Selected Lifestyle Behaviours and Academic Achievement in the Era of the Childhood Obesity Epidemic

by

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Abstract

Lifestyle behaviours, including diet, physical activity, sleep, and sedentary behaviour, have been shown to be associated both with health outcomes, including childhood obesity, and academic achievement in children and youth. The improvement of these lifestyle behaviours to prevent chronic disease is an important public health priority. In addition, academic success for children is an important target for public health as educational attainment is a key social determinant of health and supports good health across the lifespan. Schools are an ideal place to implement initiatives to improve children's lifestyle behaviours. However, further evidence is needed to justify that investments in children's healthy lifestyle behaviours are also investments in academic success, and that health promotion in school environments does not detract from, but instead complements, the mandate of schools. The aim of this thesis is to investigate the relationship of diet, physical activity, sleep, screen usage, and body weight status with academic achievement. This aim was addressed through four research objectives, aligned into five research questions. The objectives consisted of assessing the relationship between lifestyle behaviour recommendations and academic achievement taking into consideration socioeconomic factors, assessing the independent and combined importance of meeting recommendations for lifestyle behaviours, and discussing considerations for the assessment of the relationship between physical activity and academic achievement. To achieve these objectives, I employed data from three, population-based surveys of children and youth from Alberta, Nova Scotia, and Canada-wide. Two of these surveys were linked to standardized exam performance while the Canadian survey had students self-report their academic achievement. I found that adherence to established recommendations for a healthy diet, particularly for sugar intake, physical activity, screen usage, and sleep were positively and strongly associated with better academic achievement. Children

who met recommendations for free sugar intake scored almost 4% better on their academic exams compared to children who did not. In Nova Scotian children, the combined effects of adhering to all of these guidelines had a stronger association with academic achievement than the whole of their individual effects. Students who met the highest number of healthy lifestyle behaviour recommendations had up to three times the odds of meeting expectations on their exams compared to children who met the lowest number. This thesis generated novel evidence to demonstrate that adherence to healthy lifestyle behaviour recommendations are strongly associated with better academic achievement in children and early adolescents, regardless of body weight status or soecioeconomic status. This thesis generates three key recommendations for public health. First, free sugars intake among children is a key health promotion target to both improve the health of children and improve their academic achievement. Based on my findings, if all children in Alberta met the recommendations for free sugars intake, 1.4% more students would meet the Acceptable Standard on standardized exams in Language Arts, and 0.3% more would meet it in Math. In addition, 0.5% more students would meet the Excellence Standard in both Language Arts and Math. Currently, Alberta Education is committed to increasing the number of children who meet each of these standards by 0.2% each year for the next three years. Working towards the reduction of free sugars intake of Albertan students would easily meet these institutional goals with added health benefit. Secondly, this thesis demonstrates the importance of the promotion and adherence to healthy lifestyle behaviour guidelines for children. I also recommend the inclusion of free sugars guidelines in the next version of Canada's Food Guide to complement existing Canadian guidelines for diet, physical activity, sleep, and screen usage. Third, the evidence from this thesis demonstrates that school-based health promotion to improve the lifestyle behaviours of children will benefit the academic success of all children

regardless of their socioeconomic or body weight status. I recommend the broader implementation and evaluation of effective school-based health promotion initiatives in Canada. In particular, further implementation of initiatives taking a Comprehensive School Health approach and rigorous evaluation of their impact on students' academic achievement is merited given the compelling evidence generated by this thesis.

Preface

This thesis is an original work by Erin L. Faught. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name: Return on Investments in Innovative Interventions that Promote Healthy Eating and Active Living Among Children, No. Pro00049436, Approved June 24, 2014, last renewed on May 14, 2016. The thesis used data from several research projects that have also received ethical approval. These include two studies with approval from the University of Alberta Research Ethics Board: An Evaluation of New Provincial Programs to Promote Healthy Weights Among Children and Youth in Alberta, No. Pro00003799, Approved June 3, 2009, and Assessing the Impact of Healthy Eating and Physical Activity Policies on School Based Practices and Health Behaviours of Children in Nova Scotia, No. Pro00007488, Approved Oct 5, 2010. This also included a study with ethical approval from the Queens University General Research Board: the Health Behaviour of School-Aged Children Study, Approval GMISC-062-13.

This thesis contains two published articles and two manuscripts currently under peer review.

Chapter 2 of this thesis has been accepted for publication as: E.L. Faught, G. Montemurro, K.E. Storey, and P. J. Veugelers, "Adherence to dietary recommendations supports children's academic achievement," Canadian Journal of Dietetic Practice and Research 2017; doi: 10.3148/cjdpr-2017-008. [Epub ahead of print] ELF contributed to data collection, conceived of and conducted the analysis, and drafted the manuscript. GM and KS assisted in the interpretation of the analysis and critically revised the manuscript. PJV was the supervisory author and conceived of the study, led data collection, supported the conduction of the analysis, and critically revised the manuscript.

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data and revised the article critically for important intellectual content. MA: Assisted in the interpretation of the data and revised the article critically for important intellectual content. PJV: Was the supervisory author and Principal Investigator of CLASS II study from which data was used. Conceived and designed the study, acquired the data, assisted in the analysis and interpretation of the data and revised the article critically.

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List of Abbreviations

APPLE Schools	Alberta Project Promoting active Living and healthy Eating in Schools
AVHPS	Annapolis Valley Health Promoting Schools
BMI	Body Mass Index
CI	Confidence Interval
CLASS	Children's Lifestyle And School-performance Study
CSH	Comprehensive School Health
DQI	Diet Quality Index
GPA	Grade Point Average
HBSC	Health Behaviour in School-Aged Children
HFSSM	Household Food Security Survey Module
IOTF	International Obesity Task Force
IQ	Intelligence Quotient
JCSH	Joint Consortium for School Health
LOWESS	Locally Weighted Scatterplot Smoothing
MVPA	Moderate-to-vigorous Physical Activity
NHANES	National Health And Nutrition Examination Survey
NLSCY	National Longitudinal Survey of Children and Youth
OR	Odds Ratio
PAQ-C	Physical Activity Questionnaire for Older Children
PAT	Provincial Achievement Test
REAL Kids Alberta	Raising healthy Eating and Active Living Kids in Alberta
SD	Standard Deviation
SES	Socioeconomic Status
SSB	Sugar Sweetened Beverage
WHO	World Health Organization
YAQ	Harvard Food Frequency Questionnaire for Children and Youth

1. Introduction

1.1 Context: The Childhood Obesity Epidemic

Childhood obesity is an important public health concern in Canada and across the world. In Canada, the prevalence of obesity in children and adolescents aged 3-19 is 13%, while prevalence in the same age group in the United States has reached 17% (1). These values are nearly triple the prevalence of obesity observed in these countries only several decades prior (1). Though the prevalence of childhood obesity in most European countries hasn't reached the levels seen in North America, throughout the 2000's the prevalence of overweight and obesity in children and adolescents increased up to 1% each year (2). Childhood obesity is also becoming a concern in developing countries with the prevalence of obesity rising substantially since the early 1980's (3).

The high prevalence of childhood obesity is concerning given that it is associated with myriad adverse health outcomes. Children who are obese have been shown to be at risk for the development of type 2 diabetes, sleep apnea, and adverse mental health (2). Children who are obese are also more likely to become obese adults, contributing further to chronic disease risk across the lifespan including the development or continued exacerbation of type 2 diabetes, cardiovascular disease, and cancer (4). Even when obesity does not track into adulthood, the adverse effects of childhood obesity may still negatively influence adult health (2). In addition to the health and psychosocial implications of childhood obesity, the economic impacts of childhood obesity are also of concern as Canadian obese children have been shown to have health care costs that are 21% higher than their normal-weight peers (5).

1.2 Contributions of Lifestyle Behaviours to the Childhood Obesity Epidemic

While non-modifiable, genetic influences have been shown to contribute to risk of childhood obesity, modifiable lifestyle behaviours appear to be the driver of the childhood obesity epidemic unfolding. Parallel to the increasing prevalence of childhood obesity over the past several decades, secular declines in diet quality, physical activity, and sleep have been observed, while sedentary behavior has increased (6-9). The importance of these lifestyle behaviours in the etiology of childhood obesity is well documented. Obesity, at the individual level, ultimately results from an imbalance between energy intake and energy expenditure (10). Using National Health And Nutritional Examination Study (NHANES) data from the United States, Briefel et al. determined that children's consumption of energy-dense, low-nutrient foods (e.g., soft drinks, candy, salty snacks) has increased substantially in the past three decades (7). Consumption of these foods is associated with increased energy intake and reduced intake of nutrient dense-foods and important nutrients (7,11). Soft drinks alone have been found to contribute to 80% of the increase in added sugar consumption over the past four decades, and adolescents are the highest consuming age group (11). Increases in portion sizes and increased frequency of consuming meals outside the home, patterns of behavior associated with a positive energy imbalance, have also been documented among children (7,12).

Consistent declines in active transportation, participation in team sports, and free play have been observed among children, reducing opportunities for energy expenditure (8,13,14). Increases in sedentary behavior, notably screen-time activities, have been thought to displace time spent on physical activity (13,15). Sedentary behaviors have also been independently associated with risk of obesity, with likelihood of being overweight and obese being elevated in children who were sufficiently active but had high levels of sedentary activity (15). Studies

investigating the relationship between sedentary behaviors and childhood obesity been particularly focused on screen-time behaviors. Reducing sedentary screen-time has been shown to be associated with a decrease in body mass index (BMI), while presence of a screen-based device in the bedroom is positively associated with BMI (15-17).

Finally, both lower sleep duration and poorer sleep quality have been found to be associated with obesity independent of other obesity-related behaviors (18). Disturbances in sleep patterns are associated with disturbances in pathophysiological pathways, leading to increased deposits of fat, particularly in the abdominal region (18). While these behaviors all must occur at the individual level, the prevalence of poor lifestyle behaviors at the population level drives population risk of childhood obesity.

While the independent associations of lifestyle behaviors with childhood obesity are well established, there is evidence that these lifestyle behaviors are interrelated and may have a synergistic effect on obesity risk. For example, diet and sleep may have a complex reciprocal relationship. Consumption of sleep-promoting foods, micronutrient status, macronutrient balance, and timing of meals have been shown to be associated with sleep duration and quality (19). Meanwhile, experimental studies have demonstrated that sleep duration and quality can alter levels of appetite-regulating hormones such as leptin and ghrelin, impacting dietary consumption (20,21). Sedentary behavior in the form of screen-time can result in increased exposure of marketing of unhealthy foods to children and has been associated with increased consumption of unhealthy snacks (22,23). Screen usage has also been associated with delayed bedtimes resulting in less sleep (24). Children who are very physically active may spend more time in recreational facilities where unhealthy foods are heavily marketed and available (25). Finally, children who report participating in more extracurricular activities, including athletic

endeavours, also report getting less sleep (26). It is clear that though each of these lifestyle behaviors have independent relationships with risk of childhood obesity, they do not act in isolation and may have a synergistic effect on obesity risk (27) .

A downward spiral may occur as obesity itself may be considered an individual risk factor for poor lifestyle behaviors. Where obesity is present, so is increased risk of sleep-related breathing disorders that contribute to poor sleep (28). Children who are obese may be more likely to display indicators of poor mental health which may contribute to increased snacking and emotional eating (29,30). Evidently such a downward spiral is complex and ideally avoided, so the direction of attention to the risks of engaging in poor lifestyle behaviours before they begin is imperative.

1.3 Determinants of Lifestyle Behaviours

Like childhood obesity, each of the above-mentioned lifestyle behaviours have modifiable and non-modifiable risk factors of their own. Given the interrelatedness of these lifestyle behaviours as has been described, it is not surprising to find that lifestyle behaviors share many of the same risk factors, both at the individual and population level. At the individual level, modifiable risk factors for lifestyle behaviors include: consumption of family meals, children's electronic media use and access, and parental caring and encouragement of healthy practices, among others. Children who report regular consumption of dinner at the table with family members are likely to have higher quality diets than children who do not (31,32). In addition, children with regular opportunities to interact with their family, such as at family meals, have lower levels of stress, resulting in improved sleep (33,34). Children who have access to and frequently use electronic media devices are more likely to spend time being sedentary and have poor quality diets due to increases in unhealthy snacking (15,23,35). Electronic media

usage, particularly when present in the bedroom, has also been associated with decreased sleep duration (17,24). Finally, parental caring about healthy lifestyle behaviours and encouragement to engage in these behaviors has been shown to be associated with better diet quality and increased physical activity (36,37) .

Modifiable population level risk factors for lifestyle behaviors include the physical environment and policies that promote or facilitate healthy lifestyle behaviors. Attributes of the physical environment including access to recreational facilities, sidewalks and safe intersections are all associated with increased participation in physical activity in a population of children (38). The physical environment also consists of the community food environment. Community food environments where healthy foods are more accessible, (e.g., number of grocery stores compared to fast-food outlets, etc.) have been found to be positively associated with children's diets (39). Policies also provide a population level opportunity to modify risk of poor lifestyle behaviors. Examples of this are policies prohibiting the sale of sugar-sweetened beverages in schools, mandated daily physical activity in schools, and restricting TV marketing of unhealthy foods and beverages to children by industry (40-42). All of the modifiable risk factors that have been listed are opportunities for public health to intervene in order to reduce risk of unhealthful lifestyle behaviors. Based on the interrelatedness of individual and population level modifiable risk factors for lifestyle behaviors, it is clear that multi-component, multi-level interventions provide the best opportunity to address risk factors for lifestyle behaviors, consequently improving lifestyle behaviors and reducing risk of childhood obesity and other health outcomes related to poor lifestyle behaviors (43).

