The influence of social determinants of health and the built environment on the weight status of preschoolers in Alberta

by

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Abstract

Background

Underweight, overweight and obesity in early childhood can compromise health over the life course. Underweight, an indicator of undernutrition, can lead to higher morbidity, restricted growth, and delayed development. Overweight and obesity can lead to health conditions such as cardiovascular stress, skeletal stress, and asthma at an early age. Contextual factors in a child's upbringing, such as social determinants of health (SDH) and the built environment, impact health inequities and may have protective or harmful effects towards developing underweight, overweight and obesity in early childhood. My thesis has two objectives: (a) to examine associations between social determinants of health and weight status in preschool children in Edmonton and Calgary, Canada and (b) to examine relationships between built environment variables related to physical activity and excess weight status in preschoolers in Edmonton and Calgary, Canada.

Methods

In Chapter 2, I conducted a retrospective cohort study to examine associations between social determinants of health, including ethnicity, maternal immigration status, neighborhood-level income, urban versus rural residence, and material and social deprivation on weight status in preschool children in Edmonton and Calgary. I ran three multinomial regression models, where the outcome variable was child weight status. The first model studied associations between child ethnicity, maternal immigration status, neighborhood-level income, and residence with child weight status. The second and third models individually estimated associations 3 between material and social deprivation and child weight status. In Chapter 3, I conducted a retrospective cohort study to examine associations between the distance to nearest playground, distance to nearest

major park, distance to nearest school, number of street intersections, number of major parks, number of major playgrounds, and weight status in preschoolers in Edmonton and Calgary. I ran three binomial logistic regression models, where the outcome variable was child weight status examined in 2 categories (normal weight and excess weight[overweight and obesity]). The first model examined individual associations between each of the built environment variables and the likelihood of excess weight. The second model examined combined associations between all built environment variables and the likelihood of having excess weight. The third model examined combined associations between all built environment variables and odds of having excess weight, while additionally adjusting for child sex, age at BMI measurement, ethnicity, annual neighborhood-level income, and city.

Results

In Chapter 2(n=169,465), I found that children with Chinese ethnicity were less likely to have overweight (Relative Risk Ratio[RRR]: 0.63) and obesity (RRR: 0.47) and children with South Asian ethnicity were more likely to have underweight (RRR: 3.95) and obesity (RRR: 1.38). Children with mothers who immigrated to Canada were less likely to have underweight (RRR: 0.70) and obesity (RRR: 0.70). Every $10,000 increase in income was associated with a decrease in the likelihood of children having overweight (RRR: 0.94) and obesity (RRR: 0.87). Relative to the least deprived quintile, children in the most materially deprived quintile were more likely to have underweight (RRR: 1.98), overweight (RRR: 1.56) and obesity (RRR: 3.32). Children in the most socially deprived quintile were more likely to have overweight (RRR: 1.25) and obesity 4 (RRR: 1.40) (all $p<0.0001$). In Chapter 3(n=121,692), I found that distance to nearest school was related to children's weight status, whereby every 100m increase in distance to nearest school

resulted in lower odds of excess weight (Odds Ratio: 0.996; $p<0.05$). None of the other built environment measures that were considered had any impact on preschool children's weight status.

Conclusion

My findings highlight SDH-based differences in underweight, overweight and obesity prevalence in preschoolers and suggest that SDH exert a greater influence on weight status in preschoolers than the built environment. Public health efforts to prevent or manage underweight, overweight and obesity in early childhood should emphasize social determinant of health assessments in the clinical setting and target vulnerable populations based on inequities in social determinants of health to promote healthy living and manage weight status. To help explain my findings, several research avenues are suggested, including examination of (a) the link between high-quality playground and major park accessibility and weight status in preschoolers and (b) modifying effects of climate and neighborhood safety on the link between built environment and weight status in preschoolers. Further SDH research targeting underweight in Canadian preschool populations is also needed.

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CHAPTER 1: BACKGROUND

The background of my thesis will primarily focus on topics relevant to the study population in chapters 2 and 3; the cohort examined in my thesis is preschoolers, which typically includes children from 4 to 6 years old. Contextual influences on child weight will also be examined through a classification used by Pereira et al. (2019), which is based on the socioecological model (SEM); the SEM is applied often in research on pediatric obesity (Ohri-Vachaspati et al., 2015). Pereira et al. (2019) recently conducted a scoping review of the determinants of child obesity, and merged existing levels of the SEM with environment-level influences to create the following categorization: (a) the individual level (*e.g.,* child age, gender, personal behaviours); (b) the interpersonal level (*e.g.,* educational, socioeconomic or other status characteristics of parents, close relatives and peers); (c) the community level (*e.g.,* social associations, religious groups or others that the child is a part of); (d) the environment level (*e.g.,* neighborhood socioeconomic status [SES], urban design); and (e) the institutional and policy level. The influences of the social determinants of health (SDH) and built environment on weight status in young children are complex, interrelated, and can take place on multiple levels of this model.

1.1 Monitoring Child Growth in Canada

Several different metrics and reference populations are used to monitor child growth and development. In Canada, the following anthropometric measures of size and nutritional status are used for children: (a) body mass index-for-age (BMI-for-age), where child BMI (defined as weight in kilograms divided by height in meters squared) is compared to BMI of children of the same age and sex; (b) weight-for-age, where child weight is compared to weights of children of the same age and sex; (c) height/length-for-age, where child height/length is compared to heights/lengths of children of the same age and sex; (d) weight-for-length, where child weight is compared to weights of children with the same length, age and sex; and (e) head circumference-for-age, where child head circumference, measured around the head's largest area, is compared to head circumferences of children with the same age and sex (Dietitians of Canada et al. 2010; Dietitians of Canada et al., 2014b). Weight-for-age, length-for-age, weight-for-length, and head circumference-for-age are recommended for children between birth and 2 years old; weight-for-age, height-for-age and BMI-for-age are recommended for children above 2 years old (Dietitians of Canada et al., 2014a). Using these metrics, repeated measurements are used to evaluate child growth over time (Dietitians of Canada et al., 2014a).

Measures of child weight are often displayed and interpreted as percentiles and z-scores to classify growth status, relative to a reference population, based on cut-off points (Dietitians of Canada et al., 2010; Anderson et al., 2017). Z-scores (*i.e.,* standard deviation scores) represent the distance in standard deviation units and direction from the mean or median. (Anderson et al., 2017). However, a Canadian study reported misclassification of child size status (*e.g.,* wasted, at risk of overweight, overweight or obesity) when using BMI percentiles instead of BMI z-scores for children under 6 years old (Anderson et al., 2017). Z-scores have been recommended for research settings, whereas percentiles may be easier for clinicians and families to understand, so they are recommended for use in clinical settings (Wang & Chen, 2012). However, some studies on weight status in young children rely on parent-reported data, which results in measurements that are prone to bias (Rendall et al., 2014).

The current version of the World Health Organization (WHO) Growth Charts for Canada was developed based on the 2006 WHO Child Growth Standards and the WHO Growth Reference 2007 charts (Dietitians of Canada et al. 2010; Dietitians of Canada et al., 2014a). The 2006 WHO Child Growth Standards were recommended for monitoring child growth between 0 to 5 years old; they were based on children raised in communities where economic conditions favored appropriate growth, and children were raised according to Canadian and international recommendations for health and nutrition (World Health Organization, 2006). For instance, in this group, breastfed infants were used as the standard, and the charts depicted the way healthy children should grow since their growth and development were monitored longitudinally. The WHO 2006 Child Growth Standards were applicable towards Canada's multi-ethnic population because it is an international dataset of children from Brazil, Ghana, India, Norway, Oman, and the USA (World Health Organization, 2006; Dietitians of Canada et al., 2014a). At 5 years of age, measurements of the WHO 2006 Growth Standards closely matched measurements with the WHO Growth Reference 2007 charts (de Onis, 2007).

The WHO Growth Reference 2007 was recommended for monitoring child growth between 5 to 19 years old. Instead of solely relying on a reference population that trended towards overweight or obesity (resulting in overestimation of underweight and underestimation of obesity), the WHO Growth Reference 2007 charts reconstructed a population sample previously used in 1977 with novel statistical methods that also aligned the data with the WHO 2006 Child Growth Standards (de Onis, 2007). Together, the WHO Growth Charts serve as the basis for defining underweight, overweight and obesity in Canadian children.

1.2 Underweight in Canadian Children

1.2.1 Definition

The WHO defines underweight for children under 5 years old as weight-for-age below -2 standard deviations of the median (using the 2006 WHO Child Growth Standards) (World Health Organization, 2006) and defines thinness as BMI-for-age below -2 standard deviations of the median for children above 5 years old (using the WHO Growth Reference 2007) (de Onis, 2007). However, the WHO recommends using the 3rd percentile as a lower weight-for-age cut-off to define underweight children in developed countries (Dietitians of Canada et al., 2010). Underweight can be an indicator of undernutrition (World Health Organization, 2017) as well as health conditions related to undernutrition (*e.g.,* growth failure [Al Nofal & Schwenk, 2013], wasting [Myatt et al., 2018]). Underweight children may also be stunted (height-for-age z-score <-2 [Dietitians of Canada et al., 2014a]) (Myatt et al., 2018).

According to the WHO Growth Charts for Canada, the 3rd percentile (or a z-score below -2) is recommended as a lower BMI-for-age or weight-for-age cut-off to define underweight in children 2 to 10 years old (Dietitians of Canada et al., 2010). However, as mentioned in the 2014 Health Professional's Guide for using the WHO Growth Charts for Canada (2014a), weight-for-age is not recommended as a sole measure of nutrition (for any age, but especially after 10 years old) because it omits child height measurement, which provides crucial context for assessing nutritional status (Dietitians of Canada et al., 2014a).

1.2.2 Etiology

Child underweight largely stems from poor diet and insufficient calorie intake, and this can arise from factors at the individual, interpersonal and environment levels. At the individual level, child underweight in developed countries can result from a lack of eating skills that affect calorie intake (Uzogara, 2016). Developmental and behavioral problems, such as having difficulty chewing or swallowing food, may impede a child from consuming an adequate amount of food and increase the risk of child underweight (Uzogara, 2016). For example, children with autism spectrum disorder have greater risk of underweight due to food selectivity (Kahathuduwa et al., 2022). According to a Québec-based study, picky eaters were twice as likely to be underweight at 4.5 years old as children who were never picky eaters (Dubois et al., 2007). Surgical diseases, such as cleft palate, can pose a barrier to food intake (Groce et al., 2014). As well, children with food intolerance or allergies are also at higher risk of developing underweight due to restrictions in their diet (Uzogara, 2016). Other dietary restrictions may also predispose children to underweight. A longitudinal Ontario-based study of children between 0.5 to 8 years old found that a vegetarian diet was associated with higher odds of child underweight (Elliott et al., 2022). Medications (*e.g.,* fenfluramine) can also contribute to decreased appetite and weight loss (Buraniqi et al., 2022).

At the individual level, chronic conditions can also cause underweight by hindering the calorie intake and nutrient absorption required for healthy child weight (Uzogara, 2016). For example, children with recurrent infections or a compromised immune system can have reduced energy intake from their diets (Marchand, 2012). Chronic diseases that affect the liver (*e.g.,* cholestatic liver disease), pancreas (*e.g.,* cystic fibrosis), endocrine (*e.g.,* growth hormone deficiency) or gastrointestinal system (*e.g.,* Crohn's disease [Votto et al., 2020]) can also interfere with food digestion and absorption (Marchand, 2012) and delay growth. Similarly, children with genetic syndromes or renal (*e.g.,* renal failure), heart (*e.g.,* congenital heart disease [Herridge et al., 2021]) or lung (*e.g.,* cystic fibrosis) conditions may need extra calories to maintain weight and meet energy demands (Marchand, 2012).

On the interpersonal level, maternal characteristics such as having short-statured mothers may predispose children to underweight (Uzogara, 2016). Child underweight may also stem from early life food parenting practices, such as irregular or insufficient breastfeeding, food rationing or general lack of satisfactory nutrient-dense foods (Uzogara, 2016) to provide infants with insufficient nutrients for healthy growth. Parental factors, especially mothers' worries about children's weight, can also negatively influence eating patterns in early childhood through negative feeding behaviors (*e.g.,* more intrusive and less structured feeding) (Gueron-Sela et al., 2011), which may affect children's relationship with food and their eating behaviors. Lastly, at the environment level, living in food-insecure settings can pose a barrier to accessing sufficient affordable and nutritious food (Gundersen & Ziliak, 2015) and contribute to child underweight by being a barrier to having a healthy and nutritious diet (Uzogara, 2016).

1.2.3 Prevalence

1.2.3.1 Overview

The worldwide prevalence of child underweight is cause for concern, especially in low- to middle-income countries (Black et al., 2013); however, data from several population-based studies conducted from 1975 to 2016 (n=31.5 million; 5 to 19 years old) revealed a downward trend, with the prevalence of underweight decreasing in girls (from 9.2% to 8.4%) and in boys (from 14.8% to 12.4%) (NCD Risk Factor Collaboration, 2017).

1.2.3.2 Prevalence in Canada

Since the majority of child underweight occurs in countries with low and middle incomes, the prevalence of child underweight in Canada is significantly lower than the global prevalence of child underweight. The most recent national data, which are more than a decade old, estimated that the prevalence of underweight in Canadian children (5 to 17 years old) was 2.2% between 2009 and 2011 (Roberts et al., 2012).

1.2.4 Consequences

There is a lack of research of the consequences of child underweight in Canada, which requires examining evidence gathered from children living in other Western countries. A study from Australia noted associations between underweight in preschool children, greater morbidity, and higher levels of special healthcare needs (Wake et al., 2012). A study of underweight children in the Netherlands noted that, based on parental report, underweight children may be treated adversely (*e.g.,* teased, left behind, ignored) relative to normal weight children (van Grieken et al., 2013). Restricted growth due to undernutrition during childhood is linked to short adult height as well as metabolic disorders (Soliman et al., 2021).

The adverse outcomes of child underweight may be an indicator of undernutrition, which can contribute to weakened immune systems (Rytter et al., 2014), compromised brain growth (Prado & Dewey, 2014), and delayed cognitive, physical, and metabolic development (Uzogara, 2016). Child undernutrition can lead to shorter height attainment, lower educational attainment, poor educational performance, and reduced economic productivity in adulthood (Victora et al., 2008). Child undernutrition has also been linked with an increased risk of rapid weight gain, which can put children at risk of overweight and obesity (Wells et al., 2019).

1.2.5 Prevention

Among high-income countries, there is a lack of literature regarding interventions specifically targeted at preventing underweight. However, underweight children can be wasted, stunted or both (where stunting and wasting share direct causal factors [World Health Organization, 2014]), and child underweight is an indicator of undernutrition; preventing these conditions through interventions that target interpersonal, community and environment levels may also prevent underweight.

At the interpersonal level, preventing undernutrition can happen during pregnancy by maintaining adequate nutrition and healthy iron, iodine, and vitamin A levels in mothers (Lankester, 2019). In infancy, preventative approaches to stunting and wasting include breastfeeding, nutrition counselling for families regarding supplementary infant feeding, and offering food supplements, if necessary (World Health Organization, 2014). For older children, the WHO recommends improving the diversity and quality of family foods to improve stunting and wasting (World Health Organization, 2014). Overall, families must ensure that overweight and obesity are also prevented, and that children gain weight in a healthy way (Yanovski, 2017). At the community level, in the healthcare setting, Canadian healthcare providers are encouraged to include regular child growth assessments at both well-health and acute care visits to monitor growth and intervene, as necessary (Dietitians of Canada et al., 2014a). On the environment level, some studies report a link between food insecurity and increased risk of childhood stunting (Moradi et al., 2019) and underweight (Abdurahman et al., 2016); improving the accessibility of nutritious foods to reduce household food insecurity may therefore help prevent underweight. If children already have underweight, however, underweight management must be pursued.

1.2.6 Management

There is a lack of literature or recommendations regarding interventions designed to manage underweight in Canadian preschoolers. Regarding growth failure interventions in toddlers (18 months to 3 years old), however, recommendations by the Canadian Paediatric Society include evaluating the child's feeding history (*e.g.,* weaning, first experiences with food, history of food allergies) and eating behaviors (*e.g.,* general difficulty feeding, problems with textured or solid food, distractions while eating, eating with the family) (Marchand, 2012). These recommendations can be implemented through conversations with caregivers, while simultaneously assessing caregiver feedback as indicators of parent-child feeding relationships (Marchand, 2012). A physical examination is also recommended, with clinical tests such as blood tests and urinalyses performed to test for underlying medical conditions (Marchand, 2012). Intervention can include referral to a specialist. For instance, dietitians can review child diets and suggest additives to increase caloric density (*e.g.,* cream, oil, powdered milk, glucose polymers) (Marchand, 2012). Psychosocial interventions that target parental anxiety, allow children more control over the feeding process, and improve mealtime experiences, perhaps with the help of psychologists, occupational therapists, or speech pathologists when necessary (Marchand, 2012). In rare situations, medications may be used to stimulate appetite or tube feeding could be used when oral food intake is deemed unsafe (Marchand, 2012).

There may be a link between picky eating and underweight in preschoolers (Dubois et al., 2007). Managing picky eating in young children, as recommended by the Canadian Paediatric Society, should begin with a detailed diet history and eating behavior assessment (Leung et al., 2012). In this way, potential causes of picky eating (*e.g.,* parent-child feeding behavior, underlying illness) can be examined (Leung et al., 2012). Managing picky eating can involve managing unrealistic parent expectations, providing structure while allowing child autonomy during eating, adjusting diet (*e.g.,* tailoring food texture and taste towards child age, controlling snack choices), adjusting feeding behaviors (*e.g.,* introducing food in small portions, moderating snack schedule, not coercing or coaxing eating, limiting eating time), and changing the meal setting (*e.g.,* removing distractions while eating, dining with family) (Leung et al., 2012). Physical activity is encouraged to stimulate appetite (Leung et al., 2012). Supplementary vitamins can be used to improve nutrient intake, and in specific cases, children may take appetite stimulants as well (Leung et al., 2012).

1.3 Overweight and Obesity in Canadian Children

1.3.1 Definition

The WHO defines overweight and obesity differently for children based on age. For children under 5 years old, overweight is defined as weight-for-height greater than 2 standard deviations above the WHO Child Growth Standards median; obesity is defined as weight-for-height greater than 3 standard deviations above the WHO Child Growth Standards median (World Health Organization, 2006). For children above 5 years old, overweight is defined as BMI-for-age greater than 1 standard deviation above the WHO Growth Reference median; obesity is defined as greater than 2 standard deviations above the WHO Growth Reference median (de Onis, 2007).

