 2004; Kubik, Lytle, Hannan, Perry, & Story, 2003).

For their adverse effect on children's diet, competitive foods have received considerable attention in recent years. The "Smart Snacks in School" regulation, which is part of the HHFKA of 2010, mandates that starting in school year 2014-2015, competitive foods must meet nutrition standards (USDA, 2014a). According to the CDC, before the "Smart Snacks in School" regulation took effect, 39 states had enacted state-wide policies regulating competitive foods in schools, although most of these policies could not meet half of the IOM standards regarding competitive foods (CDC, 2012). An encouraging trend regarding access to competitive foods in U.S. public elementary schools was noted in 2010-2011. Access to non-IOM-approved competitive foods dropped, and the percentage of students who could only buy IOM-approved competitive foods increased steadily (Turner & Chaloupka, 2012).

Physical activity opportunities. "School PA environment" refers to all the opportunities children can take to participate in PA at school, including PE classes, recess time for elementary school students, intramural sport programs and clubs, interscholastic sports for high school students, and walking or bicycling to school programs (Story, Kaphingst, & French, 2006). In its 2012 report of *Accelerating Progress in Obesity Prevention: Solving the Weight of the Nation*, the IOM recommended that schools should provide all students in grades K-12 with enough opportunities to participate in 60 minutes of PA each school day. The report also recommended that the Congress should include a requirement in related legislation for local education agencies to develop and implement a K-12 quality physical education curriculum with professional assessments (IOM, 2012). Currently, the proportion of schools that provide PE classes for all grade levels is low. In 2006, only 4 percent of all elementary schools (excluding kindergarten) provided daily PE classes or its equivalent for the entire school year for students in all grades. This number was even lower for high schools (Lee, Burgeson, Fulton, & Spain, 2007).

There is also a wide gap among school districts in the requirements and practices related to recess, school sport programs and clubs, interscholastic sports, and walking or bicycling to school. The 2006 School Health Policies and Programs Study (Lee et al., 2007) indicated that only 39 percent of school districts required or recommended 30 minutes or more of recess time per day in elementary schools. Furthermore, only 14% of states and 18% of school districts had a policy to support or promote walking or biking to school programs (Lee et al., 2007).

School Nutrition and Physical Activity Policies

Policies targeting the school environment have been developed and implemented at the federal, state and school district levels. While varied in content, these policies share the same goal: to increase the availability, accessibility, and acceptability of healthy diet and PA in schools. Based on their legislation strategy, these policies can be categorized into three types: (1) setting nutritional standards for school foods and physical education guidelines at the federal level, (2) limiting the availability of unhealthy foods in schools at the state level, and (3) at the school district level, establishing goals and stages for complying with federal and state standards regarding school foods and PA.

The HHFKA of 2010 is an excellent example of the first type – setting nutritional standards for school foods. The focal point of the HHFKA was authorizing the USDA to establish federal nutrition standards for all foods regularly sold in schools during school days, including foods served through the NSLP/NSBP and all competitive foods (Let's Move, 2010). The new USDA NSLP/NSBP nutrition standard required schools to increase the total amount of F&Vs and lower the sodium and fat content in school meals. Also, all schools meals must be within calorie range. Table 4 presents the nutritional components of an elementary school lunch before and after the new nutrition standard was implemented (USDA, 2013c).

Table 4
Comparison of Elementary School Lunches Before and After the USDA Nutrition Standards

Food group	Before the USDA standard	After the USDA standard
F&V	2.5 cups of fruits and vegetables combined per week	3.75 cups of vegetables plus 2.5 cups of fruit per week
Vegetables	No specifications as to type of vegetable subgroup	Weekly requirement for: •0.5 cups dark green •0.75 cups orange •0.5 cups legumes •0.5 cups starchy •1 cup other

Table 4 (continued)

Food group	Before the USDA standard	After the USDA standard
Meat/Meat Alternative	7.5 oz eq.	8-10 oz eq.
Grains/Bread	8 oz eq. per week (min. 1 per day)	8-9 oz eq. per week
Whole Grains	Must be enriched or whole grain	At least half of grains offered must be whole grain-rich in the NSLP beginning SY 2012–2013 and in the SBP beginning SY 2013–2014. All grains must be whole grain-rich in both the NSLP and the SBP beginning SY 2014-15.
Milk	5 cups Variety of fat contents allowed; flavor not restricted	5 cups fluid milk must be low-fat (1% milk fat or less, unflavored) or fat-free (unflavored or flavored)
Sodium	No set targets	Target 1: SY 2014-15 Lunch ≤ 1230mg (K-5) Target 2: SY 2017-18 Lunch ≤ 935mg (K-5) Final target: 2022-23 Lunch ≤ 640mg (K-5)
Calories	Traditional menu planning Lunch: 633 per day (grades K-3) 785 per day (grades 4-12)	Only food-based menu planning allowed calorie range (min. & max.) Lunch: 550-650 (grades K-5)
Saturated Fat	< 10% of total calories	< 10% of total calories
Trans Fat	No limit	0 grams per serving

Source: Bergman et al., 2014.

The USDA later issued the “Smart Snack in School” nutrition standard to regulate all competitive foods. The main principles of the “Smart Snack in School” standard include (1) the food must have a whole grain as the first ingredient if it is a grain product or have as the first ingredient a fruit, vegetable, dairy product, or a protein food or contain at least 1/4 cup of fruit and/or vegetable if it is a combination food and (2) the food must meet the nutrition standards for calories, sodium, sugar, and fats (USDA, 2016).

Studies that evaluated the effect of the HHFKA 2010 are sporadic. Bergman and colleagues (2014) compared the nutrient content of NSLP meals before and after implementation of the USDA NSLP/NSBP nutrition standard in four Washington State elementary schools and found significant improvement in key nutrients including sodium, saturated fat, fiber, and calcium. Another study from the Rudd Center for Food Policy and Obesity (Schwartz, Henderson, Read, Danna, & Ickovics, 2015) also found that after the implementation of the USDA NSLP/NSBP nutrition standard, the percentage of students choosing fruit significantly increased and students who selected vegetables ate nearly 20% more of them. These findings added to the evidence that the new USDA nutrition standards were effective in promoting healthy diet behaviors in schools. However, neither of the studies touched the key health outcome that caused the release of the USDA NSLP/NSBP nutrition standard and “Smart Snack in School,” the body weight status of the students, probably because it was too early to evaluate the impact of the children’s dietary changes on body weight.

So far, no national standard has been issued to regulate PA in schools. However, all states and the District of Columbia have established some requirements and standards for PE in schools. Most standards are not enforced. They only require students to demonstrate competency, knowledge, and skill in PA and fitness. Moreover, there are only 21 states that specifically require schools to provide other PA except PE during school days. The number of states that mandate the amount of PA time in schools is even fewer (The State of Obesity, 2016). Oklahoma is one of the few states that mandates the minimum time of PE plus the minimum time of PA per week in grades K-8 (National Association for Sport and Physical Education and the American Heart Association, 2010).

Legislative efforts to reduce the availability of competitive foods in schools concentrate on the state level. For example, starting July 2006, Arizona banned the sale of soft drinks, candy, and gum during the school day in public elementary and middle schools (Carroll, 2005). However, restricting all competitive foods in schools is rare. More commonly, states ban the sale of soda in school vending machines or from lunch lines in school cafeterias (Taber, Chriqui, Vuillaume, Kelder, & Chaloupka, 2015). However, according to a study by Bridging the Gap (Taber et al., 2015), state laws that ban only the sale of sodas would lead to increased consumption of other SSBs in schools. Texas lifted its state-wide ban on soda in 2015 (Martin, 2015).

At the school district level, school wellness policies represent local educational agencies' main efforts to promote school food and PA environments. The Child Nutrition and WIC Reauthorization Act of 2004 required each school district participating in the

NSLP/NSBP to develop and implement a wellness policy by the first day of the 2006-2007 school year. The HHFKA 2010 strengthened this requirement and set guidelines for school wellness policies. According to these guidelines, a school wellness policy must set goals for nutrition promotion, nutrition education, and PA; provide nutrition guidelines for all foods and beverages available in schools that are consistent with national nutrition standards; inform and update the community about the policy's content and implementation; and periodically measure and publish an assessment on implementation (Piekarz et al., 2016). A recent report by Bridging the Gap found that while most of the school wellness policies included the components of nutrition education, PA, school meals, and implementation and evaluation provisions, many did not address competitive food guidelines (Piekarz, et al., 2016). Moreover, current school wellness policies are weak overall in strength (Piekarz et al., 2016).

The Modeling and Simulation Approach in Obesity Studies

A modeling and simulation approach attempts to understand a complex system as a whole. A model is a physical, mathematical, or otherwise logical representation of a system (Sokolowski & Banks, 2010). A simulation is the execution of a model. Simulation takes place when a model is amended to repeatedly observe the behavior of the model (Sokolowski & Banks, 2010).

Two types of models have been commonly used in public health research: microsimulation and cell-based models (Ringel, Eibner, Girosi, Cordova, & McGlynn, 2010). A microsimulation model is also called an agent-based model. In a microsimulation model, “agents” are constructed and endowed with “attributes” or defining characteristics to represent the entities that are affected by the policy reform. Manipulating the environment (e.g., through policy enforcement) in which the agents operate will cause the agents to react to the environment change and to each other’s behaviors. Agents’ reactions can be a dynamic “back-and-forth” process (Ringel et al., 2010), and this dynamic process will finally change the agents themselves and the system as a whole. A microsimulation model can be validated by comparing the “predicted” outcomes for a historical year with the actual outcomes, which are already known. Cell-based models, also called system dynamic models, stratify the population of interest into cells according to key attributes such as age and weight status. People will migrate from one cell to another as a response to environmental change. Cell-based models are used when the outcomes of interest are aggregate measures, the behaviors of individuals in the same cell are similar, and the feedback loops can be disregarded (Ringel et al., 2010).

Levy et al. (2011) provided a comprehensive review of existing simulation models for obesity. These simulation models focused on the health and economic outcomes of obesity, trends in obesity as a function of past trends, physiological base of obesity, environmental contributors to obesity, and policy intervention (Levy et al., 2011). So far there are no simulation models that have been built to estimate the impact of school food and physical activity environments and policies on childhood obesity. However, several studies that simulated the environmental contributors to obesity have provided insights to the current study.

Ramirez-Nafarrate & Gutierrez-Garcia (2013) presented an agent-based simulation framework to analyze the effectiveness of intervention strategies in childhood obesity control, which provided a starting point for the current study. In this proposed framework there were eight elements: age, gender, weight, height, BMI, weight status category, daily calorie intake, and energy expenditure. The amount of energy expenditure was determined by the basal metabolism, digestion process, and PA. The study simulated children's BMI distribution in three scenarios based on three levels of PA and showed that being consistent with PA of medium intensity can help to reduce obesity prevalence. However, this study did not address the impact of eating behavior on calorie intake or BMI change. Moreover, the study used intensity instead of duration or frequency to measure physical activity. In fact, the intensity of physical activity is hard to monitor with existing techniques. Therefore, data on the intensity of children's PA is lacking. Similarly, based on a physiological study of the process of energy expenditure, Hennessy et al. (2016) developed an agent-based model to evaluate multifaceted interventions on childhood obesity prevention in multiple settings. These interventions targeted both the dietary intake and physical activity of school-aged children. Differently, this model used population-based survey data to mimic the heterogeneity in calorie intake, PA level, and BMI among U.S. children. However, the links between school food environment and calorie intake or PA was still not addressed.

Abidin et al. (2014) use a system dynamics model to compare the effect of two strategies for childhood obesity prevention: improving the consumption of portion size and meal frequency. The model incorporated the linear and non-linear links between policy changes, eating behaviors, and BMI. It provided an example for the current study by examining the impact of environmental factors on obesity. The main limitation of the study was that it disregarded the heterogeneity among children and assumed that all children had the same eating behavior, PA, and metabolism rate.

Wang, Xue, Chen, and Igusa (2014) built an agent-based model to examine and test the effect of school social norms on children's BMI and fruit and vegetable consumption behavior. In this model, each child's BMI at time *t* was modeled as the result of this child's BMI at time *t-1*, the average growth trend, and the effect of school social norms. This model focused on the effect of environmental factors on the BMI of individual students and the BMI distribution for the child population. Moreover, the study used the ECLS-K data to obtain empirical parameters for and calibrate the model. It showed that high obesity prevalence would lead to an increased socially accepted mean BMI, which caused a continuous increase in BMI among children.

In their comprehensive review of existing simulation models, Levy et al. (2011) listed the necessary steps in the development of a simulation model: first, define the scope of the problem; second, choose the type of model and determine its basic structure; third, estimate parameters; fourth, validate the model; lastly, conduct sensitivity analyses. The current study will follow these steps to build a model to simulate the effect of school food and physical activity environments and policies on BMI.

Levy et al. (2011) also proposed a framework for the different types of youth-oriented obesity policies and how the effect of different policies may interact. According to this framework, school nutrition and PA policies may not only influence children's eating behaviors in school but also their diet in non-school settings. For example, policies that restrict consumption of competitive foods in schools may cause higher consumption of these foods in non-school settings, which makes these policies fail to achieve their goal of preventing childhood obesity. The current study will use this framework to examine the effect of school food and physical activity environments and policies on children's overall diet and PA.

In summary, a model is the simplified representation of a system. It has limitations. However, when simulation models are developed with a clear purpose and following the right process, they have real potential for improving our knowledge of obesity and suggesting future solutions.

CHAPTER III
METHODOLOGY

Overview of Study Design

This dissertation uses a simulation modeling approach to explore the influence of school food and PA environments on children's energy balance-related behaviors and weight gain. The modeling and simulation approach is an iterative process that consists of developing a model, simulating it, analyzing the results of the simulation, enhancing the understanding of the system based on the analysis of various simulations of the model, then validating and revising the model (Sokolowski & Banks, 2010). To develop a useful simulation model, Levy et al. (2011) believed that the following five elements must be involved: defining the scope of the problem, choosing the type of model and determining its basic structure, estimating parameters, validating the model and conducting sensitivity analyses. Sterman (2000) proposed the following steps for successful modeling: (1) articulating the problem to be addressed, (2) problem mapping, (3) simulation model formulation, (4) model testing and (5) policy design and evaluation. Following these guidelines, the following flow chart was made to illustrate the modeling and simulation process used in this study (Figure 3).

There were five steps in this process. The first step defined the problem and described the system related to childhood obesity. A conceptual framework was developed in the second step. In the third step, mathematical models were constructed to represent the effect of school food and PA environments on energy balance-related behaviors and weight gain. Assumptions were also documented in this phase. The fourth step focused on model calibration and validation using the data collected from two nationally representative studies, specifically the Early Childhood Longitudinal Study – Kindergarten Class of 1998-99 (ECLSK) and the 2003-2004 National Health and Nutrition Examination Survey (NHANES). In the fifth step, scenarios were developed in which school-based nutrition and PA policies were implemented to limit the availability of competitive foods or to promote PA opportunities. The potential effect of school nutrition and PA policies on childhood obesity prevention was estimated. The rest of this chapter describes each step in detail.

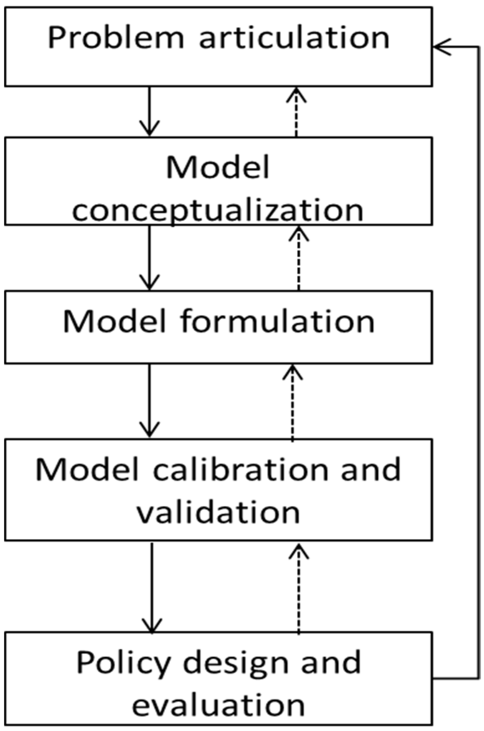

Figure 3. The modeling and simulation process.

Problem Articulation

As stated in Chapter 2, childhood obesity has become a critical public health issue in the U.S. Results of a recent study in obesity implied that obesity was not a personal disorder, but a normal response to an abnormal environment (Egger & Swinburn, 1997). As a pivotal setting for children's growth and development, whether and to what extent the school environment impacts children's weight gain are fundamental questions that need to be answered. This dissertation seeks to provide answers to these questions by examining the influence of school food and PA environments on energy balance-related behaviors and weight gain.