1.4 Socioeconomic Status, Lifestyle behaviours, and Childhood Obesity

A distinct relationship has been established between socioeconomic status and diet, physical activity, sleep, sedentary behavior and ultimately likelihood of obesity in children. A gradient of more healthful lifestyle behaviors is observed as socioeconomic factors, including familial income and parental level of education, become higher (44-46). Children who are impoverished are more likely to be exposed to poor quality or unstable housing conditions, and live in neighbourhoods that do not provide safe opportunities for physical activity or healthful, accessible food outlets (39,47). Children of low socioeconomic status are found to accumulate more screen time through television viewing due to increased likelihood of having a television in their bedroom and eating meals in front of the television, and have shorter sleep duration (46,48,49). They are also more likely to experience high levels of stress that can contribute to obesity-related chronic disease (47). In Canada, the development of income-related household food insecurity has been identified as an important and prevalent concern (50). Before a child is born, household food insecurity has been shown to contribute to poor maternal health and inevitably poor pregnancy outcomes (47), while throughout childhood food insecurity has been shown to be detrimental to children's diet quality as well as increase the odds of their likelihood of being overweight or obese (51).

Conversely, higher socioeconomic status is associated with reduced likelihood of overweight and obesity in children (31). Children of higher socioeconomic status are more likely to be breastfed early in life, have a home environment where healthier food choices are prepared and available, are more likely to have parental interest and support in their participation in sports, and engage in fewer sedentary activities (48,52). Parental modeling of healthy behaviours is much more prevalent among higher-socioeconomic status children, and overweight and obesity is much lower among parents of a high socioeconomic status (46,48).

The socioeconomic gradient in health is a key consideration when developing equitable population health strategies to promote healthier lifestyle behaviors. The resolution of the gap between low- and high-socioeconomic groups is an imperative, overarching goal of public health (46). Population health research and interventions that do not take into consideration socioeconomic inequalities in health may contribute to further exacerbation of health inequalities because they may cater to those who already have a superior health status (53). Given the complexity of the risk factors for lifestyle behaviours and childhood obesity, it is clear that strategies to improve lifestyle behaviors and mitigate childhood obesity must involve multiple sectors beyond simply health, education among them.

1.5 Ideal settings for health promotion: Schools as the 'Heart of Health'

The Ottawa Charter for Health Promotion states that "health is created and lived by people within the context of their everyday life; where they learn, work, play, and love (54)." When developing population health interventions to address childhood obesity, this statement guides the search for appropriate settings in which to implement them. For children, schools are a critical context for overall development and well-being. Though schools are not the only setting where children's development, health, and well-being are influenced, they have a host of features that make them an ideal setting for health promotion to children (55). Schools are the only public setting where children, regardless of their socioeconomic status or backgrounds, are brought together for the majority of weekday waking hours (56). Schools are characterized by the development and delivery of formal curriculum that aims to fulfill the mandate of preparing students to be responsible, competent citizens (56). The formal curriculum represents the material presented in the classroom setting intended for knowledge acquisition and skill development, together with support from those who deliver the curriculum (56). However,

schools also deliver what is considered to be the 'hidden' curriculum, which comprises of the social environment of the school: school values and culture, standards of behavior, role modeling and interpersonal relationships with staff, peers, and the wider school community (56). Because of these aspects of the hidden curriculum, schools provide substantial opportunities for socialization throughout critical years of development (57). The school's hidden curriculum also comprises the physical environment, including available play space and equipment, air quality, and spaces for food provision (56,58). Together, the formal and hidden curriculum are highly influential on children, and represent two modifiable opportunities to facilitate health for children. The formal curriculum provides opportunities to deliver health education with the desired outcome of health knowledge to empower children to maintain their health throughout their lifetime (56,59). The hidden curriculum provides the both the social and physical context for children to be enabled to able to make healthy choices. The goals of the formal and hidden curriculum, the number and diversity of children attending school for a substantial portion of their time and the infrastructure that schools provide make them an ideal location for health promotion to children.

Following the identification of schools as an important setting in which to implement health promotion initiatives, there have been a vast multitude of programs developed, implemented, and evaluated. Systematic reviews and meta-analyses of the effectiveness of school-based health promotion at reducing and preventing childhood obesity have shown inconsistent results (27,60,61). Results among different programs have high heterogeneity and either no statistically significant effect or a very small positive effect (27,60,61). Predominantly, school-based health promotion programs are single-componential, short-term, or knowledge based, which has not led to substantial or sustainable changes in lifestyle behaviours or

prevalence of obesity. In light of the lack of success in these approaches, increased emphasis has been placed on the development and implementation of long-term, sustainable programs that focus not only on the provision of health education but embedding health and wellness in the school environment and culture (59).

In Canada, the Joint Consortium of School Health (JCSH) developed a framework guided by the Ottawa Charter for Health Promotion entitled Comprehensive School Health (CSH) that aims to action this philosophy (58). Globally, similar frameworks have been developed under different names, including Coordinated School Health and Health Promoting Schools (59). Several school-based health promotion programs initiated using this framework in Canada have been implemented, and compelling evidence in favor of the effectiveness of this approach for sustained, equitable, and meaningful improvements in lifestyle behaviours and the prevalence of obesity has been generated. These programs include the Alberta Project Promoting active Living and healthy Eating in Schools (APPLE Schools) Project (62), Action Schools BC! (63), and the Annapolis Valley Heath Promoting Schools (AVHPS) program (64,65). These programs have been shown to effectively improve dietary intake, physical activity, and likelihood of obesity among student participants (62-64). Most notably, the APPLE Schools project has been shown to reduce inequalities in health between the lowest-active and most-active students in a school setting (66). Though school-based sleep interventions are few, some have been associated with improvements in sleep duration by simply adjusting start times of the school day to be later, providing the opportunity for children and adolescents to meet their sleep needs and be more attentive in the school day (67,68). School-based interventions to reduce sedentary time have been few and results have been mixed (69,70).

Despite the demonstrated successes of a CSH approach, schools report limited resources to provide health promoting opportunities or undergo the changes necessary to support a healthier environment (71,72). In a climate where resources are limited, it is difficult to incorporate health promotion and prioritize it over academic achievement. In particular, classroom time is considered a valuable and limited resource and re-allocating a portion to health promotion is considered a challenge.

Existing research has suggested that health promotion in schools may in fact support academic achievement rather than act as a competing priority (71,73-75), and academic achievement is not affected even if classroom time is re-allocated to health promotion (76). Historically, the relationship between lifestyle behaviours, in particular diet, cognitive development, and academic achievement, was investigated in order to better understand childhood development and determine how inadequate and unhealthful lifestyle behaviours may cause detriment to that process (77-79). However, the high prevalence of poor lifestyle behaviours, the consequent childhood obesity epidemic and identification as schools as ideal locations to reduce and prevent childhood obesity has become the impetus to investigate this relationship more in depth, particularly in developed countries (79). Research has shown that school policies and programs aiming to improve health are more likely to be successfully implemented when the school community feels that they fit within their mandate and values (42,80). Evidence on the relationship between healthful lifestyle behaviors and improved academic achievement may lead to greater uptake of school-based health promotion by school administrators, and an increase in perceived value of school-based health promotion for decision-makers.

1.6 Education: A Social Determinant of Health

In addition to the practical applications of investigating the relationship between academic achievement and lifestyle behaviours, health disparities among youth are shaped by underlying societal factors, including inequalities in educational attainment (75). There is a moral obligation to address these underlying factors, and although schools are leaders in addressing education and academic achievement, they are not solely responsible. Health actors must also prioritize health promoting initiatives that can also support academic achievement (73,81). Academic achievement and subsequent educational attainment has been established as a key determinant of lifetime health across a range of demographics and geographical boundaries. Exposure to formalized education has been called a 'social vaccine' – meaning a "social intervention that provides resources that can protect individuals and elevate the health of populations (82)." Overall educational attainment has been associated with increased life expectancy and decreased risk of non-communicable and some communicable diseases (83). Education provides individuals with resources that enable them to live healthier lives like cognitive skills, information and knowledge, and self-efficacy (82). Education is highly correlated with other social determinants of health like income, employment security and working conditions, as well as overall better literacy and understanding of how to invest in one's own health (84). Given education's importance to lifelong health, it is crucial to understand factors that support children early in their educational trajectory to support their highest possible academic achievement and educational attainment.

1.7 Defining Academic Achievement

Academic achievement may also be known as academic performance or school performance. Academic achievement is often considered to be an ambiguous term that captures a

broad range of ideals. For the purposes of this thesis, the working definition of academic achievement will be "an outcome that captures the quality of student's academic work such as course grades or grade point average (GPA) (85)." Some have considered academic achievement as a component of overall academic success, with success defined as "students' characteristics, knowledge, skills, attitudes, values, beliefs and behaviors as they exist after [schooling] (85)." Though academic achievement may be only one component of academic success, it is one component for which objective measurements can be taken and as such an appropriate measure for research and evaluation. There is some controversy about using academic achievement as a proxy for attainment of learning objectives as some argue that 'grades' or GPA represent only a student's performance ability and not necessarily their learning. However, 'grades' are intended to capture attainment of learning objectives and are the strongest objective measures of academic achievement, and success, available. For the purposes of this thesis, the intent is to develop policy relevant evidence, and exam grades, in particular standardized exams, are frequently a measure of assessment of how the school system is functioning and are of high value to educators, as well as a comparable measure in the literature (85,86).

Cognitive development and performance are crucial aspects of academic achievement. Cognitive development focuses on "a child's development in terms of information processing, conceptual resources, perceptual skill, language learning and other aspects of brain development…. In other words, cognitive development is the emergence of the ability to think and understand (87)." Cognitive performance is a measure of the ability to acquire knowledge, think and understand, and can be measured by speed of information processing, memory, and attention span (88). Given these definitions, it is clear that cognitive development and performance are relevant to academic achievement. However, academic achievement depends on

much more than cognitive abilities – "persistence, interest in school, and willingness to study, encouragement from social influences and cultural factors (89)" are also crucial. Because much of the literature discusses lifestyle behaviors' role in cognitive development and performance, it is important to include it here but note its distinction from and relationship with academic achievement. Cognitive development is primarily of interest when considering children's development and physiological mechanisms that may translate into academic success. The subsequent sections aim to summarize the current literature describing the relationships between diet, physical activity, sleep, sedentary behaviour, body weight status, and academic achievement as defined in the present section.

1.8 Literature Review: Relevant Determinants of Academic Achievement

1.8.1 Diet and Academic Achievement

Nutrition is essential for children's health and development, notably cognitive development. The role of specific nutrients and children's cognitive and academic outcomes is well documented. Breastfeeding in infancy has been associated with improved IQ later in childhood (90), and its nutritional composition, including long-chain polyunsaturated fatty acids, is considered to be crucial for the rapid brain development that occurs in infancy (78,91). Deficiencies in iron, zinc and iodine in childhood have been shown to be associated with poorer performance on cognitive tests and subsequent academic achievement, and supplementation in deficient populations has been shown to improve performance (77). Sugar consumption and behavioral consequences that may influence academic achievement are also well studied. Cross-sectional studies have shown that consumption of soft-drinks has been associated with self-reported mental distress, hyperactivity and conduct problems in adolescents, potentially contributing to poorer academic achievement (92). Whole grains and dietary fiber have also been

shown to be associated with improved cognitive performance in both children and adolescents (93,94). The majority of epidemiological studies investigating the relationship between nutrients and academic and cognitive outcomes rely on self-reported dietary consumption. Though these tools are validated and widely used, there is criticism that self-report dietary data is often biased and does not account for individual variability in absorption, transport and metabolism of nutrients that are more precise indicators of individual adequacy (95,96). However, some biomarkers do not provide a measure of long-term intake and are only a reflection of recent status, and as such do not provide a clear image of how status has influenced development over the long term or necessarily reflect intake (97). Until technological advancements allow for the development of non-invasive, valid, sensitive nutritional biomarkers, self-reported intake is a feasible and reasonably valid substitute (97).

Certain food groups and meals have been shown to be associated with cognitive performance and academic achievement. Breakfast consumption and academic outcomes have been the most common dietary aspect of study due to the ease of measurement of breakfast habits (79), with findings pointing towards a positive association between regular consumption of a nutritious breakfast and academic achievement (98,99). Breakfast program interventions have been shown to improve students' school attendance and punctuality, as well as improve the nutrient status of children who may be deficient, and consequently improve academic achievement in schoolchildren (100,101). Frequent consumption of vegetables and fruits, leafy greens, and dairy products has been shown to be associated with better self-reported academic performance in children and adolescents (102). Meanwhile, frequent consumption of unhealthy foods such as sugar-sweetened beverages (SSBs), fried foods, and high-fat and sugar snack foods has been associated with poorer academic and cognitive outcomes (103,104).

Studies of overall diet patterns, quality and behaviors and their association with academic achievement are less frequently conducted. While single nutrients and foods are important to study in relation to academic achievement, diet patterns are often a better predictor for overall health and disease risk and a practical target for public health interventions (104). Adherence to a 'Western-style diet', one high in fast foods, red or processed meats, SSBs, and fried foods, in childhood has been associated with poorer cognitive performance later in adolescence (104). Conversely, adherence to a Mediterranean-style diet, characterized by high consumption of plant-based products, has been shown to be associated with better academic achievement in children (105). In a Canadian context, higher overall diet quality has been shown to reduce likelihood of exam failure (106), as well as contribute to improved self-esteem and mental health indicators which may also contribute to overall academic success (29,64,107). Based on a recent systematic review, breakfast consumption and global dietary patterns are the dietary outcomes most frequently reported to have positive associations with academic achievement (108).

1.8.2 Physical Activity and Academic Achievement

As time for physical activity during school hours has declined substantially in recent years, research investigating the influence of physical activity on children's academic achievement and cognition has become prevalent. Though the literature has some inconsistencies, systematic reviews have concluded that existing literature generally supports a positive relationship between physical activity and academic achievement (109-112). In early childhood, the most critical portion of brain development over the lifetime, a review of studies using accelerometry to measure physical activity showed a relationship between higher levels of physical activity and better cognitive performance (113). As children age, physical activity continues to play a role in cognitive development and academic achievement. Cross-sectional

evidence has shown that children's academic achievement and cognitive performance has benefited from increased physical activity (114). However, several studies have suggested an inverse-U relationship between physical activity and academic achievement (13,115-117). Authors of these studies hypothesize that students who are very active may have less time to spend on their studies due to participation in sports or extracurricular activities (13). In a review of randomized control trials investigating the role of aerobic exercise on cognition and academic achievement, Lees et al (2013) found that aerobic exercise had a moderate impact on children's academic performance and cognitive performance (118) Most notably, several studies have found that even when classroom teaching time was dedicated to more opportunities for physical activity, academic achievement was not affected (76,110,118). Several studies have noted the most benefit from physical activity for math scores (114,119). Physiological mechanisms have been established for the benefits of physical activity for academic achievement, including higher blood and oxygen flow to the brain and secretion of hormones that improve mood (120,121). There is also evidence to show that participation in sports improves behavior in the classroom and attentiveness to lessons (112). Because of the inconsistencies observed in systematic reviews, I feel that further consideration of this relationship is necessary.

