Examining Associations of Community Food Environments with Individual Diet Quality and Body Weight Status of Canadian Children

by

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Abstract

Reducing the prevalence of unhealthy eating is an important challenge to address in order to reduce the burden of obesity and chronic disease. Approximately 1.6 million or one-third of Canadian children and youth are overweight or obese, and about 70% of children and youth consume less than five servings of vegetables and fruit daily. It is being increasingly recognized that food environments in which children live influence their diets and body weights. However, study findings are inconsistent, partly due to different approaches to measure the food environment. In addition, no study has examined the combined effect of the absolute and relative densities of unhealthy food outlets on diet quality and body weight status in Canadian children.

The objective of this thesis was to examine the associations of community food environments with individual diet quality and body weight status in a sample of Canadian school-aged children. The specific objectives were to: 1) assess which food environment indicator and geographic area is better able to capture associations with individual diet quality and body weight status, and 2) use the better performing indicator and geographic area to assess whether the community food environment affects individual diet quality and body weight status.

These objectives were addressed using data from Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta), a population-based survey of grade 5 students in Alberta, in addition to food retailer data provided by the Environmental Public Health Department of Alberta Health Services.

In the first study of this thesis, comparison of two food environment indicators revealed that the novel indicator, which considers the types of foods sold or served at an establishment, was better able to capture associations with diet and weight status compared to the indicator

based on store type. When geographic areas were compared, 1600m buffers around schools were better able to capture associations compared to smaller geographic areas. In the second study of this thesis, attending a school in an area with a higher relative density (proportion) of unhealthy food outlets was associated with lower diet quality, predominantly in areas where the absolute density (number) of unhealthy food outlets was also high.

These findings provide evidence that the community food environment plays a role in the development of unhealthy eating and increased body weights of school-aged children. Interventions to reduce unhealthy eating and excess weights may be most effective in areas with a higher number of unhealthy food outlets, specifically where there are few alternative healthy options available. The present findings also support the need for more precise assessment of the community food environment.

Preface

This thesis is an original work by Shannon Sim. Chapters 2 and 3 of this thesis were written in collaboration with P.J. Veugelers, C.I.J. Nykiforuk, R. Prowse, and K. Maximova. No part of this thesis has been previously published, other than in abstract form.

The studies conducted in this thesis were part of the Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta) study, which received ethics approval from the Human Research Ethics Board (REB) of the University of Alberta.

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List of Abbreviations

BMI	Body Mass Index
CHMS	Canadian Health Measures Survey
WHO	World Health Organization
DALY	Disability-Adjusted Life-Years
CCHS	Canadian Community Health Survey
SES	Socioeconomic Status
NHANES	National Health and Nutrition Examination Survey
CDC	Centers for Disease Control and Prevention
REAL Kids Alberta	Raising healthy Eating and Active Living Kids in Alberta
PAQ-C	Physical Activity Questionnaire for Children
FFQ	Food Frequency Questionnaire
YAQ	Harvard Food Frequency Questionnaire for Children and Youth
NAICS	North American Industry Classification System
mRFEI	Modified Retail Food Environment Index
CMO/CS/CLO	Choose Most Often/Choose Sometimes/Choose Least Often
CMO	Choose Most Often
CS	Choose Sometimes
CLO	Choose Least Often
FSA	Forward Sortation Area
CT	Census Tract
Y-HEI	Youth Healthy Eating Index
DQI-I	Diet Quality Index-International
LR	Likelihood Ratio
ICC	Intraclass Correlation Coefficient
AIC	Akaike Information Criterion
GIS	Geographic Information Systems
FFR	Fast Food Restaurant

Chapter I: Introduction

1.1 Healthy Eating, Overweight and Obesity, and Chronic Disease

Over the past 30 years, the prevalence of overweight and obesity has dramatically increased both in Canada and globally, constituting a pandemic. Body Mass Index (BMI) is a measure of weight status, and is calculated by dividing an individual's weight in kilograms by his or her height in square metres. Overweight among adults is defined as a BMI between 25 to <30, and obese is defined as a BMI of 30 or more.[1] Overweight and obesity is a consequence of an enduring imbalance between energy intake and energy expenditure, and constitutes an established risk factor for a number of chronic conditions, including type 2 diabetes mellitus, high blood pressure, cardiovascular disease, stroke, osteoarthritis, and some forms of cancer.[2–4] Together, these conditions present a major public health challenge. Please note: the discussion on disease burden, unhealthy eating, and obesity trends focuses on adults, as there is limited information available on children.

1.1.1 Overweight, Obesity, and Chronic Disease Burden in Canada and Globally

Excess body weight and consequent chronic diseases have placed an enormous burden on society. The 2012-2013 Canadian Health Measures Survey (CHMS) reported that 62% of Canadians were either overweight or obese, making up more than half of the Canadian population.[5] In an assessment of premature mortality of Canadian adults, defined as death before age 65, researchers estimated that approximately 20% of all premature deaths in Canada are attributable to obesity.[2] In 2011, they estimated that 10,648 of the total 52,713 premature deaths were attributed to obesity.[2] The economic burden of overweight and obesity also warrants consideration. The direct costs of overweight and obesity were estimated to be $6 billion in 2006, making up 4.1% of all health expenditures. Overweight costed $2 billion or approximately one-third of the direct costs, and obesity costed $4 billion or two-thirds of the total direct costs.[6] The indirect costs of overweight and obesity were estimated to be $5 billion, with $1.8 billion or 36% due to overweight, and $3.2 billion or 64% due to obesity.[6] This substantial demand on the health care system is due in part to the comorbidities of overweight and obesity, namely, type 2 diabetes, high blood pressure, heart disease, and cancer, among several others.[6–8] The World Health Organization (WHO) reported that 88% of deaths in Canada are from chronic diseases.[9] While more than one-fifth or 20% of Canadians live with a chronic condition,[10] individuals who are overweight or obese are more likely to have a chronic condition than those in the normal weight status range.[2,3,5] For instance, high blood pressure was more than two times more likely to occur in adults who were overweight or obese compared to those who were a normal weight in the 2012-2013 CHMS.[5] A review examining the burden of obesity in Canada reported that a striking number of chronic conditions are attributable to obesity.[2] Most notably, 61% of all diabetes cases in men and 74% of all cases in women are attributable to obesity.[2]

In 2016, over half of the global population was classified as overweight or obese, thus highlighting the severity of this pandemic.[11] Four million deaths in 2015 were related to overweight and obesity, which made up more than 7% of deaths from all causes.[7] Moreover, there were 120 million disability-adjusted life years (DALYs) attributable to overweight and obesity. The leading cause of overweight and obesity-related deaths was cardiovascular disease, followed by type 2 diabetes.[7] Countries with middle-high sociodemographic index (SDI) experienced the greatest death rate (68.1 per 100,000 population) and the highest DALYs (1890 per 100,000 population), while high SDI countries had the lowest death rate (52.6 per 100,000) and DALYs (1530 per 100,000). As previously mentioned, overweight and obesity serve as a precursor for chronic diseases, which ultimately lead to a larger disease burden. The WHO estimated that in 2016, 41 million or 71% of all deaths were attributable to various chronic diseases, making chronic disease a leading global cause of death. More specifically, cardiovascular disease constituted 44% (17.9 million) of all chronic disease deaths, cancer constituted 22% (9 million), chronic respiratory disease constituted 9% (3.8 million), and diabetes constituted 4% (1.6 million) of all chronic disease deaths.[9,12]

1.1.2 Current Trends of Overweight and Obesity in Canada and the United States

The prevalence of overweight and obesity is rapidly increasing around the world, and both Canada and the United States are no exception. Physically measured height and weight data from the 1978/79 Canada Health Survey showed that 13.8% of Canadians were obese, and 49.2% of all Canadians were either overweight or obese at the time.[3] Recent data from the Canadian Community Health Survey (CCHS) – Nutrition revealed that 68% of men and 54% of women are overweight or obese, and together, 16.9 million or approximately 60% of Canadians are now overweight or obese.[13] Further, the prevalence of obesity has increased two-fold since 1978/79, with 26.7% of Canadians now classified as obese. In terms of children and youth, approximately 1.6 million (31.5%) are overweight or obese.[14] There is a clear variation in obesity prevalence between provinces, with Saskatchewan having the highest prevalence of obese people (45.9%), followed by Newfoundland and Labrador (38.9%). British Columbia has the lowest prevalence (21.4%) of obesity, followed by Quebec (23.1%).

Overweight and obesity prevalence varies for different subsets of the Canadian population. When considering both sexes together, overweight and obesity increases with age.[13]

However, the pattern is less consistent when considering males and females separately. For women, the prevalence of overweight and obesity consistently increases with age, but for men, the prevalence tends to remain steady from 45-64 years and onward.[13] Obesity prevalence also differs according to the amount of area-level or neighbourhood deprivation. Neighbourhoods with the highest deprivation experience higher obesity prevalence compared to those with the least deprivation.[4] For example, in Regina, Saskatchewan, 26% of people who reside in low socioeconomic status (SES) areas are obese, and only 14% of people who reside in high SES areas are obese.[4] Associations of overweight and obesity with individual SES factors such as education and income, tend to differ between men and women. Women with less than high school education are more likely to have a higher BMI than women with higher levels of education, demonstrating a clear gradient in the association between education and overweight and obesity.[3,4,15] While there is no evidence of a linear gradient for men[15], those with high school graduation only tend to have a higher BMI than those with university education.[3,4] In terms of income, women living on a lower income are more likely to be obese, while there is no clear association for men.[3]

The prevalence of adult obesity in the United States is approximately 39.8%, triumphing obesity prevalence in all other countries in the world.[16,17] The prevalence of overweight and obesity together makes up more than 70% of the American population, and there are currently no signs of it slowing down.[17,18] The National Health and Nutrition Examination Survey (NHANES), which collects measured height and weight data from American adults, revealed that in 1960-62 the prevalence of obesity was 13.4% and by 2013-14 it had nearly tripled.[19] At the same time, the prevalence of overweight was relatively stable, only increasing by ~1%.

As is the case in Canada, U.S. obesity prevalence varies with different subgroups of the population. In the U.S., obesity prevalence is lower among young adults (35.7%) compared to both middle-aged adults (42.8%) and older adults (41%), but it does not significantly differ by gender for each age group.[16] However, when only comparing men and women without considering age group, women's prevalence (38.3%) is higher than men's (34.3%).[20] Education, income, and race have a more complex relationship with obesity prevalence. Similar to the pattern observed by Canadian researchers[15], women in the U.S. with a lower household income are more likely to be obese than women with a high household income, but this association is not evident for men.[20] In regards to education, both women and men who have graduated college are less likely to be obese compared to those with high school graduation or less.[20] The associations between education, income, and obesity also vary across race.[20]

1.1.3 Components of Healthy Diets and Canadian Health Eating Trends

Poor eating habits is a well-established risk factor for overweight and obesity, and the future development of chronic disease.[3,4,21,22] Prior research confirms that diets high in energy-dense foods are associated with increased BMI, while consumption of healthy foods, such as vegetables and fruit, is associated with lower BMI and a lower likelihood of obesity.[23–26] Canadians are increasingly reaching for nutrient-poor, energy-dense foods, as demonstrated by the rapid increase in obesity over the past 40 years.[3,27]

Limiting consumption of energy-dense foods and drinks and increasing consumption of vegetables, fruit and whole grains, are emphasized as priorities for obesity and chronic disease prevention.[21] These recommendations are reflected in Canada's Food Guide, the Alberta Nutrition Guidelines for Adults, and the Alberta Nutrition Guidelines for Children and Youth.[28–

[30] Canada's Food Guide recommends regular consumption of vegetables, fruits, whole grains, and plant-based proteins such as beans and legumes, while limiting highly processed foods and beverages that consist of sodium, sugar, and saturated fats. It also recognizes that surrounding food environments play a role in what people consume. Both versions of the Alberta Nutrition Guidelines categorize foods as 'Choose Most Often', 'Choose Sometimes' and 'Choose Least Often', based on the amount of total fat, saturated fat, sodium, sugar and fibre. Vegetables and fruit, whole grain products, and plant-based proteins are ranked as 'Choose Most Often', underlining the importance of having a diet rich in a variety of healthy foods.

Despite the recommendations presented in Canada's Food Guide, the overwhelming majority of Canadians do not comply with these recommendations. According to the 2016 CCHS, only 8.6 million or approximately 30% of Canadians aged 12 years or older reported consuming five or more servings of vegetables and fruit per day.[31,32] Males were less likely to report consuming five servings of vegetables and fruit per day (22.9%) compared to females (36.9%), and the proportion of males consuming five servings per day decreased from 24.8% in 2015 to 22.9% in 2016.[33] Vegetables and fruit consumption was highest for males in the 12-17 age range (27.7%), and for females in the 35-49 age range (40.4%).[32] Consumption patterns also differed by income and education levels. The proportion of individuals who reported consuming five servings of vegetables and fruit per day was highest for individuals with higher household incomes (33%). Additionally, those who completed post-secondary education were more likely to consume five servings of vegetables and fruit (31.7%) compared to those with less than post-secondary education (24.1%).[32] Evidence from the CCHS also suggests that daily vegetables and fruit consumption varies across Canada. Only 18.3% of Newfoundland and Labrador residents reported eating at least 5 servings of vegetables and fruit per day, while 38.4% of Quebec residents reported eating at least five servings.[32]

Consumption of vegetables and fruit is low, and Canadians appear to be replacing healthy foods with high-fat, energy-dense diets.[21] Approximately 62% of the Canadian diet consists of ready-to-go meals[8], and of the respondents who completed the 2004 CCHS, 25.4% aged 19 and older reported consuming fast-food the day before being interviewed.[33] According to the 2014 Alberta Community Health Survey, 43.3% of those who reside in Calgary and 45.4% of those who reside in Edmonton reported eating at a restaurant or fast-food outlet between one and three times per week.[34] In addition to the abundance of individuals consuming restaurant and fast-food, snack foods account for 23% of adults' diets.[34]

Many of the patterns observed for overweight and obesity, are complementary to vegetables and fruit consumption trends. For example, men and individuals with lower income and education levels tend to consume fewer vegetables and fruit and have a higher prevalence of obesity compared to women and individuals with higher income and education.[3,4,13,32] This inverse relationship is plausible, as vegetables and fruit consumption is a proxy for healthy eating and overall diet quality.[35] Individuals with healthy eating habits consume fewer calories and have a lower likelihood of being overweight or obese.

1.2 Introduction to Food Environments

1.2.1 Individual Change in Supportive vs. Un-supportive Environments

People's food "choices" are influenced by their environments, and it is increasingly being recognized that surrounding food environments play an important role in the types of foods that people choose and consume.[36–40] The obesogenic environment refers to an environment that supports unhealthy choices such as consuming energy-dense food and drinks and maintaining sedentary behaviour. On the other hand, the leptogenic environment promotes healthy choices such as the consumption of vegetables and fruits and active lifestyles that includes moderate to vigorous physical activity.[41] Traditional strategies to combat the increasing prevalence of obesity focus on individual change. These strategies include promoting dieting, calorie counting and encouraging healthy habits through public health messages.[42] Non-traditional strategies include creating healthy environments that remove the illusion of choice from the individual. The obesogenic environment greatly affects individual "choices," and the environment often wins against individual reasoning.[42,43] Many studies have observed associations between characteristically unhealthy food outlets, such as fast food restaurants and convenience stores, with increased BMI and poorer eating habits.[37,40,44–47] The increasing number of fast food restaurants introduces ample opportunity for individuals to eat unhealthy high-calorie meals without consideration of the health consequences. Decisions essentially become subconscious.[43] Healthy choices are more likely to be made in supportive, leptogenic environments, where individuals are encouraged to make healthier choices that would otherwise be undermined in an obesogenic environment.[4,21] Supportive environments are crucial in changing obesogenic behaviours. Without them, the system will continue to implement less-effective programs in an attempt to reduce obesity prevalence.[12,42] The current approach to reducing obesity prevalence is reactionary; implementing prevention at a population level through modifications in the environment will not only proactively prevent and reduce obesity prevalence, but will also make the healthy choice the easy choice.

1.2.2 Defining the Food Environment

Food environments are defined as the social, economic, and physical factors that affect accessibility, availability and adequacy of food within geographic areas such as communities, and they are hypothesized to influence people's food purchasing behaviours, as well as their diets.[48] Glanz et al. proposed a foundational conceptual model of the nutrition (food) environment. They identify four main types of food environments that are hypothesized to influence eating behaviours.[49] First, the community nutrition environment refers to the availability and accessibility of food outlets within a geographic area. Second, the consumer nutrition environment refers to the availability of healthy food options in stores, the price and promotion of foods, as well as the availability of nutritional information. Third, the organizational nutrition environment examines the food source availability for defined groups of people, such as the home, work or school environment. Last, the information environment considers media and advertising of certain foods and food sources. The information environment is assumed to influence the community, organizational, and consumer nutrition environments, and individual sociodemographic factors are hypothesized to modify the relationship between these nutrition environments and individual eating patterns. Of the 4 outlined nutrition environments, community and consumer nutrition environments were highlighted as research priorities.[49] This thesis will focus on the community nutrition environment.

1.2.3 International and Canadian Government Strategies that call for Change in the Food Environment

Creation and implementation of food and nutrition policies are necessary in order to alter the national and global increase in unhealthy eating, overweight and obesity, and chronic disease.

The WHO Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020 underscores the importance of creating health-promoting environments.[50] Multiple aspects of the food environment are mentioned as areas for change. Suggestions include improving the nutritional quality of food (e.g. reduce the level of sodium in food and eliminate trans fats), engaging food retailers to improve the availability and affordability of healthy food, promotion of healthy foods in public institutions, implementation of taxes to discourage the consumption of unhealthy foods, and promotion of standardized nutrition labelling.[50] Countries that successfully implement policies and programs to encourage health-promoting environments will contribute to the WHO's voluntary global targets. These targets include a 30% relative reduction in the mean population intake of sodium, a 25% reduction in the prevalence of high blood pressure, and a pause in the increasing prevalence of diabetes and obesity.[50] Additionally, health-promoting environments will help reduce the prevalence of noncommunicable disease risk factors and premature mortality.[50]

Health Canada's Healthy Eating Strategy also aims to create environments that promote making the healthy choice the easy choice for individuals. It proposes that all sectors, including health professionals, government, industry, non-government organizations, and academia, must work together to change the food environment.[51] Specific objectives proposed in the eating strategy include improving healthy eating information, strengthening food labels, improving the nutritional quality of foods, protecting vulnerable populations, and increasing access and availability of healthy foods.[51] Health Canada offers a number of strategies to implement these objectives. First, they pledge to revise Canada's Food Guide to include accurate and reliable dietary advice; this pledge has been met with the release of the new Canada's Food Guide in 2019. Second, they propose to prohibit the commercial marketing of unhealthy foods to children.