There are four types of environments: physical, economic, political, and sociocultural (Swinburn et al., 1999). This study will focus on the school physical environment, defined as availability of various types of foods and PA opportunities in schools. The energy balance-related behaviors include food choice and PA level. As a summary, the exposure variables of the study are school foods and PA environments and the outcome variables are children's eating behaviors, PA, and weight gain.

Children's body weight status is a complex system. Within this system, the amount of energy intake and energy expenditure is largely decided by their diet and PA. However, what and how much a child eats and how much time he/she spends on PA is not merely a personal choice. They are determined by the foods and PA opportunities offered in both the school and non-school settings. To assess the magnitude of the influence of school food and PA environments on children's diet, PA, and BMI is the goal of this study.

Model Conceptualization

A conceptual framework (Figure 4) was developed to represent the pathways between school food and PA environment and body weight status. In this framework, the school food environment is represented by the availability of alternative food choices, including F&Vs, sweet and salty snack foods, milk, juice, and SSBs. Based on the ecological model of obesity posed by Egger and Swinburn (1997), it is expected that children will respond to the school environment by changing their eating behaviors in schools. It is hypothesized that increased availability of a certain type of food in a school will increase consumption of that type of food among children in the school. The changed eating behavior in school is assumed to cause a change in the total energy intake. The school PA environment is represented by opportunities for PA in schools. Likewise, it is hypothesized that more opportunities for PA causes a higher PA level in school among children. The change in the school PA level is assumed to cause a change in the total energy expenditure. Positive energy balance between energy intake and energy expenditure leads to extra weight gain, which eventually influences the BMI distribution of the children in the same school. The relationship between the school food and PA environment and BMI distribution is dynamic. As obesity prevalence increases, public concerns with the adverse health and economic consequences of obesity may call for a change in school food and physical activity to support healthy eating and more PA.

Children's eating behaviors in school may or may not affect their food consumption in non-school settings. It is possible that children adjust their consumption of a certain type of food in non-school settings based on their consumption of this type of food in school. For example, when children increase consumption of F&Vs in schools, they might eat less F&Vs at home. However, it is also possible that when children have positive experiences with F&V consumption in schools, they may want to eat more F&Vs in non-school settings. Therefore this study also examines the impact of school eating behavior on total food consumption.

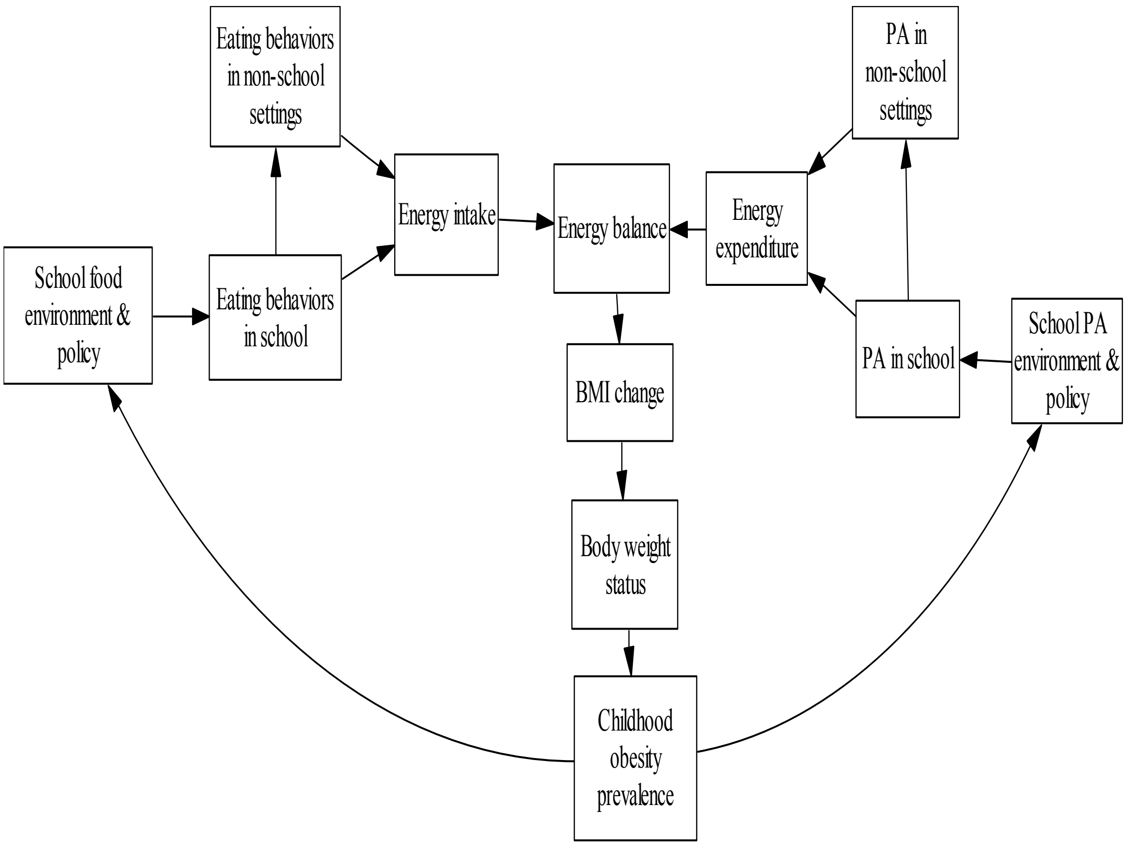

Figure 4. A conceptual framework for examining the effect of school food and physical activity environment and policies on childhood obesity.

Model Formulation

(1) The effect of school food environment on children's eating behaviors in school

The consumption of food *j* in school in a week is modeled as a function of the availability of food *j* in that school:

$$S_j = f(u_j) \quad (1)$$

(2) The effect of school eating behaviors on total food consumption

The total consumption of food *j* in school can be expressed in the following form:

$$S_j = g(C_j) \quad (2)$$

Where S_j is the consumption of food *j* in school each day and C_j captures the total consumption of food *j* each day.

(3) The effect of school PA on children's PA level

The total PA in school can be expressed in the following form:

$$SPA = h(TPA) \quad (3)$$

Where SPA is the total amount of PA in school each week and TPA captures the total PA in a week in all settings.

(4) The effect of school food and PA environments on weight gain

The key task of this study is to assess the effect of the school food and PA environment on children's energy balance-related behaviors and weight gain. Based on the conceptual framework developed in the last section, the BMI of student *i* at time *t* can be expressed in a simple form:

$$BMI_{i,t} = \Sigma u_j(0,1) k_j S_j + \alpha SPA + \beta BMI_{i,t-1} + e \quad (4)$$

Where $u_j(0,1)$ is the availability of food *j* in school, S_j is the total consumption of food *j* in school, k_j is the influence of the consumption of food *j* in school on BMI change, SPA is the amount of PA in school, α is the average net effect of school PA on BMI change, β captures the average BMI growth rate caused by diet and PA in non-school settings, and e is a random draw from a normal distribution (Mean = 0.17, Standard deviation = 0.4) reflecting the heterogeneity of the children's BMI growth based on demographic characteristics.

Four assumptions are made here. The first one is that the influence of non-school settings on BMI growth is assumed to be the same for all children. The second assumes that the influence of genetic factors on BMI growth is zero in all children. The third assumes that the price of school foods has no impact on children's food choices. The third assumes that school staff and students' views related to food and PA has no impact on children's energy balance-related behaviors. Based on assumption 3 and 4, the effect of the school food and PA environment is completely determined by the availability of varied types of foods and PA opportunities.

Model Calibration and Validation

(1) The process of model validation and calibration. Model validation is the process of determining the degree to which model-generated data can accurately represent the real-world system from the perspective of the purpose of the model (Sokolowski & Banks, 2010). Model calibration is the process of selection or refinement of model parameters to reproduce observed results (Levy, 2011). This study used data collected from the ECLSK surveys in 2002, 2004, and 2007 and NHANES in 2003-2004 to calibrate and validate the models developed in the last section. Specially, the longitudinal data collected from the ECLSK was used to estimate and validate the effect of school environments on eating behaviors in school, overall PA level, and PA in schools, and children's weight gain; the cross-sectional data collected from the NHANES 2003-2004 was used to estimate and validate the effect of school eating behavior on overall food consumption. There were four steps during the calibration and validation process. The following sections describe these steps and the analytical approaches used in each one.

First, a descriptive analysis was conducted to examine the distribution and time trend of the variables of interest, including the demographic characteristics of the sample, children's BMI, the characteristics of the schools, the availability of competitive foods in the schools, eating behaviors, and PA. In addition, depending on the appropriate measurement of the variables (categorical vs. continuous), Chi-squared tests or correlation coefficients were used to test the crude associations between variables, such as the association between the availability of competitive foods and the geographical location of the schools.

Second, linear and logistic regression analysis was used to estimate the effect of school food and PA environments on children's eating behaviors and PA levels based on models 1, 2, and 3. The identified pattern and measures obtained from this and the last step could then be used in calibration and validation of the model (4).

Table 5

Comparison of Calibration Sample and Validation Sample

Variables	Calibration sample (mean/%)	Validation sample (mean/%)	p
5th grade			
Gender			
Male	49.98	49.09	> 0.05
Race			
White	65.67	65.86	> 0.05
Black	8.40	8.85	> 0.05
Hispanic	15.80	14.86	> 0.05
Asian	5.09	4.91	> 0.05
Body weight status			
BMI	20.46(SD = 4.68)	20.41(SD = 4.70)	> 0.05
Obesity	21.22	20.30	> 0.05
Overweight	17.63	17.35	> 0.05
8th grade			
Gender			
Male	49.98	49.11	> 0.05
Race			
White	65.67	65.88	> 0.05
Black	8.40	8.86	> 0.05
Hispanic	15.80	14.87	> 0.05
Asian	5.09	4.87	> 0.05
Body weight status			
BMI	22.67(SD = 5.23)	22.61(SD = 5.11)	> 0.05
Obesity	18.02	17.85	> 0.05
Overweight	16.85	17.25	> 0.05

Note. Statistical significance of gender, race, and obesity/overweight rate between calibration sample and validation sample was tested using a two-sample test of proportions: the statistical significance of BMI between the calibration sample and the validation sample was tested using a t-test.

Third, parameters in model 4 were estimated. In this step, I split the sample into two halves at random and used the first half to calibrate the model and the second half to validate the model. Table 5 compares the calibration sample and the validation sample.

These two data sets had no significant differences on gender, race, BMI, obesity, and overweight rates for children in the 5^{th} and 8^{th} grades. For the first half of the sample, multiple linear regression analysis was used to estimate β (the average BMI growth rate caused by age), k_j (the influence of the consumption of food *j* in school on BMI change), and α (the average net effect of school PA on BMI change).

Fourth, model 4 was validated. The BMI of each child in the second half of the sample was calculated using the parameters acquired from the last step. The calculated BMI was then compared with the observed data. If the calculated BMI was not accepted, a manual turning procedure was used to adjust the parameters. A manual turning procedure calculates the difference of the key statistics measured, e.g., mean, standard deviation, percentage, between the simulated and the observed data and then searches for parameters that yield results matching the observed data. The criteria used for the iterative process of model calibration and validation include (a.) the bounds and ranges of the parameters that have been established based on published solid studies, (b.) results of models 1, 2, and 3, and (c.) the divergence of the descriptive statistics between the observed and the simulated data, i.e., the means and the standard deviations. The agreement between the observed and the simulated data was measured by using correlation coefficients, t-test, two-sample variance-comparison test, and comparing their distributional pattern.

(2) Data. Data derived from the Early Childhood Longitudinal Study – Kindergarten Class of 1998-99 (ECLSK) and the 2003-2004 National Health and

Nutrition Examination Survey (NHANES) were used to calibrate and validate the models built in the last step.

Early Childhood Longitudinal Study – Kindergarten Class of 1998-99 (ECLSK). The ECLSK is a longitudinal study that followed a cohort of nationally- representative students from kindergarten (in 1998-1999) to the time they reached 8th grade (in 2007). The children completed seven surveys in this longitudinal study. These surveys were conducted in the fall of 1998 (kindergarten), the spring of 1999 (kindergarten), the fall of 1999 (1st grade), spring of 2000 (1st grade), the spring 2002 (3rd grade), the spring of 2004 (5th grade), and the spring of 2007 (8th grade) (National Center for Education Statistics, n.d.).

The ECLSK surveyed the children, their parents or guardians, teachers, and school administrator at each round for information on the children's development, home environment, school environment, and classroom environment. Because information about eating behaviors and food consumption were collected only at the 5th grade (2004) and 8th grade (2007), this study used data from these two rounds for the development and validation of models 1, 3, and 4. The key variables for these models were BMI, PE frequency, length of each PE session, recess frequency, length of each period of recess, availability of sweet snacks, salty snacks and SSBs in school, and consumption of these foods in school. For each BMI value, the 2000 CDC Growth Chart was used to obtain the corresponding BMI percentile. A child with an age- and sex-specific BMI percentile equal to or greater than the 95th was considered obese and overweight if the age- and sex-specific BMI percentile equaled or was greater than the 85^{th} percentile but less than the 95^{th}. Children's demographic characteristics, including gender and race/ethnicity, and the characteristics of the schools they attended including the census geographic region, the percentage of minorities, and degree of urbanization were also included in the analysis. Table 6 lists the key ECLSK variables and their measures.

Table 6
Key Variables and Their Measures from ECLSK

Variable	Measures
BMI	A child's weight in kilograms divided by the square of height in meters.
Availability of sweet snacks in school	"In your school, can kids buy candy, ice cream, cookies, cakes, brownies or other sweets in the school?"
Availability of salty snacks in school	"In your school, can kids buy potato chips, corn chips (for example, Fritos, Doritos), Cheetos, pretzels, popcorn, crackers or other salty snack foods at school?"
Availability of sugar-sweetened beverages	"In your school, can kids buy soda pop (for example Coke, Pepsi, Mountain Dew), sports drinks (for example Gatorade), or fruit drinks that are not 100% fruit juice (for example Kool-Aid, Hi-C, Fruitopia, Fruitworks) in the school?"
Availability of physical education	"How many times each week do children in your class usually have physical education?" (in 5th grade) "In an average week when you are in school, on how many days do you go to physical education (PE) classes?" (in 8th grade) "How much time each day do children in your class usually spend when they participate in physical education?" (measured in 5th grade only)

Table 6 (continued)

Variable	Measures
Availability of recess	"How many days a week do children have recess?" (measured in 5th grade only) "In a typical day, how much time does your class spend in recess?" (measured in 5th grade only)
Consumption frequency of sweet snacks in school	"During the last week that you were in school, how many times did you buy candy, ice cream, cookies, cakes, brownies or other sweets at school?"
Consumption frequency of salty snacks in school	"During the last week that you were in school, how many times did you buy salty snack foods at school?"
Consumption frequency of sugar-sweetened beverages in school	"During the last week that you were in school, how many times did you buy soda pop, sports drinks, or fruit drinks at school?"
Total consumption of sugar-sweetened beverages	"During the past 7 days, how many times did you drink soda pop (for example Coke, Pepsi, Mountain Dew), sports drinks (for example Gatorade), or fruit drinks that are not 100% fruit juice (for example Kool-Aid, Hi-C, Fruitopia, Fruitworks)?"
Overall physical activity	"In a typical week, on how many days does your child get exercise that causes rapid breathing, perspiration, and a rapid heartbeat for 20 continuous minutes or more?" (in 5th grade) "On how many of the past 7 days did you exercise or participate in physical activity for at least 20 minutes that made you sweat and breathe hard, such as basketball, soccer, running, swimming laps, fast bicycling, fast dancing, or similar aerobic exercise?" (in 8th grade)

The National Health and Nutrition Examination Survey (NHANES). Because the ECLS-K provided limited information about the total consumption of various foods for children, I used the dietary intake data from NHANES 2003-2004 to estimate the effect of school eating behavior on total food consumption. NHANES is a series of surveys continuously conducted by the CDC to collect data on the health and nutritional status of adults and children in the U.S. NHANES assesses a nationally representative sample of about 5000 adults and children each year (CDC, 2014c).

NHANES interviews each participant for detailed dietary intake information. During the interview, participants are asked to recall the types and amounts of foods and beverages consumed during the 24-hour period prior to the interview and to estimate intakes of energy, nutrients, and other food components from those foods and beverages. This study focused on the consumption of sweet snacks, salty snacks, and sugar-sweetened beverages. To be consistent with the ECLSK, a sugary snack was defined as candy, ice cream, cookies, cakes, brownies, or other sweets, a salty snack was defined as potato chips, corn chips, pretzels, popcorn, crackers, or other salty snacks, and SSBs were defined as soda pop, sports drinks, or fruit drinks that were not 100% fruit juice. Food eaten in school was defined by three questions: “Was this food eaten at home?”, “What time did you begin to eat/drink the food?” and “Intake day of the week?” Food eaten between 7:00 to 15:00 on Monday through Friday, and not eaten at home, was considered eaten in schools, with the assumption that children usually do not have significant activities outside their school during regular school days.