1.8.3 Sedentary Behavior and Academic Achievement

Sedentary behavior has emerged as a distinctive area of behavioral health. Recently, researchers in the area have proposed that 'too much sitting' is distinct from 'too little exercise (6).' Even for children who do meet physical activity guidelines, a vast majority of the day may still be spent completely sedentary which has been shown to lead to risk of cardio-metabolic disease, adverse psychological effects, and risk of obesity independent of the risk stemming from physical inactivity (122,123). Given the increasing popularity and availability of screen-based

media among children, concerns have been raised about the associated rises in sedentary behavior and its adverse health effects. Also concerning is the potential for increasing screen usage to have negative effects on education through the displacement of time for homework, studying, reading and sleeping, as well as potentially negative consequences on children's behavior and attention span that have been shown to be associated with certain types of media entertainment (124-126). A recent systematic review found that television was negatively associated with cognitive development between birth and the age of 5, while reading had positive associations with cognitive development, demonstrating that the type of sedentary behavior has varying impacts on cognitive development (113). Previous literature has found that frequent TV usage throughout childhood and adolescence can result in decreased lifetime educational attainment (124). Longitudinal studies have demonstrated that frequent TV watching in childhood is associated with difficulties with attention as teenagers, lower progression in reading ability, and poorer performance on cognitive tests (127). In addition, cross-sectional studies have found that increased time spent watching television was associated with less time spent on homework, studying and reading for leisure in a dose-response manner (127).

Though screen usage in children is widely used as a proxy for sedentary time and media influences have unique effects on educational outcomes aside from time spent sedentary, sedentary time can be accumulated by a variety of activities including time spent sitting in the classroom and inactive transport. As such, accelerometry has recently become valued in the study of sedentary behaviors. However, studies evaluating objectively-measured sedentary behavior and academic performance are few. In a study evaluating the relationship between sedentary behavior and academic achievement, Syvoaja et. al found that self-reported screen time was associated with poorer academic achievement in children, while accelerometer-measured

sedentary activity had no association with academic achievement (13). The authors speculate that self-reported measures of sedentary behaviors, especially screen-time, may be more valuable when evaluating the relationship between sedentary behavior and academic performance as objective measures to not allow the distinction between potentially positive sedentary behaviors (reading, studying, homework) and negative ones (television) (13). Because of the rapid changes in availability and mode of screen usage for school-aged children (ie: tablets, cell phones), I feel that continued work elucidating this relationship is merited.

1.8.4 Sleep and Academic Achievement

Children's sleep has been shown to be consistently declining in recent decades (9). Given that inadequate sleep has been associated with impaired concentration, ability to retain information, hyperactivity and mood disorders (9), it is clear that impaired sleep may negatively influence academic achievement. Several reviews support this, with both shorter sleep duration and poorer sleep quality being linked to poorer academic outcomes (26,77). In addition, the rising prevalence of childhood obesity has also contributed to a rise in the prevalence of sleep-disordered breathing, which has also been linked to poorer academic outcomes (128). Several school-based interventions have been implemented in order to support improved sleep among children and adolescents, most notably adjusting school start times to allow for longer sleep which has been shown to be effective (68).

1.8.5 Body Weight Status and Academic Achievement

Studies have shown that children who are overweight or obese have poorer cognitive performance and academic achievement compared to their healthy-weight peers as demonstrated by recent reviews (129,130). However, it has been noted that studies including potential

mediators or moderators, including socioeconomic indicators and lifestyle behaviors, of the relationship between weight status and cognitive performance or academic achievement, were limited (129,131). Among these are a Canadian study that used cross-sectional data from Nova Scotia to investigate interrelationships between children's body weight status, self-esteem, and academic achievement while simultaneously considering diet quality, physical activity and socioeconomic status. Using structural equation modeling techniques, the authors found that body weight status did not affect academic achievement, but diet quality, physical activity, and socioeconomic status were all positively correlated with school performance (107). Further evidence that can consider all of these covariates simultaneously is required to strengthen these findings. There is no evidence to determine if the relationship between obesity and cognitive functioning is causal – does poor cognitive function result in obesity-related behaviors or does obesity impair cognitive functioning (129)? Longitudinal studies that can consider multiple covariates are lacking in this area (130).

1.8.6 Socioeconomic Status and Academic Achievement

As has been previously described, socioeconomic status (SES), most notably in regards to wealth and parental level of education, is tightly linked to the lifestyle behaviours of interest to this thesis: diet, physical activity, sleep, screen usage, and inevitably, body weight status. However, SES is also known to have strong associations with children's academic achievement (132). Children living in poverty are more likely to score poorly on their exams, have less success in school, and eventually have lower educational attainment (133). In early childhood, children of low socioeconomic status have access to fewer cognitively stimulating activities, and poverty during this crucial period of development has been shown to be linked with poorer brain development related to aspects of school readiness (133,134). While low SES is detrimental to

children in their early years of schooling, evidence has shown that gaps between low and high SES students continues to widen as children age (134). As children become adolescents, they are less likely to be placed upon a more rigorous academic track, and they are more likely to drop out of school early (134). This is based on the 'cumulative advantage theory', whereas children who experience the advantages of higher SES early in their childhood and experience early academic success can continuously build on this throughout their schooling trajectory, while children who are disadvantaged are left behind (134). Clearly, socioeconomic status is a crucial underlying consideration in questions of health and academic achievement, and failure to consider these factors is a major limitation.

In this thesis, evaluating the relationship between the socioeconomic and academic achievement is not a primary objective, with the exception of consideration for food insecurity. Rather, indicators of familial wealth and parental level of education will be considered as confounders given their link to both lifestyle behaviours and academic achievement. However, household food insecurity will also have a particular focus due to its timely policy relevance. Unique associations between food insecurity and academic achievement are described in the subsequent section.

1.8.7 Food Insecurity and Academic Achievement

In Canada, the development of income-related household food insecurity has been identified as a key concern that Canadian provincial and federal governments have failed to address (50). At the time of writing, there is no provincial or federal comprehensive policy framework in place to address household food insecurity (135). Food insecurity has established, profound negative effects on health and well-being for children, including poor early childhood

development, poor psychosocial functioning, poor diet quality and increased likelihood of overweight and obesity (136-139). Because educational attainment is associated with higher likelihood of employment and higher income, success in education provides children with a potential opportunity to leave a cycle of poverty and food insecurity (140). However, there is compelling evidence to show that food insecurity has a profoundly negative effect on children's academic achievement (136, 137). It is thought that food insecurity negatively influences children through two key pathways: children experience a poor diet and a stressful environment that prohibits their success in schools (136,137). Presently, Canadian federal and provincial governments are considering strategies to support children in food insecure households including school food programs and raises to minimum wages. In particular, the maritime provinces are experiencing very high levels of food insecurity and comprehensive interventions are needed to support families experiencing household food insecurity (141). Local evidence to support decision-making for related programs and policies is required. While there have been studies in underdeveloped countries that have investigated the association between food insecurity and academic achievement while also considering dietary quality and household income (142,143), no such study has been conducted in a North American context.

1.9 Foundation for this thesis

The healthfulness of children's lifestyle behaviors has been shown to be declining over the past several decades (7,9,144). Accordingly, adverse health consequences including obesity, type 2 diabetes, and asthma have been shown to be increasingly prevalent in children (1,145,146). Improvement of lifestyle factors is known to be protective against the preventable chronic diseases that comprise a substantial portion of the current health care burden (147).

School-based health promotion provides an ideal opportunity to intervene and contribute to the improvement of children's lifestyle behaviors and prevention of future chronic diseases.

More evidence, and local evidence specific to Canadian contexts, is required to inform decision-making about resource allocation to education to conduct health promotion in schools. In particular, evidence linking lifestyle behaviours and academic achievement was considered important. Linking lifestyle behaviours to academic achievement provides the opportunity for practical, evidence-based decision making, and the opportunity to understand the broader benefits of school-based health promotion. In Canada, several studies have lain the foundation to further build upon, including work regarding diet quality and academic achievement by Florence et al (2008), physical activity and academic achievement by Tremblay et al (2000) (117) and Ahamed et al (2007) (76), and diet and physical activity related to self-esteem, body weight status, and academic achievement by Wang et al (2008) (107). However there is still a need for further evidence, and actionable evidence, in this area, in order to support the broader implementation of school-based health promotion. Using three existing Canadian studies from which data related to diet, physical activity, sleep, sedentary behaviour, body weight status, and academic achievement could be used to investigate their interrelationships, this thesis has advanced the evidence on the association between lifestyle behaviours and academic achievement.

Two data sources involved in this thesis are the 2011 Children's Lifestyle And School-performance Study (CLASS) in Nova Scotia, and the 2012 iteration of the Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta) study in Alberta. Both of these studies comprise population-based surveys of grade 5 students and their parents that collected information about children's diets, physical activity, sleep, screen time, and body weight status

using validated questionnaires and tools, as well as information on socioeconomic status. Both of these datasets were linked to children's achievement on standardized provincial exams written in grade 6, one year following the measurement of lifestyle behaviours, body weight status, and socioeconomic status. The third data source involved in this thesis the 2013/2014 iteration of the Canadian Health Behaviour of School-aged Children (HBSC) study. The HBSC study is a population-based survey of over 30,000 students aged 11-15 that includes information about diet, physical activity, sleep, screen usage, and self-reported body weight status and academic achievement. Together, these databases allowed me to fulfill the overarching objective of my thesis which was **to evaluate the associations of diet, physical activity, sleep, and screen usage with academic achievement.**

Importantly, this work is situated within the larger ROI4Kids Project, which aims to investigate the return on investments from school-based health promotion programs and policies (www.roi4kids.ca), and thus enhances the potential impact of the findings presented in this thesis. The ROI4Kids grant comprises a team of pan- Canadian experts in the area of school-based health promotion as well as a comprehensive knowledge translation and exchange strategy. Throughout the ROI4Kids research development and progression of research objectives, including my thesis work, key knowledge end-users have been engaged to ensure the research is relevant. These knowledge users will continue to inform the research as it progresses, formally through two stakeholder workshops and informally through ongoing consultation, in order to maximize the uptake and impact of this research.

1.10 Objectives, research questions, and their development

This thesis is comprised of several, novel contributions, which, combined, provide evidence of the successful fulfillment of the overall objective of my research. Firstly, in my assessment of the literature, I found that the lifestyle behaviours of interest to this thesis were predominantly measured, analysed, and interpreted using methods and terminology that are difficult to translate outside of academia. In order to enhance the applicability and meaningfulness of my proposed research questions, I chose to evaluate lifestyle behaviours in relation to established, well-understood recommendations for healthful lifestyle behaviours including Eating Well with Canada's Food Guide (148), Physical Activity Guidelines for Children and Youth (149), the National Sleep Foundation's Sleep Recommendations for Children and Youth (150), the Canadian Sedentary Behaviour Guidelines for Children and Youth (127), and the recently released World Health Organization (WHO) Guidelines for Sugars Intake for Adults and Children (151) and Canadian 24-hour Movement Guidelines (152). Health promotion programs aiming to improve the lifestyle behaviours of children are often built around the promotion of these guidelines, and children's adequacy of lifestyle behaviours are measured against these recommendations. Evidence of the broader benefits to academic achievement, beyond health, of these guidelines, provides further support for their promotion, especially in school environments in school-based health promotion initiatives. Importantly, given the proposition that multiple lifestyle behaviours may have a synergistic effect on health and academic achievement, I also analyzed the combined effects of meeting multiple lifestyle behaviour recommendations for health. Rather than emphasizing any of these behaviours as being most important, I feel that a balance of all of these behaviours is necessary for wellness. Evidence supporting this supposition is limited and I aimed to fill this gap using Canadian data.

Secondly, through my involvement in the REAL Kids Alberta study throughout my doctoral studies, I learned about the inaction of Canadian provincial and federal governments in relation to food insecurity and felt it an important consideration in my thesis as two studies available to me had additional information about household food insecurity. Because I was already planning to assess the relationship between adherence to dietary guidelines and academic achievement among Canadian school children, and knowing that the incoming Albertan government was intending to implement school food initiatives in school environments throughout the province, I identified the assessment of the relationship between diet and academic achievement while considering students experiencing household food insecurity as a timely opportunity to support an evidence-based decision for the value of these initiatives.

Thirdly, after substantial literature reviews and obtaining my own null findings about the relationship between physical activity and academic achievement, as well as attending several conferences discussing the inconsistency of the literature and resultant health promotion messages with leading experts in the area, I felt it important to discuss methodological considerations for the analysis of the relationship between academic achievement and how these would influence health promotion messages.

The above resulted in my developing four objectives that build upon each other towards the ultimate aim of this thesis:

- **Objective #1:** To determine if adherence to established recommendations for healthful lifestyle behaviours has benefits for academic achievement, with special consideration for vulnerable populations.

- **Objective #2:** To determine the independent associations of diet, physical activity, sleep, screen usage, and body weight status with academic achievement.

- **Objective #3:** To determine the combined associations of diet, physical activity, sleep, and screen usage with academic achievement.

- **Objective #4:** To discuss methodological considerations for investigating the relationship between lifestyle behaviours and academic achievement.

In order to fulfill these objectives, I generated five research questions that comprise the subsequent five chapters. Four of these research questions have been developed into scientific manuscripts. Where applicable, their citation and publication status is provided.