The WHO Growth Charts for Canada, adapted from the aforementioned cut-offs, defines overweight and obesity differently depending on age. For children 2 to 5 years old, overweight is BMI-for-age greater than 2 standard deviations above the median, and obesity is BMI-for-age greater than 3 standard deviations above the median. For children 5 to 19 years old, overweight is BMI-for-age greater than 1 standard deviation above the median, and obesity is BMI-for-age greater than 2 standard deviations above the median (Dietitians of Canada et al. 2010; Dietitians of Canada et al., 2014b). The higher cut-offs for children below 5 years old are out of caution towards subjecting healthy children to unnecessary diets; in children 2 to 5 years old, BMI-for-age does not account for body composition and muscle mass, so some children classified as overweight using BMI-for-age may not actually be overweight (Dietitians of Canada et al. 2010; Dietitians of Canada et al., 2014a). Therefore, healthcare providers are encouraged to further examine (*i.e.,* assess comorbidities or other causes) potentially overweight children under 5 years old to avoid misclassifying normal weight children as overweight (Dietitians of Canada et al. 2010; Dietitians of Canada et al., 2014a).

1.3.2 Etiology

The fundamental cause of overweight and obesity is an imbalance between energy intake and expenditure (Romieu et al., 2017). However, the etiology of overweight and obesity in preschoolers is complex and multifaceted, and takes place across multiple levels, including individual, interpersonal, and environmental.

On the individual level, a child's genetic background may predispose them to overweight and obesity (Trandafir & Temneanu, 2016) on an endogenous level (Mason et al., 2014). Obesity susceptibility is often polygenic, and genes can predispose children to obesity by affecting appetite, metabolism and energy expenditure; however, rare monogenic mutations (*e.g.,* mutations in the obesity gene, Ob) can cause extreme obesity (Trandafir & Temneanu, 2016).

Some cases of child obesity are linked to hormonal imbalances (*e.g.,* hypothyroidism) (Mason et al., 2014). Children born large-for-gestational-age (Kaul et al., 2019) or with higher birth weight (Shi et al., 2013) have higher odds of developing child obesity. On an exogenous level (Mason et al., 2014), consuming unhealthy diets that are ultra-processed, high in trans and saturated fats, salt, food additives, sugars, and low fiber (*e.g.,* fast food) can lead to excessive energy intakes (Monteiro et al., 2019). Other lifestyle habits such as late-timed or short sleep duration (Dev et al., 2013) and high amounts of screen time (*e.g.,* television, video games) can also predispose children to overweight and obesity by encouraging late-night snacking or distracted eating (Smith et al., 2020). A systematic review by Avery et al. (2017) that included examining the links between television viewing while eating with diet quality cited findings that eating while watching television was weakly positively associated with consuming obesogenic ($r=0.23$; $p<0.05$) and fast foods ($r=0.27$; $p<0.05$). This review noted that eating while watching television was associated with more than double the odds of soft drink consumption. Overall, this review also noted that watching television was positively associated with higher BMI, higher BMI z-score and overweight in preschool children. Irregular breakfast consumption (Dubois et al., 2006) and overeating (Dubois et al., 2007) can contribute to overweight and obesity as well. There is inconsistent evidence on the relationship between physical activity and BMI in the early years (Latorre Román et al., 2016), and a review by Carson et al. (2017a) classified many studies in the field as ‘low’ or ‘very low’ quality. However, data from the Canadian Health Measures Survey (2009 – 2013) suggested that moderate-to-vigorous physical activity was negatively associated with obesity risk markers in preschool aged children (Carson et al., 2017b). Metallinos-Katsaras et al. (2007) and Smith et al. (2018) also found associations between vigorous physical activity, lower odds of overweight and greater BMI decrease over time in preschoolers.

On the interpersonal level, maternal characteristics can predispose children to overweight and obesity before birth. High maternal pre-pregnancy weight can increase the risk of children having obesity at 5 years old (Choi et al., 2022) and greater adiposity at 6 years old (Castillo et al., 2015). Maternal weight gain during pregnancy (Rao et al., 2016) can lead to children being born large-for-gestational age, which is associated with increased risk of overweight or obesity later in life (Kaul et al., 2019). Children born to mothers with gestational diabetes (Kaul et al., 2019; Choi et al., 2022) also have greater odds of having overweight or obesity, which can be due to being born large-for-gestational-age (Kong et al., 2019). Maternal smoking during (Shi et al., 2013) and after (McLean et al., 2019) pregnancy is associated with greater odds of overweight and obesity in childhood, perhaps due to altered gut microbiota in neonates and infants of smoking mothers (McLean et al., 2019). Child parity may also be a risk factor; specifically, children born to women with fewer than two previous pregnancies may be more likely to have overweight or obesity (Kitsantas & Gaffney, 2010).

Overweight and obesity in children can also be rooted in early-life food parenting practices. After birth, insufficient breastfeeding (Binns et al., 2016), early introduction of solid foods (Mannan, 2018) and formula feeding (Rossiter et al., 2015) may lead to child overweight or obesity. The protective effect of breastfeeding on obesity may be related to differences in gut microbiome, protein intake and other factors in breastfed infants (*versus* non-breastfed infants) (Kouwenhoven et al., 2022). Early-life breastfeeding practices may also explain associations between maternal diabetes status, maternal smoking, and child overweight and obesity. Oza-

Frank et al. (2014) reported associations between having maternal pre-gestational and gestational diabetes and lower initiation and continuation of breastfeeding in infants; however, maternal smoking status modified the association with breastfeeding initiation, and was associated with lower breastfeeding initiation (Oza-Frank et al., 2014).

In childhood, overweight and obesity can arise from childcare practices after infancy that adversely affect diet, physical activity, and sleep patterns. Children raised with poor parenting (*e.g.,* authoritarian parenting [Melis Yavuz & Selcuk, 2018]) and feeding (*e.g.,* restrictive feeding [Dev et al., 2013; Mahmood et al., 2021] and indulging [Hughes et al., 2021]) practices can lead to children developing unhealthy food preferences and intakes, placing them at risk of unhealthy weight gain or higher weight status. Postnatal maternal depression may predict obesity in preschoolers (Benton et al., 2015), perhaps due to characteristics that disturb maternal-infant interactions during feeding (*e.g.,* reduced sensitivity, responsiveness, and interaction) (El-Behadli et al., 2015). Parents who do not provide a healthy home food environment (Lumeng & Fisher, 2018) can contribute to overweight and obesity by limiting healthy diet choices in preschool children. An Ontario study reported associations between higher parent education and healthier overall diet quality in preschoolers (Leme et al., 2021). Grandparents may also have influence on child diet, albeit a negative one; a UK study found that grandparents of preschoolers scored lower on creating a healthy food environment relative to parents (Marr et al., 2021). Regarding physical activity behaviors in young children, interpersonal barriers can stem from parents (*e.g.,* poor parent health, limited modelling of physical activity, limited time for physical activity) and childcare providers (*e.g.,* limited participation in physical activity) (Hesketh et al., 2017). For example, a study of parent and child physical activity and screen time behaviors found that parents in the lowest physical activity quartile (*versus* highest quartile) were 2.77

times more likely to have a child in the lowest physical activity quartile (Carson et al., 2015). Many of the differences in parenting practices that predispose children to overweight and obesity can stem from socioeconomic factors; for example, parent work status may limit the amount of time available for healthy role modelling (Østbye et al., 2013). Overall, young children heavily depend on caregivers at home and in childcare settings, leaving them particularly vulnerable to influences in their immediate environment. A Canadian study by Bushnik et al. (2017) reported that child weight status was positively associated with the weight status of at least one biological parent, and having a parent with overweight (for girls) or obesity (for boys and girls) placed children at risk of having overweight or obesity.

Interpersonal influences on early child weight status can be affected by caregiver perceptions of child weight status, environment safety and value of physical activity, which affect motivation for promoting healthy diets and encouraging physical activity in children. For example, parents who misperceive their children as not overweight are less likely to enroll in weight interventions (Gerards et al., 2012). Parents with overweight themselves can underestimate the weight status of their children, including those who satisfy criteria for overweight. This issue may be explained, at least in part, by socioeconomic and cultural factors. For example, some studies suggest that mothers with lower educational attainment (Blanchet et al., 2019) or foreign-born status (Natale et al., 2015) are more likely to underestimate children's weight status. As well, parent perceptions of neighborhood safety may limit time allowed for outdoor physical activity in children, which can reduce energy expenditure and increase the likelihood of unhealthy weight gain (Kimbro et al., 2011). Maternal perceptions of increased neighborhood safety can also be positively associated with higher consumption of some healthy foods, perhaps by encouraging mothers to travel more and seek healthy food options (Mayne et al., 2021). Childcare providers can also limit opportunities for physical activity because of prioritizing academic outcomes, perceived safety risks or perceived weather risks (Hesketh et al., 2017).

The environment can also predispose children to or protect them from unhealthy diets, low physical activity, and sedentary behaviors that can lead to overweight and obesity in children. For example, an Edmonton-based study reported links between (a) low neighborhood SES and high screen time, (b) high screen time and fruit juice consumption, and (c) living near a grocery store and lower likelihood of soft drink consumption (Pabayo et al., 2012). Physical activity levels in preschool children can also be hindered or facilitated by accessibility of neighborhood facilities (*e.g.,* opportunity for active transport to childcare centers, schools, and local amenities), availability of space and equipment to play, neighborhood safety, and weather (Hesketh et al., 2017).

1.3.3 Prevalence

1.3.3.1 Overview

Globally, the prevalence of overweight and obesity for children 5 to 19 years old was 340 million in 2016 (World Health Organization, 2021). In 2018, the WHO, UNICEF and World Bank published a joint report that showed the prevalence of overweight was 5.8% for children under 5 years old; however, this estimate did not include high-income countries (Di Cesare et al., 2019). In Europe, pooled overweight and obesity prevalence estimates of children between 2 and 7 years old during 2006–2016 was 17.9%, and the pooled prevalence estimate of obesity was 5.3% (Garrido-Miguel et al., 2019). From 2017 to 2020, the prevalence of obesity among children 2 to 5 years old in the USA was 12.7% (Bryan et al., 2021).

1.3.3.2 Prevalence in Canada

According to the Public Health Agency of Canada (2017), 30% of children 5 to 17 years old had overweight or obesity in 2017. In Alberta, a study of unhealthy weights in preschoolers reported that overweight and obesity decreased between 2010 and 2017 (overweight: 17.8% to 15.7%; obesity: 4.7% to 4.2%). While the prevalence of severe obesity was low (2.2%), it remained unchanged over the study period, suggesting that factors that influenced reductions in overweight and obesity were not operational in those with severe obesity (Ball et al., 2019).

1.3.4 Consequences

Overweight and obesity in children can lead to many comorbidities; various obesity-related health conditions that were previously thought to be specific to adults are being observed in children as well (Daniels, 2006; Sahoo et al., 2015). In this section, consequences of overweight and obesity in children are displayed based on metabolic, mechanical, mental health and social milieu domains (Hadjiyannakis et al., 2016). In the metabolic domain, overweight and obesity can lead to glucose intolerance, type 2 diabetes, non-alcoholic fatty liver disease, high blood pressure, metabolic syndromes, early signs of atherosclerosis, and dyslipidemia (Daniels, 2006; Sahoo et al., 2015; Balasundaram & Krishna, 2021). Overweight and obesity in childhood add stress to the cardiovascular system and predispose children to heart disease later in life (Daniels, 2006; Sahoo et al., 2015). In the mechanical domain, overweight and obesity can lead to skeletal strain from extra weight and joint pain (Daniels, 2006). Respiratory comorbidities can contribute to asthma and sleep apnea in children with overweight and obesity (Balasundaram & Krishna, 2021). Other consequences include gastroesophageal reflux disease (Quitadamo et al., 2012).

In the mental health domain, a 2018 Ontario study revealed an association between overweight and obesity status and increased mental health service use among preschool-aged children (Carsley et al., 2018). Lastly, in the social milieu domain, children with obesity may struggle with social acceptance. Children with obesity can experience teasing and bullying (Russell-Mayhew et al., 2012). Preschool children with obesity may be negatively perceived by their peers (Su & Aurelia, 2011). A study of peer acceptance noted that preschoolers with obesity (a) had less best friend nominations and less reciprocal friendships; (b) were rated as less cooperative, agreeable, and attractive; and (c) were lonelier and teased more often (Kornilaki, 2014).

1.3.5 Prevention

Prevention of overweight and obesity in preschool children can take place at individual, interpersonal and policy levels. At the individual level, preventing overweight and obesity in early childhood involves healthy diet, limited screen time and adequate physical activity. At the interpersonal level, preventing overweight and obesity in children can begin before childbirth. Monitoring gestational weight gain, managing gestational diabetes, and abstaining from smoking during pregnancy can help reduce the risk of overweight and obesity in children. After childbirth, prevention strategies include direct breastfeeding for at least six months as well as abstaining from early introduction of solid foods or excessive formula feeding (Azad et al., 2018).

Additionally, on the interpersonal level, maintaining availability of fresh fruits and vegetables and using positive parenting techniques (*e.g.,* setting consumption limits, modelling healthy eating) can help parents shape their children's lifelong habits and prevent childhood obesity (Smith et al. 2020). The evidence indicating the importance of parental role modelling for children's physical activity appears to be less consistent, although the association is stronger in studies that reported objective *versus* self-reported data (Petersen et al., 2020). Parental support and encouragement (*e.g.,* registering children for sports and activities, paying for transportation to activities) may also be effective in increasing child physical activity (Hesketh et al., 2017). Sleep has also been included in family-based prevention interventions in infants and preschool children from higher-income families (Agaronov et al., 2018), where a higher sleep duration was associated with a lower BMI z-score (Miller et al., 2020). The success of obesity prevention programs for young children heavily relies on parent involvement, since parents largely determine their children's food and physical activity environments (Olstad & McCargar, 2009).

At the community level, in healthcare settings, healthcare providers can also be involved in obesity prevention since they are well positioned to identify young children at risk of becoming overweight (Olstad & McCargar, 2009). At the policy level, a Canadian review reported that most provinces had few nutrition, physical activity and screen time regulations related to obesity prevention in early childcare and education settings (Vercammen et al., 2020). If children already have overweight and obesity, management efforts must be pursued.

1.3.6 Management

Managing overweight and obesity in preschoolers can occur at the individual level. Individual consultation of overweight children as well as age-appropriate interactive education and hands-on experiences with physical activity are effective strategies to prevent obesity in preschoolers (Ling et al., 2016; Mehdizadeh et al., 2019).

At the interpersonal level, recent systematic reviews have supported parent inclusion in interventions for managing overweight and obesity in children. Based on a review of randomized control trials regarding overweight and obesity in preschoolers, most successful management interventions involved active parent participation and behavioral therapy techniques (Ling et al., 2016). The interventions generally targeted parenting and behavior modification, such as healthy role modelling and reorganizing the home environment to encourage healthy habits (Ling et al., 2016). Interventions often targeted the family level, with parents and children participating in separate and joint activities, and included dietary counselling, structured physical activity sessions, and parenting training on behavior management and attitude modification (Ling et al., 2016). A separate systematic review of randomized controlled trials found that interventions on this population often included motivational interviewing for parents or families, dietary interventions with an educational component, or education on nutrition and activity (Nordlund et al., 2022). A systematic review of randomized controlled trials by Seburg et al. (2015) reported that effective interventions in preschool populations involved parent behavior change targets and weight loss goals, which emphasized modeling healthy behaviors. Finally, a Cochrane review of diet, physical activity, and behavioral interventions for managing overweight and obesity in preschoolers, which included a variety of interventions in outpatient, clinical and community settings with child and/or parent involvement, reported that multicomponent interventions (with diet, physical activity and behavioral elements combined) appeared most effective (Coquitt et al., 2016).

Managing overweight and obesity in preschoolers can occur at the community level and in healthcare settings. This management begins with a clinical assessment; the 2006 Canadian Clinical Practice Guidelines on the Management and Prevention of Obesity in Adults and Children recommend that children with obesity should be evaluated through general physical examination and an assessment of family history to screen for endocrine or genetic causes of obesity (Lau et al., 2007). The European Society of Endocrinology and the Pediatric Endocrine Society also emphasize genetic testing of children with early obesity onset (before 5 years old) who also have family history of extreme obesity or have features such as hyperphagia (Styne et al., 2017). The 2006 Canadian Clinical Practice Guidelines on the Management and Prevention of Obesity in Adults and Children recommend that (a) primary care health professionals work with other healthcare team members (*e.g.,* dietitians) to create weight management programs for patients to encourage and maintain weight loss (Lau et al., 2007) and (b) healthcare professionals consider barriers that patients may have regarding obesity management. Children-specific recommendations include conducting follow-up care for at least 3 months, using family-based therapy, and prescribing "fun and recreational" activities that are tailored towards family and child strengths (Lau et al., 2007). Health professionals are discouraged from using pharmacological agents for obesity treatment, unless it is through a supervised clinical trial (Lau et al., 2007). A review of Canadian pediatric weight management clinics between 2015-2019 found that one-third (n=9) did not accept children under 5 years old (Zahn et al., 2021); this suggests that limited availability exists for younger children and their families, and that further efforts are needed to resolve this inequity.

1.4 Social Determinants of Health (SDH)

1.4.1 Definition

According to the WHO, social determinants of health are factors related to how people are born, grow, work, live, and age, as well as broader systems shaping conditions of daily life (World Health Organization, 2022). Many associations between social determinants of health (SDH) and health outcomes are interrelated and complex. The SDH, rooted in unequal power and resource (*e.g.,* goods, services, societal attention) allocation, have a significant impact on health inequities, which are defined by the WHO as "unfair and avoidable differences in health status within and between countries" (Weinstein et al., 2017; World Health Organization, 2022). Population health and illness follow social gradients, whereby certain conditions predispose or enable development of poor health (Weinstein et al., 2017). The literature on social determinants of health differs on a variety of considerations, such as (a) reference points for measuring variable differences, (b) using absolute or relative scales to measure differences, and (c) measuring outcomes in terms of favorable or adverse events. Using different measurement methods can affect analytic results and study conclusions (Keppel et al., 2005; Penmal-Aguilar et al., 2016). Therefore, existing literature on SDH must be interpreted with these limitations in mind. SDH include a range of factors, but in the context of my thesis, relevant SDH include ethnicity, maternal immigration status, neighborhood-level income, urban *versus* rural status, material and social deprivation, which are reviewed below.

1.4.2 SDH and Weight Status in Children

1.4.2.1 Ethnicity

A recent Canadian report defined ethnicity based on shared and distinctive cultural, religious, linguistic, and historical heritage (Public Health Ontario, 2021); however, ethnicity is a complex concept with inconsistent definitions and imprecise classification in the literature (Kaplan, 2014; Zhang & Finkelstein, 2019). Studies of different ethnic groups have noted disparities regarding weight status. For instance, a US-based study reported that children with American Indian/Native Alaskan ethnicity have the highest prevalence of obesity (31.2%%), with levels of obesity that are twice as high as in non-Hispanic White (15.9%) or Asian groups (12.8%) (Anderson &

Whitaker, 2009). Approximately 25% of preschoolers who are of Chinese American heritage have overweight or obesity (Lindsay et al., 2017b). Another study suggested that kindergarten children with African American or multiracial backgrounds have increased risk for overweight and obesity (Flores & Lin, 2012). The association between ethnicity and weight status in children may involve (a) body composition differences between ethnic populations, and (b) cultural influences on parent perceptions and practices. Ethnicity is closely related to race (a social term differentiating groups based on physical differences [Public Health Ontario, 2021]); therefore, racial disparities in income may also explain some associations between ethnicity and child weight status.