Policy Design and Evaluation

One of the aims of the present dissertation is to estimate the effect of school nutrition and PA policies on childhood obesity prevention. To achieve this objective, four scenarios were constructed in this step in which policies targeting the school food and PA environment were assumed to be implemented in all schools.

Scenario 1. All schools limit the availability of sweet snacks in school and do not change the availability of salty snacks and SSBs.

Scenario 2. All schools limit the availability of salty snacks in school and do not change the availability of sweet snacks and SSBs.

Scenario 3. All schools limit the availability of SSBs in school and do not change the availability of sweet and salty snacks.

Scenario 4. Each child is provided with 60 minutes of PA each school day in elementary schools and takes PE each day in middle schools.

In each scenario, simulation of every child's BMI was run multiple times (more than 20). The mean of the simulated BMI for each child was calculated and compared to the child's observed BMI. The prevalence of obesity and overweight among children in these scenarios was estimated and compared to the observed prevalence of overweight and obesity.

All statistical analyses of this study were conducted using STATA 12. Statistical significance was determined at a p-value equal to or less than 0.05.

Protection of Human Subjects

This dissertation used publicly available existing data. These data were recorded in a manner that subjects could not be identified, directly or through identifiers linked to the subjects. Therefore, it was approved by the College of Health Sciences Human Subjects Committee of Old Dominion University to be exempted from review by the Old Dominion University IRB.

CHAPTER IV

RESULTS

Characteristics of U.S. Schools and School Children Based on ECLSK data

Table 7

Demographic Characteristics of the ECLSK Children and Their BMI Distribution

Variables	5th grade (n = 11,161)		8th grade (n = 8,485)	
	% or Mean	SE	% or Mean	SE
Gender				
Male	48.77	0.00	50.06	0.00
Female	51.23	0.00	49.94	0.00
Race/ethnicity				
White*	55.93	0.00	62.13	0.01
Black*	14.26	0.00	10.19	0.00
Hispanic	17.83	0.00	16.94	0.00
Asian*	6.67	0.00	5.40	0.00
Others	5.30	0.00	5.34	0.00
Body weight status				
BMI*	20.52	0.05	22.80	0.06
Overweight*	20.91	0.00	16.96.	0.00
Obesity*	21.05	0.00	19.16	0.00

Note. Statistical significance of gender, race, obesity, and overweight proportion between 5^{th} grade and 8^{th} grade was tested using a two-sample test of proportions. Statistical significance of the mean of BMI between 5^{th} grade and 8^{th} grade was tested using a paired t-test. * indicates statistical significance between 5^{th} grade and 8^{th} grade at $p <= 0.05$.

Table 7 presents the demographic characteristics of the ECLSK children who provided BMI information and the change in their BMI distribution between 2004 (the Round 6 survey) and 2007 (the Round 7 survey). More than 55% of the ECLS-K children were non-Hispanic whites. Compared to the survey in 2004, the proportion of non-Hispanic white students was higher and the proportion of non-Hispanic black and Asian children was lower in the survey of 2007. Although the average BMI increased significantly, the percentage of children who were obese or overweight dropped significantly from the 5th grade to the 8th grade ($p < 0.05$).

Table 8

Characteristics of ECLSK Schools in 2004 and 2007

School characteristics	2004 (n = 2140)		2007 (n = 2378)	
	%	SE	%	SE
Census region				
Northeast	18.31	0.01	18.91	0.01
Midwest	22.96	0.01	24.52	0.01
South	32.28	0.01	34.42	0.01
West*	26.45	0.01	22.14	0.01
Location type				
Large and mid-size city*	44.44	0.01	38.79	0.01
Large and mid-size suburb and large town*	41.00	0.01	44.09	0.01
Small town and rural area*	14.56	0.01	17.12	0.01
Percentage of minority students				
Less than 10%	21.25	0.01	20.94	0.01
10% to less than 50%	34.72	0.01	37.54	0.01
More than 50%	44.02	0.01	41.53	0.01

Note. Statistical significance of census region, location type, and percentage of minority students between 5th grade and 8th grade was tested using a two-sample test of proportions; * indicates statistical significance between the 5th and the 8th grade at $p <= 0.05$.

Table 8 presents the characteristics of the schools the ECLSK children attended during their 5th and 8th grade years. The racial/ethnical composition of the students was not different between 2004 and 2007. Compared to the survey in 2004, the survey in

2007 included a smaller proportion of schools located in the West or large and mid-size cities. The proportion of schools located in a large and mid-size suburb, large town, small town, or rural area was higher in 2007.

Availability of Competitive Foods in School

The school food environment for U.S. children was far from satisfactory. Table 9 presents the student-reported availability of sweet snacks, salty snacks, and SSBs in schools by school characteristics in 2004 and 2007. About half of the elementary schools (surveyed in 2004) and 70% of the middle schools (surveyed in 2007) offered sweet and salty snacks in schools. Compared to sweet and salty snacks, surveyed schools had a more rigorous control on the availability of SSBs in schools. However, there were still more than 37% of elementary schools and about 62% of the middle schools that offered SSBs in schools. This number increased to 62% when the surveyed students proceeded to 8^{th} grade in 2007.The primary venue for sweet and salty snacks was the school cafeteria. Besides the school cafeteria, the vending machines in schools were also primary venues for SSBs in both 2004 and 2007.

The reported availability of all three types of competitive foods varied with the school characteristics. Schools located in the South were more likely to offer sweet and salty snacks and SSBs in both 2004 and 2007. Schools in a city, suburb, or large town were more likely to offer sweet and salty snacks in schools in 2007. Schools that had 10% to fewer than 50% minority students were more likely to offer sweet and salty snacks in 2004.

Table 9

Proportion of Schools Offering Sweet Snacks, Salty Snacks and SSBs in Schools in 2004 and 2007, by School Characteristics

School characteristics	Availability in school					
	Sweet snack		Salty snack		SSB	
	2004	2007	2004	2007	2004	2007
All schools	52.35 (0.01)	69.74 (0.01)	47.79 (0.01)	74.07 (0.01)	37.29 (0.01)	61.78 (0.01)
Census region						
Northeast	58.87 (0.02)	71.79 (0.02)	54.24 (0.03)	76.46 (0.02)	34.70 (0.02)	55.14 (0.02)
Midwest	37.99 (0.02)	61.48 (0.02)	34.84 (0.02)	66.67 (0.02)	36.68 (0.02)	61.85 (0.02)
South	71.97 (0.02)	80.28 (0.01)	64.09 (0.02)	79.56 (0.01)	47.08 (0.02)	65.80 (0.02)
West	36.98 (0.02)	61.16 (0.02)	35.30 (0.02)	71.98 (0.02)	28.32 (0.02)	61.04 (0.02)
Location type						
Large and mid-size city	47.63 (0.02)	68.82 (0.02)	43.30 (0.02)	72.87 (0.02)	38.11 (0.02)	60.96 (0.02)
Suburb and large town	58.42 (0.02)	76.96 (0.01)	53.32 (0.02)	82.98 (0.01)	35.26 (0.02)	65.85 (0.02)
Small town and rural area	44.88 (0.03)	57.01 (0.03)	40.64 (0.03)	57.70 (0.03)	39.36 (0.03)	57.66 (0.03)
Percentage of minority students						
Less than 10%	51.79 (0.02)	65.05 (0.02)	49.33 (0.02)	70.49 (0.02)	37.95 (0.02)	60.93 (0.02)
10% to less than 50%	58.85 (0.02)	75.50 (0.01)	52.88 (0.02)	79.08 (0.01)	36.85 (0.02)	64.81 (0.02)
50% or more	47.78 (0.02)	67.10 (0.02)	43.52 (0.02)	71.63 (0.01)	37.30 (0.02)	59.35 (0.02)

Note. Statistical significance among categories of census region, location type, and percentage of minority students during 5th grade and 8th grade was tested using logistic regression. Statistical significance of competitive food availability between 5th grade and 8th grade was tested using a two-sample test of proportions. SE is in parenthesis.

The proportion of schools that offered sweet snacks, salty snacks, and SSBs in school all significantly increased ($p < 0.05$) from 2004 to 2007 (Table 9), which reflected the deterioration of the school food environment as children proceeded from the 5th (2004) to the 8th (2007) grade.

Children's Eating Behaviors in School

In general, about 23% of 5th grade students had bought any sweet snacks, 16% of them had bought any salty snacks, and 13% of them had bought any SSBs in school during the last week. When these children proceeded to 8th grade, these numbers increased to 33%, 27%, and 24%, respectively.

Table 10 presents the proportion of children who consumed any sweet snacks, salty snacks, or SSBs in school when these foods were available. In schools where sweet and salty snacks were available, boys were generally more likely to consume any competitive foods, except for salty snack consumption in the 8th grade ($p < 0.05$). Significant ($p < 0.05$) racial/ethnical disparity appeared in the consumption of any salty snacks during 8th grade and consumption of SSBs during 5th and 8th grades. Compared to other racial/ethnical groups, 5th grade Hispanic children were more likely to consume any salty snacks and SSBs and non-Hispanic black children were more likely to consume any SSBs in the 8th grade. Body weight status was also associated with any consumption of competitive foods when these foods were available in schools. Obese children were more likely to consume any sweet snacks, salty snacks, and SSBs than overweight children during their 5th grade year ($p < 0.05$). However, when they proceeded to 8th grade, the difference in consumption of sweet snacks, salty snacks, and SSBs between obese and overweight children was not significant any more. Compared to children of normal weight, obese children consumed significantly fewer sweet snacks during 5th and 8th grades and fewer salty snacks during 8th grade ($p < 0.05$).

The characteristics of the schools, including the census region, location type, and the percentage of minority students in the school, were associated with children's eating behaviors conditional on availability of these competitive foods. Students of elementary and middle schools located in the South were more likely to purchase any SSBs ($p < 0.05$). Moreover, 5th grade children of schools located in the South were also more likely to consume any sweet snacks ($p < 0.05$). In the 5th grade, students of schools located in small towns or rural areas were more likely to purchase sweet snacks when these foods were offered in schools ($p < 0.05$). Children of a school that had more than 50% minority students were more likely to consume any salty snacks or SSBs during the 5th and 8th grades, when these foods were available ($p < 0.05$). Moreover, children of a school that had more than 50% minority students were also more likely to consume any sweet snacks in school during the 8th grade ($p < 0.05$).

Table 10

Percentage of 5th and 8th Grade Children Consuming Sweet Snacks, Salty Snacks and SSBs in Schools When these Competitive Foods Were Offered in Schools

Children and school characteristics	Students who purchase competitive food in schools (%)					
	Sweet snacks		Salty snacks		SSBs	
	5th grade	8th grade	5th grade	8th grade	5th grade	8th grade
All children	42.34	49.91	31.40	38.43	29.90	40.22
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Gender						
Male	44.79	50.37	32.98	37.95	32.36	43.11
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Female	40.55	49.14	30.13	39.03	28.03	37.73
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Race/ethnicity						
White	44.12	48.18	31.50	36.25	27.78	36.64
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Black	35.58	65.13	25.54	50.08	27.41	57.98
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
Hispanic	45.37	49.68	37.72	41.07	37.48	45.61
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Asian	38.68	42.45	29.59	34.58	28.74	34.38
	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
Body weight status						
Normal	46.42	53.76	33.86	40.12	31.87	40.71
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Overweight	32.20	42.92	22.61	36.46	21.21	37.98
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
Obese	42.85	43.28	34.80	34.43	35.25	40.65
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Location type						
City	42.94	49.83	32.95	38.70	30.00	38.95
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Suburb	45.56	50.40	33.19	39.74	32.10	40.90
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Rural area	48.39	46.01	35.11	36.00	37.80	38.52
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

Table 10 (continued)

Children and school characteristics	Students who purchase competitive food in schools (%)					
	Sweet snacks		Salty snacks		SSBs	
	5th grade	8th grade	5th grade	8th grade	5th grade	8th grade
Percentage of minority students						
< 10%	45.25	47.64	30.10	35.37	28.82	37.27
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
10% - 50%	44.62	50.02	32.63	37.24	29.25	38.33
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
> = 50%	46.63	51.08	38.07	43.15	40.21	45.38
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Region						
Northeast	49.71	50.30	35.15	40.63	26.21	37.29
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Midwest	35.84	48.30	28.39	34.56	25.33	36.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
South	51.58	52.34	36.67	40.67	41.38	45.96
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
West	34.64	46.19	31.26	38.49	31.82	39.75
	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)

Note. Statistical significance of gender, race, body weight status, census region, location type, and percentage of minority students during the 5th grade and 8th grades was tested using logistic regression. Statistical significance of any consumption of competitive foods between 5th grade and 8th grade was tested using a two-sample test of proportions. SE is in parenthesis.

Table 10 also presents the change in consumption of competitive foods in schools when children proceeded from the 5th to the 8th grade. Compared to 5th grade children, children in the 8th grade were more likely to consume any sweet snacks, salty snacks, and SSBs in school when these foods were available. Specifically, in elementary schools (5th grade) where sweet snacks were available, about 43% of students had consumed any sweet snacks in school during the last week. When these students proceeded to middle schools, this number increased to 50%. Among those students who consumed sweet snacks in schools, about 67% and 72% of them consumed once or twice during the last week in elementary and middle school, respectively.

When salty snacks were available in their schools, about 31% of 5th grade students bought salty snacks during the last week. When they proceeded to 8th grade in 2007, this number increased to more than 38%. Among those students who bought salty snacks in schools, the majority of them (71% of 5th graders and 72% of 8th graders) bought only once or twice during the last week.

When SSBs were available in elementary schools, about 30% of 5th grade students bought them in school during the last week. This number increased to more than 40% when these students went to the 8th grade. Among those students who bought SSBs in schools, the majority of them (68% of 5th graders and 67% of 8th graders) bought only once or twice during the last week.

One phenomenon related to obesity in children was noted. Among children who were obese, there was no significant difference in consumption of any sweet snacks ($p = 0.83$) or salty snacks ($p = 0.85$) between 5th grade and 8th grade. However, obese children in the 8th grade were significantly more likely to consume any SSBs than obese children in the 5th grade.

Physical Activity Time in School

The PA environment in schools was measured by the total time spent on PE and recess during school days. The majority of the students (67.36%) were exposed to one to two periods of PE each week, and about 60% of the PE lasted 31-60 minutes. Regarding recess, the majority of students (79.18%) had recess daily. When recess periods were offered, more than one third of them lasted 16-30 minutes, and more than half of them lasted 31-45 minutes.

The 2007 ECLSK only surveyed the days of the week that a student participated in PE. About 18% of students did not participate in any PE in a typical week, and more than 35% of students participated in PE every school day.

Because the frequency of PE and recess as well as the amount of time for each PE and recess were all estimated as an interval, e.g., 1-2 times a week, 31-60 minutes each PE, to compute the total time of school PA, I multiplied the midpoint of each response interval for frequency of PE and recess by the midpoint of each response interval for the length of each PE and recess. T-test and regression were conducted to examine any significant difference on PA time between female and male students and between different racial/ethnic groups and school characteristics. Figure 5 presents the distribution of the total school PA time for 5th grade children in 2004

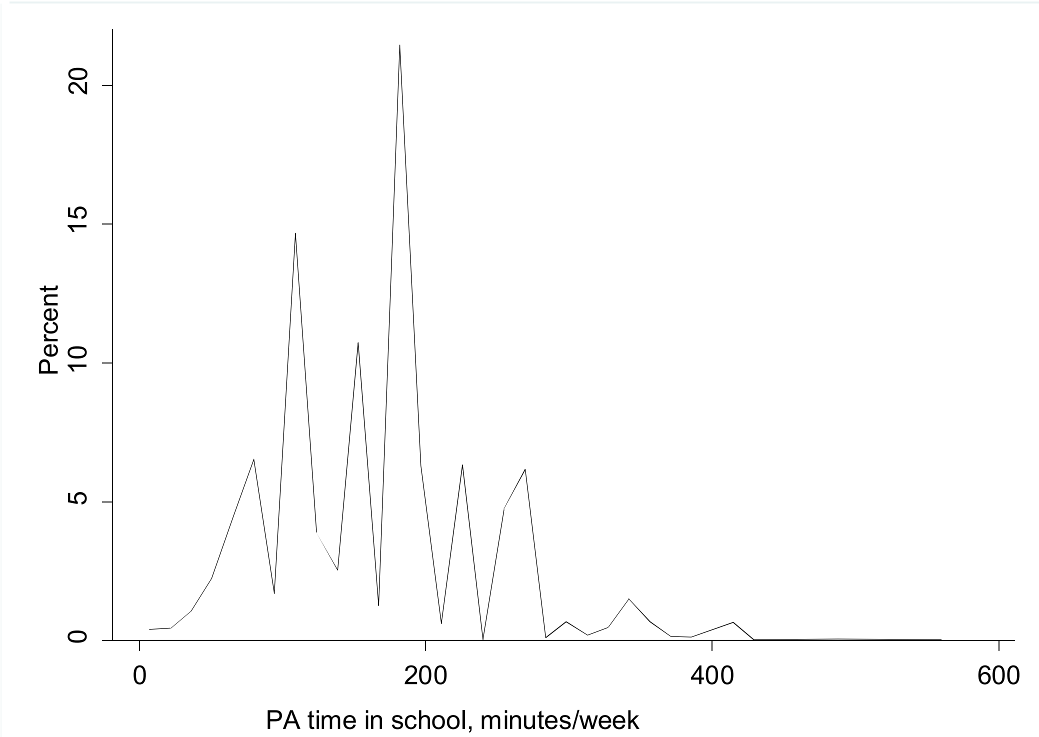

Figure 5. Total school PA time for 5th grade children in 2004.