Third, vitamin-rich foods such as vegetables and fruit will be marked with health claims to promote consumption. Fourth, accurate and standardized food labels and front of package labeling for unhealthy foods that may be high in sugar, sodium and saturated fats will be employed. Fifth, Health Canada promises to reduce the amount of sodium in prepackaged foods, develop targets for restaurants and fast-food establishments to reduce sodium content, and to completely remove industrially-produced trans fat from all foods. Lastly, they propose the Nutrition North Canada program to increase access and availability of healthy foods to northern communities.[51] Successful implementation of these strategies will inevitably change the food environment in Canada.

The 2018 Alberta Nutrition Report Card on Food Environments for Children and Youth examines and assesses multiple aspects of the food environment across Alberta.[52] There were two key indicators assessing Alberta's community food environment: 1) the high availability of healthy food vendors, and 2) the limited availability of unhealthy food vendors. Both indicators received a poor letter grade, as the benchmarks were not met, and there was no policy or program currently in place. Report Card recommendations to improve these indicators focus on zoning by-laws to change the distribution of food outlets and stores, as well as working with municipalities to implement healthy 500m zones around schools. They also suggest tax incentives for new businesses to offer healthy foods, ensuring healthy food options at food trucks, and changing zoning policies to encourage healthy food outlets, thereby improving food environments.[52]

1.3 Measurement Methods

1.3.1 Measuring the Community Food Environment

Accurately measuring the community food environment (hereafter food environment) is challenging. Although a plethora of research on food environments has recently emerged, indicators are used inconsistently, and therefore, results reported across studies are not consistent or comparable.[53,54] Factors that affect food environment measurement include: food environment measurement (e.g., density, proximity, and relative density); geographic area (e.g., varying buffer sizes and geographic area boundaries); food outlet lists (i.e., health inspector food outlet lists are more accurate than commercial business data); food retailer classification (i.e., the way food outlets are categorized as a particular outlet type, or as healthy/unhealthy).

Standardized and validated food environment measures are lacking, and a gold standard does not currently exist.[46,53,55,56] Studies have examined both objective and perceived measures of accessibility and availability of food outlet types, but objective food environments measured via geographic information systems (GIS) are the most common. These measures include proximity, absolute density, and relative density.[53,57] Proximity refers to the distance from an individual's residence (or school/work) to the nearest food outlet of a given type, such as the nearest fast food restaurant, supermarket, or convenience store. Absolute density is measured as the concentration or count of a certain type of food outlet within a geographic area, or the count of each outlet type per population. Lastly, relative density refers to the relative availability or variety of different food outlet types or categories (such as healthy/less healthy) in a geographic area.[38,57,58] While these measures might appear straight forward, there is no standardized indicator or method; therefore, they have not been consistently implemented, leading to variability in findings. For example, measures of relative density employed in the literature have examined the proportion of fast food outlets,[59–62] convenience stores,[60,62] grocery stores,[60,62] healthy outlets,[37,61,63–65] and health-harming outlets,[66] in relation to all food outlets. Ratio measures have also been used in the literature, and generally examine the ratio of unhealthy food retailers to healthy food retailers or vice versa.[40,67] The Centers for Disease Control and Prevention's (CDC) Modified Retail Food Environment Index (mRFEI) is a measure of relative density that assesses the proportion of healthy food outlets relative to both healthy and less healthy food outlets in a specified geographic area.[68]

$$mRFEI\ (\%) = \frac{\#\ Healthy\ Food\ Retailers}{\#\ Healthy\ Food\ Retailers + \#\ Less\ Healthy\ Food\ Retailers}\ x\ 100$$

Healthy food outlets include supermarkets, supercentres, and produce stores, and less healthy food outlets include convenience stores and fast food restaurants. A low percentage score indicates an overall less healthy food environment, with fewer healthy retailers, and a high score indicates an overall healthier food environment.[69]

Although choosing the 'right' food environment measure is a challenge in and of itself, the selection of a geographic area to calculate absolute and relative density measures also pose difficulties. The most common way to capture the absolute and relative density of an individual's food environment is through the use of buffer distances, but some studies have instead used standard geographic areas/boundaries, such as census tracts, block groups, and forward sortation areas (FSA).[45,53] These geographic areas are meant to act as a proxy for the surrounding community food environment. When considering all food environment literature reviewed for this thesis, buffers were the most common way to capture an individual's neighbourhood; however, standard boundaries are used more frequently in the Canadian context.[54,57] A recent systematic review reported that buffer distances examined in the literature ranged from 100m to 2 miles, highlighting the lack of consensus on which buffer sizes are relevant to residents.[53,70] Generally, studies that examined buffers larger than 1 mile were more likely to report associations in the hypothesized direction, indicating that the broader neighbourhood may be a more important predictor of obesity.[46]

Food retailer lists are essential to construct food environment measures, but obtaining a validated list is often not possible. Some researchers rely on non-validated commercial business data lists available for purchase from private companies, while others succeed in obtaining a more reliable list from government agencies (e.g., health inspector's list).[46] Business data is known to be wrought with inconsistencies; using this data without any type of validation may lead to misclassification of exposure.[71,72] For instance, if a food retailer list is incomplete or inaccurate, we are not able to capture the full picture, leading to an inaccurate depiction of the food environment. Obtaining a food retailer list from the government is not always possible, so steps should be taken to establish validity if relying on commercial business data. For example, Polsky et al. validated a subset of their restaurant list against a public health inspector's list to ensure agreement.[59]

A final factor that is known to influence the construction of food environment measures is the classification of food outlet types. To classify retailers, most studies have taken advantage of the list of retailer types provided by the North American Industry Classification System (NAICS); however, some ambiguity exists. NAICS codes classify retailers by type of economic activity.[73] Classifying food retailers with NAICS codes relies on broad categorization based on store type, which may not accurately capture whether a food outlet is healthy or unhealthy, potentially leading to misclassification food outlets. In addition, grocery store and supermarket criteria are difficult to differentiate, and there is no available code for fast food restaurants, leading to improvised definitions.[46,54,73] Alternatively, some studies do not cite any standardized list for classifying food outlets. For instance, a recent Canadian study used a public health inspector's list and retained the outlet definitions used in the original database. Food outlets were then classified as 'Less Healthy Food Retail' and 'Healthier Food Retail' based on definitions created by the researchers.[74] Without consideration of the types of foods sold and served at an establishment, the opportunity for misclassification of food retailers is ample.

1.3.2 Measuring Diet Intake and Diet Quality

An increasing number of studies are examining the relationship between community food environments and diet. Accurately assessing people's dietary intake, however, is a challenge: all dietary assessment methods are based on self-report and thus subjective and prone to random and systematic error.[75]

Vegetables and fruit consumption is commonly used as a dietary outcome in food environment research.[53,76,77] Brief screening instruments (screeners) that are usually comprised of one or two questions are a common way to obtain this information, but food frequency questionnaires (FFQ), 24-hour dietary recalls, and food diaries/records are also used. Capturing this information through screeners, may introduce systematic error, as vegetables and fruit are likely to be consumed through many food and drink avenues, making it difficult to quantify through one or two questions. Brief screeners may be more appropriate in other situations, such as when we are interested in assessing number of times fast food is consumed per week, or the number of soft drinks consumed per week.[76]

While vegetables and fruit screeners are the most commonly used in food environment research, 24-hour dietary recalls and FFQs provide more insight into dietary intake and patterns.[53,70,76] The 24-hour dietary recall is a self-report, open-ended questionnaire that collects dietary data from participants over the past 24 hours, and may be administered by a trained interviewer or through computer-based technologies. Face-to-face interviews provide comprehensive dietary data, but are expensive to administer, time-consuming, and may introduce recall bias and/or interviewer bias.[75] Alternatively, computer-based technologies are less time-consuming, cheaper, and collect equivalent dietary data.[75,78] FFQs are also self-report questionnaires, but they are closed-ended, and they estimate the usual intake of a specified list of foods. FFQs can be self-administered or conducted by a trained interviewer, but regardless of administration, they are a less time- and cost-intensive alternative to 24-hour dietary recalls.[75] Intake data collected through FFQs is known to be systematically under and over reported, as respondents are required to reflect on food consumption over a long time period. Additionally, if interviewers administer FFQs, there is potential for interviewer bias to enter the study.

A recent systematic review of dietary assessment methods in food environment research assessed 51 articles, and reported that diet intake methods used in the literature included 24-hour recalls, food records, food frequency questionnaires and screeners.[76] Of the studies that used comprehensive instruments to collect diet information, such as FFQs or 24-hour recalls, 76% reported associations in the hypothesized direction. Of the studies that used screener items, only 55% had results in the expected direction. This review stressed the importance of choosing a more detailed and validated diet intake instrument such as a 24-hour recall, when examining associations with the food environment. Measurement error in dietary instruments warrants important consideration, especially in a field where researchers frequently report null and mixed results.

Diet quality is a summary measure of various aspects of the diet and therefore relies on comprehensive assessment methods, i.e. FFQs and 24-hour dietary recalls. Although many studies examine associations between the food environment and consumption of single food items and food groups, some studies use diet quality indices.[76] The Healthy Eating Index (HEI) and Diet Quality Index-International (DQI-I) are two diet quality indices based on both food group and nutrient intakes.[79] The HEI provides both a single summary score of an individual's overall diet quality based on his or her food and nutrient intake, as well two categories: adequacy and moderation. The overall HEI score ranges from 0 (worst) – 100 (best), and is comprised of 13 components total based on aspects that make up overall diet.[79] Adequacy is calculated based on 9 components (0-60 points) related to healthy food consumption, such as vegetables and fruit intake, grain intake, dairy and protein intake. Moderation is calculated based on 4 components (0-40 points) related to refined grains, sodium, added sugars and saturated fats.[80] Alternatively, the DQI-I also contains an overall summary score that ranges from 0 (poorest score) – 100 (highest possible score), as well as four components: variety, adequacy, moderation, and balance. Variety (0-20 score range) assesses heterogeneity of food and protein sources. Adequacy (0-40 score range) measures consumption of foods and vitamins that make up a healthy diet; namely, vegetables, fruits, grains, fibres, proteins, iron, calcium, and vitamin C. Moderation (0-30 score range) assesses total fat, saturated fat, cholesterol, sodium and empty calorie foods. Finally, overall balance (0-10 score range) evaluates the proportion of energy from macronutrients, in addition to saturated fatty acid ratio.[81,82]

The HEI was developed to assess the quality of Americans' diets, but has been adapted for use in the Canadian context.[35,83,84] On the contrary, the DQI-I was developed for use internationally, and has also been used in the Canadian context.[82,85] The HEI was constructed based on dietary guidelines, and therefore, the components strongly mimic food guide recommendations.[35,86,87] For instance, the adequacy aspect, which makes up 60% of the HEI score, solely evaluates adherence to food guide recommendations. The DQI-I also speaks to the foundation of healthy eating recommendations through its wide-ranging dietary components. However, in comparison to the HEI, the DQI-I taps into a more complete image of diet quality through its assessment of dietary variety, adequacy, moderation and balance.[35,81] Studies have demonstrated associations with the DQI-I variety component[88], which cannot be captured when using the HEI.

Ultimately, both the HEI and DQI-I are comprehensive diet assessment tools, which rely on accurate collection of diet intake. As such, if the dietary assessment instrument introduces systematic error into the study, the diet index selected for use will not matter, as the data used to construct the index is inherently biased.

1.3.3 Measuring Overweight and Obesity

Despite overweight and obesity being frequently investigated outcomes in food environment research, difficulties still arise when measuring these concepts. Factors that affect BMI measurement include: age group (i.e., children are classified differently than adults); available BMI cut-offs for children (i.e., growth curve reference to assign z-scores); source of height and weight (e.g., self-reported versus physically measured).

BMI is derived from weight (kg) divided by height (cm) squared, and then classified according to weight classifications.[89] For adults, those with a BMI <18.5 are classified as underweight, those with a BMI between 18.5 and <25 are classified as normal weight, those with a BMI between 25 and <30 are considered overweight, and those with a BMI ≥30 are classified as obese. BMI for children must be interpreted relative to other children of the same sex and age. Therefore, children are classified according to sex- and age- specific Z scores or percentiles. Several growth charts exist,[90,91] but the WHO Child Growth Standards are the current standards for children's BMI classifications.[92,93] Most studies investigating the relationship between food environments and childhood overweight and obesity used the CDC's growth reference charts.[60,64,94–96] Of these studies, some reported null associations, some found associations in the expected direction, and some reported mixed associations. In a joint statement, the Dieticians of Canada, in collaboration with the Canadian Paediatric Society, the College of Family Physicians of Canada, and the Community Health Nurses of Canada, recently encouraged the use of WHO reference standards over CDC growth curves.[97] A heavier reference population was used to create the CDC growth curves, leading to fewer children being classified as overweight and obese.[97,98] Using CDC percentiles may have led to misclassification of weight status, and ultimately attenuated or reversed associations if children were categorized into the wrong weight status category.

Another factor that must be considered when using BMI is the source of height and weight data. In a Canadian study comparing self-reported and measured BMI, prevalence estimates of weight status categories differed when measured with self-reported data compared to measured data.[99] On average, self-reported height was over-reported by 0.7 cm and self-reported weight was under-reported by 2.1 kg in participants, leading to an underestimated BMI.

They also calculated the sensitivity and specificity to assess the amount of misclassification that occurs when BMI is derived from self-reported data versus measured data. In terms of sensitivity, of the individuals within the normal weight status range based on measured height and weight, 95% of males and 93% of females were correctly classified based on their self-reported height and weight. This was not the case for people who were overweight. Only 70% of males and 63% of females were correctly placed in the overweight category when self-reported data was used. The sensitivity dropped between 45-60% for men and women who were obese. On the other hand, the specificity was higher than 95% for individuals classified as obese. This indicates that respondents were not very likely to be categorized as obese based on self-reported height and weight unless they really were obese.[99] Using self-reported height and weight to derive BMI is evidently problematic. Yet, many studies continue to use it. A systematic review examining the relationship between food environments and obesity reported that almost 50% of the reviewed studies used self-reported height and weight data to construct BMI. BMI derived from self-reported data is clearly more prone to misclassification bias, and may contribute to the lack of consistent findings in the literature.

1.4 Associations of Community Food Environments with Diet and Overweight and Obesity

A number of organizations have recently emphasized the importance of fostering healthy environments to promote healthy heating and reduce the burden of overweight and obesity and chronic disease.[4,27,50] Therefore, studies investigating the effects of community food environments on diet- and health- related outcomes have considerably increased over the past decade. Many of these studies have demonstrated associations of community food environments with both proximal outcomes, such as diet-related outcomes, and distal outcomes, such as overweight and obesity. There is currently no consensus on best approaches to measure the community food environment; therefore, study findings lack consistency. The majority of available studies examining associations of community food environments with diet intake and weight status focus on adults, but studies on children are consistently emerging.[46,53,70] Please note, the rest of this literature review will continue to refer to the community food environment as the food environment.

1.4.1 Studies Examining Adults

Multiple studies among adults have detected at least one association between food environments and diet-related outcomes,[37,53,100–103] but others report opposite or null findings.[53,104,105] A recent systematic review of 38 studies suggested that there is adequate evidence that food environments are associated with diet in adults.[53] Of the 20 studies that used availability measures such as absolute density or relative density to assess the food environment, 13 found a significant association with dietary outcomes. This review included articles published through 2011, and were from primarily the United States, but also included studies from Australia and New Zealand, United Kingdom, Canada and Japan. The single Canadian study included in this review reported null associations.[53] Due to the inclusion of only one Canadian study, it is not possible to determine whether null results occurred because food environments are fundamentally different in Canada, or if methodologies led to differing conclusions.

With a cross-sectional design, Gustafson et al. studied the associations between food environments and dietary outcomes in a sample of participants residing in low-income households in Kentucky.[100] They reported that individuals who live within a 0.5-mile network distance to at least one farmers market or one grocery store were more likely to consume healthy foods, compared to those who do not live do not live within a 0.5-mile radius to one of these store types. These associations were also evident when examining store types within a 1-mile radius from participants' homes. Moreover, they examined overall Healthy Eating Index (HEI) scores as an outcome variable, but for both 0.5 and 1-mile radius' there was no association with number of farmers markets or grocery stores. When examining the relationship between the number of convenience stores within 0.5- and 1-mile buffers, results were not consistent. In the 0.5-mile buffer, there were no notable associations with dietary intake or HEI scores. However, those who lived within a 1-mile radius of four or more convenience stores were more likely to report consuming healthy foods and had overall higher HEI scores than those who did not live within a 1-mile radius of at least four convenience stores. This study used a 24-hour dietary recall to collect dietary data and derive HEI scores, both of which are valid assessment tools.[75,79] Additionally, the researchers recognized the hierarchical nature of the data, and reported the intraclass correlation coefficient (ICC) as justification for continuing with multivariate linear and logistic regression models rather than mixed effect models. However, one issue with this study is the use of a commercial business database to identify food outlets; as previously mentioned, business data is known to lack validity.

Lind et al. used a similar cross-sectional design, but observed contradictory associations between the density of convenience stores within buffers around each participant's residence and diet quality.[101] They demonstrated that among 13,860 participants that reside in metropolitan Denmark, there was no association between the number of convenience stores within 250m or 500m buffers from home with diet quality. However, when they examined 35,932 participants within urban and rural (non-metropolitan) neighbourhoods, significant associations emerged. The odds of having a low diet score was 14% higher for those with one convenience store within

500m of their residence compared to those with no convenience stores within 500m. When examining participants with two or more outlets within 500m of their residence, the odds of having a low diet score was 18% higher compared to those with no convenience stores within 500m. This study employed a validated diet quality score as the outcome variable, but there is no mention of whether the FFQ used to construct this measure is also a valid measure. They also presented the ICC to justify the use of mixed models, as opposed to non-hierarchical models. The list of convenience stores used in this study came from the Danish Veterinary and Food Administration, which is equivalent to a health inspector's list.