Shared ancestral genetic backgrounds can contribute to ethnic-specific differences in body composition. Researchers have noted ethnic-specific differences in body fatness as early as 5 months of age, where offspring of mothers with Hispanic ethnicity had greater adiposity and offspring of mothers with non-Hispanic Black ethnicity had lower adiposity when compared with offspring of mothers with White, non-Hispanic ethnicity (Sauder et al., 2017). Levels of body fat in neonates is positively associated with having obesity between 2 to 6 years old (Moore et al., 2020). Children with South Asian ethnicity may be prone to obesity and have a phenotypic profile of lower lean mass and higher body fat percentage favoring central fat storage (Sivasubramanian et al., 2021).

Ethnic differences in perceptions of children's weight can affect parental decisions regarding children's eating and activity habits, which may contribute to overweight and obesity in children. A review of qualitative literature found that ethnic minorities often equated overweight in children as 'the ideal', with families promoting rapid infant growth by supplementing breastfeeding with cereal, formula, or early solid foods (Chatham & Mixer, 2019). Ethnic differences in perceptions of child weight, such as parents (a) misperceiving children with overweight or obesity as having normal weight or (b) having a lack of concern regarding child overweight risk, can preclude opportunities for participating in weight management interventions. Based on a systematic review, parents with Caucasian ethnicity are less likely to misperceive their children's weight status than other ethnic groups (*e.g.,* Hispanic, Black, South Asian) (Blanchet et al., 2019). A UK study of 5 year olds also found that parents of girls of Pakistani, Bangladeshi, Black African, and mixed ethnicities, as well as parents of boys of Pakistani ethnicity were less likely to report concern about their child's risk of overweight than parents of children with White ethnicity (Firman & Dezateux, 2019). These perceptions can dictate differences in food parenting, which can predispose children to overweight and obesity.

Across ethnic groups, differences in parents' food-related values and practices can influence children's risk of overweight and obesity by setting an unhealthy precedent for food preferences and food intake patterns in children. For example, parents with non-White (*versus* White) ethnicity have scored higher on reactive and controlling food parenting practices (Tugault-Lafleur et al., 2021). Other studies reported that mothers with Chinese ethnicity spoon-feed their preschool-aged children and pressure their children to finish their food (Lindsay et al., 2017b), similar to parents with Somali and Latino ethnicity (Chatham & Mixer, 2019), which can contribute to unhealthy eating behaviors. A focus group that included parents of children in Mexico found that parents used junk foods (*i.e.,* highly processed foods, which are often high in sugar and/or fat) as a reward for good behavior (Rodríguez-Oliveros et al., 2011), despite evidence that high intakes of junk foods can lead to child overweight or obesity (Hemmingsson, 2018). Another review reported that populations with Hispanic and African American ethnicity are more likely to report nonresponsive feeding styles (*e.g.,* controlling, indulgent, and uninvolved) than people with White ethnicity, which can increase risk of overweight and obesity (Hurley et al., 2011). Parents with Asian ethnicity reported higher restrictive feeding practices than other ethnic groups (Wehrly et al., 2014). Extended family members (*e.g.,* grandparents) can also influence children's intakes in ethnic minority families (*e.g.,* Latino, African American) since they often play a key role in child rearing (Peña et al., 2012). Although ethnicity plays a heavy role in dictating dietary behaviors, children's weight status can also be affected by cultural perceptions and behaviors that affect physical activity.

Ethnic differences in participation in or perceptions of physical activity can set precedents for physical activity levels in early childhood. For example, the Canadian Community Health Surveys (2000 – 2005) reported that most ethnic populations (*e.g.,* Aboriginal peoples, Chinese, South Asian, Latin, Arab) are less likely to participate in leisure time physical activity compared with those of White ethnicity (Dogra et al., 2010). Parents with Asian American ethnicity primarily view play as a social or entertaining activity with less developmental value, which contrasts with parents with European American ethnicity who may generally view play as crucial for early childhood development (Jung, 2015); therefore, children with Asian American ethnicity may not have enough opportunities to maintain health through physical activity. Cultural beliefs about gender, such as in Somali and Latin cultures (*e.g.,* lack of support for co-ed physical activity), can also be a barrier to physical activity participation for girls (Chatham & Mixer, 2019). Overall, however, few studies have examined associations between ethnicity and physical activity in preschoolers (Lindsay et al., 2017a). A review of influences on physical activity among preschool from high-income countries noted that children with Caucasian ethnicity report higher levels of physical activity than children with African American or Hispanic ethnicity (Lindsay et al., 2017a).

The association between ethnicity and weight status in children is also closely linked to other SDH, including immigration status and income. For example, although ethnic-specific parenting practices are often shaped by the host country's culture and what parents learned from their own families (Chatham & Mixer, 2019), acculturation after immigration to a new country can also affect parenting practices (Evans et al., 2009). Racialized gaps in employment and income (where authors defined racialization as unequal treatment based on factors including ethnicity) can place ethnic groups (*e.g.,* South Asian, Chinese, Arab) at a socioeconomic disadvantage (Block et al., 2019), which can increase the risk of overweight and obesity in children (Zilanawala et al., 2014).

1.4.2.2 Maternal Immigration Status

Children with mothers who immigrated to Canada may be predisposed to or protected from having overweight or obesity. For my thesis, which included data from children born in Alberta, this review summarizes existing literature on associations between second-generation child immigrant status and child weight, whereby the definition of 'second-generation' includes children with at least one parent born outside of Canada (Statistics Canada, 2011). There is limited literature on Canadian second-generation immigrant child outcomes in preschool populations (Salami et al., 2022). According to a Canadian report, second-generation immigrant children between 6 to 12 years old had higher mean BMI z-scores relative to first-generation and native-born children (Blanchet et al., 2015). Similarly, another Canadian study found a higher rate of BMI increase in second-generation children between 9 to 12 years old relative to native-born children (Maximova et al., 2011). In the US, a study of second-generation preschool children reported that children of foreign-born (*versus* US-born) mothers were also more likely to have obesity (Baker et al., 2015). The mechanism through which maternal immigration status influences children's weight status is likely to involve ethnic-specific dietary and physical activity practices from immigrant parents' home countries, acculturation to the host culture (which affects dietary and physical activity practices), and income-based disparities that affect opportunities for maintaining healthy diet and physical activity in children.

Immigrants often arrive to Canada in better health than native-born Canadians, a phenomenon known as the 'healthy immigrant effect' (Lu & Ng, 2019). This can translate to healthier diets in young second-generation immigrants. When immigrants to the US retain their traditional ethnic diets from their homeland, which are often rich in low-fat foods, vegetables, and fish, this leads to healthier intakes among second-generation children (de Hoog et al., 2013). However, ethnicity-specific parenting practices (*e.g.,* indulging, authoritarian feeding) may also encourage unhealthy food preference and intake behaviors that predispose children to gaining excess weight. A US-based study of immigrant parents with Chinese and Korean ethnicity reported that early-life food insecurity in the parents' home countries was associated with the belief that their children should weigh more; early-life food insecurity in the parents' home countries was also associated with greater soda and sweet consumption in their children (among the least acculturated parents) (Cheah & Van Hook, 2012). A Canadian (Québec) study also reported that a greater proportion of children from immigrant mothers were classified as 'overeaters' at 2.5 and 3.5 years old compared to children from non-immigrant mothers; overeaters were 6 times more likely to be overweight at 4.5 years old than their 'non-overeater' peers (Dubois et al., 2007). Overall, although the home culture of immigrant parents may set a precedent for lifestyle behaviors, this influence can diminish over time with acculturation to the host culture.

Acculturation has been linked to changes in diet. In ethnic groups such as Arabs, South Asians, and Chinese, acculturation has been linked to a decrease in traditional food intake and an increase in consumption of foods more common in Western diets, which are higher in processed and energy-dense foods, including restaurant meals and fast food (Valera et al., 2015). These changes may be explained by language barriers causing difficulty for immigrants to navigate the environment, resulting in challenges in providing healthy food to children when unhealthy foods are often more inexpensive and available (Nobari et al., 2013). Food choices of immigrant parents can have a strong influence on their children's diet, but if children of immigrant parents are born in the host country and have no exposure to their parents' home culture, they are more likely to adopt unhealthy food habits from the host country (Zhang et al., 2019).

Acculturation status can also exert influence over other lifestyle behaviors, such as physical activity. According to the 2011–2012 Canadian Community Health Surveys, a higher proportion of 'recent' immigrants were less physically active compared to 'established' immigrants, and inactivity was higher among immigrants of visible minorities (Mahmood et al., 2018). Although there is a gap in the literature regarding associations between immigrant status and physical activity levels in second-generation preschoolers, levels of parental physical activity can influence their children's physical activity. A Saskatchewan-based study found the following barriers to physical activity in newcomer children over 3 years old, which were especially pronounced in visible minorities: recreational physical activity is an unfamiliar concept, cultural norms limit participation in girls, limited finances, inclement weather, safety concerns, and child preference for screen time (Lane et al., 2021). Approximately 80% of the immigrant children aged 5 years and older met physical activity recommendations (60 minutes of moderate to vigorous physical activity per day) in this study, while none of the children between 3 and 4 years old met their recommendations (180 minutes of physical activity, at any intensity, per day). Overall, however, a review of influences on preschool physical activity in high-income countries found limited and mixed results with regards to acculturation on physical activity (Lindsay et al., 2017a).

Other shared characteristics among immigrants, such as economic disparity, may also contribute to the effects of parent immigration status on child weight status. The low-income gap between immigrants and individuals born in Canada is prevalent (Picot & Hou, 2019), and many immigrants face disadvantages such as low income and lack of job security once arriving at their host country (Lightman & Good Gingrich, 2018). A US-based study found that children of immigrant mothers were at increased risk of household food insecurity (Chilton et al., 2009), which is a common side effect of low income (Tarasuk et al., 2019). Limited access to nutritious and affordable foods can encourage consumption of cheap and accessible fast-food or other unhealthy foods, increasing the risk of overweight or obesity in children.

1.4.2.3 Neighborhood-level Income

Existing studies on preschool children have noted inverse associations between neighborhood-level income and child overweight status. A longitudinal Canadian study of children 2 to 3 years old found that living in low income (*versus* middle income) neighborhoods was associated with increasing child BMI percentiles over time (Oliver & Hayes, 2008). Increased odds of child obesity (0 to 12 years old) were reported to be independently associated with low neighborhood income in a Toronto-based study (Anderson et al., 2021).

Associations between neighborhood-level income and early child overweight and obesity may manifest based on the neighborhood food environment. Although lower income neighborhoods often have fewer grocery stores and more unhealthy food outlets (Black et al., 2014) compared to higher income neighborhoods, a review by Black et al. (2014) noted mixed associations between neighborhood SES and food store access across Canadian literature. An Edmonton study found few differences in supermarket access across neighborhoods of varying SES (Smoyer-Tomic et al., 2008), studies in British Columbia and Québec found a predominance of supermarkets in low-income neighborhoods (Apparicio et al., 2007, Black et al., 2011), and an Ontario study found a predominance of convenience stores in low-income neighborhoods (Latham & Moffat, 2007) (Black et al., 2014). Greater access to grocery stores can reduce obesity by encouraging fruit and vegetable consumption (Kepper et al., 2015), while greater access to fast food outlets (Kepper et al., 2015) and convenience stores (Salois, 2012) can place children at risk for obesity by encouraging fast food consumption. For example, an Edmonton study reported that preschool children with a grocery store (*versus* without a grocery store) within 1km of their residence were less likely to consume soft drinks (Pabayo et al., 2012).

Associations between neighborhood-level income and early child overweight and obesity may also manifest based on barriers to physical activity. Low-income neighborhoods often have limited or low-quality amenities (*e.g.,* parks, recreational areas [Rigolon, 2016]) leaving insufficient opportunities for outdoor physical activity in children. Mothers living in low-income neighborhoods with low collective efficacy and increased households in poverty may discourage children from outdoor play due to safety concerns (Kimbro & Schachter, 2011). Barriers to physical activity in children can lead to increased sedentary time; according to an Edmonton study, children between 4 to 5 years old children in a low (*versus* high) SES neighborhood were more likely to have higher screen time and children with overweight or obesity were more likely to have higher screen time compared to their peers in the normal weight group (Carson et al., 2008).

1.4.2.4 Urban versus Rural Status

The risk of overweight and obesity in children may be associated with residence in urban or rural settings. Although there are limited Canadian data on whether differences between urban *versus* rural settings influence weight status in preschoolers, an 8-year longitudinal study of Canadian children between 2 and 3 years old found that living in an urban (*versus* rural) neighborhood was associated with a decreased BMI percentile across the study period (Oliver & Hayes, 2008). Another study of rural Saskatchewan children in grades 1 to 8 observed a high prevalence of overweight (n=584; 26.5%) in the study population (Karunanayake et al., 2016), where the prevalence estimate was higher than that of the national prevalence. However, a Canadian review of data that included children between 2 and 17 years old reported that excess weight did not vary by urban *versus* rural residence (Shields & Tjepkema, 2006). The exception to this finding was Alberta, where residents (2 to 17 years old) of census metropolitan areas (*versus* non-census metropolitan area residents) were less likely to have overweight or obesity (Shields & Tjepkema, 2006). There is heterogeneity within and between rural communities in Canada in terms of socioeconomic and geographic characteristics (Lavergne & Kephart, 2012), suggesting that the influence of rural residence on child weight status may also vary based on SES and geographic residence.

The pathways that lead to differences in weight between Canadian children living in urban *versus* rural settings are not well understood, and the literature on this topic is limited. It is possible that dietary, physical activity and other lifestyle risk factors for overweight and obesity have relatively different contributions based on urban *versus* rural residence. In Canada, a study of grade five students in Nova Scotia found that high access to grocery stores increased the likelihood of having a healthier diet and decreased likelihood of having overweight or obesity in children living in urban settings, whereas increased access to playgrounds, parks and recreational facilities increased physical activity in children living in rural settings and decreased the likelihood of having overweight or obesity (Veugelers et al., 2008). Parent perception of child weight may also differ based on urban *versus* rural residence. For example, a Canadian study of 6 – 14 year olds living in rural settings (n=584) reported that 26% of parents misclassified their child's weight status, where 96% of the normal weight misclassifications were underestimations (Karunanayake et al., 2016).

Regarding urban *versus* rural differences in overweight and obesity risk in other high-income countries, a US-based study of low-income preschoolers (Salois, 2012) reported that grocery stores and convenience stores had positive associations with child obesity in urban-based populations, while specialty food stores had stronger positive associations with child obesity in the rural model. This study also found that the percent of single-mother households had negative associations with child obesity in urban-based populations and positive associations with child obesity in rural-based populations. This suggests that the food and family environment have variable effects on weight status based on urban *versus* rural setting. However, other studies have linked rural status with increased weight status and unhealthy behaviors; for example, Contreras et al. (2020) reported higher BMI z-scores in preschool children living in rural (*versus* urban) settings. A separate US-based study found that preschoolers living in rural settings were more likely to exceed screen time guidelines than their peers in urban settings (Liu et al., 2012). A US-based review of data that included children 2 to 19 years old reported that children living in rural settings often had higher obesity levels but also engaged in more physical activity than their urban counterparts; this finding suggests that other environmental factors (*e.g.,* food parenting practices, other dietary influences, sedentary behaviors) may overshadow the protective effects of physical activity in children and contribute to having overweight and obesity. Overall, although there is a lack of literature on urban *versus* rural associations with dietary, physical activity and sedentary behaviors in Canadian preschool-aged children, it is possible that differential risk factors to overweight and obesity exist between urban and rural populations.

1.4.2.5 Material Deprivation

The socioeconomic status of a child's family can affect child growth and development; factors related to material deprivation (*e.g.,* parent education, employment status and household income) can have associations with weight status in children. Regarding parent education levels, a German study found that preschool children from families with medium and low education levels had twice the risk for obesity compared to children with high parental education levels (Nguyen et al., 2021). This link may be explained by shared parenting characteristics that are unique to individuals with lower education levels. In Canada, Dubois & Girard (2003) found that mothers with lower education levels had lower odds of sufficiently breastfeeding children (where insufficient breastfeeding is a risk factor for childhood obesity). A separate US-based study also found that having a college degree was associated with breastfeeding (Hendricks et al., 2006). Therefore, it is possible that parents with lower education levels may not be aware of the protective effects of long-term breastfeeding on child overweight or obesity. A separate US-based study found that preschoolers with parents who had less than high school education were also more likely to consume junk food (den Bosch & Duch, 2017). Regarding paternal influences, relative to fathers whose highest educational attainment was secondary school, fathers with trade or certificate qualifications or with university degrees were less likely to have consistently low or decreasing self-efficacy in promoting healthy diets for young Australian children (Walsh et al., 2019), suggesting that fathers with higher education are especially cognizant of the importance of healthy eating from an early age. Overall, however, individuals with higher education levels also have a higher likelihood of being employed (Organisation for Economic Co-operation and Development, 2012), and the link between education level and child weight status may be influenced by parent employment status. For example, a UK study reported that any maternal employment after childbirth was associated with early childhood overweight (Hawkins et al., 2007). Another US-based study suggested that family changes caused by maternal employment status can affect child development during the preschool period, and that high parental employment intensity (*i.e.,* number of periods both parents worked ≥35 hours per week) was positively associated with high BMI *z*-scores in preschoolers (Morrissey, 2013). This suggests that employment status restricts the amount of time available for adequate child supervision and encouragement of healthy eating and physical activity behaviors.

The combined influences of parent education level and employment status also dictate household income, which can exert additional influence over child weight status; this influence can be through risk factors associated with overweight and obesity in children. In Canada, a Québec study by Dubois & Girard (2003) reported that mothers with lower incomes had lower odds of sufficiently breastfeeding children (where insufficient breastfeeding is a risk factor for childhood obesity). Another study by Dubois *et al.* (2007) study found that preschool children reported as overeaters (where overeating was associated with higher odds of having overweight) were more likely to have lower household income. A review by Avery *et al.* (2017) noted that (a) the likelihood of eating while watching TV (a behavior associated with unhealthy food consumption and higher BMI or BMI z-score) increased with decreasing SES and (b) a greater proportion of preschoolers of parents with lower (*versus* higher) income exhibited snacking behavior. Regarding physical activity, according to data from the Canadian Health Measures Survey, children who were 3 to 4 years old and from the lowest income (*versus* highest income) households were less likely to meet physical activity guidelines (Garriguet et al., 2016). Overall, these findings may be because low-income families have financial barriers to accessing a healthy diet. Additionally, parents with low household income and extensive work hours may have less time available for healthy parenting (e.g., breastfeeding infants, supervising physical activity and healthy eating in children). Lastly, subgroups of parents with low household income may share other characteristics (e.g., lower education level, minority ethnicity, immigration status) that predispose them to (a) misperceiving child weight status or (b) having a lack of knowledge about the importance of healthy food parenting (*e.g.,* breastfeeding) and physical activity in children.