Table 11 provides descriptive statistics of the school PA time for 5th grade students by child and school characteristics. The results indicate that female and male students did not have significant differences in school PA time. Non-Hispanic black students had significantly less PA time in schools, compared to other racial/ethnic groups. The PA time provided for students varied significantly with school characteristics. Schools located in the West and rural areas provided significantly more PA time to students. Schools located in the Northeast and suburbs had less PA time for students. Schools with 50% or more of minority students also provided less PA time to students.

Table 11
School PA Time for 5^{th} Grade Children in 2004

Children and school characteristics	Mean	SD
Gender		
Male	164.70	74.44
Female	163.20	74.45
Race/ethnicity*		
White	170.00	69.39
Black	139.85	75.60
Hispanic	169.27	80.60
Asian	167.84	74.31
Body weight status		
Normal	168.84	71.16
Overweight	164.98	73.67
Obesity	160.06	71.17
Region*		
Northeast	149.45	56.97
Midwest	168.30	72.70
South	160.58	78.87
West	184.53	72.92
Location type*		
City	162.96	76.54
Suburb	161.33	69.50
Rural area	180.64	71.60
Percentage of minority students*		
< 10%	167.25	64.93
10% - 50%	176.14	74.82
> = 50%	154.06	77.76

Note. Statistical significance of gender, race, body weight status, census region, location type, and percentage of minority students during 5^{th} grade was tested using one-way ANOVA. *indicates statistical significance between categories at $p <= 0.05$.

Children's Physical Activity Level

On average children in the 5th grade exercised or participated in PA on 3.7 days of the past week. When they proceeded to 8th grade, this number increased to 4.6 days. Figure 6 illustrates the change in students' participation in PA when they proceeded from 5th grade to 8th grade.

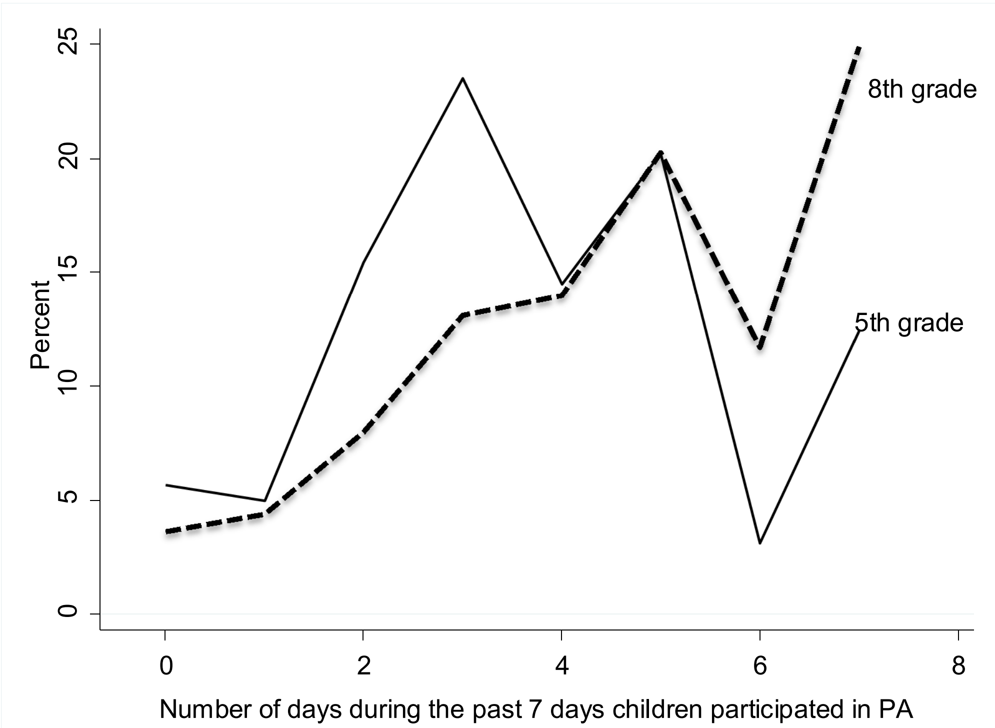

Figure 6. PA level of 5th and 8th grade children.

More than half of the children in the 5th grade and 71% in the 8th grade exercised or participated in PA more than 3 days a week. Boys were more likely than girls to exercise or participate in PA more than 3 days a week. Compared to non-Hispanic white students, minority students were less likely to exercise or participate in PA more than 3 days a week.

Effect of School Competitive Food Availability on Children's Eating Behavior in School

A part of the findings about the effect of the school food environment on children's eating behavior in school is presented in Table 10. Generally, when sweet snacks were offered in schools, the probability of a 5th grader and an 8th grader consuming any sweet snacks in school was 42.34% and 49.91%, respectively. When salty snacks were offered in schools, the probability of a 5th grader and an 8th grader consuming any salty snacks in school was 31.40% and 38.43%, respectively. When SSBs were offered in schools, the probability of a 5th grader and an 8th grader consuming any SSBs was 29.90% and 40.39%, respectively.

A further investigation into the children who had switched schools when they proceeded from 5th grade to 8th grade also showed that the availability of competitive food in school was significantly associated increased consumption of that food. Among the students who transferred from a sweet-snack-unavailable school to a sweet-snack-available school, 49.27% of them consumed some sweet snacks in school during 8th grade. Among the students who transferred from a salty-snack-unavailable school to a salty-snack-available school, about 36.81% of them consumed some salty snacks in school during 8th grade. Among the students who transferred from an SSB-unavailable school to an SSB-available school, 39.22% of them consumed some SSBs in school during 8th grade.

Effect of School Eating Behaviors on Children's Energy Intake

The proportion of students who drank any SSBs during the past 7 days was not significantly different ($p = 0.17$) between the 5th and 8th grades based on ECLSK data. Specifically, 84.91% of 5th grade students drank some SSBs during the past 7 days in 2004. During the 8th grade, 84.20% of them drank some SSBs during the past 7 days.

Table 12
Percentage of 5th and 8th Grade Students Who Consumed any SSBs During the Past 7 Days, by SSB Availability in School

	5th grade			8th grade		
	SSB unavailable	SSB available	p	SSB unavailable	SSB available	p
All students	83.45	85.67	*	82.26	85.29	*
Gender						
Male	84.80	85.90		84.30	86.72	*
Female	82.08	85.47	*	80.01	83.97	*
Race/ethnicity						
White	85.13	87.60	*	82.96	86.41	*
Black	79.20	84.18	*	82.51	84.45	
Hispanic	83.35	83.61		82.74	84.77	
Asian	78.59	77.78		74.01	77.81	

Note. * $P < 0.05$

Chi-square tests were conducted to examine the effect of SSB availability in schools on the likelihood of consuming SSBs during the past 7 days. Table 12 presents the results of the tests. The SSB availability in school had a significant impact on any SSB consumption during the past 7 days for both 5th and 8th grade students. This effect was more evident for female and non-Hispanic white students in both the 5th and 8th grades and for non-Hispanic black children in the 5th grade.

The risk ratio of SSB availability in school was 104% for children in the 5th grade and 8th grade ($p < 0.05$). In other words, SSB availability in school was associated with a 4% increase in the likelihood of any SSB consumption during the past 7 days for 5th and 8th grade students.

Table 13
Association Between Weekly SSB Consumption Frequency in School and Overall SSB Consumption Frequency During the Past 7 Days

	5th grade				8th grade			
	Coefficient	95% CI	t	p	Coefficient	95% CI	t	p
All	0.19	0.16, 0.22	11.36	*	0.24	0.22, 0.27	18.88	*
Gender								
Male	0.20	0.16, 0.25	8.38	*	0.22	0.18, 0.25	11.97	*
Female	0.18	0.13, 0.22	7.69	*	0.27	0.23, 0.30	14.71	*
Race/ethnicity								
White	0.19	0.14, 0.24	7.65	*	0.27	0.23, 0.30	15.65	*
Black	0.19	0.11, 0.27	4.70	*	0.18	0.11, 0.25	5.08	*
Hispanic	0.11	0.03, 0.19	2.79	*	0.19	0.13, 0.25	6.18	*
Asian	0.28	0.16, 0.40	458	*	0.22	0.11, 0.34	3.81	*

Note. * P < 0.05

The weekly SSB consumption in school was also significantly associated with higher overall SSB consumption during the past 7 days for children in the 5th and 8th grades. Table 13 presents the association between weekly SSB consumption in school and overall SSBs during the past 7 days. For children in the 5th grade, each unit increase in the weekly SSB consumption in school was associated with .19 additional unit of overall SSB consumption during the past 7 days. The contribution of weekly SSB consumption in school was more evident for children in the 8^{th} grade, as each unit increase in the weekly SSB consumption in school was associated with .24 additional units of overall SSB consumption during the past 7 days for children at that grade level.

The ECLSK did not measure the total snack consumption for students. As described in the previous chapter, I used NHANES 2003-2004 to estimate the effect of sweet and salty snack consumption in school on the total consumption of sugary and salty snacks for children. NHANES 2003-2004 collected detailed dietary intake information from children of all ages. Children of the same age group as the ECLSK children in the 5^{th} grade (10-12-years old) were included. Table 14 shows the comparison between the analytical sample of NHANES 2003-2004 and ECLSK children in the 5^{th} grade. It is noted that because both NHANES and ECLSK collected information on SSB consumption, statistics on children's SSB consumption were also considered as an indicator of the comparability of these two data sets.

Compared to ECLSK children in the 5^{th} grade, the proportion of girls in the NHANES analytical sample was a bit higher. NHANES also oversampled racial/ethnic minority children. The average BMI and obesity rate of the NHANES analytical sample were higher than for ECLSK children in the 5^{th} grade.

Table 14

Comparison of ECLSK 5th Grade Children and NHANES Analytical Sample

Indicator	ECLSK children in the 5th grade (mean or %)	NHANES analysis sample (mean or %)
Age in months(SD)	132.8 (4.29)	136.2 (8.33)
Male	50.17	48.14
Race/ethnicity		
Non-Hispanic White	57.00	26.86
Non-Hispanic Black	14.44	38.56
Hispanic	17.23	28.72
BMI (SD)	20.68 (4.7)	21.27 (5.36)
Obesity	21.22	25.87
Overweight	20.81	18.67
Children who consumed any SSB during study period	84.32	85.86
Children who consumed any school SSBs during study period	12.92	14.89

Table 15

Overall Consumption of Sweet Snacks, Salty Snacks and SSBs Among NHANES Children and Their Consumption of These Foods in School

	Measured in gram		Measure in kcal	
	Mean	SD	Mean	SD
All foods eaten	1772.43	745.93	2154.39	882.10
SSBs	551.52	462.07	205.3	182.58
Sweet snacks	116.99	127.1	342.90	361.23
Salty snacks	29.65	39.7	146.74	194.58
SSBs in school	54.87	165.61	19.24	53.55
Sweet snacks in school	14.24	51.48	33.06	92.46
Salty snacks in school	5.42	21.97	22.13	92.46

About 18.86% of students reported that they had consumed any sugary snacks in school during the 24-hour period prior to the survey. About 12.16% of the sample

reported that they had consumed any salty snacks in school during the 24-hour period prior to the survey. Table 15 presents the overall consumption of sweet snacks, salty snacks and SSBs among NHANES participants and their consumption of these foods in school during a 24-hour period. Generally, school sweet snacks contributed about 33 kcal, salty snacks contributed 22 kcal, and SSBs contributed 19 kcal to the total energy intake of a 10-12-year-old child per school day.

Table 16

Contribution of School Consumption of Sweet Snacks, Salty Snacks and SSBs to Overall Consumption of These Foods and Total Energy Intake

	coefficient	P-value	95% CI
School consumption of sweet snack			
Overall sweet snack consumption	0.50	*	0.26, 0.74
Energy intake	1.84	*	0.92, 2.76
School consumption of sweet snack			
Overall salty snack consumption	0.60	*	0.43, 0.77
Energy intake	1.62	*	0.51, 2.73
School consumption of sweet snack			
Overall SSB consumption	0.59	*	0.32, 0.86
Energy intake	3.11	*	1.52, 4.70

Note. * P < 0.05

Linear regression was conducted to examine the effect of school consumption of sweet snacks, salty snacks, and SSBs on the consumption of these foods and drinks in other settings and overall energy intake. The results (Table 16) indicated that a large portion of children's consumption of sweet snacks, salty snacks and SSBs was from school. Moreover, children's consumption of these foods and drinks in school was significantly associated with their energy intake. For example, about half of the total amount of sweet snack consumption was obtained from school; one unit of school consumption of sweet snack caused 1.84 units of increase in energy intake.

Effect of Physical Education on Children's Physical Activity Level

I categorized the children into those having PE < 3 times/week and PE >= 3 times/week based on their weekly PE frequency. For children with PE < 3 times/week in the 5th grade, on average they exercised or participated in PA on 3.48 days of the past 7 days. For children with PE >= 3 times/week in the 5th grade, on average they exercised or participated in PA on 4 days of the past 7 days. When they proceeded to the 8th grade, these numbers increased to 4.3 and 4.84 for children of PE < 3 times/week and children of PE >= 3 times/week, respectively.

Regression models were conducted to test the association between children's PA levels and school PE participation. Children's PA level was significantly associated with PE participation during the 5th and 8th grades. Each PE class in school was associated with 0.17 additional days of participation in PA during the past 7 days for 5th and 8th grade students. Table 17 shows the association between weekly PE frequency and children's PA levels.

Table 17

Univariate Analysis of School PE Frequency and Overall PA Levels

	Physical activity frequency during the past 7 days			
	Coefficient	95% CI	t-value	p-value
5th grade				
All	0.17	0.14, 0.20	11.20	<0.001
Gender				
Male	0.13	0.09, 0.17	6.09	<0.001
Female	0.19	0.15, 0.23	9.47	<0.001
Race/ethnicity				
White	0.18	0.15, 0.22	9.36	<0.001
Black	0.10	0.02, 0.18	2.42	<0.05
Hispanic	0.21	0.14, 0.27	6.37	<0.001
Asian	0.10	-0.03, 0.27	1.48	0.138
8th grade				
All	0.17	0.15, 0.19	15.16	<0.001
Gender				
Male	0.17	0.14, 0.20	10.78	<0.001
Female	0.16	0.13, 0.19	10.20	<0.001
Race/ethnicity				
White	0.16	0.14, 0.19	11.84	<0.001
Black	0.22	0.15, 0.29	6.17	<0.001
Hispanic	0.15	0.10, 0.20	5.76	<0.001
Asian	0.19	0.10, 0.28	4.12	<0.001

Estimated Effect of School Food and Physical Activity Environment on Children's BMI

After a thorough calibration and validation process as described in the previous chapter, k in model 4 was estimated as 0.027 for each time of sweet snack consumption during the last week, 0.025 for each time of salty snack consumption during the last week, and 0.05 for each time of SSB consumption during the last week. Compared to sweet snacks or salty snacks, SSB consumption in school had a greater influence on children's

BMI growth. The average net effect of school PA on BMI change α was estimated to be -0.0008 for 5th grade students. That meant that each minute of PA a week caused .0008 unit decreases in BMI for students in the 5th grade when other factors were kept unchanged. The general BMI growth trend β was estimated to be 1.11 in 2 years (from spring 2002 to spring 2004). Figure 7 shows the simulated and observed BMI distribution for students in the 5th grade.