- **Research Question #1:** Do grade 5 children in Alberta who adhere to recommendations from the Eating Well with Canada's Food Guide, the Dietary Guidelines for Americans 2010, and the World Health Organization Guideline: Sugars Intake for Adults and Children perform better on standardized exams written in grade 6 than children who do not meet these recommendations? (Objective 1, Chapter 2)
    - Faught EL**,** Montemurro G, Storey KE, Veugelers PJ. Dietary recommendations to improve children's diets also have benefits for children's learning. *Canadian Journal of Dietetic Practice and Research* 2017; doi: 10.3148/cjdpr-2017-008. [Epub ahead of print]
- **Research Question #2:** Are grade 5 children in Nova Scotia who are experiencing household food insecurity less likely to meet expectations on standardized exams written in

grade 6 compared to students living in food secure households, independent of their diet, household income, and parental education? (Objective 1, Chapter 3)

    - Faught EL, Williams PL, Willows ND, Asbridge M, Veugelers PJ. Disentangling the effects of food insecurity, diet, and income on children's academic achievement: indications for long-term solutions. *Public Health Nutrition*. Revise and Resubmit April 2017.

- **Research Question #3:** Do each of the diet, physical activity, sleep, screen time, and body weight status of Canadian early adolescents have independent associations with academic achievement? (Objective 2, Chapter 4)

    - Faught EL, Gleddie D, Storey KE, Davison CM, Veugelers PJ. Healthy lifestyle behaviours are positively and independently associated with academic achievement: an analysis of a nationally representative sample of Canadian early adolescents. Under review: PLOS One, March 2017.

- **Research Question #4:** What are the independent and combined associations of meeting multiple lifestyle behaviour recommendations with academic achievement for grade 5 children in Nova Scotia? (Objectives 1, 2, and 3, Chapter 5)

    - Faught EL, Ekwaru JP, Gleddie D, Storey KE, Asbridge M, Veugelers PJ. The combined impact of diet, physical activity, sleep, and screen time on academic achievement: a prospective study of grade five students in Nova Scotia, Canada. *International Journal of Behavioral Nutrition and Physical Activity.* 2017;14(29). doi: 10.1186/s12966-017-0476-0

- **Research Question #5:** Is the relationship between physical activity and academic achievement linear? (Objective 4, Chapter 6)

1.11 Structure of this thesis

This thesis employs a "paper-based" format and includes an introduction, five chapters that align with the four objectives of this thesis, and a general discussion of overall findings. The subsequent five chapters comprise analysis of the five research questions developed to address these objectives. Chapters 2, 3, 4, and 5 are written in a scientific manuscript format and have all been either published or under consideration for publication in peer-reviewed journals. Chapter 6 is a brief communication that will be developed into a manuscript intended for publication. The final chapter is a discussion of overall findings from the thesis, methodological considerations, strengths and limitations, and ultimate conclusions and recommendations.

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2 Adherence to dietary recommendations supports children's academic achievement

Faught EL**,** Montemurro G, Storey KE, Veugelers PJ. Dietary recommendations to improve children's diets also have benefits for children's learning. *Canadian Journal of Dietetic Practice and Research.* In Press December 28, 2016.

2.1 Introduction

Good nutrition, as described by the World Health Organization (WHO), 'is a cornerstone of good health (1).' Inadequate nutrition is associated with increased risk of disease, impaired mental development and reduced productivity among other effects (1). Numerous organizations, both governmental and non-governmental, have released dietary guidelines to promote better nutrition (2-4). However, Canadian children consistently fail to meet these recommendations. Over 60% of children do not meet Canadian recommendations for vegetables and fruit, while one in three children does not meet recommendations for milk and alternatives (5). Similar findings have been reported for other developed countries (6,7).

Research to date has suggested that diets of higher nutritional quality are associated with improved academic performance in children (8-11). Other studies have investigated the relationship of specific foods, nutrients, breakfast and dietary habits with cognitive development and academic performance (12-16). However, no study to our knowledge has investigated the importance of adhering to population-level dietary guidelines based on food groups, saturated fat and free sugars for academic achievement. As these are often the standard to which children's dietary adequacy is measured, understanding how meeting dietary recommendations can influence other facets of children's wellbeing, like academic achievement, is necessary.

In order to determine if adherence to dietary recommendations has benefits beyond nutritional status, we investigated the importance of adherence to dietary guidelines by Health Canada, the WHO and the United States Departments of Food and Agriculture and Health and Human Services (USDA and HHS) for children's performance on standardized exams. We hypothesized that Albertan children in grade 5 who adhere to the selected dietary recommendations will perform better on standardized exams written in grade 6.

2.2 Methods

Study Design

The present research is an analysis of secondary data acquired from the Raising healthy Eating and Active Living (REAL) Kids Alberta survey. This population-based survey reaches grade 5 children (aged 10-11 years), their parents or guardians, and their school principals throughout the province of Alberta, Canada. The present study uses data from the 2012 wave as this data is linked with educational outcomes. The survey employed a one-stage stratified random sampling design in which all Alberta schools were included in the sampling frame except for private, francophone, on-reserve, charter and colony schools (17). Parents were provided with a home survey containing a consent form for their child and demographic questions. Students provided assent and completed a student questionnaire regarding a range of health behaviors and a modified, paper-based version of the Harvard Food Frequency Questionnaire for Children and Youth (YAQ). The YAQ contains 147 questions about the frequency of eating foods over the past year, 136 of which address individual foods and 11 address behaviours (eating breakfast, eating in front of the TV, etc). Student surveys were administered by trained research assistants in classrooms during school hours. Further information on the survey methodology can be found elsewhere (17)

(http://www.realkidsalberta.ca). This work was approved by the University of Alberta's Health Research Ethics Board.

Assessment of exposure

Meeting Dietary Recommendations

Where possible, Canadian recommendations were used for this analysis of Canadian children. As there are no specific Canadian recommendations for children for saturated fat and added sugar intake, recommendations developed by the USDA and WHO were used.

Meeting WHO Free Sugar Recommendations

Free sugars are defined by the WHO as "all monosaccharides, and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juices (3)." WHO, in the first global guideline for free sugars intake, provides a strong recommendation for adults and children to reduce free sugars intake to less than 10% of total energy intake, and a further conditional recommendation to reduce free sugars intake to less than 5% of total energy intake (3). We conducted analyses to assess both recommendations. Free sugars intake was calculated as total sugars contained in sugar-sweetened beverages and sugary snack foods in grams. These grams were multiplied by the caloric load of carbohydrates (4kcal/g) and divided by the child's total energy intake to determine whether or not these recommendations were adhered to. Free sugars from sugar-sweetened beverages (SSBs) and snack foods were also separated and split into tertiles to determine independent effects from each source on academic achievement.

Meeting North American Dietary Recommendations

Each student's food group intake was calculated as number of servings from the all food groups as outlined by the recommendations for 9-12 year olds in *Eating Well with Canada's Food*

Guide (2): Vegetables and Fruit (6 servings), Grain Products (6 servings), Milk and Alternatives (3-4 servings), and Meat and Alternatives (1-2 servings). A binary variable was created to indicate if the child met or did not meet the recommended number of servings from each food group. YAQ data was also used to determine if the child's saturated fat intake was below the recommendation of <10% total energy intake per day. The Eating Well with Canada's Food Guide recommends only to 'limit' saturated fats for children. This more specific recommendation was taken from the *Dietary Guidelines for Americans 2010* (4).

Assessment of outcome

In Alberta, mandatory standardized Provincial Achievement Tests (PAT) are written to determine if students are meeting curriculum expectations. The Alberta Ministry of Education, who administers the PATs, facilitated a linkage of grade 6 PAT scores with the 2012 wave of REAL Kids Alberta survey data. Students wrote their grade 6 PAT exams approximately one year following their participation in the survey. Parent(s) or guardian(s) had the opportunity to consent both to their child's participation in the evaluation and to agree to provide the study team with access to their child's Albertan Student Number (ASN), facilitating the linkage to their child's PAT results. The study team was provided with results to all consenting students' grade 6 PAT results in the subjects of Math and Language Arts. Absolute average score from both subjects was used to represent average PAT achievement.

Confounding variables

Analyses were adjusted for child's gender, caloric intake, parental level of education, household income. Stratified analyses were also conducted by gender.

2.3 Analysis

Sample Characteristics

A total of 4,957 home surveys were distributed, a total of 2,581 (52%) of parents completed and returned their home survey as well as provided their child with consent to participate. Of those that consented to their child's participation in the evaluation, 642 (25%) parents declined to have their child's REAL Kids Alberta Evaluation data linked to their PAT results, leaving a remaining 1,939 students. 344 participants (18%) who had incomplete or missing responses for any of the variables of interest or reported a caloric intake of <500 or >5,000 kcals were excluded (18). This left a total of 1,595 students and parents to be included in the analysis, resulting in a 61% overall completion rate.

Statistical Analysis

Two-sample t-tests were applied to determine differences in demographic characteristics between children whose parents consented to the academic linkage and those that did not. Linear regression models were then applied to assess associations between the meeting of the specified recommendations and PAT scores. Where recommendations were evaluated, not meeting the recommendation was treated as the reference category to determine if meeting recommendations was associated with academic achievement. Regression models were also conducted for a subgroup of students who met the recommendation of <10% to determine if less free sugar intake, even when meeting the <10% total energy recommendation, has an association with academic achievement and to provide more support for the more conservative conditional recommendation of <5%. Multivariable linear regression models were then used with confounders included. Finally, gender-stratified multivariable linear regression models were used. Mixed-effects models were used due to the clustering effect of students within schools. All analyses were completed using the statistical software package Stata SE version 13 (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP).

2.4 Results

Descriptive statistics for children and parents are presented in Table 1. There were no significant differences in demographic variables between students whose parents provided consent for the academic linkage and those that did not. However, students whose parents did not provide consent for this linkage (but did include consent for other data to be used) were less likely to meet strong recommendations for free sugar intake and dairy products.

Table 2 illustrates associations between children's adherence to WHO recommendations for free sugars intake and academic achievement. Children who met the WHO's strong recommendation for free sugar intake (<10% total kcals from free sugars) scored 3.70% better on their PATs than those that did not considering all relevant confounders (Table 2, Model 2, β: 3.70 [95%CI: 1.83, 5.57]). Among children who met this strong recommendation, each additional percent increase (approximately 5 additional grams of free sugar for a 2,000 kcal diet) in free sugar intake between 0% and 10% total energy intake from free sugars resulted in poorer academic achievement (Table 2, Total, β: -0.54 [95%CI: -1.02, -0.66]). These results were also statistically significant when using WHO's conditional recommendation (<5% total kcals from free sugars), where children who met this recommendation scored 2.70% better on their PATs than those that did not when considering all relevant confounders (Table 2, Model 2, β: 2.70 [95%CI: 0.42, 4.98]). In a gender-stratified analysis, significant associations between adherence to free sugars guidelines and academic achievement were only found in boys. Boys who met the WHO's strong recommendation for free sugars intake scored on average 5.67% better on standardized exams compared to those that did not (Table 2, Boys, β: 5.67 [95%CI: 3.14, 8.29]). Strong associations were also observed between meeting the conditional recommendation and boy's academic achievement (Table 2, Boys, β: 4.73 [95%CI: 1.72, 7.74]). No significant

associations between adhering to free sugars recommendations and academic achievement was seen for girls, though results are indicative of some benefit to academic achievement.

A statistically significant trend of improved academic achievement with decreasing levels of free sugars consumption from snack foods was observed in boys. Compared to the highest tertile of free sugars consumption from snack foods, the children in the medium level tertile scored on average 3.81% better on PATs, while the children in the lowest level of consumption scored 4.95% better considering relevant confounders (Table 2, Boys). Boys who consumed the lowest amount of sugar from SSBs scored on average 4.10% better on PATs than boys who consumed the most (Table 2, Boys). No significant trend of sugar consumption by girls was observed in relation to academic achievement.

No associations were observed between adherence to dietary recommendations and academic achievement in either the multivariable models except for boys' adherence to the Canadian recommendation for 'Milk and Alternatives'. Adherence to the recommended servings of 'Milk and Alternatives' was associated with a PAT score that was 3.45% higher, considering all confounders) than those who did not meet this recommendation (Table 3, Boys, β: 3.45 [95%CI: 0.67, 6.23].

2.5 Discussion

The present study found that adherence to recommendations for free sugar intake and for milk and alternative products is significantly associated with improved academic achievement in boys when considering relevant confounders. No other recommendation was significantly associated with academic achievement in boys. Though findings suggest that meeting dietary recommendations is supportive of girl's academic achievement, no finding was statistically significant. This study is the first to our knowledge, both in Canada and elsewhere, to determine

that children's adherence to dietary guidelines improves academic achievement. The findings from the present study provide support for continuing to promote established dietary guidelines among children and justify the inclusion of nutrition programming in Canadian schools.

Differential findings for girls and boys may be due to several factors. First, in this study, boys were less likely than girls to meet most dietary recommendations, particularly sugar (Table 1). In addition, in this study, boys' average academic achievement was lower than that of girls', a consistent finding in recent educational literature (19). This suggests that boys may have more to gain by reducing their sugar consumption and meeting other dietary recommendations in terms of their academic achievement. However, though they are not statistically significant, positive associations between girls' academic achievement and their adherence to dietary recommendations were found. Other studies investigating the association between children's academic achievement have found significant, positive associations between a healthy diet and academic achievement irrespective of gender, suggesting that this study may have been underpowered to detect the relationship in girls (20,21). However, it is possible that girls and boys may receive differential benefit to their academic achievement from nutrition and further investigation about this is merited.

The present findings about the relationship between sugar intake and academic achievement provides further evidence in a topic area where studies are equivocal. In-school consumption of snacks that are high in simple carbohydrates has been found to be associated with reduced odds of stronger academic achievement in Chilean children (14). Cross-sectional evidence in adolescents has demonstrated an association between consumption of SSBs and hyperactivity, mental distress and poor grades (22,23). Experimental evidence in both animal models and in children has shown that foods and beverages high in added sugars may impede

cognitive functioning (24-28). However, these trials often have a very short window of measurement between consumption of foods or beverages high in free sugars and behavioral responses. This study investigated a longer-term impact of free sugars consumption by looking at academic achievement prospectively one year following a dietary assessment.