Various measures of neighborhood deprivation have been employed in the literature (van Vuuren et al., 2014; Webb et al., 2017). The Pampalon Index, which is often presented in quintiles, is a popular assessment of deprivation in Canada (Lebel et al., 2009; Carter et al., 2012; Saint-

Jacques et al., 2014; Beaulieu et al., 2019) and provides a neighborhood-level capture of residents' socioeconomic conditions. The material component of the Pampalon Index depicts the general difficulty residents have obtaining everyday goods and conveniences (*e.g.,* housing, a car). This index was created using principal component analysis using the following indicators: proportion of individuals without a high school diploma, ratio of employment to total population, and average household income (Pampalon et al., 2009). A Canadian study by Carter *et al.* (2012) found a positive association between neighborhood material deprivation and weight gain in children 4 to 10 years old. An Alberta-based study also reported that children 2 to 17 years old living in the most materially deprived areas (*versus* the least materially deprived areas) were less likely to enroll in multidisciplinary clinical care for pediatric weight management (Perez et al., 2018). This suggests that low-SES children with overweight and obesity are less likely to receive adequate treatment.

1.4.2.6 Social Deprivation

Child growth can be affected by lifestyle behaviors that are unique to single-parent households. In Canada, a Québec study reported that having a single-parent home was a risk factor for overeating (where overeating was associated with higher odds of having overweight) in children (Dubois et al., 2007). A review of preschool physical activity in high-income countries also revealed that girls from single-parent families viewed more television (partaking in sedentary behavior) compared to their peers from two-parent households (Lindsay et al., 2017a). The reason behind these links may be compromised parenting behaviors as a result of stress. Studies have noted that single and divorced mothers (relative to married or cohabiting women) endure the highest stress levels (Muhammad & Gagnon, 2010), especially while parenting preschool children, and are more likely to report symptoms of depression or anxiety (Liang et al., 2019). Based on a systematic review, some studies have noted positive associations between maternal depression and increased adiposity or BMI z-score in early childhood (Lampard et al., 2014). This link may be because single mothers lack adequate emotional resources and communal support when raising a child without a spouse or coparent; maternal stress may reduce parenting practices that protect against child obesity, such as healthy meal preparation or providing transportation to organized sports (Tate et al., 2015). It is possible that maternal stress also decreases the mother's sensitivity to her children's needs or disrupts the development of their secure attachment, which can affect children's self-control patterns and eating habits (Tate et al., 2015).

Social deprivation can be assessed through the social component of the Pampalon Index. Similar to the material deprivation index, the social deprivation index is a neighborhood-level capture of residents' household structures and was created through principal component analysis. This index was created using the following indicators: proportion of individuals who are separated, divorced, or widowed; proportion of individuals living alone; and proportion of single-parent families (Pampalon et al., 2009). Together, the social deprivation index depicts the disruption and deterioration of the household structure (Carter et al., 2012). There is scarce research on associations between the social deprivation index and preschool child weight in Canada, although a Québec study found that children between 4 to 10 years old living in areas with high social deprivation gained weight more slowly than children living in areas with lower social deprivation areas (Carter et al., 2012). The mechanism behind this difference was unclear, and researchers suggested that further study was needed to clarify the association (Carter et al., 2012). Therefore, more research is needed in this field.

1.5 The Built Environment

1.5.1 Definition

The built environment refers to the human-made or modified physical surroundings in which people live, work, and play (Gose et al., 2013). It is related to the SDH (*e.g.,* income) by shaping the environmental context that people live in (*e.g.,* access to healthy food and physical activity spaces, good air quality, adequate and accessible housing); therefore, built environments are vital settings for promoting health equity (Janzen et al., 2018). The built environment includes a range of factors (*e.g.,* transportation systems, housing), but in the context of my thesis, relevant built environment factors include access to playgrounds, major parks, distance to schools and number of street intersections, which are reviewed below. These built environment factors were selected due to their relationship with outdoor physical activity, which is a lifestyle behavior that can promote healthy weight in children (Ansari et al., 2015; Ye et al., 2021).

Limitations exist on current literature of the built environment. A review on built environment literature noted heterogeneity in variable definition and categorization, geographic approaches and metrics, spatial sizes and covariates, and population sizes (Malacarne et al., 2021). For example, studies on geographic accessibility have different definitions of neighborhood shape and size (*e.g.,* 800-m, 1200-m, etc.). Studies have used Euclidean (circular buffer where the location is a point) or network (based on the street network) buffers of varying sizes (*e.g.,* 0.4km, 2km, 5km, etc.). Different metrics, such as proximity, surface, ratios (per unit area) or counts have been used to measure density of built environment variables. As mentioned previously, varying units of area have also been used in ratio metrics for variables such as street intersection density. Although many studies on the built environment use walkability indices, there is also heterogeneity in definitions and analysis of walkability across studies (Yang et al., 2020). Additionally, a recent review on associations between the built environment and child obesity additionally noted a lack of studies exploring multiple exposure effects on child obesity (Malacarne et al., 2021). Therefore, existing findings regarding built environment and child weight status must be interpreted with these limitations in mind.

1.5.2 Built Environment and Weight Status in Children

1.5.2.1 Access to Playgrounds

The Canadian Public Health Association views unstructured play as an essential component of child well-being. However, access to play opportunities can be limited by the availability of play spaces (Canadian Public Health Association, 2019). Although there may be a link between playground access and weight status in children, there is scarce research on this field with respect to preschool populations. An Edmonton-based study did not find associations between park access and child weight status (Spence et al., 2008). An Ohio study of low-income preschoolers also found that overweight was not associated with proximity to playgrounds (Burdette, 2004). In older children, a Nova Scotia-based study of children between 10 and 11 years old found that children with greater perceived access to playgrounds, parks, and recreational facilities (based on parent survey) were both more active and less likely to have overweight or obesity (Veugelers et al., 2008). In Ontario, a study of children between 2 and 17 years old also found that children with (*versus* without) playgrounds within 1 km from their home were almost five times more likely to be classified as healthy weight (Potwarka et al., 2008). Overall, it is unclear whether playground access is linked to child weight in early childhood.

Playground access may be related to child weight status by providing opportunities for outdoor physical activity. Preschoolers in high-income countries who spend time outdoors are more likely to be physically active and the number of nearby play spaces correlate positively with physical activity levels (Lindsay et al., 2017a). For example, a New York study found that neighborhoods with a greater proportion of park areas, which included playground area as a measure, were associated with increased physical activity among children between 4 and 7 years old (Roemmich et al., 2006). In Canada, a Nova Scotia study of children between 10 and 11 years old found that children with greater perceived access to playgrounds, parks and recreational facilities (based on parent survey) were also more physically active (Veugelers et al., 2008). However, an Edmonton study did not find that playground access was associated with physical activity in preschoolers (Spence et al., 2008). This discrepancy may be attributed to other factors that encourage or hinder physical activity.

It is possible that the motivation for physical activity in children fluctuates depending on other environmental and interpersonal factors. For example, playgrounds with fixed equipment (*e.g.,* monkey bars) can encourage increased physical activity and decreased sedentary behavior (Sugiyama et al., 2010). Environmental factors, such as cold weather or a lack of appropriate outdoor clothing, can also pose a barrier to participating in outdoor physical activity (Copeland et al., 2009; Copeland et al., 2012) due to child discomfort or caregiver concerns. At the interpersonal level, children are often more physically active when their friends are present (Barkley et al., 2014), possibly due to increased enthusiasm while having a companion during play. Having more supervision and teacher facilitation during child play might also encourage increased playground physical activity; supervisors may encourage physical activity by role modelling active play, and children may participate in physical activity in order not to receive negative attention from supervisors (Graham et al., 2021; Coe, 2018).

1.5.2.2 Major Parks (Greenspaces)

Evidence is still emerging on the impact of green spaces and children's health (Gascon et al., 2016), with very limited research on the weight status of preschoolers. Green space may have a link with weight status by providing an opportunity for physical activity; a review of preschool physical activity in high-income countries noted a positive association between neighborhood greenness and physical activity (Lindsay et al., 2017a), which was in line with a previously mentioned New York study's findings that neighborhoods with a greater proportion of park area (which included nature trails as a measure) reported increased physical activity among children 4 to 7 years old (Roemmich et al., 2006). Regarding weight status outcomes, however, a recent review of the literature was unable to establish a clear link between green space access and weight status in children (Jia et al., 2020). In Calgary, parks and green spaces (defined as public parks, school fields and areas such as a public riverfront) were not associated with overweight or obesity in young children (Potestio et al., 2009). Another Edmonton study found no association between park and playground access and child weight (Spence et al., 2008). Lastly, a European study of preschoolers reported an association between low exposure to green space and increased risk of having overweight or obesity (Petraviciene et al., 2018). This suggests that other lifestyle behaviors (*e.g.,* diet, sedentary time) may overshadow the link between green space and weight status.

1.5.2.3 Distance to Schools

Given that preschoolers may attend preschool programs at nearby schools, the location of a child's school can be an important built environment feature. There is limited research on the influence of distance to nearest school and weight status in preschoolers. The mechanism of an association between distance to nearest school and weight status in preschool children may be through barriers or facilitators to physical activity during active transport (*i.e.,* using non-motorized personal transportation, such as walking and biking [Faulkner et al., 2009]) to school, as well as accessibility of playgrounds for outdoor physical activity. A recent review of the literature found very few studies on active transportation and physical activity in preschool-aged children, but available studies reported that a greater distance to school was associated with lower physical activity levels (Terrón-Pérez et al., 2021); this suggests that parents may be less motivated to use active transportation when schools are far from home. A 2018 review also noted that increased distance to school was strongly associated with decreased active transport to school, although the review also suggested that active transport to school is most common for children between 6 and 10 years old in Canada (Rothman et al., 2018), suggesting that opportunities for active transport are less likely to be used in preschool populations. According to an Australian study, parents of children between 5 and 6 years old reported a higher likelihood of active transport if their route was less than 800 meters (Timperio et al., 2006). European research that included preschoolers reported a connection between decreased distance to school and increased active transport (Oxford & Pollock, 2015; Terrón-Pérez et al., 2018). These studies also noted environmental barriers (*e.g.,* weather, having dangerous crossings on the way to school, absence of sidewalks or bike lanes) as barriers on active transport. Overall, however, Faulkner *et al.* (2009) reported a lack of association between BMI and active transport to school in children and youth. This also suggests that there are other influences (*e.g.,* diet, sedentary behavior) that overshadow links between active transport and weight status in children.

1.5.2.4 Number of Street Intersections

Measuring the number of street intersections in a buffer zone is often used to represent street intersection density, which is a common measure of street connectivity (Jia et al., 2019b) and walkability (Buck et al., 2014). Across studies, street intersection density has been calculated using several measures of area (*e.g.,* per acre [Zhu & Lee, 2008], per hectare [Jia et al., 2019a], per km^2 [Duncan et al., 2014], per mi^2 [Larsen et al., 2009]). The relationship between street intersection density and weight status in children is not well established. A recent systematic review of street connectivity reported unclear associations between street connectivity and child BMI, and this was attributed to the limited literature (Jia et al., 2019b). Another systematic review that examined the link between street intersection density and child obesity noted inconsistent findings in the literature (Malacarne et al., 2021). In Canada, there is scarce literature on street intersection density and weight status in preschoolers. An Edmonton study reported that preschool girls had lower odds of being overweight or obese if they lived in neighborhoods with more intersections; no associations between weight status and neighborhood intersections were found for preschool boys (Spence et al., 2008). In studies of other high-income countries, a US-based study reported that lower street intersection density was associated with higher BMI in 4 to 19 year olds (Duncan et al., 2014). However, a German study found no association between walkability index, which included street intersection density as a measure, and BMI in preschoolers (Zhou et al., 2020). An Australian study of 3 to 5 year olds reported that increased road intersection density was associated with decreased BMI z-score (Timperio et al., 2010).

The mechanism connecting street intersection density and BMI in preschoolers may be through opportunities for increased physical activity (Jia et al., 2019b) for leisure activity or during active transport to nearby amenities; however, a recent systematic review noted a lack of studies on transport variables, including street connectivity, and physical activity in preschoolers. A separate European study did not find any association between a walkability index (which included street intersection density as a measure) and moderate-to-vigorous physical activity in preschool children (Buck et al., 2014).

1.6 Rationale and Objectives

There are gaps in the literature on (a) SDH and underweight, overweight, and obesity in preschool children, as well as (b) built environment and overweight and obesity in preschool children. Measurement and data collection methods are inconsistent in the current literature. Therefore, the overarching objective of my thesis was to study associations between SDH and built environment characteristics with weight status in preschoolers. This was examined in the two studies included in my thesis, both of which are based on population-level data of preschoolers who received immunizations in Edmonton and Calgary. The objective of my first study (Chapter 2) was to examine the associations between SDH, including ethnicity, maternal immigration status, neighborhood-level income, urban *versus* rural residency, and material and social deprivation on weight status in preschool children in Alberta, Canada. The objective of my second study (Chapter 3) was to examine relationships between built environment variables related to physical activity, namely playgrounds, major parks, schools and street intersections, and excess weight status in preschoolers in Edmonton and Calgary, Canada.

CHAPTER 2: ASSOCIATIONS BETWEEN SOCIAL DETERMINANTS OF HEALTH AND PRESCHOOL CHILDREN'S WEIGHT STATUS: A POPULATION-BASED STUDY

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Contributions:

JW and GDCB conceived the project. JW, DCD, AS and GDCB decided on the analytic approach. AS conducted the statistical analyses. JW interpreted the results. JW drafted and revised the manuscript, in response to feedback and input from all co-authors.

2.1 Abstract

Background: Social determinants of health (SDH) may influence weight status in preschoolers. The objective of this study was to examine relationships between key SDH and preschool weight status in Alberta, Canada.

Data and Methods: In this retrospective cohort study, children's anthropometric measurements were taken at immunization visits between 2009 and 2017 in Edmonton and Calgary. Children were categorized into weight status categories based on World Health Organization criteria. Maternal data were linked to child data. The Pampalon Index was used to assess deprivation. The first multinomial logistic regression model used relative risk ratios (RRR) to study associations between ethnicity, maternal immigration status, annual neighborhood-level income, and urban *versus* rural residence with child weight status. The second and third models estimated material and social deprivation associations with child weight status.

Results: Chinese children were less likely to have overweight (RRR=0.63) and obesity (RRR=0.47), whereas South Asian children were more likely to have underweight (RRR=3.95) and obesity (RRR=1.38). Children with immigrant mothers were less likely to have underweight (RRR=0.70) and obesity (RRR=0.70). Children were less likely to have overweight (RRR=0.94) and obesity (RRR=0.87) for every $10,000 increase in income. Relative to the least deprived quintile, children in the most materially deprived quintile were more likely to have underweight (RRR=1.98), overweight (RRR=1.56), and obesity

(RRR=3.32). Children in the most socially deprived quintile were more likely to have overweight (RRR=1.25) and obesity (RRR=1.40) (all $p<0.0001$).

Conclusion: The weight status of preschoolers varied across ethnicity, maternal immigration status, annual neighborhood-level income, material deprivation and social deprivation characteristics.

2.2 Introduction

A healthy childhood is essential for optimal development and well-being across the lifespan (Hertzman & Williams, 2009). Many conditions such as obesity, heart disease, and mental illnesses have roots in childhood (Sahoo et al., 2015). Since chronic health conditions can result in a lower quality of life (Megari, 2013), interventions during early childhood can ensure optimal physical, emotional, and social development.

Millions of children worldwide suffer from underweight, overweight and obesity. There is growing awareness of the 'double-burden' of malnutrition (*i.e.,* co-existing underweight and obesity) in high-income countries (Stewart et al., 2021). Underweight, an indicator of undernutrition (World Health Organization, 2017), is a critical factor for preschool children due to its association with delayed cognitive, physical, and metabolic development (Uzogara, 2016). Overweight and obesity can increase the risk of other chronic diseases (*e.g.,* type 2 diabetes, heart disease) and impair mental health and well-being (Carsley et al., 2018; Balasundaram & Krishna, 2021). The impact of overweight and obesity on health and well-being has been heightened with the emergence of the coronavirus pandemic, since excess weight appears to increase risk of respiratory complications that accompany COVID-19 (Lighter et al., 2020).

The World Health Organization (WHO) defines social determinants of health (SDH) as conditions in which people are born, grow, live, work and age (World Health Organization, 2022). Several studies have documented important relationships between SDH and weight status in children. For example, a review of South Asian studies by Misra et al. (2019) suggested that South Asian populations generally fit the "high body fat-normal BMI-low muscle mass" phenotype. Overeating, a maladaptive behavior linked to unhealthy weight gain, was found in a greater proportion of children between 2.5 to 3.5 years old born to immigrant mothers compared to non-immigrant mothers in Québec (Dubois et al., 2007). As noted by Rao et al. (2016), Canadian children (2 to 17 years old) from lower income populations are at increased risk of obesity. Although there are few data on levels of deprivation or urban or rural residence and their associations with the weight status of Canadian children, a longitudinal study by Carter et al. (2012) found (a) positive associations between neighborhood material deprivation and child weight gain and (b) inverse associations between neighborhood social deprivation and child weight gain.

There are several limitations in the literature about the influence of SDH on weight status in preschoolers. First, many weight status assessments are based on self- or proxy-reported data, which have suboptimal reliability and accuracy (Dubois & Girad, 2007; Doolen et al., 2009). Second, there is limited literature on the links between ethnicity, having immigrant mothers, and social and material deprivation and preschool children's weight status. Third, there is almost no research on underweight children in developed countries. Understanding environmental contexts better informs targeted health interventions (Williams et al., 2008). With these issues in mind, the objective of our research was to examine the associations between SDH, including ethnicity, maternal immigration status, neighborhood-level income, urban *versus* rural residency, and material and social deprivation on weight status in preschool children in Alberta, Canada.

2.3 Data and Methods

2.3.1 Study Population This study included children born in Alberta, Canada between January 1, 2005, and November 29, 2013, who had visited public health units in Calgary and Edmonton (the two metropolitan cities in Alberta) to receive immunizations during their preschool years (age range: 4 to 6 years old) between January 2009 and November 2017.

2.3.2 SDH Data Sources and Linkage Anthropometric data from children were taken from the *Alberta Public Health Immunization Records* database. Public health nurses used standardized protocol and equipment to collect child and parent data. Information on children's date of birth, sex, age at measurement, measured height (to the nearest 0.1 cm), and measured weight (to the nearest 0.1 kg) was collected. Child date of birth was retrieved from the *Alberta Vital Statistics Birth Registry*. Child ethnicity, assumed to be equivalent to maternal ethnicity, was identified using surname algorithms from the *University of Calgary Ethnicity Program* and Ontario's *Institute for Clinical Evaluative Studies Ethnicity Program*, which allowed the data to be trichotomized as either 'Chinese', 'South Asian', or 'General Population' (Cummins et al., 1999; Quan et al., 2006; Shah et al., 2010). These algorithms were run on the earliest maternal surname in the *Alberta Health Care Insurance Plan Registry*. Maternal data (postal code, immigrant status, annual neighborhood-level income, ethnicity) were also included. Postal code data were derived from the *Alberta Health Care Insurance Plan Registry* and urban *versus* rural residency was determined using *Postal Code Translator File* from *Canada Post Corporation* and *Statistics Canada* methodology based on *Canadian Census Data*. Maternal immigration status was determined using the *Alberta Health Care Insurance Plan Central Stakeholder Registry*, which identified the previous country of mothers entering Alberta since 1984 Census data from *Statistics Canada* (2011) were linked at the Forward Sortation Area level, which was used to determine 2010 annual household income ($CDN) data at the neighborhood level as a measure of neighborhood SES.