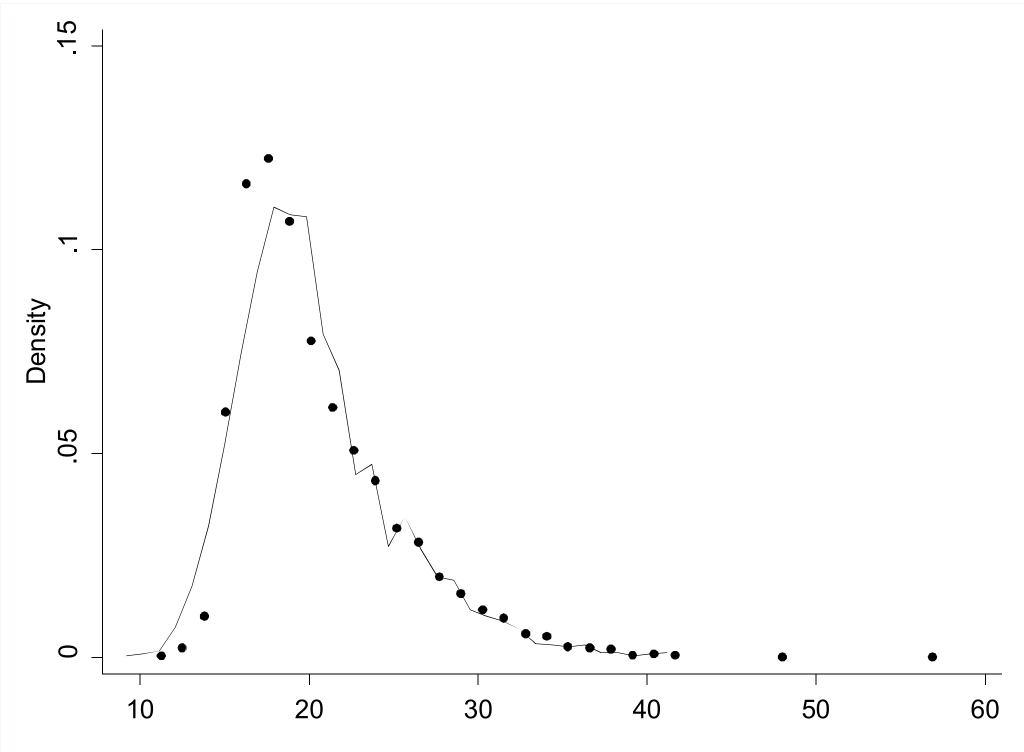

Figure 7. The simulated and observed BMI distribution for students in the 5th grade.

Table 18
Agreement Between Simulated and Observed BMI Distribution for Children in the 5th Grade

	Mean	SD	Correlation coefficient	Percentage		
				Obesity	Overweight	Normal
All						
Observed	20.42	4.70		21.22	20.81	57.97
Simulated	20.35	4.63	0.85	20.71	20.52	58.77
Male						
Observed	20.44	4.76		24.99	17.42	57.59
Simulated	20.34	4.60	0.85	22.88	20.68	56.44
Female						
Observed	20.40	4.64		17.60	24.06	58.34
Simulated	20.35	4.67	0.85	18.47	20.36	61.17

Table 18 lists the keys statistics of the simulated and observed BMI results for 5th grade students. A t-test was used to test for significant difference between the means of the simulated and observed BMI. It showed that there was no significant difference between the means of the simulated and observed BMI for the sample ($t = 1.4484$, $p = 0.15$), boys ($t = 1.38$, $p = 0.17$), and girls ($t = 0.67$, $p = 0.50$). The two-sample variance-comparison test was used to test for significant differences between the variances of the simulated and observed BMI. The results showed that the standard deviations of the simulated and observed BMI were approximately equal for the sample ($f = 1.03$, $p = 0.47$), boys ($f = 1.06$, $p = 0.31$), and girls ($f = 1.00$, $p = 0.98$). The correlation between the simulated BMI and observed BMI was as high as 0.85. The simulated and observed BMI was further categorized as obese, overweight, and normal based on the CDC 2000 growth chart. Kappa statistics were used to measure the agreement on the percentages of simulated and observed BMIs that fell into the categories of obese, overweight, and normal. The agreement was .76 for the sample (expected agreement = 0.45), .75 for boys (expected agreement = 0.44), and .76 for girls (expected agreement = 0.47).

For students in the 8^{th} grade, k in model 4 was estimated as 0.027 for each time of sweet snack consumption during the last week and 0.025 for each time of salty snack consumption during the last week. The effect of each time of SSB consumption during the last week in school on BMI was modeled as 0.06, more than twice the magnitude of the effect of sweet snack or salty snack consumption in school. The average net effect of school PA on BMI change α was estimated to be -0.05. That meant that one PE class a week caused .05 unit decreases in BMI for students in the 8^{th} grade when other factors were kept unchanged. The general BMI growth trend β was estimated to be 1.10 in 3 years (from spring 2004 to spring 2007). Figure 8 shows the simulated and observed BMI distribution for students in the 8^{th} grade.

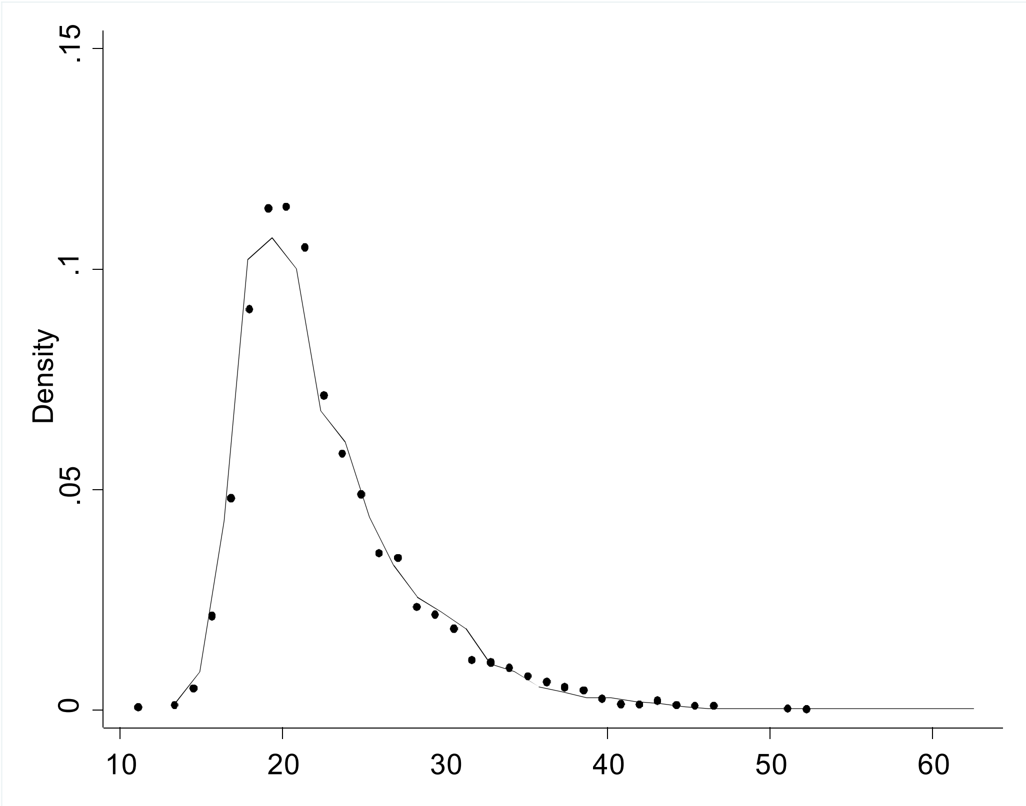

Figure 8. The simulated and observed BMI distribution for students in the 8th grade.

Table 19 lists the key statistics of the simulated and observed BMI results for 8th grade students. Similarly, the t-test was used to test for significant difference between the means of the simulated and observed BMIs. There was no significant difference between them (t = 1.17, p = 0.24). The simulated BMI repeated the observed BMI better for boys than for girls. The difference of the means between the simulated and observed BMI was not statistically significant for boys (t = 1.47, p = 0.14) but was significant for girls (t = 3.05, p < 0.05). Two-sample variance-comparison tests were used to test for significant differences in the variances between the simulated and observed BMIs. The results showed that the standard deviations of the simulated and observed BMIs were approximately equal for the sample (f = 1.03, p = 0.50), boys (f = 0.98, p = 0.69), and girls (f = 1.08, p = 0.15). The correlation between the simulated BMI and observed BMI was 0.87 for the sample, 0.88 for boys, and 0.86 for girls. The simulated and observed BMIs were further categorized as obese, overweight, and normal based on the CDC 2000 growth chart. The kappa statistic was used to test the agreement on the percentages of simulated and observed BMIs that fell into the categories of obese, overweight, and normal. The agreement was 0.79 for the sample (expected agreement = 0.48), 0.80 for boys (expected agreement = 0.48), and 0.78 for girls (expected agreement = 0.48).

Table 19
Agreement Between Simulated and Observed BMI Distribution for Children in the 8th Grade

	Mean	SD	Correlation coefficient	Percentage		
				Obesity	Overweight	Normal
All						
Observed	22.61	5.10		17.85	17.25	64.90
Simulated	22.56	5.17	0.87	18.56	17.38	64.06
Male						
Observed	22.44	5.25		20.56	14.41	65.03
Simulated	22.54	5.19	0.88	21.65	15.28	63.07
Female						
Observed	22.79	4.97		15.23	19.99	64.78
Simulated	22.57	5.16	0.86	15.57	19.41	65.01

Estimated Effect of School Nutrition and Physical Activity Policies on Childhood Obesity Prevention

Scenario 1: All schools limit the availability of sweet snacks in school and do not change the availability of salty snacks and SSBs.

If all schools limit the availability of sweet snacks and do not change the availability of salty snacks and SSBs in school, using children's observed BMI in the 3rd grade as the initial value (which means the policy starts when these children are entering the 4th grade), the mean BMI in the 5th grade will be 0.07kg/m^2 less than the observed mean BMI in the 5th grade. If this policy continued to the 8th grade, the mean BMI at that point would be 0.22 kg/m^2 less than the mean observed BMI in the 8th grade.

I then compared the obesity and overweight rate among 8th grade children without and with this policy starting when the children are entering 4th grade (using children's observed BMI at 3rd grade as the initial value), or starting when the children are entering the 6th grade (using their observed BMI in the 5th grade as the initial value [Table 20]). If this policy starts to be implemented when children are entering the 4th grade, the obesity rate among these children when they are in the 8th grade would be significantly lower than the status quo, but the overweight rate among these children when they are in 8th grade is higher than the status in quo. If the policy starts to be implemented when these children are entering the 6th grade, the obesity and overweight rates among them when they are in the 8th grade have no significant difference from the status quo.

Table 20
Comparison of the Obesity and Overweight Rate Among 8th Grade Children Without and With the Sweet-Snack-Limiting Policy Starting When the Children are Entering the 4th Grade or Starting When the Children are Entering the 6th Grade

Body Weight Status in 8th Grade	Normal weight (%)	Overweight (%)	Obesity (%)
Observed (status in quo)	63.86	16.98	19.16
Policy starts from 4th grade	66.06	17.12	16.82*
Policy starts from 6th grade	64.01	17.37	18.62

Note. The statistical significance of obesity and overweight rate among 8th grade children when the policy starts from the 4th or the 6th grade compared to the status quo was tested using the two-sample test of proportions; * $p < 0.05$.

Scenario 2: All schools limit the availability of salty snacks in school and do not change the availability of sweet snacks and SSB.

If all schools limit the availability of salty snacks and do not change the availability of sweet snacks and SSBs in school, using children's observed BMI in the 3rd grade as the initial value (which means the policy starts when these children are entering the 4th grade), their mean BMI in the 5th grade will be 0.06kg/m^2 less than the observed mean BMI in the 5th grade. If this policy continues to the 8th grade, the mean BMI at that point will be 0.21kg/m^2 less than the observed mean BMI in the 8th grade.

I then compared the obesity and overweight rate among 8th grade children under 3 situations: no policy (status quo), the policy starting when children are entering the 4th grade (using the children's observed BMI in the 3rd grade as he initial value), and the policy starting when the children are entering the 6th grade (using the children's observed BMI in the 5th grade as the initial value [Table 21]). If the policy starts to be implemented when children are entering the 4th grade, the obesity rate among these children when they are in 8th grade is significantly lower than the status quo. But the overweight rate among these children when they are in 8th grade is higher than the status quo. If the policy starts to be implemented when these children are entering the 6th grade, the obesity and overweight rates among them when they are in the 8th grade have no significant difference than the status quo.

Table 21

Comparison of the Obesity and Overweight Rate Among 8th Grade Children Without and With the Salty-Snack-Limiting Policy Starting When the Children are Entering the 4th Grade or Starting When the Children are Entering the 6th Grade

Body Weight Status in 8th Grade	Normal weight (%)	Overweight (%)	Obesity (%)
Observed (status quo)	63.86	16.98	19.16
Policy starts from 4th grade	66.06	17.08	16.92*
Policy starts from 6th grade	64.01	17.30	18.57

Note: The statistical significance of the obesity and overweight rates among 8th grade children when the policy starts from the 4th or 6th grade compared to the status quo was tested using a two-sample test of proportions; * $p < 0.05$.

Scenario 3: All schools limit the availability of SSBs in school and do not change the availability of sweet and salty snacks.

If all schools limit the availability of SSBs and do not change the availability of sweet and salty snacks in school, using children's BMI in the 3rd grade as the initial value (which means the policy starts when children are entering the 4th grade), the mean BMI by the 5th grade will be 0.07kg/m^2 less than the observed mean BMI at that point. If this policy is continued to the 8th grade, the mean BMI will be 0.24 kg/m^2 less than the observed mean BMI at that point.

Table 22
Comparison of the Obesity and Overweight Rate Among 8th Grade Children Without and With the SSB-Limiting Policy Starting when the Children are Entering the 4th Grade or Starting When the Children are Entering the 6th Grade

Body Weight Status in 8th Grade	Normal weight (%)	Overweight (%)	Obesity (%)
Observed (status in quo)	63.86	16.98	19.16
Policy starts from 4th grade	66.06	17.07	16.76*
Policy starts from 6th grade	64.01	17.34	18.40

Note: The statistical significance of obesity and overweight rates among 8th grade children when the policy starts from the 4th or 6th grade compared to the status quo was tested using a two-sample test of proportions; * $p < 0.05$.

I then compared the obesity and overweight rate among 8th grade children under 3 situations: no policy (the status quo), the policy starting when children are entering the 4th grade (using the children's observed BMI in the 3rd grade as the initial value), and the policy starting when the children are entering the 6th grade (using the children's observed BMI in the 5th grade as the initial value [Table 22]). If the policy starts to be implemented when children are entering the 4th grade, the obesity rate among these children when they are in 8th grade is significantly lower than the status quo. But the overweight rate when they are in the 8th grade is higher than the status quo. If the policy starts to be implemented when the children are entering the 6th grade, the obesity and overweight rates among these children when they are in the 8th grade have no significant difference from the status quo.

Scenario 4: Each child is provided with 60 minutes of PA each day in elementary school and takes PE each day in middle school.

If each child is provided with 60 minutes of PA each day in elementary school and takes PE each day in middle school, using the children's BMI in the 3rd grade as the initial value (which means the policy starts when the children are entering the 4th grade), the mean BMI in the 5th grade will 0.15kg/m^2 less than the observed mean BMI at that point, and the average BMI will be 0.41 kg/m^2 less than the observed mean BMI by the 8th grade.

I then compared the obesity and overweight rate among 8th grade children under 3 situations: no policy (the status quo), the policy starts when the children are entering the 4th grade (using their observed BMI in the 3rd grade as the initial value), and the policy starts when children are entering the 6th grade (using their observed BMI in the 5th grade as the initial value [Table 23]). If the policy starts to be implemented when children are entering the 4th grade, the obesity rate among these children when they are in the 8th grade is significantly lower than the status quo. The overweight rate is also lower than the status quo, but the difference is not significant. If the policy starts to be implemented when the children are entering the 6th grade, the obesity and overweight rates among these children when they are in 8th grade have no significant difference from the status quo.

Table 23

Comparison of the Obesity and Overweight Rate Among 8th Grade Children Without and With the PA-Promoting Policy Starting When the Children are Entering the 4th Grade or Starting When the Children are Entering the 6th Grade

Body Weight Status in 8th Grade	Normal weight (%)	Overweight (%)	Obesity (%)
Observed (status in quo)	63.86	16.98	19.16
Policy starts from 4th grade	66.06	16.48	16.20*
Policy starts from 6th grade	64.01	17.16	18.15

Note: The statistical significance of the obesity and overweight rate among 8th grade children when the policy starts from the 4th or 6th grade compared to the status quo was tested using a two-sample test of proportions; * $p < 0.05$.