Two recent cross-sectional studies from Canada examined the relationship between the food environment and diet.[61,105] Mercille et al. used a community sample of older adults from Montreal to determine whether the food environment affects men and women's diets differently, and how diet knowledge might act as a potential moderator.[61] To measure diet, they used principal components analysis to create two diet patterns based on measured data from a validated FFQ. Western diet patterns assessed an individual's consumption of processed meats, red meats, potatoes, sweets and refined grains, and prudent diet patterns assessed consumption of healthy foods, such as fruits, vegetables, fish and yogurt. To assess the surrounding food environments, they created a 500m buffer around participants' homes, and assessed the density, the relative proportion of fast food restaurants out of the total number of restaurants, and the relative proportion of healthy food stores out of the total number food stores. They found that surrounding food environments were not associated with western or prudent diet patterns for women. However, women with low diet knowledge who were exposed to a higher proportion of healthy food stores had lower western diet scores. Men who had a higher proportion of fast food restaurants relative to all restaurants within 500m of their residence, regardless of diet knowledge, had significantly lower prudent diet scores. This study relied on commercial business database to identify food outlets, which may have introduced error when creating the food environment indicators. Additionally, an issue in the field of food environment research is the lack of comparability due to variability in exposure and outcome assessment.[56,106] These researchers created a unique diet measure rather than using an established diet quality measure. In contrast, a study based in Calgary that examined the density of food outlet types within a 400m buffer of each participant's home employed commonly used exposure and outcome measures.[107] They used established food outlet classifications, namely, the Retail Food Environment Index (RFEI) categories. They measured diet intake with the validated Canadian Diet History Questionnaire II, and used the Canadian HEI to assess diet quality. Despite the use of validated dietary measures, they reported mostly null associations and one positive association: as the number of total food outlets within the buffer increased, diet quality scores increased.

In addition to the relationship between food environments and diet-related outcomes, overweight and obesity has also been thoroughly investigated in adults. Several studies have examined at least one positive association,[44,108–111] but most report primarily mixed and null associations.[46,59,66,112,113]

Several studies agree that a relationship exists between the density of fast food outlets and weight status. Burgoine et al. conducted a large cross-sectional study of 5,594 UK adults, and demonstrated that individuals exposed to a higher density of takeaway food outlets within home, transportation, and work food environments, had an increased BMI and higher odds of obesity compared to those who were least exposed.[109] This study made important methodological steps to improve food environment research: they used a health inspector's food retailer list to construct the food environment indicators, and they studied multiple food environments that an average adult would be exposed to. Despite many of the positive elements, a drawback of this study is temporal mismatch. The researchers explain that outcome data was collected between 2005-2013, and exposures were calculated with data from 2011; therefore, we must be careful when interpreting these findings. An earlier American study reported similar findings.[111] They found that higher fast food restaurant density per 10,000 people was associated with higher BMI and higher odds of obesity. Interestingly, they contend that different components of the restaurant environment affect weight status differently. Their finding that individuals exposed to a higher density of full-service restaurants had lower weight status substantiates this suggestion. Likewise, a recent Canadian cross-sectional study that used nationally representative Canadian Community Health Survey (CCHS) data corroborates the above observations.[45] They illustrated that within a forward sortation area (FSA) BMI increased as fast food outlet density increased. Additionally, as full-service restaurant density increased, BMI decreased.

A cross-sectional study among Canadian adults from Edmonton, Alberta provided further evidence of a relationship between the food environment and obesity.[110] Alternatively, rather than assessing the density of food outlets, they assessed the food environment with the RFEI, a ratio of the combined number of fast food outlets and convenience stores divided by the number of grocery stores within a defined geographic area. The geographic boundaries utilized in this study included 800m and 1600m buffers around respondents' postal codes. They found that within 800m buffers, individuals exposed to unhealthy food environments, characterized by a higher RFEI, had a higher odds of being obese compared to those who lived in an area with a low RFEI. However, no associations existed for 1600m buffers. This study exercised vigorous methodologies; they used an overall measure of the food environment in contrast to the use of a single outlet type, the health inspector's list was used to classify food outlets, and they also recognized the possibility of the individual data being nested within neighbourhoods. Ultimately, the ICC was very low and multilevel modeling was deemed inappropriate. One drawback of this study is the use of self-reported height and weight data. As previously mentioned, when self-reported height and weight is used to derive BMI, it often leads to underestimated BMI, and may lead to weight status misclassification. This would lead to attenuated associations. Therefore, while this study did report some significant associations, they may be underestimated. Nonetheless, self-report data is commonly used in the literature to construct BMI. Polsky et al. also conducted a study examining the relationship between the food environment and weight status in a population-based sample of Canadian adults.[59] They employed both an absolute density and relative density measure to assess the food environment within walking distance of residential areas, and found mixed results. When using the absolute density measures, the associations were in the opposite of the hypothesized direction. Individuals who lived in areas with a higher density of fast food, full service, or other restaurants, were less likely to be obese or have a high BMI, which does not align with theoretical understandings of the food environment literature.[49] In contrast, the relative density of fast food restaurants was associated with increased BMI and obesity in areas with a high number of fast food restaurants. Specifically, in areas with 5 or more fast food restaurants, individuals were more than two times as likely to be obese and have a high BMI compared to those exposed to less than 5 fast food restaurants. This study used data from the CCHS, which is a comprehensive population-based survey that collects self-report height and weight, as well as a variety of other important demographic information. The list of food retailers used to construct the food environment indicators was purchased from a commercial database, but a subset was later validated against a public health inspector's list. The authors concluded that health promoters should consider more than simply the number of food outlets that a person is exposed to; rather, they must consider the overall balance of outlets serving healthy and less healthy foods.

Overall, the available evidence on the associations between community food environments and obesity is conflicting, regardless of whether the indicator used is absolute or relative. A systematic review from 2015 found that null associations were most common in the literature, but certain elements of the food environment were associated with obesity.[46] The availability of supermarkets was repeatedly associated with lower odds of obesity, and the availability of fast food restaurants was associated with increased odds of obesity. Moreover, larger geographic areas were more likely to detect a positive association, indicating that larger neighbourhood areas may be more important than immediate surroundings. This review included studies from Canada and the United States; however, only approximately 10% were Canadian studies. An important conclusion identified by this systematic review points to the abundance of inconsistent methodologies and findings in the food environment literature, in addition to the profusion of American studies in comparison to Canadian studies.

1.4.2 Studies Examining Children

Several studies among children agree that an association exists between food environments and diet intake.[40,70,84,114,115] Similar to the literature on adults, associations are not consistently in the expected direction, and some studies report null associations.[70,94,116–118] Engler-Stringer et al. conducted a systematic review of available evidence on the effects of the community and consumer nutrition environments on children's diets, and reported that of the 26 included studies, 85% of the reviewed studies examined at least one positive association.

However, studies that used GIS-based measures were less consistent.[70] This review included studies from several different countries; 13 were from the United States, 5 were from Europe, 2 were from Australia, 2 were from Asia, and 4 were from Canada. Although each of the Canadian studies employed different exposure and outcome measures, all of the studies from Canada reported associations in the hypothesized direction. These results suggest that diet intake might partly be a result of surrounding food environments, particularly for Canadian children.

Skidmore et al. used a cross-sectional design to study the associations between proximity and density of food outlet types in neighbourhoods with food consumption in a sample of 1,721 children 9-10 years of age from the UK.[114] They showed that both distance and density of food outlets within an 800m neighbourhood buffer was scantily associated with food consumption. In terms of proximity-based measures, children who lived further away from takeaway food outlets and convenience stores were less likely to consume chocolate, crisps, sugary soft drinks, and white bread. Further, those who lived further away from supermarkets reported consuming heathier foods, such as vegetables and fruits. On the contrary, children who lived in a neighbourhood with a higher density of supermarkets, as opposed to living within close proximity, consumed more vegetables. This study collected information on food consumption via a parent proxy with a short, validated, 15-item FFQ. While living further away from takeaway food outlets was negatively associated with unhealthy food consumption, the FFQ did not include any foods, aside from white bread, that are served at fast food outlets. A shortcoming of this study is that they did not use an overall measure of diet quality, but instead relied on individual food consumption behaviours. Moreover, they reported using a comprehensive database to obtain the food outlet lists, but they do not provide justification for how the selected outlet types of interest (e.g., takeaway outlets, supermarkets, etc.) were identified. Overall, the authors concluded that although the effect is quite small, an important relationship exists between the food environment and children's food consumption, and this relationship differs depending on the method of food environment assessment.

A number of studies investigating children's community food environments also consider the food environment surrounding their schools.[40,84,94] Using a cross-sectional design, He et al. investigated the relationship of food environments surrounding home and school neighbourhoods with diet quality in sample of Canadian youth aged 11-14 years from London, Ontario.[84] They demonstrated that diet quality was higher for students who lived further than 1km away from the nearest convenience store compared to those who lived in close proximity to at least one convenience store. In terms of the school food environment, diet quality was higher for students who attended schools that were further than 1km from the nearest convenience store, compared to those who attended schools with a convenience store within 1km. Further, diet quality was lower for students who attended schools with 3 or more fast-food restaurants within 1km, compared to students with less than 3 fast-food outlets within 1km. This study suggests that the food environments surrounding children's homes and schools may serve as important predictors of diet quality. A limitation of this study is that the FFQ used to collect diet intake was self-administered, and the authors stated that this may have contributed to the low useable rate of dietary data provided by the FFQ. Similarly, Van Hulst et al. investigated the relationship of residential and school food environments with dietary intake and eating behaviours using a sample of 512 Canadian children aged 8-10 years from Quebec. Children's dietary intake was collected using three 24-hour dietary recalls, and additional questions regarding take-out food consumption and eating/snacking out behaviours were collected via a questionnaire. Proximity, density, and relative density indicators were employed to assess the food environments surrounding residential and school neighbourhoods. Several statistically significant associations were identified. For example, students who lived in residential neighbourhoods with fewer fast food outlets and convenience stores were less likely to eat or snack out, and those who lived farthest from fast food outlets reported consuming more vegetables and fruits compared to those who lived closed to fast food outlets. Additionally, students who attended schools with a higher relative density of fast food outlets and convenience stores compared to supermarkets within a 3km buffer consumed more sugar-sweetened beverages and fewer vegetables and fruits than students who went to school in neighbourhood with a lower relative density. Although a number of significant associations were reported, there were also several null findings in this study. For instance, none of the proximity indicators for schools were significantly associated with children's diets. Ultimately, the results from this study indicate that children's diets may be influenced by their residential and school food environments. Potential limitations of the study include the use of commercial business data to create food environment measures, the use of single diet components rather than a diet index, and high risk for type 1 error due to the small sample size and large number of associations tested. Regardless of these potential drawbacks, this study had many strengths. A validated tool was used to collect dietary intake, appropriate statistical tests were used to account for nesting of children within schools, and multiple food environment indicators were assessed.

The majority of the available research on children's food environments has focused on investigating associations with children's body weights. While there is more research available on children's weight status than their diets, the research even less consistent. Some studies report at least one association in the expected direction,[47,64,94,96,119] but most report null associations, or associations that are opposite of the expected direction.[47,60,64,74,95,119]

A recent cross-sectional study examined associations between food environments and weight status in a sample 944 of grade 5 and 6 students from Toronto, Canada.[74] Height and weight was measured to calculate each child's BMI, which was then classified according to International Obesity Task Force cut-points. Food environments were assessed through proximity to the nearest food outlet type, and absolute density of outlet types within 1km network service area buffer. They independently assessed fast food restaurants and supermarkets in addition to 'healthier' and 'less healthy' categories. Healthier outlets included bakeries, butcher shops, fish shops, and food stores or supermarkets, while less healthy outlets included all other retailers. The results indicated that students who lived closest to a supermarket, or in an area with a higher density of healthier food outlets, were less likely to be overweight or obese, compared to those who lived far away from a supermarket or in an area with a lower density of healthier food outlets. There was no apparent relationship between density and proximity of fast food restaurants and less healthy food outlets with overweight or obesity. This study had several strengths, including the use of measured height and weight, and the use of the public health inspector's list of food retailers. However, there are some drawbacks in this study. Individual income data was not available, so they relied on median household income exclusively. Further, data was collected from 17 schools, but the researchers do not mention the potential for a nested data structure, or provide an ICC to justify the use of a binomial logistic regression model over a mixed effects model. On the contrary, Laska et al. examined similar food environment measures, but found that children exposed to at least one restaurant within an 800m residential buffer or at least one convenience store within a 1600m residential buffer had higher BMI z-scores, but no associations existed when considering grocery stores or supermarkets.[94] They also considered the school neighbourhood environment, but they observed that statistically significant associations were in the opposite of the expected direction. For instance, BMI z-scores were lower for children who attended schools with any type of restaurant within 800m of the school. They utilized random effect models to account for clustering of students within schools, examined multiple buffer sizes, and used physical measurements for BMI and percentage body fat outcomes. However, food retailer data used to construct food environment measures was purchased from a commercial business database, which may have introduced error.

Fitzpatrick et al. focused exclusively on the influence of school food environments on adiposity in a prospective study of children between 8-10 years of age from Quebec.[96] Schools were grouped into school types based on features of the overall school food environment, including internal nutrition policies and procedures, as well as the surrounding community food environment, defined by a 750m buffer. Type 1 schools were those with an overall healthful food environment inside and surrounding the school. Type 2 schools were those with an unhealthful food environment inside the school, but a healthful food environment surrounding the school. Type 3 schools were those with an overall unhealthful food environment inside and surrounding the school. A healthy surrounding food environment was characterized by a low density of surrounding fast food outlets and convenience stores. Height, weight, waist circumference, percentage body fat, and central adiposity were measured at baseline and 2-years later for every child, and BMI z-scores were computed via CDC growth curves. The results of this study showed that children who attended schools with an overall unhealthy internal and external food environment (type 3), had a higher central adiposity 2 years later, but there were no significant associations with BMI z-scores or percentage body fat. This study has a number of strengths, including the longitudinal design, the use of measured data and alternative body fat measures. They also accounted for the nested data structure, as children were clustered within schools.

Additionally, the classification of schools into school types is a novel approach to accounting for the internal and external school food environments. Although this study has many strengths, a notable weakness is the use of a constricted cohort. The children who participated were all Caucasian and at risk for obesity. This study contributed important prospective evidence that school food environments may be important predictors of adiposity, especially in disadvantaged areas.

While some studies have reported significant associations, a systematic review of the literature by Cobb et al. reported that 85% of all associations examining the relationship between children's community food environments and obesity were null.[46] Despite the abundance of null associations, they recognized a potential relationship between convenience store availability and obesity that was not apparent for fast food outlet availability. Additionally, more than 90% of associations examining supermarket and grocery store availability were null, suggesting that no relationship exists between the presence of healthy food outlets and overweight and obesity outcomes in children.

Given the current challenges identified in the community food environment literature, this thesis will make important contributions to address these issues. Food environment measurement lacks consistency and standardization, and is met with several methodological issues. The majority of existing research has focused on proximity and absolute density of food outlets, but researchers have suggested that relative density may also be important in assessing the community food environment.[55,59,111] This thesis will use two relative density measures to assess the food environment, which will be constructed using a public health inspector's food retailer list. The mRFEI food environment indicator, which will be used in this study, is outlined in a document prepared by the CDC and is available for use by all researchers.[68] However, a more comprehensive method of assessment may be needed to determine the healthfulness of food outlets more precisely, as using outlet type alone may be too simplistic. Choose Most Often/Choose Sometimes/Choose Least Often (CMO/CS/CLO) is a novel indicator of community food environment that builds and extends upon the mRFEI. Utilizing this more extensive indicator will address an issue identified in the literature – that a binary measure based on store type (healthy versus less healthy) may not be enough to accurately capture surrounding food environments.[53] Moreover, this thesis will use multiple buffer sizes and standard geographic areas/boundaries in order to inform researchers on which buffers or boundaries may be important in future food environment investigations.

Second, tools to measure diet- and weight- related outcome variables have been inconsistent, with many studies using inaccurate diet measures and self-reported BMI, which may be contributing to the abundance of mixed results in the literature. This thesis will use a validated FFQ to collect dietary data, which will then be used to derive Y-HEI and DQI-I scores, as well as daily vegetables and fruit consumption. We will also include separate examinations of BMI Z scores and overweight and obesity. BMI will be derived from measured weight divided by measured height squared, and then classified according to WHO sex- and age- specific z-scores. WHO growth curves are recommended by health professionals in Canada. To our knowledge, no study has used children's measured height and weight as well as WHO growth curves in the food environment literature.

1.5 Objectives

The objective of this thesis is to examine the associations of community food environments with individual diet quality and body weight status in a sample of Canadian school-aged children. The specific objectives are to:

(1) Assess which food environment indicator and geographic area is better able to capture associations with individual diet quality and body weight status;

(2) Use the better performing indicator and geographic area to assess whether the community food environment affects individual diet quality and body weight status.

1.6 Structure of Thesis

This thesis follows the “paper-based” thesis format and contains four chapters. This first chapter provides a comprehensive introduction, identifies current challenges in the literature, and describes the study objectives. The second chapter includes the first study of this thesis: a cross-sectional study using data from Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta) to compare two different food environment indicators and five geographic areas. The third chapter includes the second study of this thesis, another cross-sectional study that used REAL Kids Alberta. This study assessed the joint effect of the absolute (number) and relative (proportion) densities of unhealthy food outlets surrounding schools on both diet and body weight status. The fourth and final chapter provides an overview of the research findings, interpretations, study strengths and limitations, implications, and conclusions.

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Chapter 2: Capturing associations of community food environments with diet quality and weight status: A suggested approach to standardize methodologies

2.1 Introduction

Excess body weight, unhealthy eating, and consequent chronic diseases have placed an enormous burden on society.[1,2] More than 60% of all Canadians are overweight or obese[3,4] and approximately 70% of Canadians aged 12 years and older consume less than five servings of vegetables and fruits per day.[5] Maintaining healthy weights throughout childhood, adolescence and adulthood, limiting consumption of energy-dense foods and drinks, and increasing consumption of vegetables, fruit, whole grains and pulses are emphasized as priorities for obesity and chronic disease prevention.[6] The Public Health Agency of Canada, Health Canada, and the World Health Organization have recognized the importance of fostering healthy environments to promote healthy eating and to reduce the burden of overweight and obesity and chronic disease.[1,6,7]

Over the past decade, a plethora of studies examining associations of the community food environment with diet- and obesity- related outcomes have emerged worldwide. However, study findings are inconsistent, partly due to different approaches to measure the food environment.[8–10] Many studies take advantage of the North American Industry Classification System (NAICS) to classify food retailers. However, classifying retailers according to NAICS codes relies on umbrella categories, which may not accurately capture whether a food outlet is healthy or unhealthy.[11,12] Other studies do not cite using a standardized list for classifying food outlets.[13,14] Once food outlets are classified according to either NAICS codes or unique criteria, some researchers then classify retailers as healthy or unhealthy based on store type alone.[15–20] Usually, grocery stores and fruit and vegetable markets are considered healthy food retail, while convenience stores and fast food restaurants are considered unhealthy food retail. This mirrors the Centers for Disease Control and Prevention's (CDC) Modified Retail Food Environment Index (mRFEI) criteria.[21] The mRFEI offers criteria for classifying food retailers as healthy or less healthy according to their NAICS codes; however, this binary measure based on store type may not accurately capture the foods being served or sold, leading to misclassification. On the other hand, Choose Most Often/Choose Sometimes/Choose Least Often (CMO/CS/CLO) is a novel food environment indicator that recognizes the types of foods served or sold at an establishment, and may provide more precise criteria for measuring the community food environment.