2.3.3 Material and Social Deprivation The Pampalon Index was used to calculate social and material deprivation indices (Pampalon et al., 2009). The material deprivation component assesses education, employment, and household income; the social deprivation component assesses maternal marriage status, solitary living, and single parenthood (Pampalon et al., 2009). Greater values signify greater deprivation. The indices, which have been validated as adequate predictors of health outcomes (Pampalon et al., 2014), are based on Canadian dissemination areas and cover approximately 98% of Canada's population. For our purposes, Pampalon material and social deprivation index data *(Institut national de santé publique du Québec, n.d.)* were retrieved using dissemination areas linked to maternal postal code data at childbirth and categorized into quintiles.

2.3.4 Preschool Child Weight Status: The outcome of interest was child weight status at pre-school immunization visit, which took place between ages 4 to 6 years. For children with multiple visits, we included only the last measurements in our study. Consistent with Canadian recommendations (Dietitians of Canada et al., 2014b), the WHO body mass index (BMI) growth charts were used to categorize children's weight status. BMI was calculated by dividing weight (in kg) by height (in m^2). The WHO includes different terms to describe weight status categories based on age. For children <5 years old, *overweight* and *obesity* are defined as BMI >2 and >3 standard deviations (SD) above the median, respectively. For children ≥5 years old, *overweight* and *obesity* are defined as BMI >1 and >2 SD, respectively, above the median. For our study, which included children both above and below 5 years old, we defined our weight status categories as follows: *underweight* (zBMI <-2), *normal weight* (zBMI >-2 to ≤1), *overweight* (zBMI >1 to ≤3), and *obese* (zBMI >3), irrespective of the child age at measurement. We also defined *excess weight* as a combination of the *overweight* and *obese* categories. This was done to ensure simplicity and consistency across age groups.

2.3.5 Statistical Analysis: For each weight category, we presented the child sex, anthropomorphic measurements at preschool age (weight, height, BMI, zBMI), age at measurement and SDH variables (ethnicity, maternal immigration status, urban *versus* rural residence, annual neighborhood-level income, material and social deprivation indices). To assess the independent associations of SDH factors and preschool weight, we used multinomial logistic regression models with weight status at preschool age as a four-level outcome. The models estimated relative risk ratios (RRR) and 95% confidence intervals (95% CI) of developing unhealthy weight status for each variable.

We fit data on three models. The first model included ethnicity, maternal immigration status, annual neighborhood-level income and urban *versus* rural residence. The second and third models studied the material deprivation index and social deprivation index separately with the first quintile (least deprived) as the reference category. All models were adjusted for child sex and age at preschool weight measurement. Deprivation indices were separately modelled recognizing the possible correlation between them and the other SDH variables.

To validate the results from each model, we assessed the ability of each model to discriminate between our child weight status outcome categories. This was done by estimating the polytomous discrimination index (PDI) of Van Calster et al. (2012) using the SAS macro of Dover et al. (2021). All multinomial models displayed discrimination abilities better than those of a classifier that selects at random among four categories, as all models had a PDI greater than the 25% threshold. The multinomial model that included individual SDH had the largest PDI of

0.32 (95% CI [0.32, 0.33]), followed by the model that included the quintiles of the material deprivation index (PDI, 0.30; 95% CI [0.29, 0.31]) and the model that included the quintiles of the social deprivation index (PDI, 0.30; 95% CI [0.39, 0.30]). The PDI estimates showed that modelling using individual SDH has discrimination abilities superior to modelling using deprivation indices.

The unit of analysis was the child. All statistical analyses were performed using SAS version 9.4. Given the large sample size, we defined statistical significance at a p-value <0.0001. This study was approved by the University of Alberta Research Ethics Board (Pro00020230). The ethics panel determined that the research is a retrospective database review for which participant consent for access to personally identifiable health information would not be reasonable, feasible, or practical.

2.4 Results

Our initial study population included 187,047 records, which decreased to 169,465 children and 126,635 mothers once records were excluded because of missing child identification numbers, missing height and weight data, calculated BMI values of <10 or >50 kg/m^2, and duplicate height and weight measurements. From the 169,465 children, our first model was based on 168,387 children and 125,778 mothers after additional records were excluded due to missing data regarding maternal income and urban residence. Out of the 169,465 children studied in models 2 and 3, there were 5,558 children with missing deprivation indices (due to missing dissemination area or missing maternal income data), leaving a population of 163,907 children and 122,773 mothers.

Descriptive characteristics of our starting population of children and mothers (n=169,465) are presented in Table 1. There was a significantly greater proportion of males in the overweight (56.0%) and obese (64.0%) categories (both $p<0.0001$). With regards to ethnicity and mothers who immigrated to Canada, our first model (Table 2) demonstrated that children with Chinese ethnicity (*versus* 'General Population') were less likely to have overweight (RRR=0.63; 95% CI [0.60, 0.67]) and obesity (RRR=0.47; 95% CI [0.39, 0.57]) (all $p<0.0001$). South Asian children (*versus* 'General Population') were more likely to have underweight (RRR=3.95; 95% CI [3.40, 4.59]), less likely to have overweight (RRR=0.83; 95% CI [0.78, 0.88]), and more likely to have obesity (RRR=1.38; 95% CI [1.21, 1.57]) (all $p<0.0001$). Children with maternal immigrant status (*versus* non-immigrant status) were less likely of having underweight (RRR=0.70; 95% CI [0.62, 0.79]) and obesity (RRR=0.70; 95% CI [0.65, 0.75]) (all $p<0.0001$). Our analyses related to neighborhood-level income revealed that children were less likely to have overweight (RRR=0.94; 95% CI [0.94, 0.95]) and obesity (RRR=0.87; 95% CI [0.85, 0.88]) with every $10,000 increase in neighborhood-level income ($p<0.0001$). There was no statistically significant association between urban *versus* rural residence and risk of having underweight, overweight or obesity in our first model.

Table 2.1: Child and maternal descriptive characteristics across weight status categories. (n= 169,465). Weight status categories were defined as shown, irrespective of child age at measurement, for simplicity and consistency.

	Underweight	***Normal Weight***	***Overweight***	***Obesity***
	zBMI < -2	*zBMI −2 to ≤1*	*zBMI >1 to ≤3*	*zBMI >3*
Child Characteristics				
Total n	1415	128951	35426	3673
Female {n (%)}	676 (47.8)	65249 (50.6)	15613 (44.1)*	1322 (36.0)*
Male {n (%)}	739 (52.2)	63702 (49.4)	19813 (55.9)*	2351 (64.0)*
Weight, kg {mean (SD)}	15.0 (1.9)*	18.0 (2.2)	21.7 (3.0)*	30.4 (6.4)*
Height, cm {mean (SD)}	109.5 (7.1)*	108.6 (5.8)	110.1 (6.2)*	113.5 (6.9)*
BMI, kg/m^2 {mean (SD)}	12.4 (0.5)*	15.2 (0.9)	17.8 (1.0)*	23.5 (4.2)*
BMI z-score {mean (SD)}	-2.1 (0.3)*	-0.1 (0.6)	1.8 (0.7)*	6.0 (3.1)*
Child Age at Measurement				
≤4.99 y {n (%)}	750 (53.0)*	78569 (60.9)	22189 (62.6)*	2103 (57.3)
5.00 - 5.99 y {n (%)}	580 (41.0)	44707 (34.7)	11770 (33.2)	1368 (37.2)
≥6.00 y {n (%)}	85 (6.0)	5675 (4.4)	1467 (4.1)	202 (5.5)
Birth & Infancy Characteristics				
Small-for-Gestational Age (SGA) status {n (%)}	407 (28.8)*	14393 (11.2)	2179 (6.2)*	264 (7.2)*

Appropriate-for-Gestational Age (AGA) status {n (%)}	973 (68.8)*	105841 (82.1)	28519 (80.5)*	2867 (78.1)*
Large-for-Gestational Age (LGA) status {n (%)}	35 (2.5)*	8717 (6.8)	4728 (13.3)*	542 (14.8)*
Birth weight, g {mean (SD)}	2894.9 (685.8)*	3272.3 (556.5)	3455.4 (548.2)	3457.9 (575.4)
Child Ethnicity				
General Population {n (%)}	1092 (77.2)*	115467 (89.5)	32625 (92.1)*	3295 (89.7)
South Asian {n (%)}	245 (17.3)*	5854 (4.5)	1417 (4.0)	268 (7.3)*
Chinese {n (%)}	78 (5.5)	7630 (5.9)	1384 (3.9)*	110 (3.0)*
Maternal Immigration Status				
Born in Canada {n (%)}	929 (65.7)*	99011 (76.8)	27020 (76.3)	2540 (69.2)*
Not Born in Canada {n (%)}	486 (34.3)*	29940 (23.2)	8406 (23.7)	1133 (30.8)*
Setting				
Urban Residence {n (%)}	1158 (82.4)	99616 (77.7)	27303 (77.7)	2905/3641 (79.8)
Suburban Residence {n (%)}	179 (12.7)	22014 (17.2)	5816 (16.5)	541/3641 (14.9)
Neither Urban nor Suburban Residence {n (%)}	69 (4.9)	6576 (5.1)	2037 (5.8)	195/3641 (5.4)
Neighborhood-level income, $CDN {mean (SD)}	84176.2 (19676.8)	86246.9 (20917.4)	83620.1 (20928.7)*	80210.6 (20567.0)*
Pampalon Material Deprivation Data (Quintiles)				
Q1 {n (%)}	354 (25.7)*	45543 (36.5)	10385 (30.4)*	721 (20.4)*

Q2 {n (%)}	314 (22.8)	28944 (23.2)	7695 (22.5)	735 (20.8)
Q3 {n (%)}	261 (19.0)	21164 (17.0)	6275 (18.3)	689 (19.5)
Q4 {n (%)}	233 (16.9)*	15033 (12.0)	4809 (14.1)*	656 (18.5)*
Q5 {n (%)}	215 (15.6)	14111 (11.3)	5040 (14.7)*	737 (20.8)*
Pampalon Social Deprivation Data (Quintiles)				
Q1 {n (%)}	398 (28.9)	29437 (23.6)	7231 (21.1)*	727 (20.5)
Q2 {n (%)}	245 (17.8)	23947 (19.2)	6272 (18.3)	593 (16.8)
Q3 {n (%)}	273 (19.8)	24653 (19.8)	6958 (20.3)	712 (20.1)
Q4 {n (%)}	226 (16.4)	26075 (20.9)	7403 (21.6)	791 (22.4)
Q5 {n (%)}	235 (17.1)	20683 (16.6)	6340 (18.5)*	715 (20.2)*

Q1: First quintile (most advantaged quintile)
Q2: Second quintile
Q3: Third quintile
Q4: Fourth quintile
Q5: Fifth quintile (most disadvantaged quintile)

*Indicates $p < 0.0001$ between weight status group and normal weight status.

Table 2.2: Associations between social determinants of health and child weight status using multinomial regression analyses.

	Underweight (n = 1406)		***Overweight (n = 35152)***		***Obesity (n = 3641)***	
	RRR (95% CI)*	*p*	*RRR* (95% CI)*	*p*	*RRR* (95% CI)*	*p*
Sex (Male vs Female)	1.09 (0.98, 1.21)	0.1045	1.31 (1.28, 1.34)	<.0001	1.83 (1.71, 1.96)	<.0001
Age at BMI measurement (per 1 month increase)	1.02 (1.02, 1.03)	<.0001	0.99 (0.99, 1.00)	<.0001	1.01 (1.01, 1.02)	<.0001
Chinese Ethnicity vs General Population	1.03 (0.82, 1.31)	0.7931	0.63 (0.60, 0.67)	<.0001	0.47 (0.39, 0.57)	<.0001
South Asian Ethnicity vs General Population	3.95 (3.40, 4.59)	<.0001	0.83 (0.78, 0.88)	<.0001	1.38 (1.21, 1.57)	<.0001
Maternal Immigrant vs Non-Immigrant Status	0.70 (0.62, 0.79)	<.0001	0.96 (0.93, 0.99)	0.0029	0.70 (0.65, 0.75)	<.0001
Neighborhood-level Income (Per $10000 increase)	0.96 (0.94, 0.99)	0.0081	0.94 (0.94, 0.95)	<.0001	0.87 (0.85, 0.88)	<.0001
Rural vs Urban Residence	1.05 (0.82, 1.35)	0.6859	1.04 (0.99, 1.10)	0.1145	0.92 (0.79, 1.06)	0.2561

*RRR = Relative risk ratios. RRRs are computed for each weight status relative to the normal weight status category.

In Table 3, data are presented regarding the associations between material deprivation and child weight status. Children in the most materially deprived quintile (*versus* the least deprived quintile) were more likely to have underweight (RRR=1.98; 95% CI [1.67, 2.35]), overweight (RRR=1.56; 95% CI [1.51, 1.63]), and obesity (RRR=3.32; 95% CI [2.99, 3.69]) (all p<0.0001). The relatively more materially deprived categories were associated with statistically significant increased risks of having underweight, except for the second most deprived quintile (Q4) and most deprived quintile (Q5) which had nearly identical risks for having underweight status. The greatest RRRs and RRR changes per quintile were with respect to risk of having obesity.

Table 2.3: Associations between material deprivation and child weight status using multinomial regression analyses.

	Underweight (n = 1415)		***Overweight (n = 28128)***		***Obesity (n = 7298)***	
	RRR (95% CI)*	*p*	*RRR* (95% CI)*	*p*	*RRR* (95% CI)*	*p*
Q2 vs Q1	1.39 (1.20, 1.62)	<.0001	1.17 (1.13, 1.21)	<.0001	1.60 (1.44, 1.78)	<.0001
Q3 vs Q1	1.58 (1.35, 1.86)	<.0001	1.30 (1.26, 1.35)	<.0001	2.06 (1.85, 2.29)	<.0001
Q4 vs Q1	1.99 (1.69, 2.35)	<.0001	1.41 (1.35, 1.46)	<.0001	2.76 (2.48, 3.08)	<.0001
Q5 vs Q1	1.98 (1.67, 2.35)	<.0001	1.56 (1.51, 1.63)	<.0001	3.32 (2.99, 3.69)	<.0001

Q1: First quartile (most advantaged quintile)
Q2: Second quintile
Q3: Third quintile
Q4: Fourth quintile
Q5: Fifth quintile (most disadvantaged quintile)

*RRR = Relative risk ratios. RRRs are computed for each weight status relative to the normal weight status category.

In Table 4, data are shown regarding the associations between social deprivation and child weight status. Children in the most socially deprived quintile (*versus* the least deprived quintile) were more likely to have overweight (RRR=1.25; 95% CI [1.20, 1.30]) and more likely to have obesity (RRR=1.40; 95% CI [1.26, 1.56]) ($p<0.0001$). Increased social deprivation quintiles had the most statistically significant associations with risk of having overweight, where risk generally increased with deprivation quintile. Those in the second and third most deprived quintiles (Q3 and Q4) had nearly identical risk of having overweight.

Table 2.4: Associations between social deprivation and child weight status using multinomial regression analyses.

	Underweight (n = 1415)		***Overweight (n = 28128)***		***Obesity (n = 7298)***	
	RRR (95% CI)*	*p*	*RRR* (95% CI)*	*p*	*RRR* (95% CI)*	*p*
Q2 vs Q1	0.76 (0.64, 0.89)	0.0006	1.06 (1.02, 1.10)	0.0015	1.00 (0.90, 1.12)	0.9360
Q3 vs Q1	0.81 (0.69, 0.94)	0.0068	1.15 (1.11, 1.20)	<.0001	1.17 (1.05, 1.29)	0.0042
Q4 vs Q1	0.64 (0.54, 0.75)	<.0001	1.16 (1.12, 1.20)	<.0001	1.23 (1.11, 1.36)	<.0001
Q5 vs Q1	0.84 (0.71, 0.98)	0.0310	1.25 (1.20, 1.30)	<.0001	1.40 (1.26, 1.56)	<.0001

Q1: First quartile (most advantaged quintile)
Q2: Second quintile
Q3: Third quintile
Q4: Fourth quintile
Q5: Fifth quintile (most disadvantaged quintile)

*RRR = Relative risk ratios. RRRs are computed for each weight status relative to the normal weight status category.

2.5 Discussion

The purpose of our study was to examine associations between key SDH and weight status in a large population of preschoolers. Our analyses revealed several notable findings. We found that, compared with the General Population group, children with Chinese ethnicity were less likely to have overweight and obesity, while South Asian children were more likely to have either underweight or obesity. Children with mothers who immigrated to Canada were less likely of having both underweight and obesity compared to their peers with mothers born in Canada. Children were less likely to be in the overweight and obese categories as neighborhood-level income increased. Children in the most materially deprived quintile were more likely to have underweight, overweight and obese status. Finally, children in the most socially deprived quintile were more likely to have overweight and obesity relative to the most deprived category. Overall, this study adds to the limited literature on the influence of SDH on weight status of preschoolers.

2.5.1 Ethnicity and Child Weight Status Chinese ethnicity was associated with lower risk of excess weight among children; this aligns with existing findings of lower excess weight among Chinese children in America and East Asian children and youth in Canada (Shields, 2006; Jain et al., 2012) However, our finding that children of South Asian ethnicity were associated with both increased risk for child underweight and obesity is noteworthy and novel. While a similar trend was observed for children living in South Asian countries, the populations studied were low- to middle-income (Hossain et al., 2020). To our knowledge, there is limited literature focusing on South Asian ethnicity and child underweight in high-income countries like Canada. The increased risk of child underweight associated with South Asian ethnicity may be partly explained by not applying ethnic-specific BMI cut-offs, which account for the increased fatness

in South Asians (Eyre et al., 2017). Researchers have encouraged the use of ethnic-specific BMI cut-offs and weight status classifications in children (Hudda et al., 2018; Lau et al., 2020; Wilde et al., 2020) although there is currently no globally accepted gold standard for ethnic-specific measurements. Our confidence in WHO criteria (the current gold standard for growth assessment in Canada) stems from its development, which involved large samples of children raised in optimal environments from regions including India (World Health Organization, 2006).
The Dietitians of Canada, who have taken similar ethnic-specific differences into consideration, still recommend the WHO charts as the best available reference for monitoring growth (Dietitians of Canada et al., 2010). Our research therefore suggests an ethnic-specific double burden of child weight, and further research is needed into factors associated with South Asian ethnicity and child underweight.