In summary, if school nutrition and PA policies start to be implemented when children are entering the 4th grade, the obesity prevalence estimated by the 5th and 8th grades in each scenario would be lower than the current obesity prevalence observed for 5th- and 8th-grade children. However, except for scenario 4, the estimated overweight prevalence by the 8th grade in each scenario was higher than the current overweight prevalence observed for 8th grade children. Compared to the policies targeting the availability of sweet snacks and salty snacks in school, policies targeting the availability of SSBs and PA time in school caused more decrease in overweight and obesity prevalence by the 8th grade. Moreover, compared to policies that start from the 6th grade, policies that start from the 4th grade caused more decrease in overweight and obesity prevalence by the 8th grade. These findings have significant implications for policies aimed at improving the school food and PA environment. The following chapter discusses these implications in detail. The strengths and limitations of this study will be covered as well.

CHAPTER V

DISCUSSION AND CONCLUSION

The purpose of the present study is to explore the influence of the school food and PA environment on children's BMI and energy balance-related behaviors and to examine the effect of school nutrition and physical activity policies on childhood obesity prevention. Guided by the Social Ecological Model, seven hypotheses were formulated for this study.

Using the Modeling & Simulation approach and empirical data derived from the ECLSK and NHANES 2003-2004, the present study demonstrated that availability of competitive foods in school was associated with greater consumption of those foods in schools, higher energy intake, and increased weight gain, while more PA opportunities in school were associated with higher PA levels and reduced weight gain among children. The results of this study also demonstrated the efficacy of school policies that limit the availability of competitive foods and enhance PA opportunities in school on childhood obesity prevention. In the following section of this chapter, the main findings for each hypothesis are reviewed, followed by a discussion of these findings and a comparison of them with previous studies. The implications of these findings for future policy making, the strengths, and the limitations of the present study are also discussed.

School Food Environment and Children's Eating Behaviors in School

The current study found supporting evidences for the hypothesis that competitive foods in school led to increased consumption of those foods in schools. The effect of the school food environment on children's eating behaviors in school was more evident as children proceeded from elementary school to middle school. These results are consistent with previous studies with more limited populations. Previous studies with a focus on the short-term effect of school interventions reducing the availability of chips, candy, desserts, and sugar-sweetened drinks in schools found that modification of the school food environment by eliminating or limiting the availability of competitive foods in certain venues (such as vending machines and canteens) was associated with less consumption of these foods from those venues (Cullen et al., 2006; Wordellet al., 2012).

Notably, this study found that the school food environment for U.S. children was barely satisfactory. In 2004 more than half of 5th grade students reported sweet and salty snacks were available and accessible in their schools, and more than 39% of them reported that sugar-sweetened drinks were offered in their schools. The school food environment in middle schools was even worse. In 2007, 69%, 73%, and 63% of 8th grade students reported that their schools offered sweet snacks, salty snacks, and sugar-sweetened drinks, respectively, in their schools. These results are consistent with a GAO (U.S. Government Accountability Office) report in 2005, which found that nearly 9 out of 10 schools offered competitive foods through one or more venues, including a la carte cafeteria lines, vending machines, and school stores with competitive foods, which are more commonly found in high schools and middle schools than in elementary schools (U.S. Government Accountability Office, 2005).

The unhealthy school food environment reflected in the results of this study highlighted the necessity of modifying children's eating behavior in schools through restricting competitive foods sales in schools. Nevertheless, the powerful influence of the school food environment on children's eating behavior in school suggested that attention should also be devoted to other approaches, such as adopting nationwide standards for specifying allowable and nutritional content of competitive foods.

School Eating Behaviors and Children's Diet

This study also added supporting evidence for the hypothesis that the availability of competitive foods in schools is associated with increased overall consumption of these foods in school and non-school settings. These results help us understand the interaction of children's eating behaviors in different settings. The school food environment affected not only the children's diet quality in school; it also impacted their diet at home or in other venues, such as restaurants.

The results of this study also provide insights into the debate on whether limited access to competitive foods in schools will be compensated by more consumption from other settings. Using household panel purchase data, Huang & Kiesel (2012) compared soft drink purchases before and after a soft drink ban was implemented, as well as soft drink purchases between states with a soft drink ban and states without soft drink bans. The results found that restricted availability at schools did not result in compensation at home. This suggested that limiting the availability of soft drinks in schools could eventually reduce overall consumption of soft drinks among school-age children. However, by linking state beverage policies obtained through legal research databases with SSB consumption information from the ECLSK, Taber, Chriqui, Powell, & Chaloupka (2012) found that state policies governing the sale of SSBs in school reduced in-school SSB purchases but not overall SSB consumption. Several methodological limitations might have contributed to this conclusion, e.g., schools' compliance with state policies not being verified and the cross-sectional nature of the study making it impossible to infer causality between policies and any change in SSB purchasing and consumption. Through direct estimation of the contribution of in-school consumption of sweet snacks, salty snacks, and SSBs to the total consumption of these foods (including in-school and outside-of-school consumption), the present study demonstrated that schools were an important source of sweet snacks, salty snacks, and SSBs for children. Therefore, limiting access to competitive foods in schools would lead to a reduction in the total consumption of these foods and improve the quality of children's diet, which was consistent with the findings of Huang & Kiesel (2012).

School Physical Activity Environment and Children's Physical Activity Level

Similar to the school food environment, the school PA environment for U.S. children was barely satisfactory. The National Association for Sport and Physical Education (NASPE) recommends that all elementary school children should be provided with 150 minutes of instructional PE per week and at least one daily period of recess of at least 20 minutes in length (Society of Health and Physical Educators, n.d.). The results of this study showed that in 2004 only about 13% of 5th grade children met the requirement for PE, and only 55% of 5th grade children met the requirement for recess. The proportion of 5th grade children who met both requirements was less than 6%.

Hypothesis 3 argued that more PA opportunities in school were associated with higher PA levels. The results of the present study supported this hypothesis. For children who had more PE or recesses in school, their PA levels during the previous 7 days were significantly higher. For many students, school was the main place where they participated in PAs.

In contrast to studies (Fremeaux et al., 2011) that found evidence of compensation between more PA in schools with less in other settings, the results of this study found that both the total time and the frequency of school PE and recess were positively associated with children's PA levels during the previous 7 days. The results are consistent with a previous study that used nationally representative, objectively measured physical activity data (Longet al., 2013).

These results suggest that schools play a unique role in promoting PA among children. School PE programs not only show children that it is fun to be physically active but also offer opportunities to teach children the knowledge and skills conducive to maintaining physical activity outside of school. A systematic review (Ridgers, Stratton, & Fairclough, 2006) of the PA level of children during school playtime found that school recess contributed 4.7-40% of the recommended moderate-to-vigorous physical activity (MVPA) a day for boys and 4.5-30.7% for girls.

School Food and Physical Activity Environment and Children's BMI

Using the M&S approach and empirical data, the present study demonstrated the effect of the school food and PA environment on children's BMI growth. Compared to sweet snacks and salty snacks, the detrimental effect of the availability of SSBs in school on children's BMI growth was more evident. This result was supported by previous systematic reviews about the relation between SSBs and weight gain in children (Malik, Pan, Willett, & Hu, 2013). The findings of this systematic review demonstrated an overall positive association between consumption of SSBs and weight gain in children. Moreover, in this review, the magnitude of the effect was found to be a 0.06-unit increase in BMI over 1-year period for each serving increase in SSB consumption. It should be noted that this systematic review estimated the overall SSB consumption in both school and non-school settings. The present study estimated that the effect of school SSB consumption would be 0.05-0.06-unit in BMI increase for each occasion of SSB consumption each week over a 2-to-3-year period in school, which was coincident with the findings of the systematic review (Malik et al., 2013).

The effect size of school sweet snack consumption on BMI was estimated as a 0.027-unit BMI increase for each occasion of sweet snack consumption, and the effect size of school salty snack consumption was estimated as a 0.025-unit BMI increase for each occasion of salty snack consumption. To my knowledge, this is the first study to estimate the effect of school sweet snack or salty snack availability on children's BMI growth. Since it is known that the availability of sweet snacks or salty snacks in school positively associates with overall consumption of these foods, it seems feasible to gauge the findings of the present study by examining the relationship between sweet or salty snack consumption and children's weight gain. However, findings about the relationship between sweet or salty snack consumption and weight gain in children have been inconsistent in previous studies. A study by Field et al. (2004) found that snack foods were not an important independent determinant of weight gain among children and adolescents, whereas the Bogalusa Heart Study found that the total amount of foods consumed from snacks was positively associated with overweight status among children (Nicklas, Yang, Baranowski, Zakeri, & Berenson, 2003).

The present study also demonstrated the effect of a healthy school PA environment on controlling excessive weight gain among children. In this study, the effect size of the school physical activity environment on BMI was modeled as a 0.0008-unit decrease in BMI for each minute of PE or recess time for children in the 5th grade and a 0.05-unit decrease in BMI for each PE class for children in the 8th grade. These results were in line with the findings on school-based PA interventions. A recent systematic review of the impact of long-term (lasting for more than 12 months) school-based PA interventions found an average of 2.23 kg/m^2 lower BMI increments in the intervention groups that primarily consisted of 6- to 12 year-old children (Mei et al., 2016).

School Nutrition and Physical Activity Policies and Childhood Obesity Prevention

The results of the current study found supporting evidences for the hypothesis that school policies targeting the availability of competitive foods and opportunities for school PA were capable of reducing childhood obesity. The simulation results of the present study also demonstrated the necessity of policy sustainability, which was defined as the capacity of a project or a policy to continue to deliver its intended benefits over a long period of time (Bamberger & Cheema, 1990; Shediac-Rizkallah & Bone, 1998). The magnitude of obesity prevalence reduction caused by the implementation of school food and physical activity policies was about 0.6% if these policies lasted for 2 years (from 3rd grade to 5th grade), whereas the magnitude of obesity prevalence reduction caused by the implementation of these policies was about 2% if these policies continued until these children were in the 8th grade.

Policy Implications

The findings of this study suggested that competitive foods were still commonly available in schools and consumed by children, especially middle school children. The findings also suggested that consumption of competitive foods in schools had adverse effects on children's diet and body weight status. In order to curb the epidemic of childhood obesity, any comprehensive prevention program should include the strategy of reducing low-nutrient, energy-dense foods and beverages in school. Policies affecting the foods provided in schools include limits and nutritional standards. The 2007 IOM report, *Nutrition Standards for Healthy Schools: Leading the way Toward Healthier Youth,* recommended that federally reimbursable school nutrition programs should be the main source of nutrition at school, opportunities for competitive foods should be limited, and if competitive foods are available, they should consist of nutritious fruits, vegetables, whole grains, and nonfat or low-fat milk and dairy products (IOM, 2007). As required by the

Healthy, Hunger-Free Kids Act of 2010, starting in school year 2014-15, all foods sold in schools, including those sold a la carte, in the school store, and in vending machines during the school day, must meet nutrition standards set by the USDA. Consistent with the IOM recommendation, the USDA nutrition standards established that any food sold in schools must be a “whole grain-rich” product; have as the first ingredient a fruit, a vegetable, a dairy product, or a protein; be a combination food that contains at least 1/4 cup of fruit and/or vegetables or contains 10% of the daily value of one of the nutrients of public health concern in the 2010 Dietary Guidelines for Americans (USDA, 2016). Recent surveys based on nationally representative data collected by the Bridging the Gap Study indicated that the nation’s schools have made progress in limiting access to competitive foods or replacing unhealthy competitive foods with healthy foods, but more effort was still needed to improve the school food environment (Turner, Terry-McElrath, Johnston, O’Mally, & Chaloupka, 2012).

This study demonstrated that improving PA opportunities for children, in addition to restricting the availability of unhealthy competitive foods in schools, could prevent childhood obesity. To prevent a positive energy balance among children, efforts must also be directed to the school PA environment. The 2012 IOM report, *Accelerating Progress in Obesity Prevention: Solving the Weight of the Nation,* recommended that the federal and state governments, state and local education agencies, and local school districts should ensure provision of adequate opportunities to all students in grades K-12 to engage in 60 minutes of physical activity per school day, and that state legislatures and departments of education should enact policies with appropriate funding to ensure the provision of daily quality physical education at school for all students in grades K-12 (IOM, 2012). However, school policies at all levels that include a strong physical activity component are still lacking. Further, although some states have established school policies to meet the national school-based PA guidelines, implementation, monitoring, and evaluation of these policies are either nonexistent or insufficient (Carlson et al., 2013).

The key settings for children to live, learn, and play are the home, school, and community. Modifying the school food and physical activity environment, by itself, is not enough to curb the obesity epidemic. Integrated actions that systematically improve food consumption and physical activity in all settings are needed. The 2012 IOM report, *Accelerating Progress in Obesity Prevention: Solving the Weight of the Nation,* identified five opportunities for public health policy to promote healthy weight among adults and children. They are: making schools a national focal point for obesity prevention, making physical activity an integral and routine part of life, ensuring that healthy food and beverage options are routinely an easy choice, marketing what matters for a healthy life, and expanding the role of health care providers, insurers, and employers in obesity prevention (IOM, 2012).

The results of the present study confirmed that policies that were implemented in children's early stages of school life were more effective in preventing obesity. A continuum of prevention interventions across the life course is essential in curbing the obesity epidemic. A variety of policy and regulatory steps should be taken to create supportive environments for healthy eating and PA for children and families during children's early years. For example, the community should ensure that indoor and outdoor recreation areas encourage all children, including infants, to be physically active. Another example is requiring that health and education professionals should be well trained and educated and have the right tools to increase children's healthy eating and counsel parents about their children's diet (IOM, 2011). Further, sustained policies have been shown to be the most effective in preventing childhood obesity in this study. To curb the childhood obesity epidemic in the U.S., sustained policies at all levels, which are likely to be achieved through planning and budgeting for the longer term, as well as identification of cost-effective interventions are needed to ensure healthy lifestyle changes (WHO, 2012).

Strengths and Limitations

The most distinctive strength of this study is the use of a simulation modeling approach to examine the effect of the school environment on childhood obesity. This study formulated four models to examine the effects of school food and PA environments on children's BMI and energy balance-related behaviors in school and non-school settings. In the BMI model, each child was assumed to be placed in a school with a starting condition (e.g., a starting BMI) and given a set of adaptive rules for interaction with the environment. Each child's interaction with their school food and PA environment then produced output for his/her own self and for his/her group as a whole. This approach allowed us to gain insights on the effect of a series of school-based food and PA policies on children's BMI and childhood obesity—a study that was too costly or difficult to estimate using traditional approaches. The M&S approach also allowed us to take into account the feedback of school-based policies. In this study, the BMI change of each child in the 8^{th} grade was calculated based on their BMI in last time interval (5^{th} grade), which was a result of previous school-based policies. The second strength of this study is the use of a combination of different national data sets. So far, no single data set can perfectly address all the research questions of this study. The ECLSK and NHANES are the two nationally representative surveys that provide the most comprehensive data on children's diet, PA, and anthropometric measures. Each has strengths and limitations. NHANES provides detailed information on children's diet and PA but has a cross-sectional nature. The ECLSK is a longitudinal survey but offers limited information on children's overall diet and PA. They complemented each other in this study. They made it possible to systematically examine the effect of school food and physical activity environments on children's BMI and energy balance-related behaviors. This study also accounted for the heterogeneity of individuals and difference in gender and race.

This study has several limitations. First, while it is considered as strength of this study, the use of different data sets also posed a challenge. The ECLSK and NHANES are different in study design, sample composition, and survey method. It is likely that findings based on NHANES data cannot be generalized to the ECLSK sample. To overcome this limitation, an analytical sample extracted from the 2003-2004 NHANES was constructed to match the ECLSK sample. Second, information on diet and PA was self-reported and therefore subject to measurement errors. However, objective measurement of diet and PA for a large population is challenging and expensive, and despite the self-reporting limitation, these data sets have been widely used in related research. Third, consumption of competitive foods and PA in the ECLSK were measured in terms of frequency. Consumption frequency may not accurately reflect the total amount of food consumed or energy intake. Also PA frequency is a sketchy measure of PA level, which should be calculated by the total time spent in PA multiplied by the PA intensity in that time frame. The use of consumption and PA frequency rather than amount or calories will increase the disparity in food consumption and PA among children. Fourth, the estimation of average BMI growth did not control for confounding factors. Fifth, the small size of the NHANES analytical sample may cause biased results as to the effect of school competitive foods on children's energy intake. Finally, the simulation models in this study were built on several assumptions and validated with one data set. They may not represent the complexity and details of the real system. However, the purpose of using modeling and simulations is to give insights, not to produce a copy of the real system.