Our findings support the WHO's strong and conditional recommendations for sugar intake for adults and children. The conditional recommendation is described as such becase there is 'less certainty about the balance between the benefits and harms or disadvantages of implementing a recommendation (3)' of <5% total energy from free sugars. The present study provides evidence to support a further reduction of free sugars to less than 5% of total energy in two ways. First, we found that adherence to this recommendation of less than 5% of total energy from free sugars was associated with 2.70% higher achievement on PAT exams. Secondly, among children who were within the strongly recommended range of 0-10% total energy from free sugars, each additional percentage increase within that range in total energy from free sugars resulted in half a percentage poorer achievement on PAT exams. These findings provide evidence that a more conservative recommendation for free sugars intake would benefit children.

The present study also noted a positive relationship between adherence to guidelines for milk and alternatives and academic achievement. Previous research has shown that higher consumption of milk products is associated with lower consumption of SSBs, suggesting that the consumption of one displaces the other (29,30). Additional analyses revealed that in this sample, consumption of fluid milk was associated with lower SSB consumption. When both adherence to free sugar recommendations and servings of milk were included in a multivariate model, both continued to have independent, positive associations with academic achievement. This suggests that milk may both decrease SSB consumption and have independent benefits for academic

achievement. Another Canadian study found that students who perform better in school are more likely to consume milk daily (9). However, a mechanism linking milk and dairy products to academic achievement in childhood and adolescents is lacking. It is possible that increased milk consumption is a reflection of higher socioeconomic status and better diet quality overall. As milk and alternatives are a key source of nutrients that are important to children's development, their promotion and provision in school environments may be an opportunity to improve children's nutrition and academic achievement while reducing their consumption of SSBs that are harmful to health and academic achievement.

It should be noted that though no association was found between adherence to other food groups or saturated fat recommendations and academic achievement, and no significant association was found between adherence to recommendations and girls' academic achievement, this does not decrease the importance of efforts to help children meet these recommendations. Meeting all dietary recommendations has crucial benefits for children's health and their promotion in locations where children frequent remains necessary (31,32).

The present research has several strengths. The analysis used a large, population-based sample of Canadian children. Prevalence of overweight and obesity in the sample was similar to the prevalence seen at the Canadian national level (33). Daily percentage caloric intake from total sugar was also similar to recent national level estimates (34). The evaluation used a comprehensive, validated food frequency questionnaire and academic results from standardized, province-wide exams. This research also addresses an important need for evidence-based decision making for health promotion. As schools are an ideal location for health promotion, they are frequently called upon to facilitate environments that support children in meeting dietary recommendations (8-11,32,35). However, as a key mandate of schools, academic outcomes often

receive resource priority over health promotion (36). As such, the association between health behaviors and academic achievement is an important area of investigation to demonstrate that the inclusion of health promotion in school settings is a complement, not a competing priority.

This study has limitations that are important to consider. Self-reported dietary measures are prone to social desirability bias. Though we were able to consider many relevant confounders, residual confounding, including the effects of other important lifestyle behaviours such as physical activity and sleep, may still be distorting some of the effects observed in this study. In addition, the socioeconomic status of families who consented to a linkage of survey data with PAT data reported higher income compared to families that did not consent to the linkage though differences were not statistically significant. Families who chose not to participate in the evaluation may be of lower socioeconomic status than those who did, which may influence the generalizability of these findings. Though information on exposures was collected one year prior to writing PATs, the effect of health behaviors on cognition and academic achievement likely develops over a longer period of time. Further research with longitudinal follow-up, with special consideration to child gender, is recommended.

2.6 Relevance to Practice

The present study highlights the broader benefits to children of meeting established dietary recommendations beyond nutritional adequacy. These findings can be used to inform the continued development of dietary recommendations and to support decision-making about the value of school-based health promotion. Practitioners who work directly with children and their families can use this information to demonstrate the value of following dietary recommendations and achieving a nutritious diet.

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2.8 Tables

Table 2.1 Characteristics of grade 5 students participating in the REAL Kids Alberta Evaluation in Alberta, Canada in 2012

Characteristics of Children	Total (n=1,595)	Girls (n=863)	Boys (n=732)
Energy intake, mean (SD), kcal	1853.9 (839.0)	1791.4 (814.4)	1927.5 (861.9)
Age, mean (SD), y	10.96 (0.36)	10.94 (0.34)	10.98 (0.36)
Overweight (including obese), mean, %	28.0	29.8	27.0
Obese, mean, %	8.5	7.2	9.5
Achievement on standardized exams, mean (SD)	62.8 (14.2)	64.2 (14.0)	61.3 (14.3)
Children who meet selected dietary recommendations	%	%	%
Free sugars (<10% total energy)[a]	67.8	69.9	65.2
Free sugars (<5% total energy)[a]	22.3	23.9	20.3
Vegetables and Fruit[b]	29.5	32.1	27.1
Grain Products[b]	15.0	15.6	12.6
Milk and Alternatives[b]	59.4	57.0	60.8
Meat and Alternatives[b]	86.3	86.5	86.1
Saturated Fat intake (<10% total energy)[c]	52.9	48.5	55.4
Total daily grams of sugar intake, mean (SD)	125.3 (65.4)	119.3 (62.5)	132.4 (69.1)
Percentage kcal from total sugar, mean (SD), %	26.8 (6.3)	26.4 (5.9)	27.3 (6.7)
Daily grams of free sugar intake (SSBs and snacks), mean (SD), g	41.8 (33.7)	39.1 (32.0)	45.1 (35.4)
Percentage daily kcal from free sugar (SSB and snacks), mean (SD), %	8.7 (4.89)	8.5 (4.8)	9.06 (5.0)
Daily grams of saturated fat, mean (SD), g	21.2 (10.5)	20.3 (10.1)	22.4 (10.8)
Percentage daily kcal from saturated fat, mean (SD), %	10.3 (2.06)	10.1 (2.0)	10.4 (2.08)
Parental Education, %			
Secondary or Less	23.9	23.1	22.5
College Diploma	39.5	36.7	36.1
University or Graduate degree	36.6	27.3	38.4
Household Income (CAN$), %			
<=50,000	21.0	19.4	18.1
50,001-75,000	16.9	12.6	12.9
75,001-100,000	20.1	15.1	13.8
>=100,001	42.0	27.5	30.3

[a]based on the WHO Sugars intake for adults and children Guideline
[b]based on the Eating Well with Canada's Food Guide
[c]based on the Dietary Guidelines for Americans 2010

Table 2.2 Relationship between children's adherence to WHO recommendations for free sugars intake and their academic performance

	Academic Performance (Average Provincial Achievement Test Achievement)					
	Total		**Girls**		**Boys**	
	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
Free sugars[a] intake <10% total kcals						
No (reference)	-	-	-	-		
Yes	**3.70 (1.83, 5.57)**	**<0.001**	1.52 (-1.05, 4.10)	0.248	**5.67 (3.14, 8.29)**	**<0.001**
Free sugars[a] intake <5% total kcals						
No (reference)			-	-	-	-
Yes	**2.70 (0.42, 4.98)**	**0.02**	1.22 (-1.72, 4.16)	0.42	**4.73 (1.72, 7.74)**	**0.002**
Sugar from snack foods (% of total kcals)						
High (reference)	-		-	-	-	-
Medium	**2.49 (0.36, 4.60)**	**0.020**	2.01 (-0.74, 4.76)	0.15	**3.81 (0.99, 6.63)**	**0.008**
Low	**3.25 (0.88, 5.61)**	**0.007**	1.89 (-1.83, 5.61)	0.32	**4.95 (2.58, 7.33)**	**<0.001**
Sugar from SSBs[b] (% of total kcals)						
High (reference)	-		-	-	-	-
Medium	2.23 (-0.28, 4.73)	0.081	2.07 (-1.05, 5.19)	0.19	1.52 (-1.92, 4.95)	0.38
Low	**2.64 (0.51, 4.79)**	**0.015**	0.82 (-2.39, 4.02)	0.62	**4.10 (1.40, 6.81)**	**0.003**
Sub group analysis: Among children who are below the recommendation of <10% energy from free sugars						
% increase in free sugar intake	**-0.54 (-1.02,-0.66)**	**0.03**	-0.36 (-1.10, 0.37)	0.331	**-0.72 (-1.30, -0.15)**	**0.01**

Results in **bold** are statistically significant (p<0.05)
All models adjusted for child gender (except for gender stratified models), parental education and household income, energy intake, and school type
[a]Free sugar calculated as % total caloric intake from sugars in SSBs and snack foods.
[b]SSB: Sugar-sweetened beverage

Table 2.3 Relationships between children's adherence to North American dietary guidelines and their academic performance

	Academic Performance (Average Provincial Achievement Test Achievement)					
	Total		**Girls**		**Boys**	
Vegetables and Fruit[a]	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
No (reference)	-	-	-	-	-	-
Yes	0.70 (-1.13, 2.53)	0.45	1.41 (-0.99, 3.82)	0.25	-0.37 (-3.60, 2.87)	0.83
Milk and Alternatives[a]						
No (reference)	-	-	-	-	-	-
Yes	**2.37 (0.72, 4.01)**	**0.005**	1.29 (-0.94, 3.53)	0.26	**3.45 (0.67, 6.23)**	**0.02**
Grain Products[a]						
No (reference)	-	-	-	-	-	-
Yes	0.21 (-2.59, 3.00)	0.88	1.29 (-2.44, 5.02)	0.50	1.21 (-4.94, 2.52)	0.53
Meat and Alternatives[a]						
No (reference)	-	-	-	-	-	-
Yes	-0.14 (-2.89, 2.62)	0.92	-0.22 (-4.71, 4.26)	0.92	0.01 (-3.57, 3.59)	1.00
Saturated Fat[b]						
No (reference)	-	-	-	-	-	-
Yes	-0.55 (-2.41, 1.31)	0.743	0.52 (-1.98, 3.02)	0.41	-1.79 (-4.23, 0.66)	0.15

Results in **bold** are statistically significant ($p<0.05$)

All models adjusted for child gender (except for gender stratified models), parental education and household income, energy intake, and school type

[a]Food group recommendations derived from the *Eating Well with Canada's Food Guide*

[b]Saturated fat recommendations are derived from the *Dietary Guidelines for Americans 2010*.

3 Food insecurity, income, and diet in relation to academic achievement in Canadian school-aged children

Faught EL, Williams PL, Willows ND, Asbridge M, Veugelers PJ. Disentangling the effects of food insecurity, diet, and income on children's academic achievement: indications for long-term solutions. *Public Health Nutrition*. Under review January 2017.

3.1 Introduction

Above all other characteristics, socioeconomic status is the most universal determinant of health status in the population (1). As socioeconomic status increases, so does the likelihood of better health throughout the lifespan (1). One of the mechanisms by which low socioeconomic status can be detrimental to health is through the development of household food insecurity(2). In developed countries, food insecurity refers to inadequate household access to food due to financial constraints (3). In Canada, the overall prevalence of household food insecurity is 12.0%, and no statistically significant decreases have been seen since rigorous measurement of Canadian household food insecurity began in 2005 (4). Given the established profound negative associations food insecurity has with health and well-being outcomes, including poor diet, overweight and obesity, poor childhood development, poor psychosocial functioning, and adverse mental health (5-8), strategies to address this concern are imperative.

For children, good education is one means to leave poverty and thrive through the remainder of their lifespan (9,10). However, studies have revealed that food insecurity in childhood is associated with detrimental impacts on healthy development and thus, academic success in childhood may be negatively affected, allowing poverty and consequent food insecurity to persist into subsequent generations (9). Many studies have been conducted to investigate the association between food insecurity and academic achievement, and results are

largely consistent to suggest the detrimental effect of food insecurity on children's school performance (11-15).

Our objective was to provide further support for findings associating food insecurity and poor academic achievement among children. We aimed to address this objective using a large, population-based health survey of grade 5 (10-11 year old) children in Nova Scotia, Canada, prospectively linked to results from exams written one year later, and including important confounders. Nova Scotia has been shown to one of the highest prevalences of food insecurity of all of the provinces in Canada at 15.2% (4), 32% of food bank users in Nova Scotia are children (16), and food insecurity among Nova Scotian children has been shown to contribute to poor diet quality and a higher body mass index (17). Provided this, further and local evidence on the negative impacts of food insecurity on children in Nova Scotia is important in order to motivate interventions to address the high prevalence of food insecurity. To elucidate the relationship between household food insecurity and academic achievement, we also considered other contributors to academic achievement including diet and other lifestyle behaviours (18), parental education (19), and household income (20). We hypothesize that food insecurity will be negatively associated with children's academic achievement over and above the associations of household income, parental education level, and diet quality.

3.2 Methods

We used data from the Children's Lifestyle and School performance Study (CLASS) II conducted in Nova Scotia, Canada, in the spring of 2011. CLASS was a population-based survey aiming to evaluate the lifestyle behaviours, health, and school performance of grade 5 students (10-11 year old children). All schools with grade 5 classes in Nova Scotia were invited

to participate, and as such, all members of the population of interest were included in the sampling frame. Two-hundred and sixty-nine (94.1%) school administrators of 286 eligible schools agreed to their school's participation. Once a school agreed to participate, parents or guardians of all grade 5 students received a home package for their completion. This package contained a consent form allowing the child's participation in the study and a home booklet directed at the parent containing questions concerning household food security, socioeconomic status, demographic factors and other questions related to the home environment and the child's behaviors. Parents were also asked for consent to link their child's survey information to their performance on standardized provincial exams they would write in grade 6, one full year following the measurement of exposures of interest and potential confounders.