In addition to misclassifying retailers, variability and inconsistencies also occur because the community food environment can be captured for different geographic areas. For example, researchers have examined standard geographic areas/boundaries that an individual resides in, such as a forward sortation area (FSA) or census tract (CT), while the majority employ geographic (buffer) distances surrounding people's residences or schools (e.g., 1600 metre circular buffers surrounding an individual's home).[9,11] Buffer distances examined in the literature ranged from 100m to 2 miles, highlighting the lack of consensus on which buffer sizes are relevant to residents.[10,22]

Given the existing gaps and absence in consistency in the literature, coupled with the increasing interest in the community food environment as an intervention target to prevent obesity, poor diet, and chronic disease, our objectives are to: 1) employ and compare the CDC's mRFEI with CMO/CS/CLO, a novel and more comprehensive indicator of community food environment, and 2) use the better performing indicator to examine and compare food environments calculated for varying buffer distances and standard geographic areas/boundaries.

2.2.0 Methods

2.2.1 Study Design and Participants

The present study used survey data on diet, body weight status, and socio-demographic information from the 2014 Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta), a population-based survey of grade five students in Alberta, Canada. A one-stage stratified random sampling technique was used to select a sample of 140 elementary school from across Alberta. All elementary schools in Alberta with grade five students, except private schools, francophone schools, on-reserve schools, charter schools and colony schools, were eligible for selection. Within each geographic area (urban, rural, metropolitan), schools were proportionally selected at random. All grade five students, their parent(s), and school principals of the selected schools were invited to participate. In total, 2,958 students were granted parental consent to participate in the study.[23] For the present study, we worked with the subsample of students who reside in Edmonton and Calgary, thereby restricting the sample to 989 students from 41 schools. Two schools each had only two students participate; multi-level analysis requires at least five students (units) per school (cluster), and therefore, students attending these two schools were excluded from our analyses, leaving 984 students from 39 schools. An additional 133 students who were missing exposure and/or outcome data were also eliminated, resulting in 851 eligible students from 39 schools. It is recommended that students with caloric intakes less than 500 or greater than 5,000 calories per day be excluded from analyses[24]; exclusion of these participants yielded results that remained robust. Therefore, the present analyses are based on the sample regardless of caloric intake.

Students who enrolled in the study completed the Canadian version of the Harvard Food Frequency Questionnaire for Children and Youth (YAQ)[25] under the supervision of project assistants. This comprehensive survey is used to assess each child's eating habits and nutrient intake.[26] Students were also surveyed on their lifestyle behaviours and knowledge of existing health and wellness programs in Alberta. Additionally, research assistants used standardized tools (stadiometers and calibrated digital scales) to measure each student's standing height and weight. The parent(s) or guardian(s) of students enrolled in the study also completed a self-report survey, with questions pertaining to the home environment and demographic information. Lastly, school principals completed a survey on the school food environment and school programs.

2.2.2 Outcome of Interest: Diet Quality, Vegetables and Fruit Consumption, and Body Weight Status

Outcome variables included diet quality, vegetables and fruit consumption, BMI and bodyweight status. Diet quality was assessed with both the Youth Healthy Eating Index (Y-HEI)[27] and the Diet Quality Index-International (DQI-I).[28] Daily vegetables and fruit consumption was examined as number of servings per day. BMI was derived from measured weight divided by measured height squared, and then classified according to WHO age- and sex-specific Z scores.[29] Children with a Z score greater than 1 were classified as overweight or obese.

2.2.3 Exposure of Interest: Community Food Environments

Part 1:

The Environmental Public Health Department of Alberta Health Services provided a list of all food retailers in Edmonton and Calgary. Food retailers from this list were included in food environment calculations if they were known to serve or sell food and were open for public access. Full-service restaurants were not included, as the Centers for Disease Control and

Prevention's (CDC) criteria does not consider them.[21] Food retailers were ranked according to two food environment indicators: the Modified Retail Food Environment Index (mRFEI) and Choose Most Often/Choose Sometimes/Choose Least Often (CMO/CS/CLO).

The mRFEI is an indicator of community food environment developed by the CDC, which classifies food retailers as either healthy or less healthy based on the type of food outlet.[21] Food outlet types were assigned according to the Canadian version of the North American Industry Classification System (NAICS) codes, which varies slightly from the American version that was used to construct the mRFEI criteria. The categories included: supermarkets and other grocery stores (445110), fruit and vegetable markets (445230), general-line food merchant wholesalers (452910 & 413110), convenience stores and gasoline stations with convenience stores (445120 & 447110), and limited service eating places (722512). Healthy retailers included supermarkets and grocery stores, fruit and vegetable markets, and warehouse clubs and supercentres, while less healthy food retailers included convenience stores and limited service eating places. Typically, the mRFEI assesses the relative availability of *healthy* food retailers within census tracts or identified boundaries in proportion to both healthy and less healthy food retailers. However, recent studies have focused on relative availability of *unhealthy* food retailer types.[17,19,30–32] Therefore, the relative availability of less healthy food retailers within 1600m buffers surrounding schools was calculated as: 100 x (number of less healthy outlets/total number of outlets). The absolute density (number of outlets) of less healthy food outlets within 1600m buffers surrounding schools was also calculated. We used 1600m buffers to compare these two food environment indicators because it has been suggested that the larger food environment may be more important than immediate surroundings[11], and previous studies have used 1600m buffers to assess the community food environment.[15,33–41]

The CMO/CS/CLO indicator was developed by a Registered Dietician (RD) who ranked food retailers' menus according to the Alberta Nutrition Guidelines for Children and Youth.[42] Food retailers were ranked as Choose Most Often (CMO), Choose Sometimes (CS), or Choose Least Often (CLO). Alberta's nutrition guidelines categorizes foods into these three categories based on the amount of total fat, saturated fat, sodium, sugar and fibre, and also recommends that CMO foods are consumed daily, CS foods are consumed only a few times throughout the week, and CLO foods are only consumed once a week or less.[42] Food retailers that were most healthful, including sandwich outlets, smoothie outlets, grocery stores and salad bars, were considered as CMO. CS food retailers included sit-down restaurants, cafeterias, coffee outlets, supplements and processed grocery stores. CLO retailers included pizza, Asian, burger and taco outlets, ice cream shops, lounges/bars and food outlets that serve fried foods. The relative density of CLO outlets within 1600m of schools was calculated as: 100 x (number of CLO outlets/total number of outlets). The absolute (number) density of CLO food outlets within 1600m buffers surrounding schools was also calculated. The present study compared the mRFEI with the CMO/CS/CLO based on: 1) whether associations in the regression analyses were statistically significant and coefficients were in the hypothesized direction, and 2) model fit statistics. (Food retailer classifications for CMO/CS/CLO and mRFEI are outlined in Appendix A).

Part 2:

After comparing the mRFEI and CMO/CS/CLO, we used the better performing food environment indicator to examine and compare food environments at various standard geographic areas/boundaries and buffer distances. We derived food environment exposures (absolute and relative densities) for each forward sortation area (FSA) and census tract (CT) that a school was located in, as well as 1600m, 1000m, and 800m circular buffers around each of the 39 schools. FSA is a large geographic area, identified by the first three characters of a postal code.[43] On the other hand, a CT is a small geographic area that has a population between 2,500-8,000 persons.[44] Comparisons of food environments for different geographic areas was based on: 1) whether associations in the regression analyses were statistically significant and coefficients were in the hypothesized direction, and 2) model fit statistics.

2.2.4 Statistical Analysis

Due to the hierarchical nature of our data, we used a series of likelihood ratio (LR) tests for each outcome variable to assess whether 2-level multilevel mixed-effect regression models provided better fit compared to ordinary least squares regression models. We also examined the intraclass correlation coefficients (ICC) of null models. Multilevel mixed-effect linear and logistic regression models with children nested in schools were the preferred models and were used to assess associations of community food environments with Y-HEI, DQI-I, vegetables and fruit consumption, BMI and body weight status. We also tested whether 3-level (level 1: students; level 2: schools; level 3: FSA/CT) models provided better fit compared to 2-level models, but 2-level models persisted.

Sociodemographic variables and food environment scores were described using means and standard deviations for continuous variables, and frequency measures for categorical variables. Unadjusted associations of food environment indicators with diet and weight status outcomes were first examined. Multivariable mixed-effect linear and logistic regression models were used to adjust for individual and area-level confounders; namely, child's gender, child's total energy intake (for diet outcomes)[24], physical activity level (Physical Activity Questionnaire for Children score) (for weight status outcomes), parent's education (high school or less, college or university, graduate university), household income (<$25,000, $25,000-$50,000, $50,001-$75,000, $75,000-$100,000, >$100,000) and area-level material deprivation (quintile 1 being least deprived, and quintile 5 being most deprived).[45] Missing values combined with 'prefer not to answer' for the income confounding variable were considered as a separate category in the regression analysis. Akaike Information Criterion (AIC) statistics were examined in fully adjusted models to compare whether: 1) food environment calculated with the mRFEI or CMO/CS/CLO produced a better fitting model, and 2) food environments calculated for each boundary/buffer provided better model fit statistics. All data analyses were performed with Stata/SE 15 statistical software package (Stata Corp., College Station, TX).

2.3 Results

Of the 851 participants with complete exposure and outcome information, the average Y-HEI score was 63.2, the average DQI-I score was 62.1, and the average number of vegetables and fruits consumed per day was 4.98 (Table 2.1). The average BMI Z score was 0.69, and the prevalence of overweight or obesity was 40.2%.

On average, FSAs had the most food outlets (87.3) followed by 1600m buffers around schools (56.3), 1000m buffers (22.0), CTs (18.1), and 800m buffers (13.0) (Table 2.2). When considering the mRFEI criteria, all areas were dominated by less healthy food outlets. Food environments calculated for FSAs surrounding schools had the highest proportion of less healthy food outlets (89.9%), followed by 1600m buffers (87.5%), 800m buffers (85.5%), 1000m buffers (85.3%), and CTs (84.3%). When considering the CMO/CS/CLO criteria, food environments calculated for 800m buffers surrounding schools had the highest proportion of CLO outlets

(71.3%), followed by 1000m buffers (69.3%), FSAs (67.8%), CTs (66.9%), and 1600m buffers (66.6%).

Part 1:

When considering the mRFEI, neither the absolute nor the relative density of less healthy food outlets within 1600m of schools was associated with Y-HEI, DQI-I, BMI Z score, or body weight status in a statistically significant manner (Table 2.3). Before adjusting for potential confounders, in a univariate model containing the absolute density of less healthy food outlets, the relative density of less healthy food outlets was associated with daily vegetables and fruit consumption. Results indicated that for every 10% increase in the proportion of less healthy outlets within 1600m buffers around schools, vegetables and fruit consumption among study participants decreased by 0.62 servings per day ($p<0.05$), conditional on the random effect. This association appeared no longer to be statistically significant after adjusting for potential confounders.

When considering the CMO/CS/CLO, neither the absolute nor the relative density of CLO outlets had a statistically significant association with DQI-I or daily vegetables and fruit consumption (Table 2.3). Before adjusting for potential confounders, in models containing the absolute density of CLO food outlets, the relative density of CLO outlets was significantly associated with Y-HEI, BMI Z score, and overweight or obese status. Specifically, for every 10% increase in the proportion of CLO outlets within 1600m buffers around schools, Y-HEI decreased by 1.69 units ($p<0.01$), BMI Z score increased by 0.21 units ($p<0.01$), and the odds of overweight or obesity increased by 38% (<0.01), conditional on the random effect. Additionally, in a model containing the relative density of CLO outlets, the absolute density of CLO food outlets was associated with increased BMI Z scores. After adjusting for potential confounders, all significant associations appeared no longer to be statistically significant. The Pearson correlation coefficient assessing the relationship between mRFEI (%Less healthy) and CMO/CS/CLO (%CLO) was 0.16.

For 8 out of 10 models, AIC statistics were lower for models that used CMO/CS/CLO compared to mRFEI criteria (Table 2.3). Fully adjusted models that examined DQI-I as the outcome variable and employed the mRFEI yielded slightly lower AIC statistics compared to models that used the CMO/CS/CLO (6151.91 vs. 6152.01), although differences were negligible. Unadjusted models that examined vegetables and fruit consumption as the outcome variable also produced lower AIC statistics for the mRFEI model compared to the CMO/CS/CLO model (4664.42 vs. 4667.61). Once fully adjusted for potential confounding variables, the AIC values reversed; model fit statistics were lower for the CMO/CS/CLO model than the mRFEI model (3991.45 vs. 3993.20).

Part 2:

Overall, there were no significant associations for the absolute nor relative density of CLO food outlets in CTs, 1000m or 800m buffers surrounding schools (Table 2.4 and Table 2.5). In unadjusted models, there were significant associations of relative density of CLO outlets within 1600m of schools with Y-HEI, BMI Z score, and overweight/obese status, in models containing the absolute density. For every 10% increase in the proportion of CLO outlets within 1600m buffers around schools, Y-HEI decreased by 1.69 units ($p<0.01$), BMI Z score increased by 0.21 units ($p<0.01$), and the odds of overweight or obesity increased by 38% ($p<0.01$), conditional on the random effect. Once adjusted for potential confounders, these associations were no longer significant. In addition, absolute density of CLO outlets within 1600m around schools was associated with BMI Z score in unadjusted models containing relative density. As the number of CLO outlets increased by 10, BMI Z score increased by 0.065 units ($p<0.05$), conditional on the random effect. After adjusting for potential confounders, the association was no longer significant. In models containing the absolute density of CLO outlets, the relative density of CLO outlets within a school's FSA was also associated with Y-HEI in unadjusted models. For every 10% increase in the proportion of CLO outlets, Y-HEI decreased by 1.59 units ($p<0.01$), conditional on the random effect. Again, after adjusting for potential confounders, this association was no longer significant.

For 7 out of 10 models, AIC statistics were lower for models that assessed community food environments surrounding schools within 1600m buffers compared to 1000m or 800m buffers (Table 2.4). Unadjusted models examining DQI-I as the outcome variable produced lower AIC values for 1000m buffers compared to 1600m or 800m buffers. When fully adjusted, AIC values were lower for 800m buffers compared to 1000m and 1600m buffers. For the standard geographic areas/boundaries, 6 out of 10 model AIC statistics were lower for community food environments assessed at the FSA level compared to CT level (Table 2.5). For several comparisons, the differences in AIC statistics between the two models was small (less than 1).

In sensitivity analyses, exclusion of children who reported consuming less than 500 or more than 5000 calories per day revealed similar findings to those in Table 2.3, Table 2.4 and Table 2.5.

2.4 Interpretation

In the first part of this study, we observed that the novel food environment indicator (based on more refined classifications) was better able to capture associations with diet and weight status with less error, compared to the indicator developed by the CDC. When the CDC's indicator was used to measure the food environment, several associations were in the opposite of the expected direction, while most associations captured by the novel indicator were in the hypothesized direction. The second part of this study revealed that larger geographic areas (1600m buffers) were better able to capture associations with less error compared to smaller areas. Additionally, when comparing food environments calculated for standard geographic areas/boundaries surrounding schools, the larger boundary (FSA) produced models with less error compared to the smaller boundaries (CT). Both boundary sizes produced inconsistent associations, with several in the opposite of the hypothesized direction. Using larger geographic areas to examine the food environment produced the most consistent results overall. Ultimately, we observed few associations, and all of them disappeared after adjustment for potential confounders.

The absence of statistically significant differences, as observed in this study using the mRFEI, is often observed in the food environment literature. While there are studies that have reported associations of community food environments with diet and weight status outcomes, several have reported null findings, and many have reported results in the opposite of the expected direction.[9–11,22] An et al. conducted a cross-sectional study examining associations of food outlet types within 0.5 mile buffers surrounding schools and residences with diet quality of American children.[46] The study found no evidence that the absolute density of any food outlet types is associated with children's diet quality. A recent systematic review by Wilkins et al.

examined similar findings.[9] The review assessed 113 studies on children and adults from the United States, Canada, United Kingdom, Australia, Germany and New Zealand, published between 2004 and 2017. Overall, 76% of all associations from the included studies were null.

Various studies have also examined multiple buffer sizes and boundaries to reveal which is most accurate in assessing the community food environment. Caspi et al. suggested that some studies may not have found a meaningful association because the chosen buffer or boundary was not relevant to the population participating in the study.[10] While this may be true, Cobb et al. suggested that the broader neighbourhood may be more important than immediate surroundings.[11] The present study aligns with both of these thoughts. We observed several inconsistent associations when examining smaller geographic areas. Edmonton and Calgary are not typical walkable cities[47], and therefore examining larger geographic areas makes sense. Although we conducted our analyses with a sample of young children who may not have the opportunity to walk to and from school, we assumed that children reside in the same neighbourhood as their school, and their parents may visit food outlets in the surrounding neighbourhood.

The present study showed that the novel food environment indicator, which considers the types of foods sold or served at an establishment (CMO/CS/CLO), outperformed the indicator based on food outlet type (mRFEI). The abundance of null and opposite findings in the literature may be suggestive of the need for more precise assessment methods that consider more than food outlet type. Future studies should use tools that consider the types of food served or sold at an establishment in order to provide a more accurate assessment of the associations of community food environments with diet and body weight status outcomes.

Study findings should be interpreted bearing in mind the potential limitations. This study employed a cross-sectional design; however, exposure and outcome data were not collected simultaneously. Food retailer data was from 2016, while the REAL Kids Alberta survey data was collected in 2014. This is lag between exposure and outcome data collection is common in food environment studies.[48,49] We adjusted for several important confounding variables; however, residual confounding may have persisted despite adjustment. Assessment of dietary intake was based on self-report, which may be prone to measurement errors due to poor recall or social desirability bias. Even so, the Harvard YAQ has been validated for use with children. While REAL Kids Alberta is a population-based study, this research limited analyses to children residing in Edmonton and Calgary due to the availability of food environment data. Therefore, generalizability of study findings may be limited. A final limitation of this research is the relatively small sample size. We ran multiple statistical tests, which may have increased the likelihood of a type 1 error.