Conclusion

In conclusion, using a simulation model and empirical data derived from the ECLSK and NHANES, the present study demonstrated the adverse effect of poor school food and PA environments on children's BMI growth, diet behavior, and PA in school and non-school settings. School-based policies that limit the availability of competitive foods and enhance PA opportunities are capable of reducing childhood obesity. The results of this study also indicated that systematically improving the food and PA environment in the home and the community is essential for obesity prevention. Since baseline BMI plays an influential role in children's BMI growth, preventive interventions should be taken as early as the first years of children's life. Simulation models are a useful method for exploring the effects of proposed interventions on the environmental factors that affect childhood obesity and energy balance-related behaviors.

REFERENCES

Abidin, N. Z., Mamat, M., Izham, T. H. T., Dangerfield, B., & Baten, Md. A. (2014). System dynamics modeling and its implications for childhood obesity prevention: Evidence from improving the consumption of portion size and meal frequency. *Applied Mathematical Science, 8* (66), 3283-3296. http://dx.doi.org/10.12988/ams.2014.43247

Albertson, A. M., Reicks, M., Joshi, N., & Gugger, C. K. (2016). Whole grain consumption trends and associations with body weight measures in the United States: Results from the cross sectional National Health and Nutrition Examination Survey 2001–2012. *Nutrition Journal,15*(8). doi**:** 10.1186/s12937-016-0126-4

American Academy of Pediatrics. (2014). *About childhood obesity*. Retrieved from http://www2.aap.org/obesity/about.html.

American Cancer Society (2011). *Cancer facts & figures 2011*. Retrieved from http://www.cancer.org/acs/groups/content/@epidemiologysurveilance/documents/document/acspc-029771.pdf

Bamberger, M., & Cheema, S. (1990). *Case studies of project sustainability: Implications for policy and operations from Asian experience*. Washington, DC: The World Bank.

Banks, Carson, Nelson, & Nicol. *Introduction to simulation*. [PDF document].Retrieved from Lecture Notes Online Website www.ece.ut.ac.ir/Classpages/S86/ECE462 /slides/Chapter1.pdf

Barlow, S. E., & the Expert Committee. (2007). Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: Summary report. *Pediatrics*, *120*(Supplement 4), S164—S192.

Bayol, S. A., Farrington, S. J., & Stickland, N. C. (2007). A maternal 'junk food' diet in pregnancy and lactation promotes an exacerbated taste for 'junk food' and a greater propensity for obesity in rat offspring. *British Journal of Nutrition, 98*, 843–851

Bergman, E. A., Englund T., Taylor K. W. Watins, T., Schepman, S. & Rushing, K. (2014). School lunch before and after Implementation of the Healthy Hunger-Free Act. *The Journal of Child Nutrition & Management*, *38*(2).

Bes-Rastrollo, M., Martínez-González, M. A., Sánchez-Villegas, A., Arrillaga, C. de la F., & Martínez, J. A. (2006). Association of fiber intake and fruit/vegetable consumption with weight gain in a Mediterranean population. *Nutrition, 22*(5), 504-511

Bodor, J. N., Rice, J. C., Farley, T. A., Swalm, C. M., & Rose, D. (2010).The Association between obesity and urban food environments. *Journal of Urban Health, 87*(5), 771–781

Bodor, J. N., Rose, D., Farley, T. A., Swalm, C., & Scott, S. K. (2008). Neighborhood fruit and vegetable availability and consumption: the role of small food stores in an urban environment. *Public Health Nutrition, 11*(4), 413-420.

Bodor, J. N., Ulmer, V. M., Dunaway, L. F., Farley, T. A., & Rose, D. (2010). The rationale behind small store interventions in low-income urban neighborhoods: Insights from New Orleans. *The Journal of Nutrition, 140*, 1185-1188.

Braithwaite, I., Stewart, A.W., Hancox, R. J., Beasley, R., Murphy, R., & Mitchell, E. A. (2013). The worldwide association between television viewing and obesity in children and adolescents: Cross-sectional study. *PLOS ONE, 8*(9).

Cabrera Escobar, M. A., Veerman, J. L., Tollman, S. M., Bertram, M. Y., & Hofman, K. J. (2013). Evidence that a tax on sugar sweetened beverages reduces the obesity rate: A meta-analysis. *BMC Public Health,13*, 1072.

Caldwell, E. M., Kobayashi, M. M., DuBow, W. M., & Wytinck, S. M. (2008). Perceived access to fruits and vegetables associated with increased consumption. *Public Health Nutrition, 12*, 1743-50.

California Center for Public Health Advocacy. (2014). *Legislative Success*. Retrieved from http://www.publichealthadvocacy.org/legsuccess.html.

Carlson, J.A., Sallis, J.F., Chriqui, J.F., Schneider, L., McDermid, L.C., & Agron, P. (2013). State policies about physical activity minutes in physical education or during school. *Journal of School Health, 83*(3), 150-156.

Carroll, D. (2005, April 29). Reducing schools's revenues. *The Arizona Republic.* Retrieved from http://archive.azcentral.com/arizonarepublic/tempe/articles /0429t-junkfoodZ10.html

CDC. (2009). *Youth physical activity: The role of school*. Retrieved from http://www.cdc.gov/healthyyouth/physicalactivity/toolkit/factsheet_pa_guidelines_ schools.pdf

CDC. (2010). *The CDC guide to strategies for reducing the consumption of sugar-sweetened beverages.* http://www.cdph.ca.gov/SiteCollectionDocuments /StratstoReduce_Sugar_Sweetened_Bevs.pdf

CDC. (2012). *Competitive foods and beverages in U.S. schools: A state policy analysis.* Atlanta: U.S. Department of Health and Human Services.

CDC. (2014a). *About BMI for children and teens*. Retrieved from http://www.cdc.gov /healthyweight/assessing/bmi/childrens_bmi/about_childrens_bmi.html

CDC. (2014b). Youth risk behavior surveillance—United States, 2013. *MMWR ,63*(SS-4).

CDC. (2014c). *NHANES 2011–2012 overview.* Retrieved from http://www.cdc.gov/nchs/nhanes/nhanes2011-2012/overview_g.htm

CDC. (2015). *Childhood obesity facts.* Retrieved from http://www.cdc.gov /healthyschools/obesity/facts.htm

Chan, C. B., Spangler, E., Valcour, J., & Tudor-Locke, C. (2003). Cross-sectional relationship of pedometer-determined ambulatory activity to indicators of health. *Obesity Research, 11*(12), 1563-1570

Chriqui, J. F., Resnick, E. A., Schneider, L., Schermbeck, R., Adcock, T., Carrion, V., & Chaloupka, F. J. (2013). *School district wellness policies: Evaluating progress and potential for improving children's health five years after the federal mandate. School Years 2006–07 through 2010-11.* Retrieved from www.bridgingthegapresearch.org.

Christian, M., & Gereffi, G. (2010). The marketing and distribution of fast food. In M.

Freemark (Ed.) Pediatric Obesity: Etiology, Pathogenesis, and Treatment. Retrieved from https://www.researchgate.net/publication/256007409_The_Marketing_and_Distribution_of_Fast_Food

Cullen, K. W., Watson, K., Zakeri, I., & Ralston, K. (2006). Exploring changes in middle-school student lunch consumption after local school food service policy modifications. *Public Health Nutrition, 9*(6), 814-820

Cullen, K.W., & Zakeri, I. (2004). Fruits, vegetables, milk, and sweetened beverages consumption and access to `a la carte / snack bar meals at school. *American Journal of Public Health, 94*(3), 463–467.

Deshmukh-Taskar, P., Nicklas, T. A., Morales, M., Yang, S-J., Zakeri, I., & Berenson, G. S. (2006). Tracking of overweight status from childhood to young adulthood: The Bogalusa Heart Study. *European Journal of Clinical Nutrition, 60*, 48–57.

Egger, G. & Swinburn, B. (1997). An “ecological” approach to the obesity pandemic. *BMJ, 135*

Ervin, B. R., & Ogden, C. L. (2013). Trends in intake of energy and macronutrients in children and adolescents from 1999-2000 through 2009-2010. *NCHS Data Brief, 113*.

Ervin, B. R., & Ogden, C. L. (2013). Trends in intake of energy and macronutrients in children and adolescents from 1999-2000 through 2009-2010. *NCHS Data Brief*, *113*.

Ervin, B. R., Kit, B. K., Carroll, M. D., & Ogden, C. L. (2012). Consumption of added sugar among U.S. children and adolescents, 2005–2008. *NCHS Data Brief, 87*.

Field, A. E., Austin, S. B., Gillman, M. W., Rosner, B., Rockett, H. R., & Colditz, G. A. (2004). Snack food intake does not predict weight change among children and adolescents. *International Journal of Obesity and Related Metabolic Disorders, 28*(10), 1210-1216.

Field, A. E., Gillman, M. W., Rosner, B., Rockett, H. R., & Colditz, G. A. (2003). Association between fruit and vegetable intake and change in body mass index among a large sample of children and adolescents in the United States. *International Journal of Obesity, 27*,821–826.

Finkelstein, D.M., E.L. Hill, & Whitaker, R. C. (2008). School food environments and policies in US public schools. *Pediatrics, 122*(1), e251–e259.

Food Research and Action Center (2010). *How competitive foods in schools impact student health, school meal programs, and students from low-income families.* Retrieved from http://frac.org/pdf/CNR05_competitivefoods.pdf

Frederick, C. B., Snellman, K., & Putnam, R.D. (2014). Increasing socioeconomic disparities in adolescent obesity. Proceedings of *the National Academy of Sciences of the United States of America*, *111*(4), 1338–1342

Fremeaux, A. E., Mallam, K. M., Metcalf, B. S., Hosking, J., Voss, L. D., & Wilkin, T. J. (2011). The impact of school-time activity on total physical activity: The activitystat hypothesis (EarlyBird 46). *International Journal of Obesity, 35*(10), 1277–1283.

Frumkin, H. (2006). Introduction: safe and healthy school environments. In H. Frumkin,

R. J. Geller, I. L. Rubin, & J. Nodvin (Eds.), *Safe and healthy school Environments*. New York: Oxford University Press.

Fryar, C. D., Carroll, M. D., & Ogden, C. L. (2012). *Prevalence of overweight, obesity, and extreme obesity among adults: United States, trends 1960-1962 through 2009-2010*. Retrieved from http://www.cdc.gov/nchs/data/hestat /obesity_adult_09_10/obesity_adult_09_10.htm

Fryar, D. C., Carroll, M. D., Ogden, C. L. (2014) *Prevalence of overweight, obesity, and extreme obesity among adults: United States, 1960-1962 through 2011-2012*. Retrieved from http://www.cdc.gov/nchs/data/hestat/obesity_adult_11_12 /obesity_adult_11_12.htm

Glanz, K., Rimer, B.K., & Lewis, F.M. (Eds.). (2002). *Health behavior and health education: Theory, research and practice*. San Fransisco: Wiley & Sons.

Gustat, J., Rice, J., Parker, K. M., Becker, A. B., & Farley, T. A. (2012). Effect of changes to the neighborhood built environment on physical activity in a low-income African American neighborhood. *Preventing Chronic Disease, 9* (110165).

Hammond, R. A. (2009). Complex systems modeling for obesity research. *Preventing Chronic Disease, 6*(3),A97. Retrieved from http://www.cdc.gov/pcd/issues/2009 /jul/09_0017.htm.

Harris, K. C., Kuramoto, L. K., Schulzer, M., & Retallack, J. E. (2009). Effect of school-based physical activity interventions on body mass index in children: A meta-analysis. *Canadian Medical Association Journal, 180*(7), 719-726.

Hennessy, E., Ornstein, J. T., Economos, C. D., Herzog, J. B., Lynskey, V., Coffield, E., & Hammond, R. A. (2016). Designing an agent-based model for childhood obesity intervention: A case study of ChildObesity180. *Preventing Chronic Disease, 13* (150414). DOI: http://dx.doi.org/10.5888/pcd13.150414.

Hill, J. O., Wyatt, H. R., & Peters, J. C. (2012). Energy balance and obesity. *Circulation, 126*, 126-132

Horgen, K. B., & Brownell, K. D. (2002). Comparison of price change and health message interventions in promoting healthy food choices. *Health Psychology, 21*(5), 505–512.

Huang, R., & Kiesel, K. (2012). Does limited access at school result in compensation at home? The effect of soft drink bans in schools on purchase patterns outside of schools. *European Review of Agriculture Economics, 39* (5), 797-820. doi: 10.1093/erae/jbs003

IOM. (2007) *Nutrition standards for foods in schools: Leading the way toward healthier youth*. Washington, DC: National Academies Press.

IOM. (2012). *Accelerating progress in obesity prevention: Solving the weight of the nation*. Washington, DC: National Academies Press

IOM. (201l). *Early childhood obesity prevention policies*. Washington, DC: National Academies Press.

Izumi, B. T., Zenk, S. N., Schulz, A. J., Mentz, G. B., & Wilson, C. (2011). Associations between neighborhood availability and individual consumption of dark-green and orange vegetables among ethnically diverse adults in Detroit. *Journal of the American Dietetic Association, 111*(2), 274-279.

Johnson, L., Mander, A. P., Jones, L. R., Emmett, P. M., & Jebb, S. A. (2008). Energy-dense, low-fiber, high-fat dietary pattern is associated with increased fatness in childhood. *The American Journal of Clinical Nutrition, 87*,846–54

Juster, F. T., Ono, H., & Stafford, F. P. (2004). *Changing time of American youth: 1981-2003*. Retrieved from http://www.ns.umich.edu/Releases/2004 /Nov04/teen_time_report.pdf

Kaiser, K. A., Brown, A. W., Brown, M. M. B., Shikany, J. M., Mattes, R. D., & Allison, D. B. (2014). Increased fruit and vegetable intake has no discernible effect on weight loss: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition, 100*(2), 567-576.

Kelishadi, R., & Azizi-Soleiman, F. (2014). Controlling childhood obesity: A systematic review on strategies and challenges. *Journal of Research in Medical Sciences*, *19*(10), 993–1008.

Kesten, J. M., Griffiths, P. L., & Cameron, N. (2011). A systematic review to determine the effectiveness of interventions designed to prevent overweight and obesity in pre-adolescent girls. *Obesity Reviews, 12*(12), 997-1021.

Kim, S. A., Moore, L. V., Galuska, D., Wright, A. P., Harris, D., Grummer-Strawn, L. M., … Rhodes, D. G. (2014, August 8). Vital Signs: Fruit and vegetable intake among children — United States, 2003–2010. *MMWR, 63*(31), 671-676

Kit, B. K., Carroll, M. D. & Ogden, C. L. (2011).Low-fat milk consumption among children and adolescents in the United States, 2007–2008. *NCHS Data Brief, 75*.

Kremers, S., de Bruijn, G.-J., Visscher, T., van Mechelen, W., de Vries, N., Brug, J. (2006). Environmental influences on energy balance-related behaviors: A dual-process view. *International Journal of Behavioral Nutrition and Physical Activity*, 3, 9.

Kruger, D. J., Greenberg, E., Murphy, J. B., DiFazio, L. A., & Youra, K. R. (2014).Local concentration of fast-food outlets is associated with poor nutrition and obesity. *American journal of health promotion, 28*(5), 340-343.

Kubik, M.Y., Lytle, L. A., Hannan, P. J., Perry, C. L., & Story, M. (2003). The association of the school food environment with dietary behaviors of young adolescents. *American Journal of Public Health, 93*(7), 1168–1173.

Lasater, G., Piernas, C., & Popkin, B. M. (2011). Beverage patterns and trends among school-aged children in the US, 1989-2008. *Nutrition Journal, 10*,103

Lee, S. M., Burgeson, C. R., Fulton, J. E. & Spain, C. G. (2007). Physical education and physical activity: Results from the School Health Policies and Programs Study 2006. *Journal of School Health, 77*(8):435-463.

Let's Move. (2010). *Child nutrition reauthorization: Healthy, Hunger-Free Kids Act of 2010*. Retrieved from http://www.whitehouse.gov/sites/default/files /Child_Nutrition_Fact_Sheet_12_10_10.pdf

Levi, J., Segal, L. M., Thomas, K., Laurent, R. St., Lang, A., & Rayburn, J. (2013). *How* *obesity threatens America's future 2013*. Retrieved from http://healthyamericans.org /assets/files/TFAH2013FasInFatReportFinal%209.9.pdf

Levy, D. T., Marbry, P. L., Wang, Y. C., Gortmaker, S., Huang, T. T.-K., Marsh, T., … Swinburn, B. (2011). Simulation model of obesity: A review of the literature and implications for research and policy. *Obesity Reviews, 12*, 378-394

Li, F., Harmer, P., Cardinal, B. J., Bosworth, M., & Johnson-Shelton, D. (2009). Obesity and the built environment: Does the density of neighborhood fast-food outlets matter? *American Journal of Health Promotion, 23*(3), 203-209.