2.5.2 Maternal Immigration Status and Child Weight Status Our findings suggest a protective effect of maternal immigration status against child underweight and obesity, which may be explained by new immigrants' retention of healthier eating habits (de Hoog et al., 2013). There is a lack of literature on preschool weight in second-generation Canadian children (Salami et al., 2022). Our findings contrast with a Canadian report, which found that second-generation immigrant children between 6 to 12 years old had higher mean BMI z-scores relative to first-generation and native-born children (Blanchet et al., 2015). This is likely due to the different (and older) child populations that were used in the report. Given the lack of published data on the association between mothers who immigrated to Canada and child underweight in high-income countries such as Canada, our findings provide unique perspective on this issue.

2.5.3 Income and Child Weight Status Our finding that increased neighborhood-level income was associated with lower risk of excess weight aligns with existing literature. Although Fiechtner et al. (2015) included a wide age range (4 to 18 years old) in their study of neighborhood median income and child weight status, they found that lower neighborhood-level income amplified detrimental effects of the food environment (*e.g.,* close proximity to convenience stores) on increased child BMI z-score. Based on data collected from children (ages 2 to 11) from Canada, Oliver & Hayes (2008) reported similar findings with higher BMI percentile values for children living in low-income neighborhoods. The association between income and child weight status may be related to gradients in affordable healthy food access, unhealthy food access and opportunities for physical activity.

2.5.4 Deprivation and Child Weight Status A study by Carter *et al.* (2012) reported a positive association between neighborhood material deprivation and weight gain in children 4 to 10 years old, and this coincides with our finding that increased material deprivation was associated with greater risk of being overweight and obesity. The influence of material deprivation on children's weight status may be operational through income- or employment-related barriers to healthy lifestyle habits, which manifest as overweight or obesity in children. For example, a UK study reported that any maternal employment after childbirth was associated with early childhood overweight (Hawkins et al., 2007), which may be related to limited time for preparing healthy meals and supervising healthy eating or physical activity in children. Interestingly, we found that increased material deprivation was associated with greater risk of child underweight as well. There is currently scarce literature on associations between material deprivation and child underweight in high-income countries. However, research from the UK did not find an association between deprivation and underweight prevalence in children (Stewart et al., 2021). Given that our study is the first to suggest an association between material deprivation and underweight in a high-income country, further study into the mechanism by which material deprivation affects weight status is needed to offer insight into this association.

We also found some increased risk of excess weight in children associated with social deprivation. Our findings contrast with Carter *et al*. (2012) who found an inverse association between social deprivation and child weight gain. However, the study included a smaller cohort (n=1,580) and broader age range (4 to 10 years old), whereas our findings illustrate a more comprehensive picture of our population's specific age range. A possible explanation for this association is that socially deprived parents may be more prone to stress and depression, which compromise their motivation to encourage healthy eating and physical activity in children. Positive associations have been noted between maternal chronic depression and increased risk of child overweight (Lampard et al., 2014).

2.5.5 Study Strengths and Limitations Despite our study strengths (*e.g.,* large population of children, objective variable measures), we acknowledge limitations in this study. First, our limited three-category ethnicity classification questions the generalizability and precision of our findings towards ethnicities that are not South Asian or Chinese, or children of mixed ethnicity. However, the algorithms used still offered a high-level categorization beyond the General Population grouping, revealing levels of risk that varied across different ethnic groups. Second, this study lacks information on children outside of Edmonton and Calgary, which limits perspective on rural and remote communities where excess weight may be more prevalent. Third, the Central Stakeholder Registry that was used to determine mothers who immigrated to

Canada was unable to capture secondary migration (prior residence in a different province) and durations of residence in Alberta, which may provide additional perspective on associations between having mothers that immigrated to Canada and child weight.

2.6 Conclusion

In a large, retrospective, population-based cohort study, we found significant associations between ethnicity, mothers who immigrated to Canada, neighborhood-level income, deprivation and child weight status. Our noteworthy findings suggest a double burden of malnutrition in the South Asian population, a protective effect of mothers who immigrated to Canada on unhealthy child weight, associations between increased material deprivation and child underweight and association between increased social deprivation and child excess weight. Further research into the mechanisms behind these association is required to inform policy planning and targeted health interventions. Further research into geographical trends in child weight status is also required.

CHAPTER 3: ASSOCIATIONS BETWEEN BUILT ENVIRONMENT MEASURES RELATED TO PHYSICAL ACTIVITY AND EXCESS WEIGHT IN PRESCHOOLERS: A RETROSPECTIVE COHORT STUDY

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Contributions:

JW and GDCB conceived the project with input from JG and AW. JW and GDCB decided on the analytic approach. AW linked postal code data to built environment measures. JW conducted the statistical analyses. JW interpreted the results. JW drafted and revised the manuscript, in response to feedback and input from all co-authors.

3.1 Abstract

Introduction: The built environment, which includes man-made or modified structures that create living, working, and recreational spaces, can impact health outcomes. Features of the built environment including walkability and access to park spaces can influence weight status. The impact of the built environment on young children's weight status remains largely unexplored. Our purpose was to examine relationships between built environment variables related to physical activity and weight status in preschoolers.

Methods: In this retrospective cohort study, children's anthropometric measurements were taken at 4-6 years old between 2009–2017 in Edmonton and Calgary and were linked to maternal data. World Health Organization criteria for body mass index z-score (zBMI) were used to categorize children as either *normal weight* ($-2 \leq zBMI < 1$) or *excess weight* ($zBMI \geq 1$). Built environment variables were calculated based on the maternal postal code, including distance to nearest playground, distance to nearest major park, distance to nearest school, street intersection density, number of playgrounds, and number of major parks accessible within an 800m 'buffer zone' around the six-digit postal code centroid. Unadjusted and adjusted (for other built environment variables, sex, age, ethnicity, neighborhood-level income, city) binomial logistic regression models were used to estimate the association between built environment variables and children's excess weight.

Results: Our analysis included 121,692 children (n= 59,673 girls; n=73,507 from Calgary). Our unadjusted models found that children had greater odds of being in the excess weight group for

every 100m increment in distance to nearest playground (OR: 1.006; 95% CI [1.002, 1.010]; $p<0.05$) and major park (OR: 1.008; 95% CI [1.006, 1.011]; $p<0.05$). Children had lower odds of being in the excess weight group with every 100m increment in distance to nearest school (OR: 0.992; 95% CI [0.990, 0.993]; $p<0.05$). Individuals with ≤500 intersections within their 800m buffer zones had lower odds of being in the excess weight category per 100 intersection increase in their buffer zone (OR: 0.963; 95% CI [0.952, 0.974]; $p<0.05$), and children with 2 (OR: 0.931; 95% CI [0.889, 0.975]; $p<0.05$) or ≥3 (OR: 0.923; 95% CI [0.882, 0.965]; $p<0.05$) parks in their buffer zones had lower odds of being in the excess weight category relative to children with 0 playgrounds in their 800m buffer zones. However, after adjusting for other built environment variables and sociodemographic variables, only the distance to nearest school was significantly related to children's weight status, whereby every 100m increase in distance to nearest school resulted in lower odds of excess weight (OR: 0.996; 95% CI [0.994, 0.997]; $p<0.05$).

Conclusions: Built environment variables were associated with excess weight in preschoolers. However, in general, these relationships became non-significant in our adjusted analyses. Further research into additional environmental characteristics (*e.g.,* neighborhood safety, weather) is required to further inform this lack of association.

3.2 Introduction

Overweight and obesity in children are common, complex, and include a range of negative health-related consequences. Children with overweight and obesity are more likely to retain excess weight into adulthood and develop obesity-related chronic diseases at a younger age (Sahoo et al., 2015). Although there is a well-established positive between physical activity and child health (Ekelund, 2012), children in western industrialized countries have become less active over recent years due to increasingly sedentary lifestyles (Barnett et al., 2012). With easy access to energy dense foods, children who lead sedentary lifestyles may be more likely to be in positive energy balance, placing them at risk of obesity (World Health Organization, 2016). Children's environments, including their neighbourhoods and communities, can have a profound impact on their lifestyle behaviors and well-being (Maitland et al., 2014; Tandon et al., 2014). Specifically, the built environment (*i.e.,* man-made structures built to support human activity) may influence children's physical activity, including both quantity and quality.

The evidence linking physical activity-related built environments and weight status in children is mixed. For example, a study of 49,770 children between 4 to 19 years old reported links between fewer parks and lower intersection density and higher BMI z-score (Duncan et al., 2014). Lovasi et al. (2011) found that increased park access was related to smaller skinfolds in preschool children. On the contrary, a study of 7,020 urban, low-income preschoolers showed that proximity to playgrounds was not associated with overweight status (Burdette et al., 2004). Although studies have found positive links between increased green space and physical activity or lower BMI z-score (Lachowycz & Jones, 2011; Gilliland et al., 2012), an Ontario study of children between 2 to 17 years old showed no relationship between children's weight status and their proximity to parks (Potwarka et al., 2008). A Calgary-based study also found no association between parks and green spaces with child overweight and obesity (Potestio et al., 2009). This heterogeneity may be due to the use of a variety of ages, measures, outcomes, and designs, with little replication across studies (Dunton et al., 2009). For example, the boundary size used for exploring built environment variables varies from 0.40 to 8.05 kilometres across studies (Dunton et al., 2009). Further, some researchers have applied walkability indices, which are composed of different built environment elements and measures (*e.g.,* grocery store accessibility, land use mix), making comparisons between studies difficult (Yang et al., 2020). Lastly, some studies on children's weight are based on child or parental reports rather than objective measurements, which may lead to inaccurate reporting and misclassifications (Shields et al., 2011). To date, few reports have examined the effects of the built environment on health outcomes among preschool-aged children (*i.e.,* 4–6 years old) (Gascon et al., 2016). With these issues in mind, the objective of our research was to examine relationships between built environment variables related to physical activity, namely playgrounds, major parks, schools and street intersections, and excess weight status in preschoolers in Edmonton and Calgary, Canada.

3.3 Data and Methods

3.3.1 Study Population. Our study cohort included preschool children (4–6 years old) born in the province of Alberta, Canada between January 1, 2005, and November 29, 2013. Before starting kindergarten, children visited public health units in Calgary and Edmonton (the two largest cities in Alberta) to receive immunizations between January 2009 and November 2017.

3.3.2 Built Environment Data Sources and Linkage. Built environment variables, considered a proxy for local neighborhood structure, were selected based on their etiological link with pediatric obesity through the pathway of physical activity (Jia et al., 2019b; Malacarne et al., 2021). Built environment data were then linked to maternal postal code from the *Alberta Health Care Insurance Plan Registry*, where maternal postal code (*i.e.,* A1A 1A1) data were available per fiscal year up to March 2015. The most recent postal code that corresponded to each child's immunization visit was used for linkage to built environment data. The following six features of the built environment were examined: distance to the nearest playground (metres [m]), distance to the nearest major park (m), distance to the nearest school (m), number of street intersections within 800m along the street network (counts), number of playgrounds within 800m along the street network (counts), and number of major parks within 800m along the street network from each postal code centroid (counts). For this study, we applied the following operational definitions: 'playground' – a group of playground structures as defined from each municipality's open data, often found in smaller parks and at elementary schools; 'major park' – a park >10,000m^2 with a significant natural feature (*e.g.,* meadow, wetland, river); and 'street intersection' – an intersection of two polylines within the street network. Built environment variables were generated using ArcGIS Pro 2.9 with the Network Analyst toolbox (Esri, 2021), which included several steps. First, the centroids were determined for all six-digit postal codes within Calgary and Edmonton (DMTI Spatial, 2016). Second, network access buffers were generated at 800m radiating out from the postal code centroid along the street network. We selected 800m as the analytic unit of analysis since studies have cited it as a ~10-minute walking distance for young children and parents (Panter et al., 2010; Paddle et al., 2018), and parents recommended it as a reasonable walking distance for their child (Timperio, 2004). Third, the number of playgrounds, major parks, and intersections were summed within these network buffers. For the distance to nearest playground, major park, and school, a nearest network path was generated between the postal code centroid and the subject of interest along the street network. All relevant data pertaining to these variables were sourced from open data made available by Calgary and Edmonton municipal governments.

3.3.3 Social Determinants of Health Data Sources and Linkage. Child anthropometric data were obtained from the *Alberta Public Health Immunization Records* database. Public health nurses used a standardized protocol and equipment to collect child and parent data. Information on children's date of birth, sex, age at measurement, measured height (to the nearest 0.1 cm), and measured weight (to the nearest 0.1 kg) was collected. Child date of birth was obtained from the *Alberta Vital Statistics Birth Registry*. Child ethnicity, assumed to be equivalent to maternal ethnicity, was derived using surname algorithms from the *University of Calgary Ethnicity Program* and Ontario's *Institute for Clinical Evaluative Studies Ethnicity Program*. The algorithms were run on the earliest maternal surname in the *Alberta Health Care Insurance Plan Registry* to categorize each surname as either 'Chinese', 'South Asian', or 'General Population' (Cummins et al., 1999; Quan et al., 2006; Shah et al., 2010). Census data from *Statistics Canada* (2011) were linked at the Forward Sortation Area level, which was used to determine 2010 annual household income ($CDN) at the neighborhood level as a measure of neighborhood SES. City of residence was categorized as 'Calgary' for postal codes beginning with 'T2' or 'T3,' and 'Edmonton' for postal codes beginning with 'T5' or 'T6.'

3.3.4 Preschool Child Weight Status. The World Health Organization (WHO) body mass index (BMI) growth charts were used to determine children's weight status (Dietitians of Canada et al., 2014b). BMI was calculated by dividing weight (in kg) by height (in m^2). The WHO includes different terms to describe weight status categories based on age. For children <5 years old, *overweight* and *obesity* are defined as BMI >2 and >3 standard deviations (SD), respectively, above the median. For children ≥5 years old, *overweight* and *obesity* are defined as

BMI >1 and >2 SD, respectively, above the median. For consistency in our analyses, which included children < and ≥5 years old, we classified children's weight status as either *normal weight* (zBMI ≥-2 to ≤1) or *excess weight* (zBMI >1). Children with *underweight* (zBMI <-2) and other extreme outliers (zBMI >5) (Vidmar et al., 2004) were excluded from our analyses.

3.3.5 Statistical analysis. Unadjusted univariate, unadjusted multivariate, and adjusted binomial logistic regression models were used to examine associations between the six built environment variables (independent variables) and children's weight status (normal *vs* excess weight) (dependent variables). We first ran a multicollinearity analysis to assess correlations between the built environment variables prior to fitting the combined models; multicollinearity was deemed not an issue as shown by an analysis of the correlation coefficients, variance inflation factor and eigenvalue and condition index associations. The distributions of built environment variables differed between Edmonton and Calgary, so we included 'city' as a variable in a combined model where Calgary was treated as the reference. Subsequently, we ran three models for each built environment variable: (a) a univariate model; (b) an unadjusted multivariate model with all built environment variables; and (c) an adjusted model with all built environment variables plus child sex, age at BMI measurement (4, 5, or 6 years), ethnicity, annual neighborhood-level income (per $10,000 CDN increase), and city (Calgary or Edmonton).

The built environment variables were analyzed as continuous (distance to nearest playground, major park, and school, and number of street intersections) and categorical (number of playgrounds and major parks, 0, 1, 2, or 3+). The sociodemographic adjustment variables were child sex, age at BMI measurement (per year increase), ethnicity (General Population, Chinese, or South Asian), annual neighborhood-level income (continuous), and city (Calgary or

Edmonton). Our models estimated odds ratios (OR) and 95% confidence intervals (95% CI) of being in the excess weight category. Our analyses included the number of playgrounds and major parks within the 800m buffer in categories (0, 1, 2, 3+); the distance to nearest playground, major park, and school was examined in 100m increments; and the number of street intersections within the 800m buffer was studied in 100m increments.

To examine the assumption of linearity between the continuous built environment variables and the outcome of having excess weight, we also fit models that used spline functions to transform the built environment variables. We assessed and compared the fit of linear and spline models using Akaike Information Criterion and visual inspection of plots of log odds of excess weight *versus* built environment variables. The model with the best fit was the model that did not transform any of the 3 distance variables but used a piecewise linear function with 1 knot at 500 to transform the street intersection count within the 800m buffer. Therefore, in our models, we estimated two effects for the intersection density in neighborhoods (≤500 and >500 street intersections).

3.4 Results

In total, we included 121,692 children in our analyses (Figure 3.1). Descriptive characteristics of our study population are presented in tables 3.1 and 3.2, which included 73,507 (60.4%) children from Calgary and 48,185 (39.6%) children from Edmonton. After we classified children based on their weight status, we had 94,996 (78.1%) children in the normal weight category and 26,696 (21.9%) children in the excess weight category. Normal weight and excess weight groups differed in child age, child ethnicity, setting, income and built environment measures (all $p<0.05$).

Figure 3.1: Flow chart of population of children included in analyses.

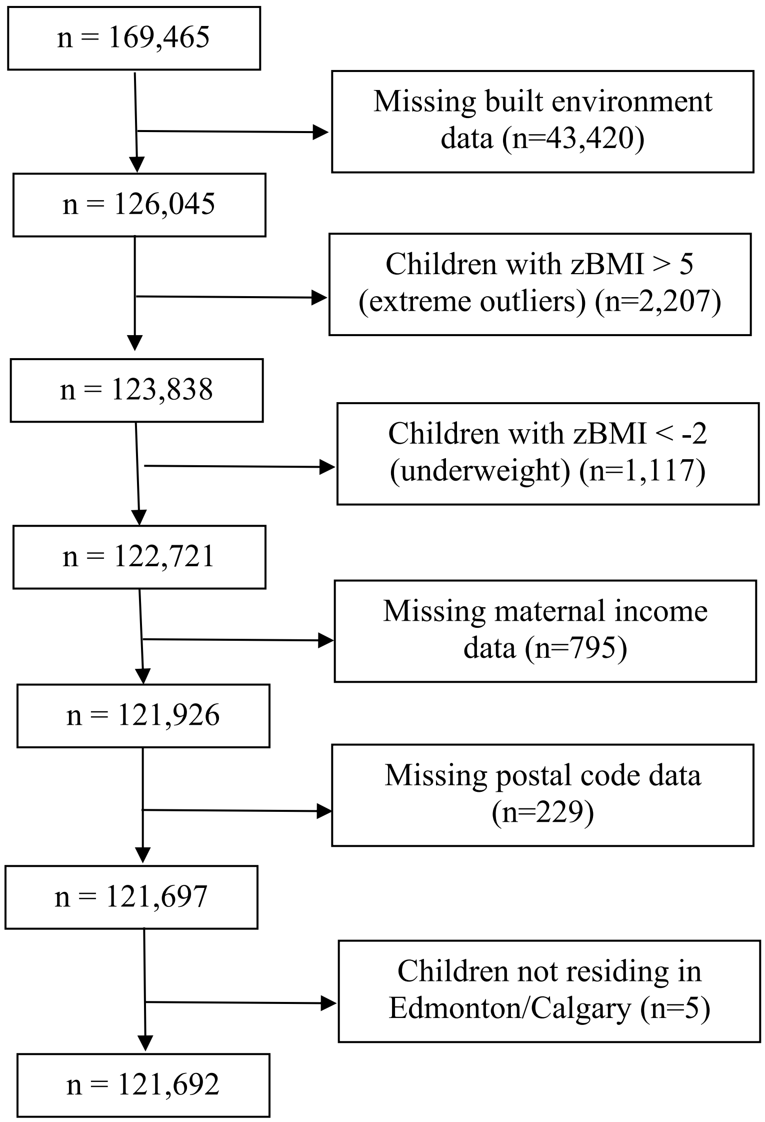


Table 3.1: Continuous descriptive characteristics across weight status categories.