Regardless of the limitations, this study has many strengths. We used data from a population-based survey that used a validated FFQ to collect dietary intake, and trained research assistants to measure each child's height and weight. The food retailer list used to construct food environment measures was obtained from the public health inspector, which is preferred over business data lists, which are known to be inaccurate.[50,51] Most studies use food environment indicators that classify food outlets based on type alone (fast food, convenience, supermarket, etc.), which introduces the potential for misclassification. This study employed a new food environment indicator, developed by a Registered Dietician who ranked food retailers' menus according to the primary types of foods served at the establishment. Many food outlets that are classically considered fast food, such as Chopped Leaf and Freshii, offer healthy food options, and this should be considered when classifying food outlets. We compared this new three-category indicator with the CDC's mRFEI, which has two categories. To our knowledge, this is the first study to employ two food environment indicators and compare them. Many studies employ several measures of the food environment (absolute density, relative density, proximity), but no study has used different tools to classify food environments and subsequently compared them. We adjusted for area- level socioeconomic status (SES) to account for the clustering of unhealthy food outlets in lower SES areas.[52] Lastly, we tested associations for several buffer and boundary sizes.

2.5 Conclusion

While this study did not examine any statistically significant associations in fully adjusted models, findings are nonetheless important. Study findings suggest that future studies should use the CMO/CS/CLO food environment indicator, which offers a more comprehensive approach for classifying food retailers. Additionally, 1600m buffers may be valuable when used to assess the food environments of cities with similar walkability to Edmonton and Calgary. The lack of significance observed suggests that focusing on relative and absolute density separately may not be appropriate. This study contributes important evidence on effective methods to measure the community food environment and better capture the effect it has on children's diets and body weights.

Table 2.1. Characteristics of grade 5 students residing in Edmonton and Calgary participating in the 2014 REAL Kids Alberta Study (n=851)

Participant Characteristics	Mean±SD or n(%)
Diet Quality	
Y-HEI	63.2±9.3
DQI-I	62.1±10.7
Daily vegetables and fruit	4.98±3.75
BMI z score	0.69±1.29
Weight Status	
Overweight	204 (24.0%)
Obese	138 (16.2%)
Gender	
Male	402 (47.2%)
Female	449 (52.8%)
Parental Education	
High school or less	167 (19.6%)
College or university	465 (54.6%)
Graduate university	180 (21.2%)
Prefer not to answer/missing	39 (4.6%)
Household Income	
Less than $25,000	53 (6.2%)
$25,000 - $50,000	92 (10.8%)
$50,001 - $75,000	68 (8.0%)
$75,001 - $100,000	78 (9.2%)
> $100,000	211 (24.8%)
Prefer not to answer/missing	349 (41.0%)
PAQ-C	3.29±0.7
Total daily energy intake	1939.0±1161.6
Area-level material deprivation	
Q1 (least deprived)	125 (15.0%)
Q2	231 (27.7%)
Q3	184 (22.0%)
Q4	135 (16.2%)
Q5 (most deprived)	160 (19.2%)

CMO = choose least often; CS = choose sometimes; CLO = choose least often; Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index International; PAQ-C = Physical Activity Questionnaire for Children score; BMI = Body Mass Index.

Table 2.2. Average absolute and relative densities of food outlet types within each geographic area

	Mean (min-max)				
	FSA	CT	1600m	1000m	800m
Total # outlets	87.3 (13-243)	18.1 (0-88)	56.3 (11-124)	22.0 (0-75)	13.0 (0-58)
mRFEI					
# Healthy outlets	8.6 (1-27)	1.78 (0-7)	6.77 (1-21)	2.62 (0-10)	1.67 (0-8)
# Less healthy outlets	78.7 (12-216)	16.3 (0-85)	49.5 (10-111)	19.4 (0-65)	11.3 (0-50)
%Less healthy (less healthy/total)	89.9 (80.4-97.8)	84.3 (0-100)	87.5 (70.8-97.0)	85.3 (0-100)	85.5 (0-100)
CMO/CS/CLO					
#CMO	16.2 (2-48)	3.43 (0-17)	10.8 (2-26)	4.38 (0-18)	2.54 (0-14)
#CS	12.6 (1-33)	3.19 (0-32)	8.15 (1-33)	2.82 (0-21)	1.54 (0-15)
#CLO	58.4 (7-169)	11.5 (0-40)	37.3 (8-93)	14.8 (0-52)	8.92 (0-39)
%CLO (CLO/total)	67.8 (49.5-81.6)	66.9 (0-100)	66.6 (46.5-89.7)	69.3 (0-100)	71.3 (0-100)

1. FSA = forward sortation area; CT = census tract; 1600m, 1000m, 800m = buffer sizes around schools
2. mRFEI = Modified Retail Food Environment Index developed by the Centers for Disease Control and Prevention; CMO/CS/CLO = Choose Most Often/Choose Sometimes/Choose Least Often
3. #Healthy = number of healthy food outlets; #Less healthy = number of less healthy food outlets; %Less healthy = proportion of less healthy food outlets relative to all; #CMO = number of choose most often food outlets; #CS = number of choose sometimes food outlets; #CLO = number of choose least often food outlets; %CLO = proportion of CLO food outlets relative to all.

Table 2.3. Associations of unhealthy food outlets with diet and body weight outcomes according to mRFEI and CMO/CS/CLO within 1600m of schools

	mRFEI			CMO/CS/CLO		r=0.16[a]
	β (95%CI)	*p-value*	AIC	β (95%CI)	*p-value*	AIC
Y-HEI						
Univariate			6203.67			6194.23*
Proportion(%)	1.36 (-0.22, 2.94)	0.092		**-1.69 (-2.67, -0.70)**	**0.001**	
Count(#)	-0.051 (-0.36, 0.26)	0.75		-0.17 (-0.54, 0.19)	0.35	
Multivariable			6050.23			6048.82*
Proportion(%)	0.34 (-1.36, 2.03)	0.70		-0.96 (-2.07, 0.14)	0.088	
Count(#)	0.17 (-0.13, 0.47)	0.27		0.071 (-0.33, 0.47)	0.73	
DQI-I						
Univariate			6447.58			6446.81*
Proportion(%)	-0.42 (-2.00, 1.16)	0.60		-0.44 (-1.54, 0.65)	0.43	
Count(#)	-0.064 (-0.37, 0.24)	0.68		-0.14 (-0.54, 0.26)	0.49	
Multivariable			6151.91*			6152.01
Proportion(%)	0.42 (-1.04, 1.89)	0.57		-0.085 (-1.06, 0.89)	0.86	
Count(#)	-0.030 (-0.28, 0.22)	0.82		-0.084 (-0.43, 0.26)	0.63	
VF Consumption						
Univariate			4664.42*			4667.61
Proportion(%)	**-0.62 (-1.21, -0.036)**	**0.038**		-0.21 (-0.63, 0.21)	0.32	
Count(#)	0.016 (-0.098, 0.13)	0.78		-0.0057 (-0.16, 0.15)	0.94	
Multivariable			3993.20			3991.45*
Proportion(%)	0.13 (-0.33, 0.58)	0.58		-0.25 (-0.55, 0.051)	0.10	
Count(#)	0.027 (-0.053, 0.11)	0.51		0.0047 (-0.10, 0.11)	0.93	
BMI z score						
Univariate			2831.01			2821.45*
Proportion(%)	-0.13 (-0.36, 0.11)	0.30		**0.21 (0.067, 0.36)**	**0.004**	
Count(#)	0.045 (-0.0019, 0.092)	0.060		**0.065 (0.011, 0.12)**	**0.019**	
Multivariable			2773.88			2769.53*
Proportion(%)	0.098 (-0.14, 0.33)	0.42		0.15 (0.0029, 0.30)	0.050	
Count(#)	0.023 (-0.019, 0.065)	0.28		0.052 (-0.0020, 0.11)	0.059	
	OR (95%CI)	*p-value*	AIC	OR (95%CI)	*p-value*	AIC
Overweight/obese						
Univariate			1133.70			1127.72*
Proportion(%)	0.72 (0.50, 1.03)	0.073		**1.38 (1.09, 1.76)**	**0.008**	
Count(#)	1.07 (0.99, 1.14)	0.082		1.09 (1.00, 1.19)	0.058	
Multivariable			1098.79			1096.24*
Proportion(%)	1.08 (0.78, 1.50)	0.63		1.19 (0.95, 1.48)	0.14	
Count(#)	1.03 (0.97, 1.09)	0.33		1.06 (0.98, 1.15)	0.14	

1. [a] Pearson correlation between mRFEI (%Less healthy) and CMO/CS/CLO (%CLO).
2. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
3. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
4. Multivariable models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
5. AIC: Akaike information criterion. * specifies the lower AIC value, indicative of a better model fit.
6. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index.
7. Bolded results are statistically significant (p<0.05).

Table 2.4. Associations of absolute and relative density of CLO outlets with diet- and weight- related outcomes for different geographic areas (buffers)

	1600m			1000m			800m		
	β (95%CI)	*p-value*	AIC	β (95%CI)	*p-value*	AIC	β (95%CI)	*p-value*	AIC
Y-HEI									
Univariate			6194.23*			6204.94			6205.41
%CLO	**-1.69 (-2.67, -0.70)**	**0.001**		-0.27 (-0.84, 0.29)	0.34		-0.16 (-0.66, 0.35)	0.55	
#CLO	-0.17 (-0.54, 0.19)	0.35		-0.48 (-1.48, 0.53)	0.35		-0.59 (-1.94, 0.77)	0.40	
Multivariable			6048.82*			6051.56			6051.88
%CLO	-0.96 (-2.07, 0.14)	0.088		-0.16 (-0.69, 0.38)	0.56		0.020 (-0.47, 0.51)	0.94	
#CLO	0.071 (-0.33, 0.47)	0.73		0.0095 (-0.94, 0.96)	0.98		-0.076 (-1.44, 1.29)	0.91	
DQI-I									
Univariate			6446.81			6446.52*			6446.93
%CLO	-0.44 (-1.54, 0.65)	0.43		-0.024 (-0.60, 0.55)	0.93		0.19 (-0.32, 0.70)	0.47	
#CLO	-0.14 (-0.54, 0.26)	0.49		-0.65 (-1.67, 0.37)	0.21		-0.57 (-1.94, 0.80)	0.42	
Multivariable			6152.01			6150.69*			6148.58
%CLO	-0.085 (-1.06, 0.89)	0.86		0.052 (-0.41, 0.52)	0.83		0.29 (-0.14, 0.72)	0.19	
#CLO	-0.084 (-0.43, 0.26)	0.63		-0.49 (-1.31, 0.33)	0.24		-0.84 (-2.05, 0.37)	0.17	
VF Consumption									
Univariate			4667.61			4667.45*			4668.55
%CLO	-0.21 (-0.63, 0.21)	0.32		-0.077 (-0.30, 0.14)	0.49		-0.030 (-0.22, 0.17)	0.77	
#CLO	-0.0057 (-0.16, 0.15)	0.94		-0.18 (-0.57, 0.20)	0.35		0.0040 (-0.52, 0.53)	0.99	
Multivariable			3991.45*			3991.51			3993.60
%CLO	-0.25 (-0.55, 0.051)	0.10		-0.076 (-0.22, 0.066)	0.29		-0.026 (-0.16, 0.11)	0.71	
#CLO	0.0047 (-0.10, 0.11)	0.93		-0.18 (-0.43, 0.073)	0.17		-0.12 (-0.50, 0.25)	0.52	
BMI z score									
Univariate			2821.45*			2833.13			2833.15
%CLO	**0.21 (0.067, 0.36)**	**0.004**		-0.0081 (-0.095, 0.079)	0.86		0.0080 (-0.068, 0.084)	0.84	
#CLO	**0.065 (0.011, 0.12)**	**0.019**		0.10 (-0.053, 0.26)	0.20		0.14 (-0.069, 0.34)	0.19	
Multivariable			2769.53*			2775.38			2774.82
%CLO	0.15 (0.00029, 0.30)	0.050		-0.022 (-0.096, 0.053)	0.57		-0.022 (-0.090, 0.045)	0.52	
#CLO	0.052 (-0.0020, 0.11)	0.059		0.047 (-0.085, 0.18)	0.48		0.10 (-0.088, 0.29)	0.29	

	OR (95%CI)	*p-value*	AIC	OR (95%CI)	*p-value*	AIC	OR (95%CI)	*p-value*	AIC
Overweight/obese									
Univariate			1127.72*			1136.713			1136.59
%CLO	**1.38 (1.09, 1.76)**	**0.008**		1.03 (0.89, 1.18)	0.72		1.05 (0.93, 1.19)	0.39	
#CLO	1.09 (1.00, 1.19)	0.058		1.19 (0.93, 1.51)	0.16		1.21 (0.88, 1.67)	0.24	
Multivariable			1096.24*			1099.282			1098.69
%CLO	1.19 (0.95, 1.48)	0.14		0.99 (0.89, 1.10)	0.84		0.99 (0.90, 1.09)	0.85	
#CLO	1.06 (0.98, 1.15)	0.14		1.09 (0.91, 1.32)	0.35		1.19 (0.90, 1.57)	0.22	

1. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
2. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
3. Multivariable models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
4. AIC: Akaike information criterion. * specifies the lower AIC value, indicative of a better model fit.
5. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index; %CLO = proportion of CLO food outlets relative to all; #CLO = number of CLO food outlets.
6. Bolded results are statistically significant (p<0.05).

Table 2.5. Associations of absolute and relative density of CLO outlets with diet- and weight- related outcomes for different standard geographic areas/boundaries (FSA and CT)

	FSA			CT		
	β (95%CI)	*p-value*	AIC	β (95%CI)	*p-value*	AIC
Y-HEI						
Univariate			6198.066*			6205.349
%CLO	**-1.59 (-2.79, -0.39)**	**0.009**		-0.059 (-0.45, 0.34)	0.77	
#CLO	-0.13 (-0.31, 0.055)	0.17		0.44 (-0.39, 1.26)	0.30	
Multivariable			6050.795			6048.653*
%CLO	-0.70 (-2.11, 0.70)	0.33		0.11 (-0.23, 0.44)	0.54	
#CLO	-0.054 (-0.25, 0.14)	0.59		0.70 (-0.051, 1.44)	0.068	
DQI-I						
Univariate			6447.936			6447.681*
%CLO	0.098 (-1.14, 1.33)	0.88		0.040 (-0.35, 0.43)	0.84	
#CLO	-0.037 (-0.23, 0.15)	0.71		0.26 (-0.56, 1.08)	0.54	
Multivariable			6151.593			6151.217*
%CLO	0.24 (-0.90, 1.39)	0.68		0.15 (-0.15, 0.45)	0.33	
#CLO	-0.051 (-0.21, 0.11)	0.53		0.12 (-0.57, 0.81)	0.74	
VF Consumption						
Univariate			4667.592*			4668.524
%CLO	0.25 (-0.22, 0.72)	0.30		-0.014 (-0.16, 0.14)	0.85	
#CLO	0.0018 (-0.071, 0.072)	1.00		0.045 (-0.27, 0.36)	0.78	
Multivariable			3994.065			3993.34*
%CLO	-0.0046 (-0.38, 0.70)	0.98		0.042 (-0.051, 0.14)	0.38	
#CLO	-0.0075 (-0.059, 0.044)	0.78		0.038 (-0.17, 0.25)	0.72	
BMI z score						
Univariate			2833.001*			2834.074
%CLO	0.10 (-0.10, 0.30)	0.33		0.025 (-0.038, 0.088)	0.44	
#CLO	0.014 (-0.016, 0.045)	0.35		0.026 (-0.10, 0.16)	0.70	
Multivariable			2775.922*			2776.268
%CLO	-0.062 (-0.26, 0.13)	0.53		0.0021 (-0.049, 0.053)	0.94	
#CLO	-0.0027 (-0.029, 0.024)	0.85		0.0075 (-0.11, 0.12)	0.90	
	OR (95%CI)	*p-value*	AIC	OR (95%CI)	p	AIC
Overweight/obese						
Univariate			1137.274*			1137.372

%CLO	1.18 (0.86, 1.62)	0.30		1.06 (0.96, 1.16)	0.27	
#CLO	1.01 (0.97, 1.06)	0.58		1.03 (0.84, 1.25)	0.81	
Multivariable			1098.365*			1099.961
%CLO	0.85 (0.66, 1.10)	0.23		1.02 (0.95, 1.09)	0.62	
#CLO	0.98 (0.95, 1.02)	0.37		0.98 (0.83, 1.16)	0.83	

1. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
2. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
3. Multivariable models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
4. AIC: Akaike information criterion. * specifies the lower AIC value, indicative of a better model fit.
5. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index; %CLO = proportion of CLO food outlets relative to all; #CLO = number of CLO food outlets; FSA = Forward Sortation Area; CT = Census Tract.
6. Bolded results are statistically significant ($p<0.05$).

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Chapter 3: Associations of Absolute and Relative Density of 'Choose Least Often' Food Outlets with Diet Quality and Weight Status of Canadian Children

3.1 Introduction

In Canada, the prevalence of obesity has increased two-fold over the past 30 years, placing it at the forefront of the public health agenda. Approximately 60% of Canadian adults are overweight or obese, and one-third of Canadian children and youth are classified as overweight or obese.[1,2] Childhood overweight and obesity persists into adulthood and is a risk factor for a number of chronic diseases, such as cardiovascular disease, type 2 diabetes, hypertension, and some cancers.[3–5] An unhealthy diet is a well-established risk factor for overweight and obesity.[4–6] Consumption of healthy foods, such as vegetables, fruit, legumes and wholegrains, is emphasized as a priority for chronic disease and obesity prevention.[6] Yet, approximately 70% of Canadians aged 12 years and older report consuming less than five servings of vegetables and fruits per day.[7] Traditional strategies to combat the increasing prevalence of obesity and unhealthy eating focus on individual change; however, the continued surge in obesity suggests that innovative strategies that consider the broader environment are needed.[8] Recent evidence has demonstrated associations of community food environments with both proximal outcomes, such as diet[9–17], and distal outcomes, such as overweight and obesity[13,18–23], presenting a potential prevention target at the population level.

Studies investigating the effects of community food environments on diet- and health-related outcomes have increased over the past decade. While many have detected an association with diet and obesity, some report null or contradictory findings.[9,24–26] We have previously demonstrated that improper classification of food retailers as healthy or less healthy based on store type may explain the inconsistencies observed in the literature (Chapter 2). In addition, several studies employ measures of absolute density (number) and proximity, but few have used relative density (proportion) to assess the community food environment. Relative density refers to the availability of different food outlet types or categories in a geographic area, relative to all food outlets.[27] Researchers have suggested that relative density may be more important than absolute density when assessing the community food environments.[23,28] Using data from the Canadian Community Health Survey (CCHS), Polsky et al. recently examined an interaction between the absolute and relative densities of fast food restaurants and found that living in an area with both high absolute and relative densities of fast food restaurants was associated with increased weight status among adults aged 18 years or older (n=10,199).[19] However, there have been no such investigations in children.