Trained research assistants traveled to participating schools and administered surveys to children who had returned a signed consent to participate. Students completed two surveys – a student survey developed by the CLASS research team containing questions about their lifestyle behaviours and self-perceptions, and the Harvard Food Frequency Questionnaire for Children and Youth (YAQ) adapted for Canadian use (21). Parental consent to participate in the survey was provided for 5,913 students, with an average response rate of 67.7% per school. Participants were further excluded from analysis if consent was not obtained for an academic linkage or if the linkage was not successful, if their energy intake was <500 kcals or >5,000 kcals (22) or if other relevant data were missing. Following all exclusions, data were used from 4,430 participants with Reading results, and 4,625 participants with Writing results, and 4,310 participants with Mathematics results, giving an overall completion rate of 74.9%, 78.2% and 72.8% respectively. 4,105 (69.4%) participants had a successful linkage with all three exams.

Food Insecurity

Parents of participating students also completed a survey. The United States Department of Agriculture's Household Food Security Survey Module (HFSSM) is a validated tool that is widely used to assess the prevalence of food insecurity in populations as well as trends in prevalence of food insecurity over time. To reduce respondent burden, household food security was assessed using the six-item short-form HFSSM(23). Although less precise and somewhat less reliable than the 18-item measure, it avoids asking questions about children's food security, which can be sensitive in some survey contexts(23). It has shown to be reliable and valid with respect to the longer-form, 18-item questionnaire, though it cannot be used to identify the most severe forms of food insecurity where children may be experiencing hunger(23). The item was scored as provided in the guide and households were categorized as high or marginal food security (0-1 affirmative response), low food security (2-4 affirmative responses), and very low food security (5-6 affirmative responses. Unlike the 18-item HFSSM, the 6-item survey does not measure the most severe range of adult food insecurity, in which children's food intake is likely to be reduced.

Socioeconomic Status

Household income and parental level of education were assessed using two questions on the home survey. Possible responses to 'What is your current household income from all sources?' were 'Less than $20,000', '$20,001 to $40,000', '$40,001 to $60,000', '$60,001 to $80,000', '$80,000 to $100,000', 'More than $100,000', or 'Unsure/prefer not to answer'. Responses were collapsed and recoded into five categories: '<=20,000', '20-001- 40,000', '40,001-60,000', '>=60,000'and 'Prefer not to answer/missing'. Possible responses for 'What is the highest level of education you have received?' were 'No Schooling', 'Elementary', 'Secondary', 'Community College/Technical College', 'University', 'Graduate University', and

'Prefer not to answer/Missing'. Responses were collapsed and recoded into four categories: 'Secondary or Less', 'College Diploma', 'University or Graduate Degree', and 'Prefer not to answer/Missing'.

Diet

Children's diet was assessed using the YAQ. Data from the YAQ were used to derive a score from the Diet Quality Index-International (DQI) – a score from 0 – 100 ranking children's diet quality based on adequacy, balance, moderation and variety (24). DQI was divided into tertiles and treated as a categorical variable to generate meaningful comparisons and regression coefficients. Data from the YAQ were also used to assess children's adherence to guidelines about added sugars outlined by the World Health Organization in the Free Sugars Guidelines (25) as well as recommendations for saturated fats derived from the USDA Dietary Guidelines for Americans (26). Energy intake was also derived from responses to the YAQ.

Potential Confounders

Potential confounders included child's sex and region of residence as determined by the home survey. Heights and weights to determine body weight status were measured directly by research assistants during visits to schools to administer the child surveys. Body weight status was defined using International Obesity Task Force age- and sex- specific cutoffs (27). Self-reported adherence to other lifestyle recommendations including sleep, screen time, and physical activity were included as potential confounders. Sleep duration was assessed using usual bed and wake times of children by parents, screen time was self-reported by children on the student survey, and physical activity was assessed using the Physical Activity Questionnaire for Children and Youth (PAQ-C), which generates a score of 0-5 to describe children's levels of moderate-to-

vigorous physical activity (28). Adherence to sleep recommendations was assessed using the National Sleep Foundation guidelines for this age group which is 9-11 hours (29). Adequate physical activity was assessed using developed PAQ-C cutoffs that align with optimum minimal cardiorespiratory health for children, found to be a score of 2.9 for girls and 2.7 for boys (30). Adherence to screen time recommendations was assessed using the Canadian Sedentary Behaviour Guidelines (31) which recommend less than 2 hours per day of screen time for children of this age group.

Academic Achievement

Results from mandatory, standardized exams for all children were provided by the Nova Scotia Department of Early Education and Child Development. Test scores were provided by as dichotomous and coded as either 'meeting expectations' and 'not meeting expectations' as per standardized provincial criteria in the subjects of Reading, Writing, and Mathematics. The Nova Scotia Departmnet of Early Education and Childhood Development, who administers these exams, provides rubrics for the exams to determine if children are meeting or not meeting provincial expectations. Further information on this process can be found at http://plans.ednet.ns.ca/about-plans.

Analytic Approach

All analyses were weighted for non-response to represent provincial estimates of the grade 5 student population in Nova Scotia (32). Parents provided the postal code of their household, and using this data, the neighbourhood level income of participants compared to non-participants using Canadian census data. It was found that non-response was highest among the lowest income decile neighbourhoods in Nova Scotia and weights were calculated in order to

account for this disproportionate non-response (32). We applied mixed effects models due to the clustering of students within schools. Univariable logistic regression was first used to assess the associations between food security status and children's academic achievement, dichotomized into meeting and not meeting recommendations for mathematics, reading and writing. The full multivariable model includes all three variables adjusted for potential confounders: child's body weight status, meeting of physical activity, sleep, and screen time recommendations, child sex, and region of residency. All analyses were conducted using Stata version 14.1 IC (StataCorp, Texas, USA).

3.3 Results

The prevalence of varying levels of household food insecurity was 15.9%, with 9.2% of these households reporting low food security and the remaining 6.7% reporting very low food security. Twenty percent of households reported an income less than $20,000 CAD. Meanwhile, 87.4%, 89.1%, and 70.6% of students met expectations for reading, writing and mathematics respectively. Children had a median DQI of 62.2 (where 60 points is a cutoff for good diet quality (24)); 54.3% and 62.6% of students met recommendations for saturated fats and free sugars, respectively.

Unadjusted analyses between food insecurity and academic achievement are presented in Table 2. In unadjusted analyses, food insecurity had a strong, negative relationship with test scores in all three academic subjects (reading, writing, and mathematics). Low food security was associated with 0.70, 0.65, and 0.59 times the odds of meeting expectations in reading, writing, and math, respectively. Very low food security was associated with 0.48, 0.52, and 0.38 times the odds of meeting expectations in reading, writing, and math, respectively.

The multivariate models (Table 3) represent a fully adjusted model, where the relationship between food insecurity and academic achievement is adjusted for socioeconomic status, diet, weight status, meeting recommendations for physical activity and screen time, sex, and region of residence. Considering all influences, children who reside in households reporting very low food security had 0.65 times the odds of meeting expectations in reading and 0.62 times the odds of meeting expectations in mathematics (Table 3, OR: 0.65 [95% CI: 0.44, 0.96]; Table 4, OR: 0.62 [95% CI: 0.45, 0.86]). Socioeconomic status, including household income and parental level of education, and diet quality continued to have significant effects on academic achievement while considering all relevant confounders and measures of food insecurity. In addition, meeting recommendations for added sugars was strongly and positively associated with increased likelihood of meeting recommendations in all three academic subjects considered all other covariates. Children who met added sugars recommendations had 1.46, 1.41, and 1.25 times more likely to meet recommendations in reading, writing, and mathematics respectively (Multivariate Model, Table 3). Male sex was strongly negatively associated with likelihood of meeting expectations in reading (Table 3, Multivariate Model (Reading): OR: 0.58 [95% CI: 0.47, 0.70]) and writing (Table 3, Multivariate Model (Writing): OR: 0.45 [95% CI: 0.37, 0.56]), but showed no association with likelihood of meeting expectations mathematics. Children living in urban residences had 0.70 times the odds of meeting expectations in mathematics compared to children in rural residences (Table 3, Multivariate Model (Math): OR: 0.70 [95%CI: 0.56, 0.87)]. None of body weight status, meeting recommendations for saturated fat, physical activity, and sleep had any significant associations with meeting expectations in any academic subject.

3.4 Discussion

This study revealed that, for children's academic achievement, food insecurity is not simply a proxy for living in a low-income household or for lacking access to healthy foods (12). While income and diet were shown to have strong, positive associations with children's academic achievement, consistent with previous work (9,11,33), very low food security was shown to have a negative association above and beyond those of socioeconomic status and diet. This study provides new information about the detrimental effects of prevalent household food insecurity on Nova Scotian children. It also addressed the need to assess the potential confounding effects of income on this relationship (12). In addition, while there have been many studies that have considered nutrient inadequacy in analyses of food insecurity and academic achievement (14,34), in developed contexts studies that include indicators of dietary adequacy are lacking. Though diet is considered to be on the causal pathway between food insecurity and academic achievement, food insecurity is not a proxy for poor diet in children (12), and eliciting the effects of food insecurity on academic achievement above and beyond its effects through diet is important for intervention development.

Provided that educational attainment is tightly linked with future health and well-being across the lifespan (1,2), the detrimental effects of food insecurity on academic achievement in childhood may contribute to the perpetuation of food insecurity and compromised health across the lifespan and to subsequent generations (9). Though other studies have also shown an association between food insecurity and children's academic achievement (11,12,15), studies in a Westernized context that include overall diet quality in their analyses are lacking. Similar to our findings, Hannum et al found that socioeconomic status and long-term undernourishment had strong effects on literary scores with food insecurity having a persistent negative effect following

adjustment for these variables among children aged 9-12 from villages in rural China (14). The relationship between long-term undernourishment and academic achievement may provide some explanation as to why very low food security and not low food security was shown to be negatively associated with academic achievement.

The negative impact of food insecurity on children's academic achievement is considered to be predominantly due to a resultant poor diet and to a stressful home environment and consequent poor psychosocial development (12,35-37). Food insecurity has already been shown to be associated with poor diet quality Nova Scotian students, and we acknowledge that poor diet is located on the causal pathway between food insecurity and academic achievement (17). This analysis offered the opportunity to investigate the magnitude of the association of food insecurity and academic achievement outside of the effects through poor diet. The effects of poor psychosocial development may in part explain the association between food insecurity and academic achievement that we observed. Studies have shown that children experiencing household food insecurity are at risk of both behavioral and emotional issues, affecting their ability to be engaged in school (35). Children from food insecure households are less likely to get along with peers and are more likely to see a psychologist during their formative years (36). Parents in food insecure households are also more likely to develop experience high levels of stress and adverse mental health, which may influence their ability to care for and support their children in academic pursuits (37,38). As such, interventions that support healthy psychosocial development for children and psychosocial support for parents experiencing food insecurity are necessary.

In response to previous findings that food insecurity can result in poor diet (7,17,39) and, consequently, poor school performance, school breakfast and other food programs have been

suggested and implemented (9). The findings from the present study confirmed the association between poor diet quality and poor academic achievement, supporting programs that seek to reduce nutritional deficits. Studies evaluating the effects of school food programs on academic achievement have largely been supportive of a positive effect of programming on children's school performance, particularly for students who may be affected by food insecurity and consume a poor diet (9,11,40-43). Improvements in academic achievement may be due to both the improvement of students' nutritional status and improvements in school attendance and punctuality (41). Employment status and adequate income have both been shown to alleviate the severity of household food insecurity (44), suggesting the potential of employment and income support policies to directly address food insecurity. Analysis of the potential impact of increases to the minimum wage and Income Assistance in Nova Scotia, however, provide compelling evidence that moderate increases to minimum wage and income assistance fall considerably short of improving household food security (45,46).

The findings from the present study support existing literature calling for interventions to feed children experiencing food insecurity and to provide income support as potential means to reduce household food insecurity. The negative association between food insecurity and academic achievement above and beyond income and diet implies that food insecurity may negatively affect children's academic achievement regardless of whether food and income programs are able to make up for any nutritional or income deficits. While food programs may improve children's diet quality in the immediate term, added sugar consumption was found to have a separate, negative association with academic performance, citing the need to also actively reduce children's sugar consumption alongside supplementing the diet with healthy foods. In addition, findings from this study regarding the strong, positive association of higher parental

level of education with children's academic achievement, above and beyond all other considered influences, confirms the importance of education for this generation of children for the prevention of food insecurity in the next generation of children (19). Thus, investments in long-term, comprehensive approaches to improve academic achievement for children experiencing food insecurity are needed to support children in leaving the persisting cycle of food insecurity across generations. Comprehensive school health approaches have been shown to effectively address inequalities in well-being among children and may be a valuable investment to support vulnerable children (47).

Food insecurity in Canada has been shown to be costly for the Canadian health care system. Compared to food-secure Canadian households, households that experience severe food insecurity have annual health care costs that are 76% ($1092) higher (44). Along with estimates of the cost of poverty to the health care system (48) and of inadequate nutrition (49), these findings complement existing literature and suggest that investments in policy and programs that aim to prevent poverty, inadequate nutrition, and food insecurity are investments that are sure to yield substantial and compounding savings in the long term.

This study has several strengths. First, this study draws on a large, population-based sample of children with data linked to objective measures of academic achievement. The breadth of the data from this sample allowed us to consider multiple important factors in our analysis of food insecurity and academic achievement that have been identified as important considerations in analyses of the relationship between food insecurity and academic achievement. This study utilized a widely used and validated measure of household food insecurity. We have corrected for potential non-response bias through our analyses. This study also has several limitations. The 6-item HFSSM does not measure child food insecurity, and as such we could not infer if the

child who participated in the study was experiencing food insecurity to the same degree as other members of a food insecure household. Although children live in a household where food insecurity is experienced, they may not be hungry or experience a compromised diet. However, the inclusion of diet quality allows opportunity to identify nutrient inadequacies due to hunger, and to understand how food insecurity contributes to academic achievement outside of its effects via diet. Further study of this objective using the long-form HFSSM, or another tool, that can identify if children are experiencing hunger through food insecurity, is necessary. Though the YAQ is a validated questionnaire, similar to any subjective or invasive dietary measurement, it may still be prone to bias. Finally, it is possible that residual confounding may be affecting results.