		Normal Weight *zBMI -2 to ≤1*	**Excess Weight** *zBMI >1*
Child Characteristics			
	Total n	94996	26696
	Height, cm {mean (SD)}	108.3 (5.8)	110.0 (6.2)
	Weight, kg {mean (SD)}	17.9 (2.2)	21.9 (3.4)
	BMI, kg/m2 {mean (SD)}	15.2 (0.9)	18.0 (1.4)
	BMI z-score {mean (SD)}	0.4 (0.9)	3.0 (0.8)
Setting			
	Neighborhood-level Income, $CDN {mean (SD)}	84328.1 (20501.1)	81200.9 (20312.2)
Built Environment Measures*			
	Distance to Nearest Playground, meters {mean (SD)}	510.5 (327.4)	517.0 (334.0)
	Distance to Nearest Major Park, meters {mean (SD)}	820.5 (509.3)	842.7 (523.7)
	Distance to Nearest School, meters {mean (SD)}	1063.3 (938.7)	995.2 (881.2)
	Number of Street Intersections within 800m buffer {mean (SD)}	750.2 (462.4)	737.6 (464.3)
	Number of Major Parks within 800m buffer {mean (SD)}	0.7 (0.9)	0.7 (0.9)
	Number of Playgrounds within 800m buffer {mean (SD)}	2.0 (1.4)	1.9 (1.4)

*All built environment variables had $p<0.05$ by ANOVA comparing built environment measures between normal weight and excess weight status categories.

Table 3.2: Categorical descriptive characteristics across weight status categories.

		Normal Weight *zBMI -2 to ≤1*	**Excess Weight** *zBMI >1*
Child Sex*			
	Female {n (%)}	48186 (80.8)	11487 (19.2)
	Male {n (%)}	46810 (75.5)	15209 (24.5)
Child Ethnicity*			
	General Population {n (%)}	82274 (77.5)	23928 (22.5)
	South Asian {n (%)}	5470 (79.3)	1431 (20.7)
	Chinese {n (%)}	7252 (84.4)	1337 (15.6)
Setting*			
	Calgary {n (%)}	58971 (80.2)	14536 (19.8)
	Edmonton {n (%)}	36025 (74.8)	12160 (25.2)

*$p<0.05$ by $\chi 2$ test comparing weight status distribution across categories of each descriptive variable.

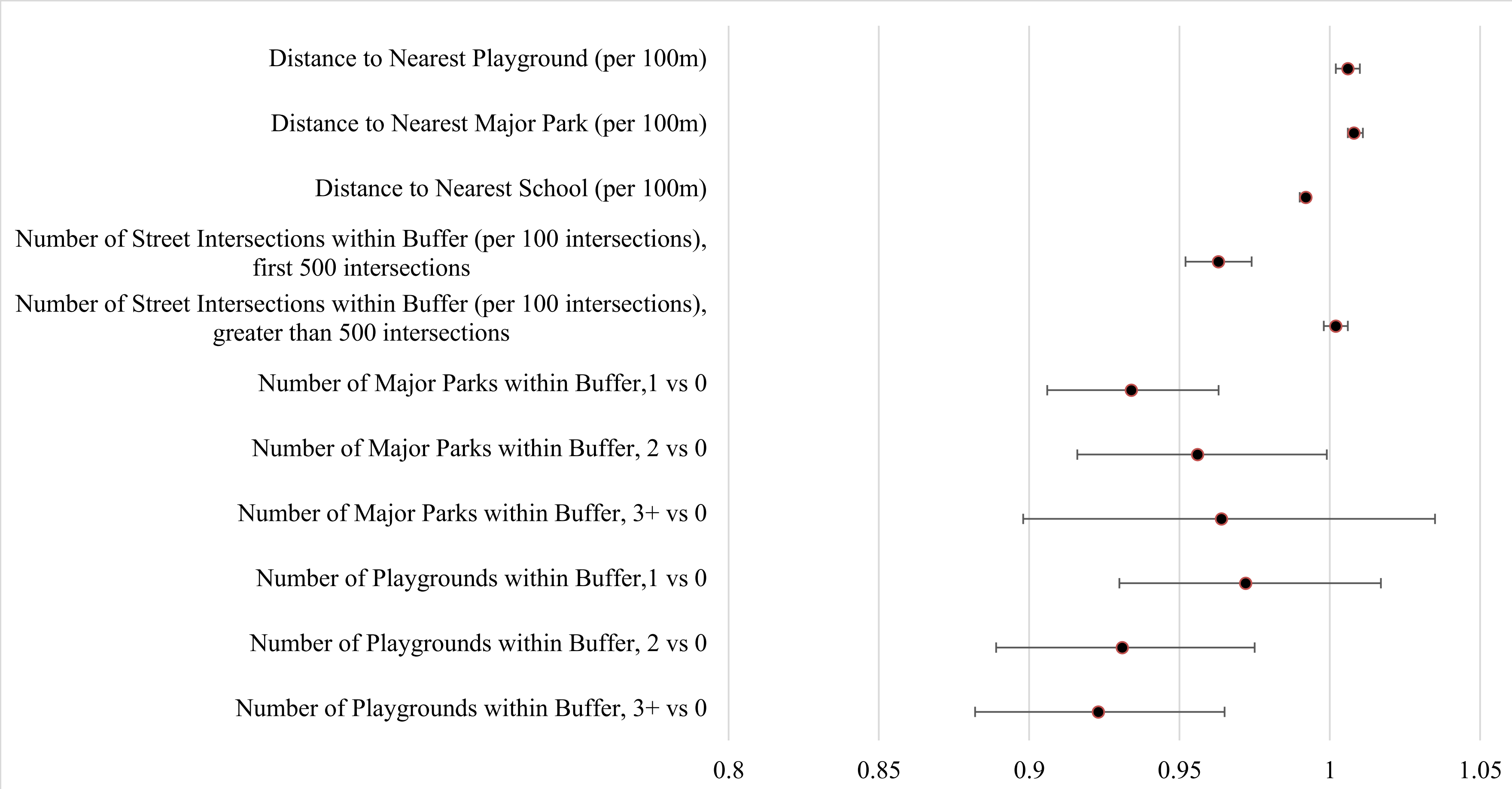
As shown in Table 3.3 and Figure 3.2, our individual, unadjusted binomial regression models revealed statistically significant associations between built environment variables and excess weight. For example, children had greater odds of being in the excess weight group for every 100m increment in distance to nearest (a) playground (OR: 1.006; 95% CI [1.002, 1.010]; p<0.05) and (b) major park (OR: 1.008; 95% CI [1.006, 1.011]; p<0.05). Conversely, for every 100m increment in distance to nearest school, children had lower odds of being in the excess weight group (OR: 0.992; 95% CI [0.990, 0.993]; p<0.05). Individuals with ≤500 (n=41,569) intersections within their 800m buffer zones had lower odds of being in the excess weight category (OR: 0.963; 95% CI [0.952, 0.974]; p<0.05) per 100 intersection increase in their buffer. Finally, relative to children with 0 playgrounds in their 800m buffer zones, children with 2 (OR: 0.931; 95% CI [0.889, 0.975]; p<0.05) or ≥3 parks (OR: 0.923; 95% CI [0.882, 0.965]; p<0.05) in their buffer zones had lower odds of being in the excess weight category.

Table 3.3: Associations between built environment variables and weight status in children using binomial regression analyses.

		OR**	95% CI	aOR***	95% CI
Distance to Nearest Playground (per 100m)		1.006*	1.002, 1.010	1	0.994, 1.005
Distance to Nearest Major Park (per 100m)		1.008*	1.006, 1.011	1.004*	1.001, 1.008
Distance to Nearest School (per 100m)		0.992*	0.990, 0.993	0.991*	0.990, 0.993
Number of Street Intersections within 800m Buffer (per 100 intersections)	*≤500 intersections*	0.963*	0.952, 0.974	0.978*	0.966, 0.990
	>500 intersections	1.002	0.998, 1.006	1	0.996, 1.004
Number of Major Parks within 800m Buffer	*1 vs 0*	0.934*	0.906, 0.963	0.976	0.941, 1.012
	2 vs 0	0.956*	0.916, 0.999	1.004	0.955, 1.055
	≥3 vs 0	0.964	0.898, 1.035	1.042	0.966, 1.123
Number of Playgrounds within 800m Buffer	*1 vs 0*	0.972	0.930, 1.017	0.96	0.907, 1.015
	2 vs 0	0.931*	0.889, 0.975	0.93*	0.875, 0.989
	≥3 vs 0	0.923*	0.882, 0.965	0.929*	0.871, 0.990

*p<0.05.
**unadjusted odds ratio (OR) based on univariate models for each built environment measure.
***adjusted odds ratio (aOR) based on a multivariate model including all other built environment measures.

Figure 3.2: Forest plot of unadjusted odds ratios of having excess weight, based on univariate binomial regression models of each built environment measure.



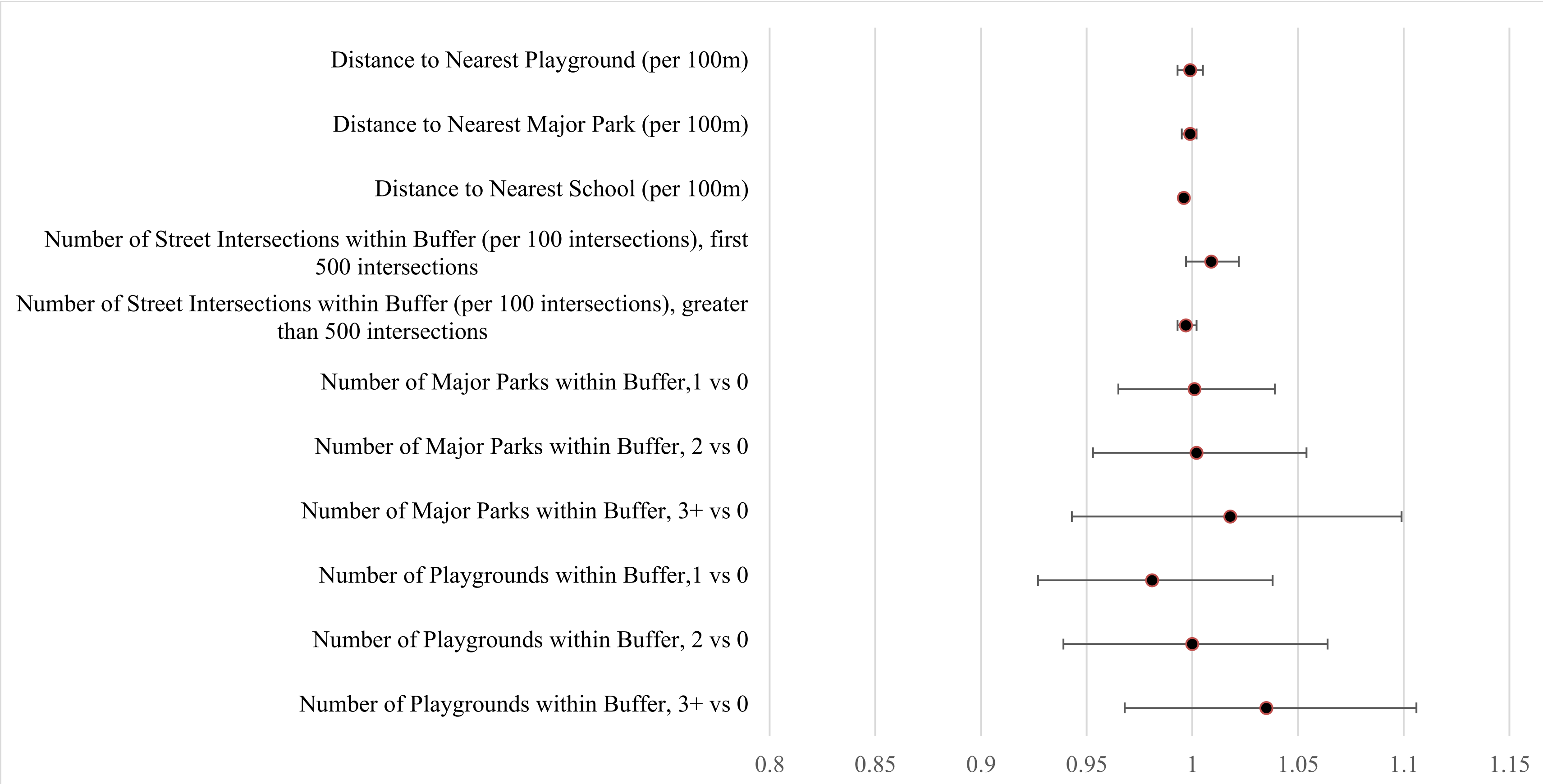
When all six built environment measures (Table 3.3) were included in the model, we obtained comparable results, with the exception of the distance to nearest playground that no longer associated with child excess weight status. However, after controlling co-variates (including child sex, child age, ethnicity, neighborhood-level income, and city of residence; Table 3.4, Figure 3.3), distance to the nearest school was the only built environment variable that remained associated with children's weight status; specifically, for every 100m increase in distance to nearest school, children had lower odds of being in the excess weight group (OR: 0.996; 95% CI [0.994, 0.997]; $p<0.05$).

Table 3.4: Associations between built environment variables and weight status in children using multivariate binomial regression analyses, adjusted for SDH variables.

		aOR**	95% CI
Distance to Nearest Playground (per 100m)		0.999	0.993, 1.005
Distance to Nearest Major Park (per 100m)		0.999	0.995, 1.002
Distance to Nearest School (per 100m)		0.996*	0.994, 0.997
Number of Street Intersections within Buffer (per 100 intersections)	*≤500 intersections*	1.009	0.997, 1.022
	>500 intersections	0.997	0.993, 1.002
Number of Major Parks within Buffer	*1 vs 0*	1.001	0.965, 1.039
	2 vs 0	1.002	0.953, 1.054
	≥3 vs 0	1.018	0.943, 1.099
Number of Playgrounds within Buffer	*1 vs 0*	0.981	0.927, 1.038
	2 vs 0	1	0.939, 1.064
	≥3 vs 0	1.035	0.968, 1.106
Sex (Male vs Female)		1.37*	1.333, 1.408
Age (per 1 year increase)		0.861*	0.840, 0.883
Ethnicity (Chinese vs General Population)		0.645*	0.607, 0.685
Ethnicity (South Asian vs General Population)		0.889*	0.837, 0.945
Neighborhood-level Income (Per $10000 increase)		0.943*	0.936, 0.950
City (Edmonton vs Calgary)		1.378*	1.331, 1.427

*p<0.05
**adjusted odds ratio (aOR) controlling for all of the built environment measures, age, sex, income, ethnicity and city.

Figure 3.3: Forest plot of adjusted odds ratios of having excess weight, based on a multivariate binomial regression model of all built environment variables and adjusted for SDH variables.



3.5 Discussion

The purpose of our study was to study associations between built environment variables related to physical activity and weight status in a population of preschoolers. Our unadjusted individual models revealed associations between increased distance to nearest playground and distance to nearest major park with greater odds of having excess weight, while an increased distance to nearest school, number of street intersections within each 800m buffer zone (up to 500 intersections) and number of playgrounds (2 or 3 *vs* 0) in their 800m buffer zones was associated with lower odds of having excess weight. However, after we adjusted for other built environment and sociodemographic variables, the only association that remained significant was the association between increased distance to nearest school and lower odds of having excess weight. Overall, our analyses provide a novel, population-level perspective on built environment influences on excess weight in preschoolers, both individually and in the context of other built environment and sociodemographic factors.

Our findings that the distance to nearest playground and number of playgrounds in each 800m buffer were not correlated with excess weight in preschools provides a novel addition to the limited literature on playgrounds and excess weight. To date, the literature on this topic has been mixed. A US-based study by Roemmich et al. (2006) that included 59 children between 4 to 7 years old found that neighborhoods with increased playground areas were associated with increased physical activity. However, similar to our results, a German study (n=22,678; child age: 4 to 8 years old) found no association between playground availability and child BMI (Zhou et al., 2020). Our measurement of playground availability assumed that children largely accessed playgrounds that were closest to their homes, although we acknowledge that children and their families may prefer other play areas that are closer to where their friends live or have novel features (Tucker et al., 2007), which may have impacted our findings.

Our analyses revealed that the distance to the nearest major park and number of major parks in each 800m buffer were not associated with preschoolers' excess weight. This result aligns with two previous studies that examined relationships between parks and green spaces and overweight or obesity in children (Potwarka et al., 2008; Potestio et al., 2009). It is possible that families may not be aware of or prefer major parks that are closest to them. For physical activity in adults, an Ontario study by Kaczynski et al. (2008) found that specific park features (*e.g.,* wooded area, paved trail) were more important than distance in predicting park use (Kaczynski et al., 2008). This observation suggests that qualitative features of parks and green spaces may be more important than proximity.

Our finding that increased distance to the nearest school was correlated with lower odds of excess weight in preschoolers was novel. Given that there is little research on this measure with respect to preschool child weight (Terrón-Pérez et al., 2021), more studies are needed to provide context for this association. Our finding contradicts a survey of parents of children 5 to 6 years old in Australia, where parents were more likely to actively commute to school with children, using methods such as walking, if the distance was less than 800m (Terrón-Pérez et al., 2018). Although we considered this association to be affected by lower *vs* higher income neighborhoods, where the latter may be farther away from schools, our inclusion of income in the combined model accounted for this possibility. Instead, we may be observing children who do walk further in their neighborhood with their parents to school site-based preschool programming and playgrounds, compared to children who may live closer to these sites.

We found that increased street intersection density did not correlate to odds of having excess weight status. This contradicts some literature, such as a Massachusetts (USA) study by Duncan et al. (2014), who found an association between decreased intersection density and higher BMI z-score in children 4 to 19 years old. These findings, however, may not translate directly to our study given the different age ranges. On the other hand, the German study by Zhou et al. (2020) also found no association between walkability index (partly comprised of street intersection density) and child BMI. Although meta-analyses of the literature have found positive associations between street connectivity and physical activity, there is still no conclusion on associations between street connectivity and child BMI. Moreover, there may be broad cultural norms in Alberta, Canada that influence transportation decision-making. As mentioned by Jia et al. (2019), it is also possible that the health benefits of more walkable neighborhoods are countered by easier access to unhealthy food outlets.