While previous studies have examined the effect of absolute and relative densities on diet and weight outcomes separately[9,24], no study considered the effect of multiple dimensions of the community food environment 1) using CMO/CS/CLO to classify food retailers, 2) with dietary outcomes, 3) using a sample of Canadian children, 4) in the area surrounding schools. The present study examined the combined effect of the absolute and relative density of characteristically unhealthy food outlets within 1600m buffers around schools in Edmonton and Calgary with diet- and weight- related outcomes.

3.2.0 Methods

3.2.1 Study Design and Participants

We used data from a provincially representative sample of grade five students participating in the 2014 Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta) study. REAL Kids Alberta is a population-based health survey of grade five students, their parents, and schools. A one-stage random sampling method was used to proportionally select 140 schools from urban, rural and metropolitan areas. All elementary schools in Alberta with grade five students, excluding private schools, francophone schools, on-reserve federal schools, charter school and colony schools, were eligible to participate. Participation was open to all fifth-grade students, their parents, and school principals of the selected schools. Of the 4,993 home surveys sent home with children, 3,284 were returned, and 2,958 students received parental consent to participate in the study.[29] For the present study, we worked with the subsample of students who reside in Edmonton and Calgary. Therefore, our sample was restricted to 989 students and 41 schools. Two schools each had only two students participate; multi-level analysis requires at least five students (units) per school (cluster), and therefore, students attending these two schools were excluded from our analysis, leaving 984 students from 39 schools. Additionally, 133 students who were missing exposure and/or outcome data were also eliminated from analyses, leaving 851 students from 39 schools. It is recommended that students with caloric intakes less than 500 or greater than 5,000 calories per day be excluded from analyses[30]; exclusion of these participants yielded results that remained robust. Therefore, the present analyses are based on the sample regardless of calorie intake.

The REAL Kids Alberta study included a student survey on lifestyle behaviours and knowledge of existing health and wellness programs in Alberta, as well as a Canadian version of the Harvard Food Frequency Questionnaire for Children and Youth (YAQ).[31] This extensive food frequency questionnaire assesses children's eating habits and nutrient intakes. Students completed both surveys under the supervision of research assistants. Research assistants also measured each child's standing height and weight using stadiometers and calibrated digital scales. Parent(s) of students enrolled in the study were asked to complete the home survey, which included questions pertaining to the home environment and demographic information. School principals also completed a survey on the school food environment and school programs.

3.2.2 Outcome of Interest: Diet Quality, Vegetable and Fruit Consumption, and Body Weight Status

The outcomes of interest were diet quality, daily vegetables and fruit consumption, body mass index (BMI) and body weight status. We used a Canadian adapted version of the Youth Healthy Eating Index (Y-HEI) to assess children's diet quality.[32] The Y-HEI assesses adherence to dietary guidelines for children and youth. Daily vegetables and fruit consumption was assessed as the number of servings consumed per day. BMI was derived from measured weight divided by measured height squared and then assigned WHO age- and sex- specific Z scores.[33] A dichotomous variable was created to categorize each student as either overweight/obese (>+1SD) or not.

3.2.3 Exposure of Interest: Community Food Environments

The Environmental Public Health Department of Alberta Health Services provided a list of all food retailers in Edmonton and Calgary in 2016. All food retailers known to serve or sell food, and were open for public access were retained, except for full-service restaurants. Food retailers were ranked according to Choose Most Often/Choose Sometimes/Choose Least Often (CMO/CS/CLO) criteria. The CMO/CS/CLO indicator was created by a Registered Dietician (RD) who ranked food retailers' menus according to the Alberta Nutrition Guidelines for Children and Youth.[34] In the Nutrition Guidelines, foods are categorized as Choose Most Often (CMO), Choose Sometimes (CS), or Choose Least Often (CLO) based on the amount of total fat, saturated fat, sodium, sugar and fibre. Additionally, it is recommended that CMO foods are consumed daily, CS foods are consumed only a few times throughout the week, and CLO foods are only consumed once a week or less. CMO food retailers included those that were most healthful, including sandwich outlets, smoothie outlets, grocery stores and salad bars. CS food retailers included those that served some healthy food options, including sit-down restaurants, cafeterias, coffee outlets, supplements and processed grocery stores. CLO food retailers included pizza outlets, Asian outlets, burger and taco outlets, ice cream shops, lounges/bars and food outlets that serve fried foods.

Each school's address was geocoded by a Geographic Information Systems (GIS) analysist to identify 1600m circular buffers around each individual school. Within each 1600m buffer, we derived the absolute (number) and relative (proportion) density of CLO outlets. The relative density of CLO outlets was calculated as: 100 x (number of CLO outlets / total number of outlets).

3.2.4 Statistical Analysis

Associations of community food environments with diet quality, vegetables and fruit consumption, and body weight status were assessed using multilevel mixed-effect regression models to account for the hierarchical nesting of students within schools. We examined the intraclass correlation coefficients (ICC) of null models and employed a series of likelihood ratio (LR) tests to assess whether 2-level multilevel mixed-effect regression models provided better fit compared to ordinary least squares regression models. Multilevel mixed-effect linear and logistic regression models with children nested in schools persisted.

Analyses included four models for each outcome variable: Model 1 examined associations of absolute and relative densities of CLO outlets within 1600m buffers around schools. Model 2 examined associations of absolute number of total outlets and the relative density of CLO outlets within 1600m buffers around schools. Model 3 examined the associations of relative density of CLO outlets for each level of absolute exposure to CLO outlets. Absolute density of CLO outlets was divided into tertiles to distinguish between lower (0-20 outlets), medium (21-35 outlets), and higher (36+ outlets) exposure (Figures 3.1 and 3.2). Model 4 examined associations of relative density of CLO outlets for each level of absolute exposure to total food outlets. Absolute density of total outlets was divided into tertiles to separate lower (0-33 outlets), medium (34-54 outlets), and higher (55+ outlets) exposure. For each model, we first examined unadjusted associations. Then, multivariable mixed-effect linear and logistic regression models were used to adjust for potential confounders, including child's gender, child's total energy intake (for diet outcomes)[30], physical activity level (Physical Activity Questionnaire for Children score) (for weight status outcomes), parent's education (high school or less, college or university, graduate university), household income (<$25,000, $25,000-$50,000, $50,001-$75,000, $75,001-$100,000, >$100,000), and area-level material deprivation (quintile 1 being least deprived area, and quintile 5 being most deprived area).[35] Missing values combined with 'prefer not to answer' for the income confounding variable were considered as a separate category in regression analyses. All data analyses were performed with Stata/SE 15 statistical software package (Stata Corp., College Station, TX).

3.3 Results

Of the 851 participants with complete exposure and outcome information, the average Y-HEI score was 63.2, the average DQI-I score was 62.1, and the average number of vegetables and fruits consumed per day was 4.98 (Table 3.1). The average BMI Z score was 0.69, and the prevalence of overweight or obesity was 40.2%.

Within 1600m of schools, there was an average of 56.3 total food outlets (Table 3.2). Moreover, there was an average of 10.8 CMO outlets, 8.15 CS outlets, and 37.5 CLO outlets. The average relative density of CLO outlets was 66.6%.

In models containing both the absolute and relative density of CLO food outlets within 1600m surrounding schools, the relative density of CLO outlets was significantly associated with decreased Y-HEI ($p<0.01$), increased BMI Z score ($p<0.01$), and an increased odds of overweight or obesity ($p<0.01$) (Table 3.2). After adjusting for potential confounding variables, none of the associations remained significant.

In models that examined the absolute density of total food outlets and the relative density of CLO food outlets, the relative density of CLO food outlets was significantly associated with decreased Y-HEI ($p<0.001$), increased BMI Z scores ($p<0.01$), and increased odds of overweight or obesity ($p<0.01$) (Table 3.3). After adjusting for potential confounding variables, the only association that remained significant was for BMI Z scores. Specifically, for every 10% increase in the proportion of CLO outlets within 1600m buffers around schools, BMI Z scores increased by 0.18 units ($p<0.05$), conditional on the random effect.

We also examined associations of the relative density of CLO food outlets with each diet and weight status outcome for each level of absolute exposure to 1) CLO food outlets, and 2) total food outlets. In the first set of stratified models, we examined the relative density of CLO food outlets for schools exposed to either lower, medium or higher density of CLO food outlets (Table 3.4). For students who attended schools with a higher number of CLO outlets within 1600m, the relative density of CLO food outlets was significantly associated with Y-HEI (β=-

3.85 [95%CI: -5.64, -2.07], p<0.001), vegetables and fruit consumption (β =-0.85 [95%CI: -1.36, -0.35], p<0.01), and BMI Z score (β=0.36 [95%CI: 0.10, 0.62], p<0.01), conditional on the random effect. The associations for DQI-I and overweight/obesity did not reach statistical significance, but the coefficients were in the expected direction. No significant associations were observed for students attending schools exposed to a lower or medium absolute density of CLO food outlets. In the second set of stratified models, we examined the relative density of CLO food outlets for schools exposed to either lower, medium or higher density of total food outlets (Table 3.5). For students who attended schools with a higher number of total food outlets within 1600m, the relative density of CLO food outlets was significantly associated with Y-HEI (β=-3.90 [95%CI: -5.66, -2.14], p<0.001) vegetables and fruit consumption (β =-0.88 [95%CI: -1.38, -0.37], p<0.01), and BMI Z score (β=0.35 [95%CI: 0.10, 0.60], p<0.01), conditional on the random effect. Again, this association was not evident for DQI-I or overweight/obesity, but the coefficients were in the expected direction. No significant associations were observed for students attending schools exposed to a lower or medium absolute density of total food outlets.

In sensitivity analyses, exclusion of children who reported consuming less than 500 or more than 5000 calories per day revealed similar findings to those in Table 3.3, Table 3.4, Table 3.5, and Table 3.6. Therefore, the present analyses are based on the full sample. Due to many participants with missing data on household income, the present analyses were also performed with household income removed as a covariate, which produced similar findings. Therefore, final models included income as a covariate.

3.4 Interpretation

This study demonstrated that attending a school in an area with a higher number of unhealthy food outlets or all food outlets, is associated with lower diet quality, lower vegetables and fruit consumption, and higher BMI, specifically where the proportion of unhealthy food outlets is also high. Put differently, being exposed to a higher number of food outlets (all types or unhealthy) in the area surrounding a school has the worst effect on diet and weight status outcomes when unhealthy food outlets are main type of food outlet available. This study also revealed that examining multiple dimensions of the food environment may better capture the association between the availability of unhealthy food outlets and diet quality.

The present study examined few associations when considering the number and proportion of unhealthy food outlets separately; this was not surprising. While several studies examining single dimensions of the community food environment have reported a relationship with diet- and obesity- related outcomes, findings have shown to be overall inconsistent.[24,36,37] Cobb et al. conducted a systematic review of 71 studies (published between 2004 and 2013) from Canada and the United States, on the relationship between community food environments and obesity in children and adults.[24] This review reported that of the 21 studies that focused on children, 85% of all associations were null in final adjusted models. Wilkins et al. conducted an updated systematic review that extended upon the review by Cobb et al.[24,36] They similarly examined the relationship between the community food environment and obesity in both children and adults, but included studies published between 2004-2017 from the United States, Canada, United Kingdom, Australia, Germany and New Zealand. Of the 113 studies included in the review, 76% of all associations were null.[36] Results from the present study were for the most part in the expected direction. One statistically significant association persisted after adjustment in the main effect models, and the rest were null.

The majority of food environment research has focused on single dimensions of the community food environment, but researchers have suggested that relative density (proportion) may also be important.[19,23,28] Polsky et al. used a representative sample of 10,199 Canadian adults drawn from the CCHS to examine the joint effect of the number and proportion of fast food restaurants (FFR) on weight status, in addition to considering them separately. The study found a significant association between the proportion of FFR with increased BMI and obesity, particularly in areas with a higher number of FFR. On the contrary, the number and proportion of FFR did not yield meaningful results in the expected direction when considered separately. We applied the same approach in this study, and examined significant associations between the proportion of unhealthy food outlets with diet quality, vegetables and fruit consumption, and BMI Z scores, in areas with both a higher number of unhealthy food outlets and all outlets.

This study addresses several gaps identified in the literature. Researchers agree that food environment measurement requires improvements to achieve consistency and standardization.[9,27,36,37] The CMO/CS/CLO indicator was developed by a Registered Dietician with consideration of the types of foods sold or served at an establishment. Most studies have either used North American Industry Classification System (NAICS) codes to classify retailers,[24,38] or relied on its own categorization.[39,40] Both approaches typically rely on classifying the food environment according to food retailer type (such as fast food or limited service, convenience, grocery, etc.) rather than the types of food being served or sold. Such approaches are prone to misclassification error since not all food retailers that are considered ‘fast food’ outlets are necessarily unhealthy. For example, Chopped Leaf and Freshii are fast food restaurants that serve foods made with fresh and natural ingredients. Our study offers a novel indicator to classify food retailers, which considers the primary types of foods served or sold, and has been shown to perform better than the CDC's mRFEI. The CMO/CS/CLO indicator used in the present study aligns with existing provincial nutrition guidelines,[34,41] and therefore lends itself to future revisions of the recommendations, in addition to other policy developments. Researchers have also suggested that more studies focused on children's diets are needed[42], and that multiple dietary measures should be employed to establish convergent validity.[9] Our study examined children's diets with three diet outcomes, in addition to BMI Z scores and weight status, which provides critical evidence to address these gaps.

Findings from our study should be interpreted with consideration of the potential limitations. Our study was cross-sectional and used exposure and outcome data that were not collected at the same time; therefore, we cannot establish temporal sequence. Food environment data was collected in 2016, and dietary and weight status data were collected in 2014. However, temporal lag of exposure and outcome data within 2 years is common in food environment research.[43,44] We adjusted for several potential confounding variables that are commonly adjusted for in the literature, but residual confounding may have persisted. Dietary data was collected through self-report, which may be prone to measurement error; however, we used a validated FFQ to reduce the possibility of bias. REAL Kids Alberta is a population-based study, but we only included children from Edmonton and Calgary in our analyses, which precludes our ability to generalize findings. A final limitation is the relatively small sample size. We ran multiple statistical tests, which may have increased the likelihood of a type 1 error.

Our study has several strengths. We used data from a population-based survey that collected dietary data with a validated FFQ, and used standardized tools to measure each child's height and weight. Our food environment indicator was derived from a food retailer list obtained from the public health inspector, which is preferred over business data lists.[45,46] The food environment indicator used in our study is novel, and may offer greater precision compared with binary classifications based on store type. To assess children's weight status, we used age- and sex- specific Z scores from the WHO[33], which is the current standard for children. We used both relative and absolute densities among children's food environment to better capture their combined effect on diet and weight outcomes. Lastly, we adjusted for area- level socioeconomic status (SES) to account for clustering of unhealthy food outlets in lower SES neighbourhoods.[47] The area-level SES tool used in this study has been validated for use in Canada.[35]

3.5 Conclusion

Study findings highlight the importance of the combined effect of absolute and relative densities of both unhealthy and all food outlets on diet and weight status outcomes. We found that attending a school in an area with both a higher number of unhealthy or all food outlets, and a high proportion of unhealthy outlets was associated with lower diet quality and increased body weights in children. To our knowledge, we are the first to examine this association with diet-related outcomes in Canadian children. Our findings suggest that areas with a higher concentration of food outlets and few healthy options (high proportion of unhealthy outlets) are in need of public health intervention. Interventions should work to lower the proportion of unhealthy food outlets in these areas, by either increasing the number of healthy food outlets, or decreasing the number of unhealthy outlets. Other potential avenues for prevention may include implementing zoning laws or improving the nutritional quality of foods served at unhealthy food outlets.