Food security is an important issue that has shown no signs of decreasing in Nova Scotia and in Canada (4). As of this paper's writing, there are no provincial or federal initiatives in place that have the explicit goal of reduction of food insecurity among Canadians (44). Because children's academic success is a crucial determinant of their future opportunities, prosperity, and health, substantial investments and long-term comprehensive approaches are needed to curtail persisting food insecurity, and support to succeed academically for students living in food insecure households is necessary.

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3.6 Tables

Table 3.1 Characteristics of grade 5 students participating in the CLASS study in Nova Scotia, Canada, in 2011

Characteristics	
Age, mean (SD), y	11.0 (0.4)
Proportion Male (%)	47.2
Food Security Status (%)	
High Food Security	78.2
Low Food Security	9.2
Very Low Food Security	6.7
Missing	5.9
Household Income (CAN$), %	
<=20,000	20.3
20,001 - 40,000	13.3
40,001 - 60,000	24.1
>= 60,001	19.8
Prefer not to answer/Missing	22.5
Parental Education, %	
Secondary or Less	17.3
College Diploma	38.4
University or Graduate degree	36.3
Prefer not to answer/Missing	8.0
Diet Quality Index, mean (SD)	61.7 (9.9)
Rural Residence, %	30.3
Meeting Dietary Recommendations:	
Saturated Fat Intake (<10% total energy)	54.3
Free Sugars Intake (<10% total energy)	62.6
Weight Status, %	
Normal Weight	65.3
Overweight or obese	34.7
Academic Achievement (%)	
Meets expectations – Reading	87.4
Meets expectations – Writing	89.1
Meets expectations – Mathematics	70.6
Meets Physical Activity Cutoffs (>2.7 for girls, >2.9 for boys)	76.7
Meet Screen Time Recommendations (<2 h/day)	77.7

Table 3.2. Relationship for food security status with odds of meeting expectations on standardized exams among grade 5 students participating in the CLASS study in Nova Scotia, Canada, in 2011

	Univariate Relationships					
	Reading		Writing		Math	
Characteristics	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Food Security Status						
High Food Security (reference)	-	-	-	-	-	-
Low Food Security	**0.70 (0.51, 0.96)**	**0.03**	**0.65 (0.44, 0.96)**	**0.03**	**0.59 (0.45, 0.78)**	**<0.001**
Very Low Food Insecurity	**0.48 (0.34, 0.68)**	**<0.001**	**0.52 (0.35, 0.76)**	**0.001**	**0.38 (0.29, 0.51)**	**<0.001**

OR: Odds Ratio

Table 3.3 Relationship for food security status, diet, socioeconomic indicators, and relevant confounders with odds of meeting expectations on standardized exams among grade 5 students participating in the CLASS study in Nova Scotia, Canada, in 2011

	Fully Adjusted Model					
	Reading		**Writing**		**Math**	
Characteristics	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Food Security Status						
High food security (reference)	-	-	-	-	-	-
Low Food Security	0.99 (0.69, 1.41)	0.96	0.86 (0.58, 1.29)	0.47	0.90 (0.66, 1.22)	0.50
Very Low Food Insecurity	**0.65 (0.44, 0.96)**	**0.03**	0.73 (0.47, 1.12)	0.15	**0.62 (0.45, 0.86)**	**0.004**
Household Income						
<=20,000			-	-	-	-
20,001 - 40,000	1.17 (0.84, 1.63)	0.36	1.40 (0.98, 2.01)	0.07	**1.37 (1.07, 1.73)**	**0.01**
40,001 - 60,000	1.25 (0.86, 1.81)	0.25	1.43 (0.96, 2.14)	0.08	**1.33 (1.04, 1.70)**	**0.03**
>= 60,001	**1.90 (1.24, 2.90)**	**0.003**	**1.95 (1.21, 3.17)**	**0.007**	**1.85 (1.38, 2.50)**	**<0.001**
Parental Education						
Secondary or Less	-	-	-	-	-	-
College Diploma	1.25 (0.94, 1.66)	0.12	1.16 (0.84, 1.60)	0.37	**1.33 (1.07, 1.65)**	**0.01**
University or Graduate degree	**1.84 (1.34, 2.52)**	**<0.001**	1.31 (0.92, 1.86)	0.14	**2.38 (1.89, 2.98)**	**<0.001**
DQI - tertiles						
Low	-	-	-	-	-	-
Medium	**1.44 (1.09, 1.91)**	**0.01**	**1.59 (1.19, 2.13)**	**0.002**	**1.23 (0.99, 1.54)**	**0.06**
High	**1.76 (1.28, 2.43)**	**0.001**	**1.66 (1.15, 2.41)**	**0.007**	**1.53 (1.16, 2.20)**	**0.003**
Meet recommendations for saturated fat	1.05 (0.82, 1.34)	0.71	0.97 (0.74, 1.27)	0.81	0.80 (0.64, 1.01)	0.06
Meet recommendations for free sugars	**1.46 (1.17, 1.82)**	**<0.001**	**1.41 (1.13, 1.65)**	**0.002**	**1.25 (1.04, 1.49)**	**0.02**
Weight Status			-	-		
Normal Weight	-	-	-	-	-	-
Overweight or obese	1.05 (0.82, 1.34)	0.12	0.83 (0.85, 1.38)	0.17	0.98 (0.82, 1.18)	0.85
Meet physical activity cutoffs	1.03 (0.80, 1.34)	0.80	1.08 (0.85, 1.38)	0.51	1.11 (0.93, 1.33)	0.23
Meet recommendations for TV	0.95 (0.75, 1.21)	0.69	1.30 (1.00, 1.70)	0.049	1.01 (0.82, 1.24)	0.94
Meet recommendations for sleep	1.41 (0.89, 2.24)	0.15	1.53 (1.01, 2.32)	0.046	1.46 (0.99, 2.14)	0.19
Sex						
Boy	**0.58 (0.47, 0.70)**	**<0.001**	**0.45 (0.37, 0.56)**	**<0.001**	1.12 (0.95, 1.31)	0.18
Girl	-		-	-		
Urban Residence	1.09 (0.85, 1.38)	0.50	0.84 (0.64, 1.10)	0.21	**0.70 (0.56, 0.87)**	**0.001**

OR: Odds Ratio
SES: Socioeconomic Status
DQI: Diet Quality Index

4 Healthy lifestyle behaviours are positively and independently associated with academic achievement: an analysis of a nationally representative sample of Canadian early adolescents

Faught EL, Gleddie D, Storey KE, Davison CM, Veugelers PJ. Healthy lifestyle behaviours are positively and independently associated with academic achievement: an analysis of a nationally representative sample of Canadian early adolescents. Under review: PLOS ONE, March 2017.

4.1 Introduction

The diet, physical activity, sleep, and screen time of children and youth are an important concern both to public health professionals and to society today. Consistently, population-level evaluations demonstrate that young people in Canada are failing to achieve established healthful recommendations for all of these lifestyle behaviours [1-3]. Consequently, young people are experiencing adverse health consequences at unprecedented rates, including obesity [4] and type 2 diabetes [5] , putting them at risk for ill health and chronic disease across their lifespan.

In addition to consequences to health, these lifestyle behaviours (diet, physical activity, sleep, and screen time) have been shown to be associated with young people's academic achievement. Reaching optimal nutrition, physical activity, and sleep levels have demonstrated importance for academic achievement [6-8] while excess recreational screen time has been shown to negatively influence academic achievement [9]. In addition, overweight and obesity have been associated with poorer academic achievement [10], although recent reviews have noted that studies including potential mediators and moderators of this relationship, such as lifestyle behaviours and socioeconomic status, have rarely been considered in these analyses [11,12]. The high prevalence of unhealthy lifestyle behaviours and their negative associations with academic achievement is concerning for young people as school engagement and education

are demonstrated protective factors against the development of adverse health over the entire lifespan [13,14]. Thus, unhealthy lifestyle behaviours contribute to adverse health consequences through direct physiological effects and by negatively influencing the likelihood of succeeding in school, resulting in lower socioeconomic status later in life [15]. The health-education relationship also suggests that effective interventions which improve the lifestyle behaviours of youth, such as school-based health promotion, can have direct benefits on health as well as improve educational attainment, resulting in a healthier, more prosperous, and productive next generation [16]. Several school-based health promotion programs have been shown to achieve demonstrated improvements in lifestyle behaviours and academic achievement, though studies assessing this are few and further evidence is needed [17-19].

Although each of diet, physical activity, sleep, screen time, and body weight status have established relationships with academic achievement, few studies [20-22] have considered all of these health behaviours simultaneously in an analysis to determine their independent effects on academic achievement. Findings from these limited studies indicate that exhibiting a healthy diet, adequate physical activity and sleep, and reduced screen time, have individual, positive associations with academic achievement regardless of body weight status [20-22]. This evidence is supportive of school health approaches that are multi-componential, as focusing on singular lifestyle behaviours may not have as substantial as an effect on academic achievement as would considering multiple healthy lifestyle behaviours. In addition, this evidence supports the idea that health promotion for the improvement of lifestyle behaviours is beneficial for the academic achievement all students, not simply those who are overweight or obese.

Our objective is to complement and expand on existing studies aiming to investigate the independent effects of physical activity, diet, sleep, screen time, and body weight status on

academic achievement using a large, population-based sample of early adolescents (age 11-15) from all provinces in Canada. This is the largest study to date and the first to use a representative sample of early adolescents in Canada. These findings can be used to inform population-level interventions to improve the lifestyle behaviours of children and youth and consequently reduce their likelihood of adverse health and academic achievement outcomes.

4.2 Methods

This work is a secondary data analysis from the Canadian version (Cycle 7) of the 2014 Health Behaviour in School-aged Children (HBSC) study [23]. This questionnaire is conducted in more than 40 countries across the world in collaboration with the World Health Organization (WHO) [23]. In Canada, this survey was carried out among a representative sample of Grade 6-10 (focused on 11-15 year old) students in all 13 provinces and territories excluding students who were on First Nation or Indian reserves, private and home schooled students, youth not in a school setting, or incarcerated youth [24]. Surveys asked a wide variety of questions about health and lifestyle behaviours as well as socio-demographic information. All provinces and territories invited to participate in the survey consented to participation, and there was a 77% student response rate, resulting in 29,837 student participants [24]. After excluding students without complete information for key variables, 28,608 (96%) students were considered in the analysis, resulting in an overall inclusion rate of 74%. Sampling weights were applied to the sample in order to achieve representativeness of Canadian youth by grade, gender and province or territory. Ethical approval for the HBSC study in Canada was obtained from the Queen's University General Research Ethics Board (Approval GMISC-062-13) and from Health Canada and the Public Health Agency of Canada.

Academic Achievement

Students self-reported their academic achievement by responding to the following question: 'Which of the following best describes your marks during the past year?' Possible responses were: 'Mostly A's/above 85%/or level 4', 'Mostly A's and B's/between 70 and 84%/or level 3 and 4', 'Mostly B's and C's/between 60 and 69%/or level 3', 'Mostly C's/between 50 and 59%/ or level 2', and 'Mostly letter grades below C/below 50%/or level 1'. For ease of readibility, these categories are henceforth referred to by their letter categories.

Physical Activity

Physical activity was assessed using the question: "Over a typical or usual week, on how many days are you physically active for a total of at least 60 minutes per day?" Possible responses were 0, 1, 2, 3, 4, 5, 6, or 7 days per week. This question corresponds with the Canadian 24-hour Movement Guidelines for Children and Youth [25] which recommend 60 minutes of physical activity per day for children 11-17. Because several studies have found the relationship between physical activity and academic achievement to have an inverse-U shape rather than a positive dose-response shape [26,27], we divided the days per week achieving 60 minutes of physical activity into three categories: 0-2 days, 3-5 days, and 6-7 days.

Dietary Aspects

Diet was assessed using a short food frequency questionnaire and several free-standing questions about dietary habits. In order to reduce the number of variables and identify essential groupings of data from the short food frequency questionnaire, we conducted exploratory factor analysis with varimax rotation. This method was used to identify foods and behaviours from the diet-related questions that frequently occur together, such as children reporting frequently eating

'vegetables' being also more likely to frequently eat 'orange vegetables (carrots, squash, sweet potato, etc.),' which are two separate items in the questionnaire. The factor scores that were generated were used in regression analyses to quantify each factor's association with academic achievement.

Our factor analysis of diet-related variables identified three factors from 16 variables. We named these: (1) Junk Food, (2) Vegetables, Pulses, and Fruit, and (3) Healthy Eating Habits. The Healthy Eating Habits factor comprised of responses to questions about the frequency of eating breakfast and consuming meals in the presence of family. Although the food frequency questionnaire item 'Game from hunting (moose, caribou, venison, etc.)' was included in the factor analysis, it did not load onto any factor using the specified cutoff (0.4) and as such was not included. Table 1 lists all food frequency questionnaire items and their loadings onto respective factors. All factor loadings indicate that the higher the item is reported being consumed, the associated factor score increases. Conversely, if the item was reported to be consumed infrequently, the factor score decreases.

Table 4.1: Factor loadings of items from short food-frequency questionnaire onto determined dietary aspects

Dietary Aspect	**Factor Loadings**
Junk Food and Drinks	Sweets (candy or chocolate) (0.55), Coke or other soft drinks that contain sugar (0.73), Diet Coke or other diet soft drinks (0.49), Eating in a fast food restaurant (0.50), Potato chips (0.69), Energy drinks (Red Bull, Rock Star, Guru, etc.)(0.52), Sports drinks (Gatorade, Powerade, etc.)(0.60)
Vegetables, Pulses, and Fruit	Fruits (0.76), Vegetables (0.81), Orange vegetables (carrots, squash, sweet potato, etc.)(0.76), Fruit juice (0.40), Meat alternates (beans, lentils, tofu, eggs, peanut butter, etc.) (0.54)
Healthy Eating Habits	Eating breakfast on weekdays (0.68), Eating breakfast on the weekends (0.65), Eating breakfast with family members (0.73), Eating evening meals with family members (0.59)

*Higher factor loadings indicate higher contribution of the item to overall factor score.