Lightwood, J., Bibbins-Domingo, K., Coxson, P., Wang, Y. C., Williams, L., & Goldman, L. (2009). Forecasting the future economic burden of current adolescent overweight: An estimate of the coronary heart disease policy model. *American Journal of Public Health, 99*(12), 2230-2237.

Long, M. W., Sobol, A. M., Cradock, A. L., Subramanian, S. V., Blendon, R. J., & Gortmaker, S. L. (2013). School-day and overall physical activity among youth. *American Journal of Preventive Medicine, 45* (2), 150-157. doi: 10.1016/j.amepre.2013.03.011.

Malik, V. S., Pan, A., Willett, W. C., & Hu, F. B. (2013). Sugar-sweetened beverages and weight gain in children and adults: A systematic review and meta-analysis. *The American Journal of Clinical Nutrition, 98*(4), 1084-1102.

Malik, V. S., Schulzeh, M. B., & Hu, F. B. (2006). Intake of sugar-sweetened beverages and weight gain: A systematic review. *The American Journal of Clinical Nutrition,* *84*(2), 274-288

Manson, J. E., Colditz, G. A., Stampfer, M. J., Willett, W. C., Rosner, B., Monson, R., R., … Hennekens, C. H. (1990). A prospective study of obesity and risk of coronary heart disease in women. *New England Journal of Medicine, 322*,882-889

Martin, B. (2015, June 18). Texas agriculture commissioner repeals restrictions on deep fryers, sodas in schools. *The Dallas Morning News.* Retrieved from http://www.dallasnews.com/news/texas/2015/06/18/texas-agriculture-commissioner-repeals-restrictions-on-deep-fryers-sodas-in-schools

Masse, L. C., de Niet-Fitzgerald, J. E., Watts, A. W., Naylor, P., & Saewyc, E. M. (2014). Associations between the school food environment, student consumption and body mass index of Canadian adolescents. *International Journal of Behavioral Nutrition and Physical Activity, 11*(29)

McLeroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An ecological perspective on health promotion programs. *Health Education Quarterly, 15*(4):351-377. Retrieved from http://tamhsc.academia.edu/KennethMcLeroy/Papers/81901 /An_Ecological_Perspective_on_Health_Promotion_Programs

Mei, H., Xiong, Y., Xie, S., Guo, S., Li, Y., Guo, B., & Zhang, J. (2016). The impact of long-term school-based physical activity interventions on body mass index of primary school children – a meta-analysis of randomized controlled trials. *BMC Public Health*, *16*, 205.

Michael, L. W., Sobol, A. M., Cradock, A. L., Subramanian, S.V., Blendon, R. J., &

Gortmaker, S. L. (2013). School-day and overall physical activity among youth. *American Journal of Preventive Medicine, 45*(2), 150–157

Michimi, A., & Wimberly, M. C. (2010). Associations of supermarket accessibility with obesity and fruit and vegetable consumption in the conterminous United States. *International Journal of Health Geographics, 9*, 49

Mullally, M. L., Taylor, J. P., Kuhle, S., Bryanton, J., Hernandez, K. J., MacLellan, D. L., …Veugelers, P. J. (2010). A province-wide school nutrition policy and food consumption in elementary school children in Prince Edward Island. *Canadian Journal of Public Health, 101*(1), 40-43

National Center for Education Statistics. (2016). *Public School Enrollment*. Retrieved from http://nces.ed.gov/programs/coe/indicator_cga.asp

National Center for Education Statistics. (n.d.). *Early Childhood Longitudinal Program: Kindergarten Class of 1998-99 (ECLS-K)*. Retrieved from http://nces.ed.gov /ecls/kindergarten.asp

Ness, A. R., Leary, S. D., Mattocks, C., Blair, S. N., Reilly, J. J., Wells, J, … Riddoch, C. (2007). Objectively measured physical activity and fat mass in a large cohort of children. *PLOS Medicine, 4*(3), 476-484. doi: 10.1371/journal.pmed.0040097

Nicklas, T. A., Yang, S., Baranowski, T., Zakeri, I., & Berenson, G. (2003). Eating patterns and obesity in children. The Bogalusa Heart Study. American Journal of Preventive Medicine, 25(1), 9–16.

Ogden, C. L., & Carroll, M. D. (2010). *Prevalence of obesity among children and* *adolescents: United States, trends 1963-1965 through 2007-2008*. Retrieved from http://www.cdc.gov/nchs/data/hestat/obesity_child_07_08/obesity_child_07_08.htm

Ogden, C. L., Carroll, M. D., Fryar, C. D. & Flegal, K. M. (2015). Prevalence of obesity among adults and youth: United States, 2011–2014. *NCHS data brief, 219*.

Ogden, C. L., Carroll, M. D., Kit, B. K. & Flegal, K. (2014). Prevalence of childhood and adult obesity in the United States, 2011-2012. *Journal of the American Medical Association, 311*(8), 806-814. doi:10.1001/jama.2014.732.

Ogden, C. L., Carroll, M.D., & Flegal, K. M. (2008). High body mass index for age among US children and adolescents, 2003-2006. *Journal of the American Medical Association*, *299*(20), 2401-2405

Oluyomi, A. O., Whitehead, L. W., Burau, K. D., Symanski, E., Kohl, H. W., & Bondy, M. (2014). Physical activity guideline in Mexican-Americans: Does the built environment play a role? *Journal of Immigrant and Minority Health, 16*(2), 244-255.

Piekarz, E., Schermbeck, R., Young, S. K., Leider, J., Ziemann, M. & Chriqui, J. F. (2016). *School district wellness policies: Evaluating progress and potential for improving children's health eight Years after the federal mandate. School Years 2006-07 through 2013-14*. Retrieved from www.bridgingthegapresearch.org /_asset/98nbk1/WP_2016_monograph.pdf

Ramirez-Nafarrate, A. & Gutierrez-Garcia, J. O. (2013). An agent-based simulation framework to analyze the prevalence of child obesity. In R. Pasupathy, S.-H. Kim, A.

Tolk, R. Hill & M. E. Kuhl (Eds.), Proceedings of *the 2013 Winter Simulation Conference*.

Rennie, K. L., Johnson, L., & Jebb, S. A. (2005). Behavioral determinants of obesity. *Best Practice & Research Clinical Endocrinology & Metabolism, 19*(3), 343-358. doi:10.1016/j.beem.2005.04.003

Ridgers, N. D., Stratton, G., & Fairclough, S. J. (2006). Physical activity levels of children during school playtime. *Sports Medicine, 36*(4), 359–371

Ringel, J. S., Eibner, C., Girosi, F., Cordova, A., & McGlynn, E. A. (2010). Modeling health care policy alternatives. *Health Service Research, 45*(5), 1541-1558. doi: 10.1111/j.1475-6773.2010.01146.x

Roger, J. Z. & Still, C. (n.d.). *Obesity and type 2 diabetes*. Retrieved from http://www.obesityaction.org/educational-resources/resource-articles-2/obesity-related-diseases/obesity-and-type-2-diabetes

Rosenheck, R. (2008). Fast food consumption and increased caloric intake: A systematic review of a trajectory towards weight gain and obesity risk. *Obesity Reviews, 9*(6), 535-547.

Ruiz, J. R., Rizzo, N. S., Hurtig-Wennlöf, A., Ortega, F. B., Wa¨rnberg, J., & Sjöström, M. (2006). Relations of total physical activity and intensity to fitness and fatness in children: The European Youth Heart Study. *American Journal of Clinical Nutrition, 84*, 299–303.

Schulz, L. O., & Schoeller, D. A. (1994). A compilation of total daily energy expenditures and body weights in healthy adults. *American Journal of Clinical Nutrition, 60*(5), 676-681.

Schwartz, M. B., Henderson, K. E., Read, M., Danna, N., & Ickovics, J. R. (2015). New school meal regulations increase fruit consumption and do not increase total plate waste. *Childhood Obesity, 11*(3), 242-247.

Shediac-Rizkallah, M. C., & Bone, L. R. (1998). Planning for the sustainability of community-based health programs: Conceptual frameworks and future directions for research, practice and policy. *Health Education Research, 13*, 87-108.

Society of Health and Physical Educators. (n.d.). *Physical activity guidelines*. Retrieved from http://www.shapeamerica.org/standards/guidelines/paguidelines.cfm

Sokolowski, J. A. & Banks, C. M. (2010). *Modeling and simulation fundamentals: Theoretical underpinnings and practical domains*. Hoboken, N.J.: John Wiley.

Sterman, J. D. (2000). Business dynamics: *Systems thinking and modeling for a complex world*. Boston MA: Irwan McGraw-Hill

Story, M., Kaphingst, K. M., & French, S. (2006). The role of schools in obesity prevention. *The Future of Children, 16*(1).

Story, M., Nanney, M. S., & Schwartz, M. B. (2009). Schools and obesity prevention: Creating school environments and policies to promote healthy eating and physical activity. *The Milbank Quarterly, 87*(1), 71–100.

Swinburn, B., Egger, G., & Raza, F. (1999). Dissecting obesogenic environments: The development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Preventive Medicine, 29*,563-570.

Taber, D. R., Chriqui, J. F., & Chaloupka, F. J. (2012). Differences in nutrient intake associated with state laws regarding fat, sugar, and caloric content of competitive foods. *Archives of Pediatrics and Adolescent Medicine, 166* (5), 452-458.

Taber, D. R., Chriqui, J. F., Powell, L. M., & Chaloupka, F. J. (2012). Banning all sugar-sweetened beverages in middle schools: Reduction of in-school access and purchasing but not overall consumption. *Archives of Pediatrics and Adolescent Medicine,* 166 (3), 256-262. doi: 10.1001/archpediatrics.2011.200.

Taber, D. R., Chriqui, J. F., Vuillaume, R., Kelder, S. H., & Chaloupka, F. J. (2015). The association between state bans on soda only and adolescent substitution with other sugar-sweetened beverages: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 12*(suppl 1), S7.

The State of Obesity. (2015). *State school-based physical activity and health-screening laws*. Retrieved from http://www.stateofobesity.org/state-physical-activity-laws/

Thornton, L. E., Lamb, K. E., & Ball, K. (2013). Employment status, residential and workplace food environments: Associations with women's eating behaviors. *Health Place, 24*, 80-89. doi: 10.1016/j.healthplace.2013.08.006.

Trasande, L., Liu, Y., Fryer, G., & Weitzman, M. (2009). Effects of childhood obesity on hospital care and costs, 1999-2005. *Health Affairs, 28*(4), w751-760.

Turner, L., & Chaloupka, F. J. (2012) Encouraging trends in student access to competitive beverages in US public elementary schools, 2006-2007 to 2010-2011. *Archives of*

Pediatrics and Adolescent Medicine, 166(7), 673-5. doi: 10.1001/archpediatrics.2012.48

Turner, L., Terry-McElrath, Y., Johnston, L. D., O'Malley, P. M., & Chaloupka, F. J. (2012). *Beverages sold in public schools: Some encouraging progress, additional improvements are needed — A BTG Research Brief*. Retrieved from http://www.bridgingthegapresearch.org/_asset/7jf02g/BTG_competitive_beverage_brief_final-8-7-12.pdf

U.S. Department of Health and Human Services. (2015). *2015 – 2020 Dietary Guidelines for Americans*, *8th Edition*. Retrieved from http://health.gov/dietaryguidelines /2015/guidelines/.

U.S. Government Accountability Office. (2005). *Competitive foods are widely available and generate substantial revenues for schools* [PDF document]. Retrieved from www.gao.gov/new.items/d05563.pdf

USDA Food and Nutrition Service. (2001). *Children's diets in the mid-1990s: Dietary intake and its relationship with school meal participation*. Washington, DC: Gleason, P., & Suitor, C.

USDA. (2012).*Nutrition standards in the National School Lunch and School Breakfast Programs*. Federal Register, 77(17).

USDA. (2013a). *National School Lunch Program*. Retrieved from http://www.fns.usda.gov/sites/default/files/NSLPFactSheet.pdf

USDA. (2013b). *National School Breakfast Program*. Retrieved from http://www.fns.usda.gov/sites/default/files/SBPfactsheet.pdf

USDA. (2013c). National School Lunch Program and School Breakfast Program: Nutrition standards for all foods sold in school as required by the Healthy, Hunger-Free Kids Act of 2010. *Federal Register, 78*(125). Retrieved from http://www.gpo.gov/fdsys/pkg/FR-2013-06-28/pdf/2013-15249.pdfUSDA. 2014.

USDA. (2014a). *Healthier school day*. Retrieved from http://www.fns.usda.gov /healthierschoolday/tools-schools-focusing-smart-snacks

USDA. (2016). *A Guide to Smart Snacks in Schools*. Retrieved from http://www.fns.usda.gov/tn/guide-smart-snacks-schools

Vioque, J., Weinbrenner, T., Castelló, A., Asensio, L. & Garcia de la Hera, M. (2008). Intake of fruits and vegetables in relation to 10-year weight gain among Spanish adults. *Obesity, 16*(3), 664-70. doi: 10.1038/oby.2007.121.

Wang, Y. (2011).Disparities in pediatric obesity in the United States. *Advances in Nutrition, 2*, 23-31. doi: 10.3945/an.110.000083

Wang, Y. C., McPherson, K., Marsh, T., Gortmaker, S. L., & Brown, M. (2011). Health and economic burden of the projected obesity trends in the USA and the UK. *Lancet, 378*(9793), 815-825

Wang, Y., Xue, H., Chen, H., & Igusa, T. (2014). Examining social norm impacts on obesity and eating behaviors among US school children based on agent-based model. *BMC Public Health*, *14* (1). doi: 10.1186/1471-2458-14-923

WHO. (2000). *Obesity: Preventing and Managing the Global Epidemic*. Geneva: World Health Organization.

WHO. (2012). Population -based prevention strategies for childhood obesity. Retrieved from http://www.who.int/dietphysicalactivity/childhood /WHO_new_childhoodobesity_PREVENTION_27nov_HR_PRINT_OK.pdf

Wiggins, S., Keats, S. & Han, E. (2015). *The rising cost of a healthy diet*. Retrieved from https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications...files/9580.pdf

Wijtzes, A. I., Bouthoorn, S. H., Jansen, W., Franco, O. H., Hofman, A., Jaddoe, V. W. V. , …Raat, H. (2014). Sedentary behaviors, physical activity behaviors, and body fat in 6-year-old children: The Generation R Study. *International Journal of Behavioral Nutrition and Physical Activity, 11*.

Wordell, D., Daratha, K. B., Mandal, B., Bindler, R. C., Butkus, S. N., & Ochs, L. (2012). Changes in school food environment affects food behavior and food choices. *Journal of the Academy of Nutrition and Dietetics, 112*(1), 137-141.

Zenk, S. N., Lachance, L. L., Schulz, A. J., Mentz, G., Kannan, S., & Ridella, W. (2009).Neighborhood retail food environment and fruit and vegetable intake in a multiethnic urban population. *American Journal of Health Promotion, 23*(4), 255-264. doi: 10.4278/ajhp.071204127.

VITA

NAME: Ruicui Liu
College of Health Sciences
2114 Health Science Bldg
Norfolk, VA 23529

EDUCATION

2001 Renmin University of China, Beijing, China
Bachelor of Arts, Journalism

2008 Old Dominion University, Norfolk, VA
Master of Science, Health Education and Promotion

2016 Old Dominion University, Norfolk, VA
Doctor of Philosophy, Health Service Research

RELATED EXPERIENCES

2001-2004 Journalist
YangCheng Evening News Newspaper Group, Guangzhou, China

2006-2007 Graduate Assistant
Department of Teaching & Learning, Old Dominion University, Norfolk, VA

2013-2015 Graduate Assistant
School of Community & Environmental Health, Old Dominion University, Norfolk, VA

ACTIVITIES AND HONORS

1999 *Shanghai Securities News* Scholarship
2000 Outstanding Academic Performance Scholarship, Renmin University of China
2001 Outstanding Academic Performance Scholarship, Renmin University of China
2002 Guangdong Province Excellent Reporting Prize, 3rd Place
2003 Guangdong Province Excellent Reporting Prize, 2nd Place
2009 Old Dominion University Graduate Student Fellowship
2010 Old Dominion University Graduate Student Fellowship
2011 Old Dominion University Graduate Student Fellowship
2012 Old Dominion University Graduate Student Fellowship
2015 Dissertation Fellowship, College of Health Sciences, Old Dominion University