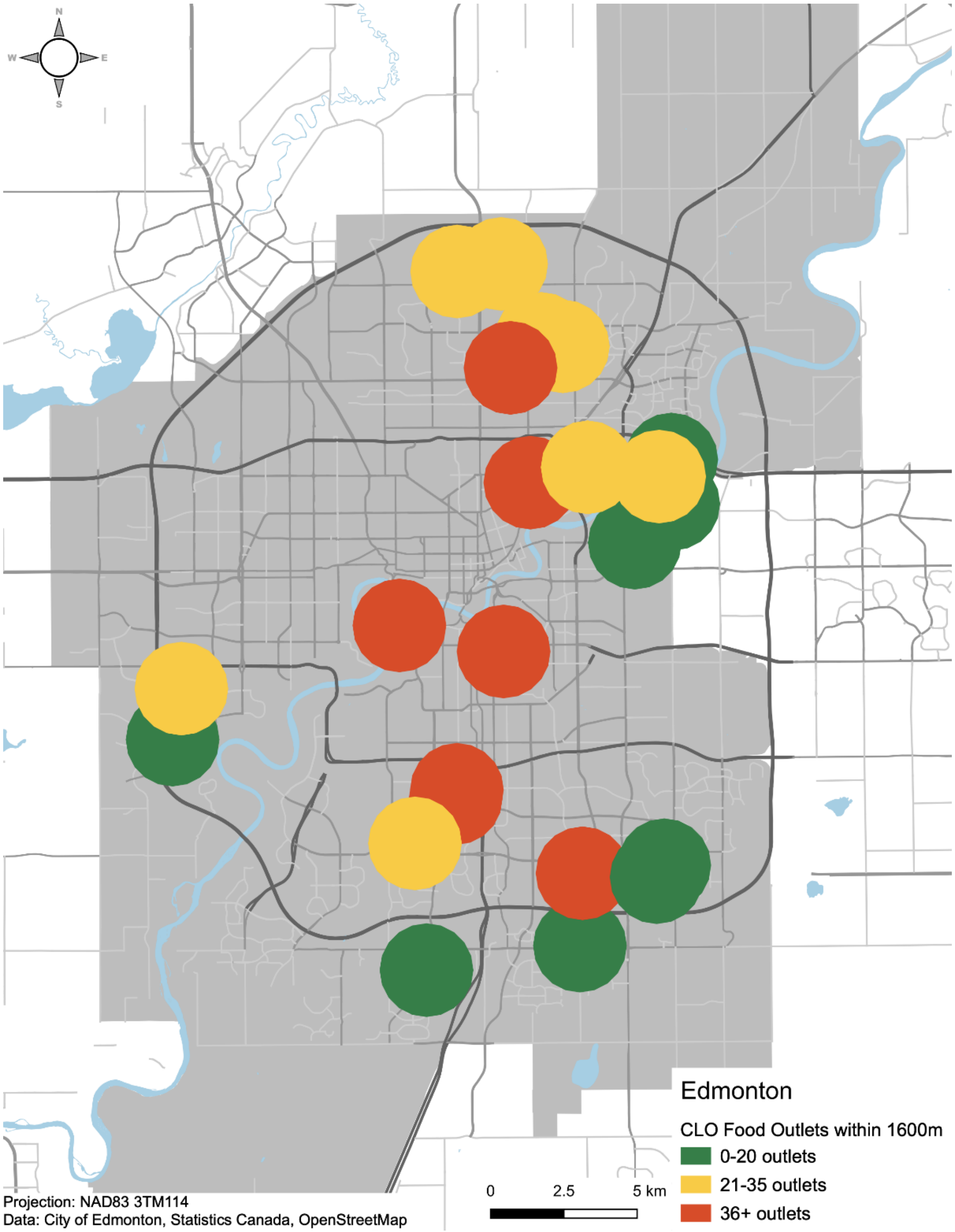

Figure 3.1. Number of CLO food outlets within 1600m of schools in Edmonton

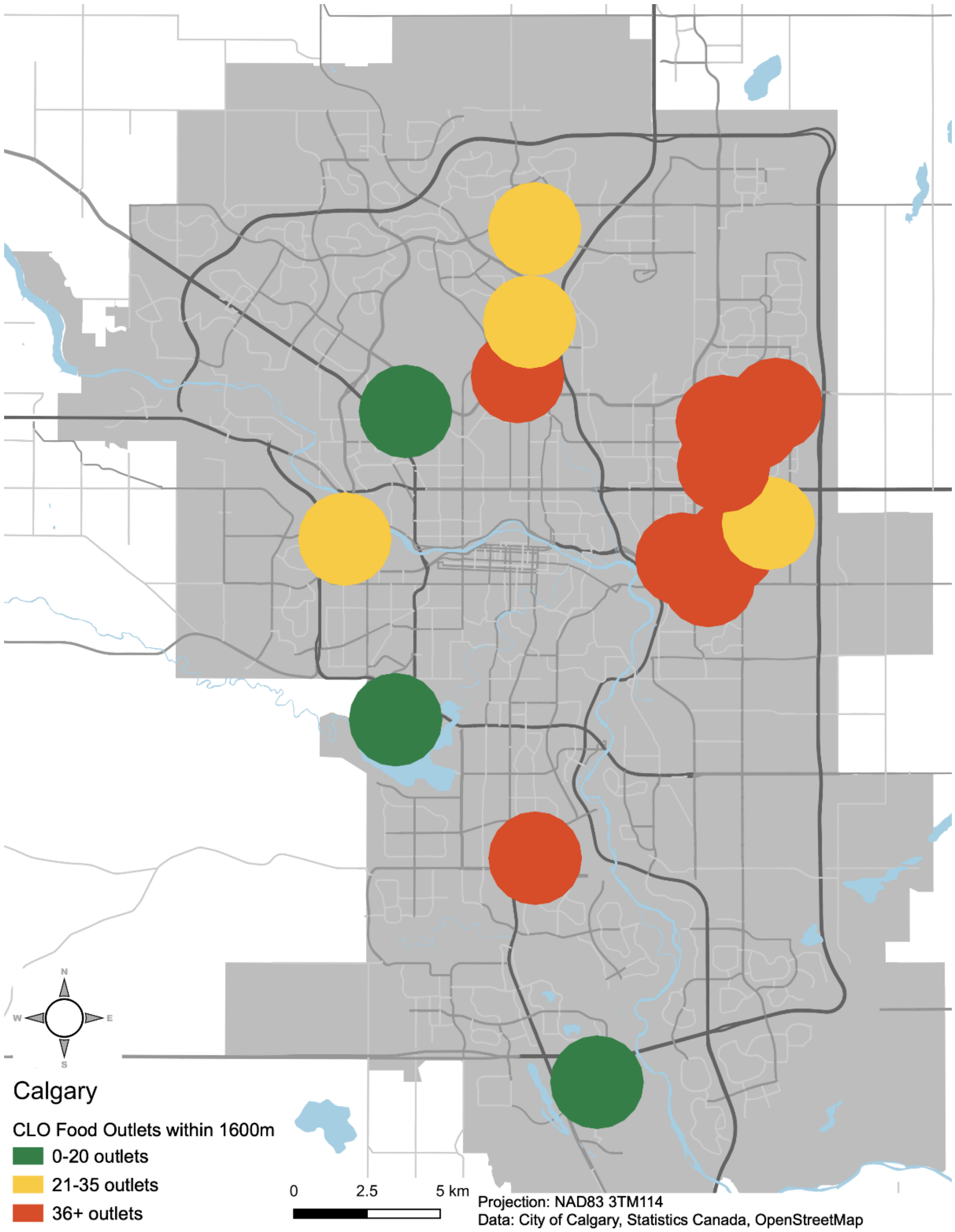

Figure 3.2. Number of CLO food outlets within 1600m of schools in Calgary

Table 3.1. Characteristics of grade 5 students residing in Edmonton and Calgary participating in the 2014 REAL Kids Alberta Study (n=851) and food outlet availability around schools

Participant Characteristics	Total population (n=851)	Lower (0-20 outlets) (n=306)	Medium (21-35 outlets) (n=293)	Higher (36+ outlets) (n=252)
	n (%)	n (%)	n (%)	n (%)
Gender				
Male	402 (47.2%)	151 (49.4%)	134 (45.7%)	117 (46.4%)
Female	449 (52.8%)	155 (50.7%)	159 (54.4%)	135 (53.6%)
Parental Education				
High school or less	167 (19.6%)	33 (10.8%)	55 (18.8%)	79 (31.4%)
College or university	465 (54.6%)	187 (61.1%)	166 (56.7%)	112 (44.4%)
Graduate university	180 (21.2%)	72 (23.5%)	57 (19.5%)	51 (20.2%)
Prefer not to answer/missing	39 (4.6%)	14 (4.6%)	15 (5.1%)	10 (4.0%)
Household Income				
Less than $25,000	53 (6.2%)	11 (3.6%)	19 (6.5%)	23 (9.13%)
$25,000 - $50,000	92 (10.8%)	18 (5.9%)	32 (10.9%)	42 (16.7%)
$50,001 - $75,000	68 (8.0%)	21 (6.9%)	22 (7.5%)	25 (9.9%)
$75,001 - $100,000	78 (9.2%)	27 (8.8%)	30 (10.2%)	21 (8.3%)
> $100,000	211 (24.8%)	119 (38.9%)	60 (20.5%)	32 (12.7%)
Prefer not to answer/missing	349 (41.0%)	110 (36.0%)	130 (44.4%)	109 (43.3%)
Weight Status				
Overweight	204 (24.0%)	73 (23.9%)	72 (24.6%)	59 (23.3%)
Obese	138 (16.2%)	32 (10.5%)	48 (16.4%)	58 (23.0%)
Material Deprivation				
Q1 (least deprived)	125 (15.0%)	90 (29.4%)	0 (0%)	35 (14.8%)
Q2	231 (27.7%)	91 (29.7%)	140 (47.8%)	0 (0%)
Q3	184 (22.0%)	49 (16.0%)	51 (17.4%)	84 (35.6%)
Q4	135 (16.2%)	57 (18.6%)	39 (13.3%)	39 (16.5%)
Q5 (most deprived)	160 (19.2%)	19 (6.2%)	63 (21.5%)	78 (33.1%)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Diet Quality				
Y-HEI	63.2±9.3	63.7±9.3	62.8±9.3	63.2±9.3
DQI-I	62.1±10.7	62.5±9.8	61.4±11.0	62.5±11.3
Daily VF servings	4.98±3.8	4.90±3.5	4.98±3.5	5.10±3.5
BMI Z Score	0.69±1.3	0.50±1.2	0.72±1.2	0.88±1.4
PAQ-C	3.29±0.7	3.4±0.65	3.2±0.69	3.3±0.69
Total daily energy intake	1939.0±1161.6	1922.2±1061.8	1933.0±1281.6	1969.4±1134.5
Food Environment Characteristics (1600m)	Mean (Min-Max)	Mean (Min-Max)	Mean (Min-Max)	Mean (Min-Max)
#Total outlets	56.3 (11-124)	25.4 (11-43)	40.8 (30-51)	89.2 (55-124)
#CMO	10.8 (2-26)	5.18 (2-9)	6.92 (2-10)	17.6 (8-26)
#CS	8.15 (1-33)	4.81 (1-19)	4.91 (1-11)	12.9 (5-33)
#CLO	37.3 (8-93)	15.4 (8-20)	28.9 (22-35)	58.7 (36-93)
%CLO (CLO/total)	66.6 (46.5-89.7)	62.4 (46.5-72.7)	71.3 (60.5-89.7)	66.0 (47.7-75)

1. CMO = choose least often; CS = choose sometimes; CLO = choose least often; %CLO = proportion of CLO food outlets; Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index International; PAQ-C = Physical Activity Questionnaire for Children score; VF = Vegetables and Fruit Servings; BMI = Body Mass Index.

2. Stratified by categories of absolute exposure to CLO food outlets; Low refers to 1600m buffers with 0-20 CLO food outlets; Medium refers to 1600m buffers with 21-35 CLO food outlets; Higher refers to 1600m buffers with more than 36 CLO food outlets.

Table 3.2. Associations of absolute and relative density of CLO food outlets within 1600m of schools with diet and weight status in the REAL Kids Alberta Study (n=851)

	Univariate		Multivariable	
	β (95%CI)	*p-value*	β (95%CI)	*p-value*
Y-HEI				
%CLO	**-1.69 (-2.67, -0.70)**	**0.001**	-0.96 (-2.07, 0.14)	0.088
#CLO	-0.17 (-0.54, 0.19)	0.35	0.071 (-0.33, 0.47)	0.73
DQI-I				
%CLO	-0.44 (-1.54, 0.65)	0.43	-0.085 (-1.06, 0.89)	0.86
#CLO	-0.14 (-0.54, 0.26)	0.49	-0.084 (-0.43, 0.26)	0.63
VF Consumption				
%CLO	-0.21 (-0.63, 0.21)	0.32	-0.25 (-0.55, 0.051)	0.10
#CLO	-0.0057 (-0.16, 0.15)	0.94	0.0047 (-0.10, 0.11)	0.93
BMI Z Score				
%CLO	**0.21 (0.067, 0.36)**	**0.004**	0.15 (0.00029, 0.30)	0.50
#CLO	**0.065 (0.011, 0.12)**	**0.019**	0.052 (-0.0020, 0.11)	0.059
	OR (95%CI)	*p-value*	OR(95%CI)	*p-value*
Overweight/obese				
%CLO	**1.38 (1.09, 1.76)**	**0.008**	1.19 (0.95, 1.48)	0.14
#CLO	1.09 (1.00, 1.19)	0.058	1.06 (0.98, 1.15)	0.14

1. β coefficients and 95% confidence interval (95%CI) from multilevel mixed-effect linear regression models (multiplied by 10).
2. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
3. Multivariable models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
4. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index; %CLO = proportion of CLO food outlets relative to all; #CLO = number of CLO food outlets.
5. Bolded results are statistically significant ($p<0.05$).
6. Table with all covariate coefficients and p-values is in Appendix B.

Table 3.3. Associations of absolute density of all food outlets and relative density of CLO food outlets within 1600m of schools with diet and weight status in the REAL Kids Alberta study (n=851)

	Univariate		Multivariable	
	β (95%CI)	*p-value*	β (95%CI)	*p-value*
Y-HEI				
%CLO	**-1.78 (-2.76, -0.79)**	**<0.001**	-0.87 (-2.01, 0.26)	0.13
#Total	-0.070 (-0.32, 0.18)	0.58	0.099 (-0.17, 0.37)	0.47
DQI-I				
%CLO	-0.52 (-1.60, 0.57)	0.35	-0.090 (-1.11, 0.93)	0.86
#Total	-0.073 (-0.34, 0.20)	0.60	-0.025 (-0.26, 0.21)	0.83
VF Consumption				
%CLO	-0.21 (-0.63, 0.20)	0.31	-0.24 (-0.55, 0.073)	0.13
#Total	-0.00037 (-0.10, 0.10)	0.99	0.014 (-0.059, 0.086)	0.71
BMI Z Score				
%CLO	**0.25 (0.10, 0.39)**	**0.001**	**0.18 (0.021, 0.33)**	**0.026**
#Total	**0.042 (0.0058, 0.079)**	**0.023**	0.033 (-0.0033, 0.069)	0.075
	OR (95%CI)	*p-value*	OR(95%CI)	*p-value*
Overweight/obese				
%CLO	**1.45 (1.14, 1.84)**	**0.002**	1.22 (0.97, 1.53)	0.084
#Total	1.06 (1.00, 1.12)	0.059	1.04 (0.99, 1.10)	0.095

1. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
2. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
3. Multivariable models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
4. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index; %CLO = proportion of CLO food outlets relative to all; #Total = number of total food outlets.
5. Bolded results are statistically significant ($p<0.05$).

Table 3.4. Associations of %CLO with diet quality and weight status for each level of absolute exposure to #CLO outlets within 1600m buffers around schools

	Lower (0-20)		Medium (21-35)		Higher (36+)	
	β (95%CI)	*p-value*	β (95%CI)	*p-value*	β (95%CI)	*p-value*
Y-HEI	1.05 (-1.20, 3.29)	0.36	0.27 (-1.15, 1.70)	0.71	**-3.85 (-5.64, -2.07)**	**<0.001**
DQI-I	0.23 (-2.07, 2.53)	0.84	1.10 (-0.36, 2.56)	0.14	-1.61 (-3.45, 0.24)	0.089
VF Consumption	-0.41 (-1.04, 0.22)	0.20	0.15 (-0.25, 0.54)	0.47	**-0.85 (-1.36, -0.35)**	**0.001**
BMI Z Score	0.17 (-0.15, 0.50)	0.29	0.099 (-0.11, 0.31)	0.35	**0.36 (0.10, 0.62)**	**0.006**
	OR (95%CI)	*p-value*	OR (95%CI)	*p-value*	OR (95%CI)	*p-value*
Overweight/Obese	1.40 (0.78, 2.50)	0.26	1.18 (0.86, 1.63)	0.31	1.55 (0.98, 2.46)	0.060

1. Lower refers to 1600m buffers with 0-20 CLO food outlets; Medium refers to 1600m buffers with 21-35 CLO food outlets; Higher refers to 1600m buffers with more than 36 CLO food outlets.
2. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
3. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
4. All models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
5. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetable and Fruit; BMI = Body Mass Index.
6. Bolded results are statistically significant (p<0.05).

Table 3.5. Associations of %CLO with diet quality and weight status for each level of absolute exposure to #Total outlets within 1600m buffers around schools

	Low (0-33)		Medium (34-54)		High (55+)	
	β (95%CI)	*p-value*	β (95%CI)	*p-value*	β (95%CI)	*p-value*
Y-HEI	2.21 (-0.17, 4.59)	0.069	-0.055 (-1.29, 1.18)	0.93	**-3.90 (-5.66, -2.14)**	**<0.001**
DQI-I	1.81 (-0.68, 4.30)	0.15	0.44 (-0.86, 1.74)	0.51	-1.69 (-3.54, 0.16)	0.073
V+F Consumption	0.14 (-0.54, 0.82)	0.68	-0.034 (-0.39, 0.32)	0.85	**-0.88 (-1.38, -0.37)**	**0.001**
BMI Z Score	0.13 (-0.21, 0.47)	0.45	0.13 (-0.044, 0.31)	0.14	**0.35 (0.10, 0.60)**	**0.006**
	OR (95%CI)	*p-value*	OR (95%CI)	*p-value*	OR (95%CI)	*p-value*
Overweight/Obese	1.28 (0.72, 2.28)	0.40	1.22 (0.90, 1.66)	0.21	1.55 (0.98, 2.47)	0.062

1. Low refers to 1600m buffers with 0-33 total food outlets; Medium refers to 1600m buffers with 34-54 total food outlets; High refers to 1600m buffers with more than 55 total food outlets.
2. β coefficients and 95%CI from multilevel mixed-effect linear regression models (multiplied by 10).
3. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models (multiplied by 10).
4. All models adjusted for gender, total energy intake (or physical activity for models examining BMI/weight status), parental education, household income, and area-level material deprivation.
5. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index.
6. Bolded results are statistically significant ($p<0.05$).

3.6 References

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4.0 Discussion

4.1 Summary

In this thesis, we examined the associations of community food environments, defined using two different food environment indicators and varying areas sizes (or buffer distances) surrounding schools, with individual diet- and weight- related outcomes in a sample of Canadian school-aged children. Results from the first study were used to inform the second study.

In the first study (Chapter 2), we examined the absolute (number) and relative (proportion) densities of unhealthy food retailers for two food environment indicators: the mRFEI, developed by the CDC, and the CMO/CS/CLO, a recently developed food environment indicator. We also examined the number and proportion of unhealthy food outlets within different geographic areas around schools, including 1600m, 1000m, 800m, FSAs, and CTs. The first part of the study demonstrated that the availability of unhealthy food outlets was associated with lower diet quality and higher weight status when defined with the CMO/CS/CLO indicator, and lower vegetables and fruit consumption when defined with the mRFEI. After adjustment for potential confounders, these associations were no longer evident. Using the mRFEI to assess the community food environment yielded several counterintuitive associations with diet quality and weight status. Compared to the mRFEI, the CMO/CS/CLO indicator was better able to capture the associations with diet and body weight status (based on model fit statistics, which assess how well the model aligns with the data). The second part of the study revealed that within larger areas surrounding schools (i.e. 1600m and FSA), the availability of unhealthy food outlets was associated with lower diet quality and increased body weight status before accounting for potential confounders. Comparison of different geographic areas suggested that 1600m geographic areas around schools were better able to capture associations compared to smaller areas.

The second study (Chapter 3) used CMO/CS/CLO, the novel food environment indicator, and a larger geographic area to examine the joint effects of the number and proportion of unhealthy food outlets or all food outlets with diet and weight status outcomes. We found that the number of both unhealthy food outlets and all food outlets modified the effect of the proportion of unhealthy food outlets on diet and weight status outcomes. Namely, attending a school in an area saturated with a higher number of unhealthy or any kind of food outlet combined with a higher proportion of unhealthy outlets, resulted in decreased diet quality and vegetables and fruit consumption. These findings suggest that the community food environment plays a role in the development of poor diets and unhealthy weights in children who attend schools in areas with a higher number of unhealthy or any outlets, with unhealthy outlets being the primary type of available outlet within the area.