Overall, our finding that most of the built environment variables did not associate with significantly different odds of having child excess weight may be attributed to some additional factors. First, anecdotally, the preschool age range of our study population is heavily dependent on parental supervision; preschool children would therefore be more affected by parent lifestyle in comparison to older children. As a result, preschool child use of the built environment depends on parent availability for supervision as well as parent preference for outdoor physical activity. Parental perception of neighborhood safety or heavy traffic may also predict outdoor physical activity levels (Timperio, 2004). Secondly, preschool child excess weight may have more association with the home food environment and parental feeding styles (Braden et al., 2014), which may overshadow built environment influences. Lastly, although this study only examined frequency and distance of outdoor amenities for physical activity, outdoor physical activity is dependent on climate; associations have been found between extreme weather conditions and less physical activity in young children (Edwards et al., 2015). It is also possible that children residing in colder regions make greater use of indoor play spaces, although data on indoor play spaces was not available for our study.

3.5.1 Study Strengths and Limitations. Our study brings valuable insight into the limited literature on built environment associations with preschool child weight, and our study strengths include using a large population of children, including objective measures of a wide range of variables, and examining interactions between other built environment variables and common sociodemographic measures. However, one of the limitations in our study is the assumption that children depend on playgrounds, major parks and schools closest to them for access to outdoor physical activity. Although this may not be true for many children, this was the most straightforward approach to analyzing our objective data. Another limitation was the lack of postal code data following 2015. Lastly, we did not have data available for additional potential moderator variables such as neighborhood safety (*e.g.,* perceived safety, crime rates), preferred mode of travel or quality of amenities at playgrounds and parks, that may have provided additional context for our findings.

3.6 Conclusion

In our adjusted models, we found no consistent relationship between the built environment and excess weight in preschoolers. Overall, our findings suggest that the built environment has little impact on excess weight in preschoolers in Edmonton and Calgary. Further research into qualitative aspects of the built environment and additional environmental characteristics (*e.g.,* neighborhood safety, weather patterns) is needed to determine if and how the built environment is related to excess weight in preschoolers.

CHAPTER 4: CONCLUSIONS

4.1 Overview of Findings

Studies included in chapters 2 and 3 examined the relationships between social determinants of health and weight status in preschool children in Alberta, Canada. In Chapter 2, I examined associations between ethnicity, maternal immigration status, neighborhood-level income, urban *versus* rural residency, material deprivation and social deprivation with risk of underweight, overweight and obesity status. Results showed that children with Chinese ethnicity were 0.63 times as likely to have overweight and 0.47 times as likely to have obesity, and children with South Asian ethnicity were 3.95 times as likely to have underweight. Children with South Asian ethnicity were 1.38 times more likely to have obesity. Children with mothers who immigrated to Canada were 0.70 times as likely to have underweight and 0.70 times as likely to have obesity. Children were 0.94 times as likely to have overweight and 0.87 times as likely to have obesity for every $10,000 increase in neighborhood-level income. Relative to the least deprived quintile, children in the most materially deprived quintile were 1.98 times as likely to have underweight, 1.56 times as likely to have overweight and 3.32 times as likely to have obesity. Children in the most socially deprived quintile were 1.25 times as likely to have overweight and 1.40 times as likely to have obesity.

In Chapter 3, I examined associations between built environment variables related to physical activity, namely playgrounds, major parks, schools, and street intersections, with odds of having excess weight. In adjusted models, I only noted an association between distance to nearest school and odds of having excess weight, where every 100m increase in distance to nearest school resulted in children having 0.996 times the odds of having excess weight. According to this study, there was a general lack of association between built environment measures and children's weight status. Overall, my findings from chapters 2 and 3 have important implications for public health efforts towards managing underweight, overweight and obesity in preschool children.

4.2 Implications for Public Health

My research suggests that a child's SDH and, to a lesser extent, the built environment context influence their risk of having underweight, overweight, or obesity in the preschool years. Therefore, public health efforts towards preventing and managing underweight, overweight and obesity in preschoolers must address factors beyond individual-level behaviors. I believe my findings have implications that can be addressed through public health initiatives. While promoting healthy weights for all children is important, the relatively high prevalence of overweight and obesity (*versus* underweight) in Canada suggests that public health initiatives targeting excess weight represent a greater priority, which is reflected below in the order of topics discussed.

The first noteworthy finding from my studies was that almost none of the built environment metrics included in my research were independently related to the odds of overweight and obesity in preschoolers after analyses were adjusted for SDH. The only exception was distance from the nearest school, whereby greater distance to the nearest school had lower odds of having overweight and obesity. Overall, the lack of association between most built environment measures with weight status suggests that associations between the built environment and child weight status may be more important in the longer term (*e.g.,* over 9 years [Jia et al., 2019]) and/or in older children (*e.g.,* 8 to 10 years old [Ghenadenik et al., 2018]). The associations between the built environment variables and weight status in preschoolers became non-significant after adjusting for SDH variables, which suggests that variables including ethnicity and neighborhood-level income exert a greater influence on weight status compared to the built environment. Although the evidence is strong to suggest the built environment impacts a variety of health outcomes in different populations (*e.g.,* diabetes, depression, anxiety [McCormack et al., 2019]), my findings indicate that the weight status of preschoolers in Alberta is influenced to a greater extent by other factors including several SDH. Therefore, public health efforts to prevent or manage overweight and obesity among preschoolers in Alberta should target vulnerable populations based on SDH (*e.g.,* South Asians, low-SES neighborhoods, neighborhoods with low social cohesion). Interventions can start through assessments in the clinical setting; a US-based systematic review of SDH screening tools used in pediatrics noted that clinicians rarely screen for SDH in pediatric clinical care settings because of time constraints, a lack of knowledge on community resources addressing SDH, and discomfort discussing sensitive topics (*e.g.,* income) with families (Morone, 2017). Public health efforts towards overweight and obesity management in young children can involve training health professionals (*e.g.,* nurses) to overcome these knowledge- and perception-based barriers and encourage SDH assessments in clinical settings (*e.g.,* distributing questionnaires, interviewing families). Screening for SDH in clinical settings can encourage referrals to community-based resources for families in need and can inform on population needs that can benefit from targeted interventions (Morone, 2017).

The second noteworthy finding from my research was related to socioeconomic variables and children's weight status. Specifically, my data showed that children had a lower risk of having overweight and obesity for every $10,000 increase in neighborhood-level income and individuals in the most (*versus* least) materially deprived quintile had increased risk of overweight and obesity. These data highlight that lower neighborhood SES is associated with increased risk of overweight and obesity in preschoolers. Therefore, public health efforts towards preventing and managing unhealthy weights in preschoolers should address neighborhood-level barriers to achieving and maintaining healthy weights in low SES neighborhoods. Currently, interventional research addressing preschool weights in low SES neighborhoods by modifying amenities (*e.g.,* grocery store access, recreation center quality) is scarce. However, a California study of 5 to 8 year olds reported a positive association between parent-reported child usage of community centers (for physical activity) and the number of amenities (*e.g.,* picnic tables, benches, grass) observed in the community center (McKenzie et al., 2013). This suggests that increasing the number of amenities in community centers might encourage increased usage and physical activity in younger children, which could have a positive impact on a variety of health outcomes, including weight status. The findings by McKenzie et al. (2013) are in line with recommendations from another study in which parents and youth suggested improving existing parks and recreation centers to promote physical activity in children between 3 to 14 years old (Finkelstein et al., 2017). Although McKenzie et al. (2013) found an inverse relationship between the number of free physical activity programs available and the neighborhood income level, the study also found a low number of free programs overall. This suggests a need for more free physical activity programs available to children in low-income neighborhoods to encourage accessibility of physical activity opportunities. US-based studies on the impact of neighborhood-level factors on child overweight and obesity call for community-based policy interventions that increase access to healthy food outlets (*e.g.,* grocery stores, farmers' markets) and recreation centers in low-SES neighborhoods through loans, grants, and tax benefits (Singh et al., 2010) to promote healthy weights. Additionally, providing community shuttle services or subsidized transportation to access grocery stores or recreational centers can increase the accessibility of healthy food and physical activity options for young children and their families (Finkelstein et al., 2017). When possible, healthcare professionals should inquire about a family's SES (*e.g.,* employment and income level, education level) and neighborhood SES (*e.g.,* neighborhood safety, grocery store accessibility) when evaluating causes for overweight and obesity in children. This can ensure families get the support they need, including referrals to community-based groups or intervention that help manage overweight and obesity in children.

The third noteworthy finding from my research was the link between South Asian ethnicity and a higher risk of having underweight and obesity. It is possible that there are divergent mechanisms that predispose children to increased underweight and obesity in preschoolers in Alberta. Public health interventions that target underweight in South Asian preschoolers should acknowledge that a high proportion of families adhere to vegetarian diets and target interventions towards these groups accordingly. For example, incorporating supplements (*e.g.,* B_{12} [Redecillas-Ferreiro et al., 2020]) can protect against nutrition deficiencies, encourage healthy development, and protect against undernutrition, which can manifest as underweight. Public health interventions designed to address obesity in preschoolers in South Asians can begin before childbirth; healthcare providers can educate South Asian mothers on perinatal risk factors for child obesity that are unique to South Asians and intervene early. For example, mothers with South Asian (*versus* White European) ethnicity have double the risk of gestational diabetes (a risk factor for higher birth weight and child obesity). Studies have suggested that dietary interventions during pregnancy can reduce the incidence of gestational diabetes in South Asians (Desai et al., 2021). Because pregnant mothers with South Asian ethnicity face unique barriers to healthy lifestyle modifications (*e.g.,* maintaining consumption of unhealthy traditional foods), South Asian lifestyles and perceptions should be addressed in interventions to overcome such barriers (Desai et al., 2021) (*e.g.,* by recommending healthy substitutions to unhealthy ingredients in South Asian diets). Similarly, interventions during childhood should also address themes specific to South Asians, such as countering the perception that physical activity is not a priority (Desai et al., 2021) or that a 'chubby' baby is a healthy baby (Misra et al., 2019), which may discourage physical activity or decrease motivation for healthy dietary changes in children with South Asian ethnicity. The traditional involvement of grandmothers in supporting South Asian families also suggests that interventions should address the roles played by grandparents in supporting healthy nutrition during both pre- and post-natal periods (Kandasamy et al., 2020). Encouraging healthy lifestyles that protect against child underweight and obesity in South Asians can involve other stakeholders. For example, partnering with cultural community centers can encourage knowledge dissemination on healthy eating and physical activity in children with South Asian ethnicity, and partnering with grocery stores that cater to South Asians to create affordable "healthy food baskets" (Ahima, 2014) may improve dietary intakes in children. Given the ethnic-specific predisposition to child underweight and obesity in South Asians, health care providers should monitor children's growth and development to promote healthy weights (Peña et al., 2012).

The fourth noteworthy finding is that children in the most (*versus* least) socially deprived quintile had increased risk of child overweight and obesity. High levels of social deprivation indicate a need for social support systems. Therefore, public health efforts should encourage network and friendship building in parents of young children to alleviate stress, establish a sense of social cohesion, and motivate healthy lifestyle changes that protect against child overweight and obesity. For example, weight management interventions can include discussion-based activities that foster support networks between families. A qualitative evaluation of a weight management program for children between 5 to 15 years old and their parents reported that the social cohesiveness was the most valuable part of the program and that social cohesion encouraged talking through issues together, motivating parents to change family members' attitudes regarding lifestyle changes (Edmunds et al., 2014). Social cohesion stemmed from open discussion of the parents' difficulties making lifestyle changes (*e.g.,* changing family members' attitudes towards child weight management), whereby parents realized that they shared mutual problems and bonded over this similarity. This suggests that similar approaches in existing programs can improve social supports in parents of young children. Another US-based study of parents with young children recommended encouraging social networks to promote intervention outcomes by encouraging group discussions rather than lecturing during intervention sessions; this interactivity fostered greater trust between intervention participants and feelings of cohesion within the group (Gesell et al., 2015). Utilizing these approaches to build social cohesion in parent groups may improve weight outcomes in preschool children by encouraging parent engagement in interventions and motivating healthy lifestyle changes post-intervention. In addition, studies have noted that parent perceptions of neighborhood safety can encourage or hinder outdoor physical activity in children (Suglia et al., 2016). Therefore, in communities with low social cohesion, interventions that improve the neighborhood social environment and promote healthy lifestyles can promote communal bonds, social norms that support healthy behaviors, and feelings of safety and security, which may encourage healthy lifestyle changes that prevent or manage childhood overweight and obesity (Suglia et al., 2016).

The fifth noteworthy finding is that children in the most (*versus* least) materially deprived quintile had increased risk of child underweight. Although underweight in children is often attributed to health conditions or chronic diseases in high-income countries, this study is one of only a few to suggest that area-level socioeconomic differences influence underweight in children (White et al., 2016). Although there is a lack of literature on the mechanism of this association, it is possible that families living in low-SES neighborhoods experience food insecurity resulting in children having underweight. Alternatively, Canadians in materially deprived neighborhoods may not have sufficient access to grocery stores to adequately nourish children with pre-existing health conditions that predispose them to underweight. Although there is a gap in the literature on associations between materially deprived communities and underweight in preschool children, this finding highlights that low neighborhood-level SES is a barrier to maintaining healthy weight in early childhood and suggests a need for public health initiatives to minimize the impact of neighborhood-level barriers in children with low neighborhood SES when preventing or managing underweight in children. For example, public health initiatives should establish more accessible and affordable healthy food outlets to encourage a sufficiently nourishing diet in children at risk of underweight. Given that a large proportion of families residing in low-income neighborhoods also have low income at the family level, implementing community-level programs similar to the US-based Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) (*e.g.,* providing whole grain food vouchers, produce vouchers) can be effective in reversing the upward trend of obesity prevalence in low-income children (Pan et al., 2019). A study by Frisvold et al. (2019) showed that the use of WIC program vouchers for specific food items (*e.g.,* whole grain foods) was effective in increasing the consumption of those items by adult program participants, although this trend did not last once children aged out of WIC program eligibility. This suggests that similar public health efforts in Canada may need to implement additional approaches (*e.g.,* providing government grants to encourage organic farming, capping retail costs of organic food, implementing junk food taxes) to ensure long-lasting dietary changes. Similar to overweight and obesity, healthcare professionals should also inquire about a family's SES (*e.g.,* employment and income level, education level) and neighborhood SES (*e.g.,* neighborhood safety, grocery store accessibility) when evaluating causes for underweight in children. This information can offer insight into the needs of underweight children that require intervention and help develop SDH-based interventions targeting underweight.

4.3 Need for Further Research

Based on the findings from my two studies, there are several avenues for future research, with descriptions of future research focused on overweight and obesity first, followed by underweight. The first finding was a lack of association between playground access, major park access and odds of having overweight and obesity in preschool children. Although our findings align with those of another Edmonton study (Smoyer-Tomic et al., 2004), further research is needed to examine links between accessibility of high-quality playground (Smoyer-Tomic et al., 2004) and major parks (*e.g.,* playgrounds with *versus* without fixed equipment, major parks with more *versus* less shaded areas) and weight status in preschoolers. This is important because families may be attending playgrounds or major parks for outdoor play based on quality-based preferences instead of proximity. If an association exists between accessibility of high-quality playgrounds and major parks with lower odds of overweight or obesity in young children, this information can direct efforts towards improving the quality (*versus* quantity and general distance) of existing playgrounds to encourage outdoor physical activity in young children. Our findings were based on data from preschool children in Edmonton and Calgary, so it is also possible that built environment designs and spatial layouts differ between cities. Therefore, conducting similar analyses in other Canadian cities and provinces may illuminate city-specific or province-specific associations between the built environment and weight status in preschoolers. Parent motivation for outdoor physical activity can also be affected by outdoor weather and neighborhood safety. Therefore, further studies into the availability and accessibility of outdoor amenities that control for weather patterns and neighborhood safety will also better contextualize associations between the built environment and child weight status. Qualitative studies on parent perspectives of barriers and facilitators to outdoor physical activity in preschool-aged children in Alberta will also add insight into motivations behind playground and park usage in this population, especially for families living in different communities (*e.g.,* urban *versus* rural or remote communities). Lastly, it is also possible that the food environment, which was not explored in my research, exerts a greater influence than the built environment on weight status in early childhood. For example, a study by Salois (2012) noted an inverse association between density of full-service restaurants and having obesity as well as a positive association between convenience store density and having obesity in 2 to 4 years old from lower-income settings. Further study of the link between the food environment and weight status in preschoolers is needed to inform public health priorities and interventional research.

The second finding was a link between ethnicity and having underweight, overweight and obesity status. Although the ethnicity classification used in my study provided some insight and was able to distinguish ethnicity-specific differences in children's weight status, it lacked precision since it separated the cohort into only 3 categories and most children were categorized as 'General Population.' Therefore, a more specific measure of ethnicity (and culture) with additional categories that reflect the population of Alberta (*e.g.*, Filipino, Indigenous, mixed ethnicity) is needed to capture the diversity of ethnic-specific associations with child weight status. My finding that there was an association between having South Asian ethnicity and having increased risk of having underweight and obesity status also suggests a double-burden of malnutrition within South Asian children residing in Alberta. Although a predisposition to obesity is associated with South Asian ethnicity in Western countries (Sivasubramanian et al., 2021), the association between South Asian ethnicity and underweight status in a high-income country is novel and requires further research. Replication of this study across Canadian provinces would further inform whether the association between having South Asian ethnicity and child underweight extends beyond children in Alberta, and the findings of these studies can inform provincial and national interventions targeting South Asians.

The third finding was an association between children who lived in neighborhoods that were the most (*versus* least) materially deprived quintile and having increased risk of underweight. The association between neighborhood material deprivation and underweight status in high-income countries is novel, and further longitudinal research is needed to understand (a) whether material deprivation can cause children to transition from normal weight to underweight or (b) whether material deprivation exacerbates pre-existing underweight status in children. Additional research into neighborhood-level characteristics (*e.g.,* access to grocery stores, access to convenience stores, access to restaurants) related to child nutrition, as well as individual parts of the material deprivation index (*i.e.,* parent income, employment, and education) with respect to child underweight outcomes can also provide perspective on specific characteristics of materially deprived neighborhoods that may predispose young children to having underweight. Although the prevalence of underweight among children in high-income countries is low, research in this field can determine whether there are any modifiable risk factors for underweight in preschoolers that can inform preventative and management interventions.

4.4 Concluding Remarks

In summary, my thesis identified associations between SDH, measures of the built environment, and weight status in preschoolers. Findings from my research add to existing literature and can be used to target preventative and management interventions towards vulnerable populations. My findings also open new avenues for research into the mechanisms behind SDH associations with having underweight, other aspects of the built environment, neighborhood, and weather influences on weight in preschool populations and longitudinal study designs to further inform my current findings.

Early childhood is a key period of development and a critical determinant of health across the life course (Maggi et al., 2010; Halfon et al., 2022), and unhealthy weights in early childhood can have lifelong, adverse consequences. Therefore, the SDH in early childhood can establish trajectories of health vulnerability that can persist throughout life (Maggi et al., 2010). Understanding the associations between SDH, built environment measures, and weight status in early childhood is a crucial step towards health equity. Investing in early childhood health through SDH-specific interventions designed to prevent or manage unhealthy weights can have lifelong health benefits.

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