4.2 Embedding in Existing Literature

A key observation identified in the food environment literature is the abundance of null findings, as well as results that are in the opposite of the hypothesized direction.[1–4] Even so, community food environments are continuously emphasized as a potential predictor of poor diets and increased weight.[5,6] A number of methodological issues exist in the food environment literature, which may be contributing to the lack of consistent findings.

The mRFEI and other indicators based on food outlet type do not consider the type of food served or sold at an establishment, which may generate substantial misclassification. The

CDC measure, the mRFEI, defines a less healthy retailer as any fast food restaurant or convenience store.[7] These food outlet types are typically defined according to NAICS codes, which offer very broad categories.[8] Existing food retailers have started to change their menus and introduce healthier food options[9,10], and new food outlets focused on serving and selling healthy foods have emerged.[11,12] With these changes, grouping food retailers together based on the amount of service received may be dated. Outlets such as Subway, Chopped Leaf, and Freshii are all considered fast food restaurants, but they offer healthy food options. Classifying these food outlets as less healthy or 'fast food' may dilute or reverse the associations of food environments with diet and weight status outcomes. Indeed, models based on the mRFEI in the first study of this thesis produced coefficients that were in the opposite of the hypothesized direction. Classifying food outlets based on outlet type may be an important culprit that underlies inconsistent or null findings in previous studies.[1,2,4] Evaluating food retailers at the population level is challenging and using approximations is often the solution. The downside of using approximations or simplifications is the large amount of error that is introduced. Reviewing menus offers improvement and potentially improves precision. However, it is not possible to eliminate the potential for error.

Several studies focused on children have assessed the community food environment using more than one food environment measure (absolute density, relative density, and proximity),[13–17] but to our knowledge, no study has used two different indicators to classify food retailers and then compared them. In addition, there are no studies in children that include absolute density with relative density. We did this to account for the fact that an area with 2 unhealthy outlets and 2 healthy outlets has a relative density of 1; this is also true for an area that has 50 unhealthy outlets and 50 healthy outlets. However, the potency of the exposure is not the same. This approach provides a more sophisticated assessment of the food environment than prior studies based on one aspect only.

Many studies have employed multiple geographic areas and boundaries. However, Caspi et al. suggests that some studies may not have found an association because the chosen buffer or boundary was not relevant to the population participating in the study.[1] They suggest rationalizing the buffer distance used. While we compared multiple buffers and boundaries, ultimately, we limited the analyses to larger buffers, as most Albertans reside in car-dependent neighbourhoods, and families often drive within a larger area to source their food.[18] Further, the systematic review by Cobb et al. found that studies that employed a larger geographic area to assess the food environment were more likely to find expected associations compared to using smaller buffers.[2] Therefore, they suggested that the broader neighbourhood may be more important than immediate surroundings. Both studies within this thesis corroborate these earlier conclusions. Although we conducted our analyses with a sample of school-aged children (10-11 years of age) who may not have the opportunity to walk to and from school, we assumed that children reside in the same neighbourhood as their school, and their parents may source food from food outlets in the surrounding neighbourhood. For this reason, findings may not be easily replicated in other population groups, such as adolescents who are more independent, and adults.

4.3 Strengths and Limitations

This research contains several strengths and limitations that must be considered. Both studies presented in this thesis were cross-sectional, which hinders our ability to establish temporal sequence. Likewise, exposure and outcome data were not collected at the same time; the exposure of interest was derived using a public health inspector's food list from 2016, while the dietary and weight status outcomes were collected in 2014. However, temporal lag of exposure and outcome data within 2 years is common in food environment research.[19,20]

The results presented in this thesis considerably differed between univariate and multivariate analyses. Previous studies have adjusted for confounding variables similar to those adjusted for in the present studies. The first study of this thesis examined statistically significant associations before adjusting for confounders. After adjustment, associations were no longer statistically significant. Previous food environment studies have reported null findings after adjustment for confounding variables.[2,4] Despite adjustment for potential confounders, residual confounding may have persisted.

While the REAL Kids Alberta study collects data from schools across Alberta, we limited our analyses to Edmonton and Calgary, as data on food retailers was only available to us for these two cities. Limiting analyses to children who reside in Edmonton and Calgary precludes the generalizability of our findings. Urban food environments differ greatly from rural food environments, and food environment measures may not be applicable in both urban and rural settings.[21]

Information bias may be present in both studies. Dietary intake was based on self-report, which may be prone to measurement error. Measurement error may have hindered us from capturing the true levels of food intake. Individuals may simply have poor recall and are not able to recall the type and amount of foods that they consume accurately.[22] FFQs typically ask participants to recall the types and frequencies of foods consumed over the past year. This may be difficult to remember and quantify, especially for children. Social desirability bias is another type of information bias that should be considered when using self-report data; some participants may regard their diets a sensitive topic and underestimate unhealthy eating or overestimate healthy eating.[23] Regardless of the potential limitations attached to self-report dietary data, use of a validated FFQ remains a cost-effective way to collect complex dietary data and is the primary dietary assessment tool in large epidemiological studies.[22,24]

A final limitation is that our sample size is relatively small. Food retailer data was only available for Edmonton and Calgary, and once children missing exposure and/or outcome information were removed, the final sample size was 851 students from 39 schools. We ran multiple statistical tests, which may have increased the likelihood of a type 1 error. Despite the smaller sample size, the ICCs obtained from the unconditional null models revealed that heterogeneity existed between schools, but it was low. Therefore, a larger sample size may not be necessary.

While a number of potential limitations exist, this thesis also has a several strengths. Both studies used data from the REAL Kids Alberta population-based study, which collects comprehensive dietary data with a validated FFQ, as well as measured height and weight. It has been suggested that including more than one dietary measure is essential for establishing convergent validity.[1] We assessed the relationship between community food environments with multiple dietary and nutritional outcomes, including the Y-HEI (adapted for the Canadian context), DQI-I (an internationally used index), daily vegetables and fruit consumption, BMI Z scores, and weight status. To assess children's weight status, we used age- and sex- specific Z scores from the WHO, which is the current standard for children.[25,26] Both studies used a food retailer list from the public health inspector to create exposure variables. This is recommended over business data lists, which are known to be inaccurate.[27,28] We used both relative and absolute density to capture the food environment, and in the second study we assessed the combined effect of them on diet and weight outcomes. In the first study of this thesis, we employed a novel food environment indicator comprised of three categories, which was developed in Alberta by a Registered Dietician (RD) who ranked food retailers' menus, and compared it with the CDC's mRFEI, which has only two categories and is more prone to misclassification. We also used several buffer and boundary sizes and compared them to assess which one better captures associations. Lastly, in order to account for clustering of unhealthy food outlets in lower socioeconomic status (SES) neighbourhoods[29], we adjusted for area-level SES using a well-established and validated tool.[30]

4.4 General Implications

The prevalence of unhealthy eating, overweight/obesity, and chronic disease have continued to increase despite healthy eating recommendations.[31] Obesogenic environments have hindered individual-level interventions from reducing unhealthy eating, overweight/obesity, and chronic disease. Knowledge from the studies presented in this thesis support the notion that surrounding food environments play a role in the quality of food people consume, which thereby influences their weight status. This information can inform policies at the population level, thus contributing to primary prevention of unhealthy eating and increased body weights. Shifting the population distribution through the creation of more leptogenic environments is a promising solution. The CMO/CS/CLO indicator used in this thesis aligns with existing provincial healthy eating recommendations,[32,33] and therefore lends itself to future revisions of these recommendations and policy developments in general. In addition, it facilitates contextualization of results within existing recommendations, which could be used by policy- and decision-makers.

Results from the second study of this thesis suggest that children attending schools in areas with both a higher number and proportion of unhealthy food outlets have worse diets and higher BMIs; therefore, population level interventions are urgently needed. Potential avenues to create healthier food environments may focus on zoning laws, and specifically changing the distribution of unhealthy food outlets. Research from this thesis corroborates recent Canadian research in adults to support the notion that adding healthy food outlets to an area containing an abundance of unhealthy food outlets may lead to changes in healthy eating and weight status by improving the availability healthy food.[34] Another strategy is to develop and implement policies that improve the nutrition of foods served at unhealthy food outlets.[6] Addressing the high prevalence of unhealthy eating, overweight and obesity, and chronic disease is critical to reduce the high levels of premature mortality due to these conditions, and the economic burden that these conditions put on the healthcare system.

Previous studies that focused on one element of the food environment have yielded inconsistent or null findings.[2,35] Therefore, future research should work to examine the joint effect of both absolute and relative densities of surrounding food environments. Moreover, future studies should not rely on food environment indicators based solely on the type of outlet, and should incorporate information about the foods being served or sold. This thesis focused on a sample of Canadian school-aged children but examined food environments surrounding their schools. Future studies should assess the effect of the food environment surrounding children's residences to corroborate our study findings. Lastly, future studies should assess these relationships in adolescents, who are generally more independent than school-aged children.

4.5 Conclusion

The two studies conducted within this thesis provide contributions to the growing food environment literature. Efforts to reduce the prevalence of unhealthy eating, overweight and obesity, and chronic disease in Canada have primarily focused on individual prevention. The creation of health-promoting environments, as suggested by the WHO[6], offers an important approach that may intensify the effect of the individual level interventions. Making healthy diet changes while surrounded by unhealthy food outlets hinders an individual's ability to make healthy food choices. Local governments should target areas with a higher number of unhealthy food outlets, specifically where there are few alternative healthy options available (high relative proportion of unhealthy outlets) to create supportive food environments where the healthy choice is the easy choice. This thesis contributes important evidence to help build Canadian consensus on effective approaches to reduce the high prevalence of unhealthy eating and excess body weight among Canadian children.

4.6 References

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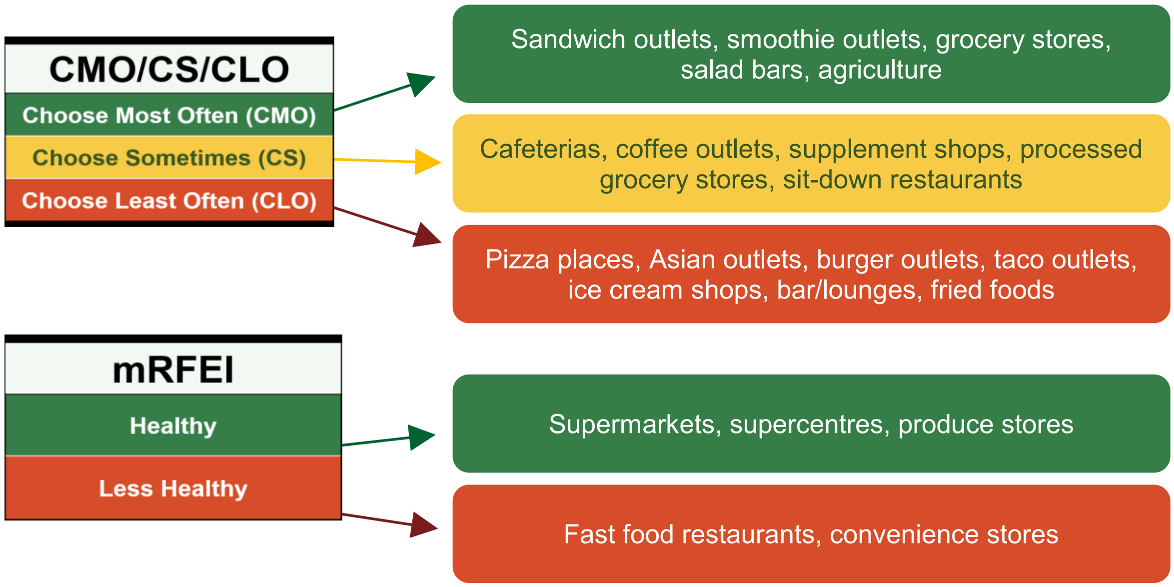
Appendix A: Food Retailer Classifications for CMO/CS/CLO and mRFEI



	mRFEI	CMO/CS/CLO
THE CHOPPED LEAF	Less Healthy	Choose Most Often
McDonald's	Less Healthy	Choose Least Often
Tim Hortons	Less Healthy	Choose Sometimes
Sobeys	Healthy	Choose Most Often

Appendix B: Fully adjusted associations of %CLO and #CLO food outlets with dietary and weight status outcomes within 1600m of schools in the REAL Kids Alberta Study (n=851)

	β (95%CI)	*p-value*
Y-HEI		
%CLO	-0.096 (-0.21, 0.014)	0.088
#CLO	0.0071 (-0.033, 0.047)	0.73
Gender	**-1.49 (-2.70, -0.28)**	**0.016**
Total energy	**0.0014 (0.00084, 0.0019)**	**<0.001**
Education		
High school or less	1.47 (-1.66, 4.60)	0.36
College/University	1.79 (-1.21, 4.79)	0.24
Graduate university	2.56 (-0.60, 5.73)	0.11
Income		
Less than $25,000	-1.76 (-4.35, 0.84)	0.19
$25,000-$50,000	**-3.84 (-5.96, -1.72)**	**<0.001**
$50,001=$75,000	0.048 (-2.32, 2.42)	0.97
$75,001-$100,000	0.97 (-1.27, 3.20)	0.40
>$100,000	0.82 (-0.83, 2.48)	0.33
Material Deprivation		
Q2	-1.78 (-4.48, 0.92)	0.20
Q3	-1.80 (-4.69, 1.10)	0.22
Q4	-2.80 (-5.82, 0.21)	0.068
Q5	-3.07 (-6.28, 0.14)	0.061
DQI-I		
%CLO	-0.0085 (-0.11, 0.089)	0.86
#CLO	-0.0084 (-0.043, 0.026)	0.63
Gender	-0.50 (-1.79, 0.79)	0.45
Total energy	**0.0041 (0.0036, 0.0047)**	**<0.001**
Education		
High school or less	0.059 (-3.28, 3.40)	0.97
College/University	0.38 (-2.82, 3.57)	0.82
Graduate university	2.42 (-0.95, 5.80)	0.16
Income		
Less than $25,000	0.85 (-1.91, 3.61)	0.54
$25,000-$50,000	-2.21 (-4.46, 0.053)	0.056
$50,001=$75,000	1.54 (-0.98, 4.07)	0.23
$75,001-$100,000	-0.92 (-3.31, 1.46)	0.45
>$100,000	-0.19 (-1.95, 1.57)	0.83
Material Deprivation		
Q2	-2.0 (-4.16, 0.17)	0.071
Q3	-0.84 (-3.30, 1.62)	0.50
Q4	-1.55 (-4.12, 1.03)	0.24
Q5	-2.27 (-5.11, 0.58)	0.12
VF consumption		
%CLO	-0.025 (-0.055, 0.0051)	0.10
#CLO	0.00047 (-0.010, 0.011)	0.93

Gender	0.029 (-0.32, 0.38)	0.87
Total energy	**0.0023 (0.0022, 0.0025)**	**<0.001**
Education		
High school or less	0.51 (-0.40, 1.43)	0.27
College/University	0.098 (-0.78, 0.97)	0.83
Graduate university	0.30 (-0.63, 1.22)	0.53
Income		
Less than $25,000	0.0075 (-0.75, 0.76)	0.98
$25,000-$50,000	-0.41 (-1.03, 0.21)	0.20
$50,001=$75,000	-0.16 (-0.86, 0.53)	0.64
$75,001-$100,000	-0.075 (-0.73, 0.58)	0.82
>$100,000	0.30 (-0.18, 0.79)	0.22
Material Deprivation		
Q2	-0.24 (-0.96, 0.48)	0.51
Q3	-0.18 (-0.97, 0.60)	0.65
Q4	0.11 (-0.71, 0.92)	0.80
Q5	-0.27 (-1.15, 0.61)	0.55
BMI Z Score		
%CLO	0.015 (0.000029, 0.030)	0.50
#CLO	0.0052 (-0.00020, 0.011)	0.059
Gender	**0.22 (0.043, 0.39)**	**0.014**
PAQ-C	**-0.14 (-0.27, -0.011)**	**0.034**
Education		
High school or less	-0.14 (-0.58, 0.30)	0.53
College/University	-0.056 (-0.48, 0.36)	0.79
Graduate university	0.13 (-0.31, 0.58)	0.56
Income		
Less than $25,000	0.26 (-0.10, 0.62)	0.16
$25,000-$50,000	-0.024 (-0.32, 0.27)	0.87
$50,001=$75,000	-0.00062 (-0.33, 0.33)	0.99
$75,001-$100,000	-0.035 (-0.35, 0.28)	0.83
>$100,000	**-0.24 (-0.47, -0.0083)**	**0.042**
Material Deprivation		
Q2	**0.39 (0.029, 0.75)**	**0.034**
Q3	0.35 (-0.040, 0.74)	0.079
Q4	0.24 (-0.16, 0.64)	0.25
Q5	0.35 (-0.084, 0.78)	0.12
	OR(95%CI)	*p-value*
Overweight/obese		
%CLO	1.02 (0.99, 1.04)	0.14
#CLO	1.01 (1.00, 1.01)	0.14
Gender	**1.53 (1.14, 2.07)**	**0.005**
PAQ-C	**0.73 (0.58, 0.91)**	**0.005**
Education		
High school or less	0.95 (0.45, 1.98)	0.89
College/University	0.96 (0.48, 1.96)	0.92

Graduate university	1.37 (0.65, 2.89)	0.41
Income		
Less than $25,000	1.35 (0.73, 2.49)	0.33
$25,000-$50,000	0.86 (0.53, 1.41)	0.56
$50,001=$75,000	1.12 (0.64, 1.96)	0.68
$75,001-$100,000	0.99 (0.58, 1.68)	0.97
>$100,000	0.70 (0.46, 1.05)	0.082
Material Deprivation		
Q2	**3.02 (1.71, 5.35)**	**<0.001**
Q3	**2.84 (1.51, 5.32)**	**0.001**
Q4	**2.67 (1.40, 5.08)**	**0.003**
Q5	**2.71 (1.35, 5.44)**	**0.005**

1. β coefficients and 95% confidence interval (95%CI) from multilevel mixed-effect linear regression models.
2. Odds ratios (OR) and 95%CI from multilevel mixed-effect logistic regression models.
3. Y-HEI = Youth Healthy Eating Index; DQI-I = Diet Quality Index-International; VF = Vegetables and Fruit; BMI = Body Mass Index; PAQ = Physical Activity Questionnaire for Children score; %CLO = proportion of CLO food outlets relative to all; #CLO = number of CLO food outlets.
4. Reference groups for income and education are 'missing/prefer not to answer'; Reference group for gender is 'female; Reference group for material deprivation is 'Q1'.
5. Bolded results are statistically significant ($p<0.05$).