Sleep

Students reported their bedtime ("turned out the light and gone to sleep") and wake-up time on school days and weekend days over the past week. Sleep duration was organized into categories of meeting and not meeting recommendations in reference to age group-specific thresholds in the Canadian 24-hour Movement Guidelines for Children and Youth [25]. Children between the ages of 8-13 are recommended to get between 9 and 11 hours of sleep per night, whereas youth between the ages of 14-17 are recommended to get 8 and 10 hours of sleep per night.

Screen Time

Average daily screen time was assessed using four questions about typical usage of various screens on weekdays and weekends. Students were asked for both a typical weekday and a typical weekend day: How many hours a day, in your free time, do you usually spend watching TV, videos (including YouTube or similar services), DVDs, and other entertainment on a screen? Possible responses were: 'None at all', 'About half an hour a day', 'About one hour', etc, until 'About 7 or more hours a day.' This question is also asked for 'time spent playing games on a computer, console, tablet (like iPad), smartphone, or other electronic device (not including moving or fitness games)?, 'time spent playing moving or fitness video games such as Wii Fitness, Dance Central, or Sports Champions on Wii, Xbox KINECT, or Playstation Moves?', and 'time spent using electronic devices such as computers, tablets (like iPad), or smartphones for other purposes (e.g., homework, emailing, tweeting, Facebook, chatting, surfing the internet)?'. Responses were totaled for all devices for weekdays and weekends; the average of these two totals was calculated to represent average daily screen time during a typical week.

Body Weight Status

Height and weight were self-reported by students in the unit of their choice. Reponses for height were converted to centimeters if reported in inches and responses for weight were converted to kilograms if reported in pounds. These values were used to calculate body mass index (kg/m^2), which became a measure of body weight status as per age- and sex- specific WHO Child Growth Standards [28]. Children were classified as being thin if they were more than 2 standard deviations below the mean and severely thin if they were more than 3 standard deviations below the mean. These two categories were collapsed into one because of small cell sizes. Children were classified as overweight if they were more than 1 standard deviation above the mean and obese if they were more than two standard deviations above the mean [28].

Socioeconomic Status

Socioeconomic status was determined using the Family Affluence Scale (FAS). The FAS is a validated scale that is used across all countries using the HBSC survey, and has been used in aggregate analyses focusing on the relationship between SES and adolescent health [29]. The FAS comprises of questions that ask about material goods (vehicles, individual bedrooms, and computers) and vacations to assess family wealth. The FAS generates a score between 0-9, with values of 0-2 corresponding with low affluence, 3-5 corresponding with medium affluence, and 6-9 corresponding with high affluence [29]. These categories were used in this analysis with low affluence as the reference category.

Statistical Analysis

Multi-level ordinal logistic regression was employed. As participating students are nested within school environments, while schools are nested within provinces, students are more likely

to be similar to other students within their school environment, and in their province or territory, as education is under the jurisdiction of provinces and territories in Canada. As such, both schools and provinces were treated as levels of clustering within the sample. Ordinal logistic regression was employed due to the categorical nature of the outcome. Odds ratios are interpreted as the likelihood of being in a higher academic grading group – for example – odds ratios above unity represent increased odds of reporting academic grades of 'Mostly A's' compared to the adjacent lower academic grading group 'Mostly A's and B's', or increased odds of being in the academic grading group 'Mostly A's and B's' compared to the adjacent lower academic grading group 'Mostly B's and C's', etc. for all categories of possible academic grading response. Conversely, odds ratios below unity represent lower likelihood of being in the next highest academic grading group. Lifestyle behaviours (physical activity, diet, sleep, and screen time) and confounders (age, sex, and SES) were first considered individually in a univariate analysis to assess unadjusted effects, and then were included together in a fully adjusted model.

4.3 Results

Table 2 describes the demographic characteristics of participating students within the HBSC survey who were included in the present analysis. Most students (47.9%) reported getting 'Mostly A's and B's' on their schoolwork, the second highest possible ranking of academic achievement. Most students (45.6%) reported getting 60 minutes of physical activity 3-5 days per week. Approximately two-thirds of children met recommendations for sleep (66.3%). Only 5.9% of students reported meeting recommendations for screen time (<2 hours per day), while 57.5% of students reported getting 7+ hours of screen time per day. Median screen time on weekdays was 6.5 hours, while median screen time on weekends was 9 hours (not shown).

Finally, the majority of students reported heights and weights that resulted in a normal body mass index (69.4%). Three percent of students were severely thin or thin, 18.9% were categorized as overweight, and 8.7% were obese.

Table 4.2: Descriptive statistics of participants in the 2014 Health Behaviour of School-Aged Children Questionnaire in Canada (based on weighted estimates of 28,608 observations)	
Sex, %	
Girl	50.9
Boy	49.1
Age, mean (range)	14.1(8.7-18.4)
Family Affluence Scale, %	
Low Affluence (0-2 points)	2.2
Medium Affluence (3-5 points)	30.5
High Affluence (6-9 points)	67.3
Grade, %	
6	15.4
7	19.4
8	19.7
9	23.6
10	21.9
Academic Achievement, %	
Mostly A's/Above 85%	28.2
Mostly A's and B's/Between 70 and 84%	47.9
Mostly B's and C's/Between 60 and 69%	19.0
Mostly C's/Between 50 and 59%	3.9
Mostly letter grades below C/Below 50%	1.0
Physical Activity (days per week active for at least 60 minutes), %	
6-7 days	38.1
3-5 days	45.6
0-2 days	16.3
Diet Factor Score (mean=0, SD=1), range	
Junk Foods and Drinks	-2.51, 5.30
Vegetables, Pulses, and Fruit	-3.79, 3.04
Healthy Eating Habits	-4.41, 2.48
Sleep, %	
Meeting Recommendations	66.3
Not Meeting Recommendations	33.7
Screen Time, %	
<2 hours	5.9
2-4 hours	14.5
4-7 hours	22.1
>7 hours	57.5
BMI Group	
Normal	69.4
Severely Thin or Thin	3.0
Overweight	18.9
Obese	8.7

*SD = standard deviation

Table 3 shows the associations of physical activity, dietary factor scores, sleep, screen time, gender, body mass index, and family affluence score (as a measure of socioeconomic status) with academic achievement. The univariate column represents unadjusted odds ratios between individual factors and level of academic achievement. Fewer days where adequate physical activity was achieved, increasing junk food score, not meeting sleep recommendations, increasing number of hours a day spent using screens, and being overweight or obese were negatively associated with likelihood of achieving a higher academic grading level. Youth who reported achieving 60 minutes of physical activity for 0-2 days per week had half the odds of being in a higher academic grading group compared to children who had 60 minutes of physical activity 6-7 days per week (Table 3, Univariate Model, OR: 0.50: 95%CI [0.47, 0.54]). Children who reported 7+ hours of screen time per day also had half of the odds of being in a higher academic grading group compared to those who met the recommended <2 hours per day (Table 3, Univariate Model: OR: 0.50, 95%CI [0.46, 0.55]). Higher consumption of Vegetables, Pulses, and Fruits, higher scores in Healthy Eating Habits, female sex, and higher affluence were positively associated with likelihood of achieving higher academic grades. Female gender and Healthy Eating Habits had the strongest positive univariate relationships, with females having 1.54 times the odds of being in a higher academic grading group compared to males, and every one unit increase in Healthy Eating Habits score resulting in 1.50 times the odds of being in a higher academic grading group. Obesity and not meeting recommendations for sleep duration had the strongest negative associations with academic achievement, with presence of obesity resulting in 0.54 times the odds of being in a higher academic grading group compared to normal weight students, and having a sleep duration that is less than recommended resulting in 0.70

times the odds of being in a higher academic grading group compared to those with the recommended sleep duration.

Table 4.3: Results of multi-level ordinal logistic regression of the association of lifestyle behaviours and potential confounders with academic achievement among 11-15 year old Canadians in 2014		
	Univariate	Multivariate**
	Odds Ratios* (95% CI)	Odds Ratios* (95% CI)
Physical Activity (days per week active for at least 60 min)		
6-7 days (reference)	1.00	1.00
3-5 days	**0.77 (0.73, 0.80)**	**0.87 (0.81, 0.94)**
0-2 days	**0.50 (0.47, 0.54)**	**0.67 (0.61, 0.74)**
Diet Factor		
Junk Foods and Drinks	**0.73 (0.72, 0.75)**	**0.74 (0.71, 0.76)**
Vegetables, Pulses, and Fruit	**1.40 (1.37, 1.44)**	**1.32 (1.28, 1.37)**
Healthy Eating Habits	**1.50 (1.46, 1.54)**	**1.49 (1.43, 1.54)**
Sleep		
Adequate (reference)	1.00	1.00
Not recommended	**0.70 (0.66, 0.73)**	**0.87 (0.81, 0.93)**
Screen Time		
<2 hours (reference)	1.00	1.00
2-4 hours	1.09 (0.98, 1.22)	**1.20 (1.03, 1.39)**
4-7 hours	0.90 (0.82, 1.00)	1.10 (0.96, 1.27)
>7 hours	**0.50 (0.46, 0.55)**	**0.76 (0.66, 0.87)**
Sex		
Male (reference)	1.00	1.00
Female	**1.54 (1.47, 1.61)**	**1.48 (1.39, 1.59)**
BMI Group		
Normal (reference)	1.00	1.00
Severely Thin or Thin	0.97 (0.83, 1.12)	0.90 (0.75, 1.09)
Overweight	**0.72 (0.68, 0.77)**	**0.85 (0.78, 0.92)**
Obese	**0.54 (0.50, 0.59)**	**0.66 (0.59, 0.74)**
Socioeconomic status		
Low affluence (reference)	1.00	1.00
Medium affluence	**1.85 (1.60, 2.14)**	**1.58 (1.26, 1.97)**
High affluence	**3.15 (2.72, 3.64)**	**2.48 (1.99, 3.09)**

*Odds Ratios for ordinal logistic regression. Odds ratios above 1 represent increased odds of being in a higher academic grading category (achieving all A's compared to A's and B's, or A's and B's compared to B's, etc.), odds ratios below 1 represent reduced likelihood of being in a higher academic grading category.

**Multivariate model adjusted for all variables listed here as well as student age.

The multivariate results in Table 3 represent odds ratios that are fully adjusted for all variables of interest and potential confounders considered in the analysis. The negative association between fewer days of physical activity and academic achievement continued, although the effects were slightly attenuated. Compared to youth who reported getting 60 minutes per day of physical activity 6 or 7 days a week, youth who reported getting 3-5 days or 0-2 days had 0.87 and 0.67 times the odds of being in a higher academic grading group, respectively (Table 3, Multivariate Model: OR: 0.87, [95%CI 0.81, 0.94], and OR: 0.67, [95%CI 0.61, 0.74]). Relationships between dietary aspects and academic achievement remained consistent with univariate results. For every unit increase in score for Junk Foods and Drinks, students had 0.74 times the odds of being in a higher academic grading group (Table 3, Multivariate Model: OR: 0.74 [95% CI: 0.71, 0.76]). For every unit increase in Vegetables, Pulses, and Fruit score and Healthy Eating Habits score, students had 1.32 and 1.49 times the odds of being in a higher academic grading group, respectively. Students with inadequate sleep duration had 0.87 times the odds of being in a higher academic grading group compared to those with adequate sleep duration (Table 3, Multivariate Model: OR: 0.87 [0.81, 0.93]). Compared to students who met recommendations for screen time time (<2h per day), students who had 2-4 hours had 1.20 times the odds of being in a higher grade group, while students who had 7+ hours per day had 0.76 times the odds of being in a higher grade group (Table 3, Multivariate Model: OR: 1.20 [95%CI: 1.03, 1.39], and OR: 0.76 [95% CI: 0.66, 0.87]). Reporting 4-7 hours of screen time did not have a significantly different association with academic achievement compared to students who met recommendations. Female sex continued to have a strong, positive association with likelihood of being in a higher academic grading group. Girls had 1.49 times the odds of being in a higher academic grading group compared to boys (Table 3,

Multivariate Model: OR: 1.48 [95% CI: 1.39, 1.59]). Although the strength of the relationship was reduced in the full multivariate model, overweight and obesity continued to have a negative relationship with academic achievement. Students who were overweight and obese had 0.85 and 0.66 times the odds, respectively, of being in a higher academic grading group compared to normal weight students. Severe thinness and thinness did not have a significant relationship with academic achievement in either model. Finally, increasing Family Affluence Score had a positive relationship with academic achievement. Students who lived in a high affluence household had 2.48 times the odds of being in a higher academic grading group than students who were in a low affluence household (Table 3, Multivariate Model: OR: 2.48 [95%CI: 1.99, 3.09]).

4.4 Discussion

Using a large, nationally representative sample of early adolescents from Canada, we found that all of physical activity, diet, sleep, and screen time had independent effects on academic achievement. We observed that increased consumption of vegetables, pulses, and fruits and healthy eating habits, female sex, and higher level of affluence were positively associated with higher academic achievement. Fewer days of achieving adequate physical activity, increased consumption of junk foods and drinks, not meeting recommendations for sleep duration, higher screen time, and overweight and obesity were negatively associated with higher academic achievement. This is the largest study to date, of the few that have been conducted, to consider all of these predictors in their independent relationships with academic achievement, and the first to use a nationally representative population of Canadian early adolescents. The findings about the independent associations of lifestyle behaviours with academic achievement are consistent with the limited studies that have previously investigated this objective.

Students who had fewer days of achieving the recommended amounts of physical activity in a week had decreased likelihood of achieving a higher academic grading level. Students achieving the fewest days of adequate physical activity had 33% reduced odds of being in a higher grade group compared to students achieving the highest number of days. Studies investigating the importance of physical activity and physical fitness for academic achievement have been predominantly indicative of a positive relationship between higher levels of physical activity and academic achievement, although there have been some inconsistencies [7,30-32]. This study supports previous findings that suggest a positive, linear relationship between physical activity and academic achievement [30,33,34]. The positive influence of physical activity on academic achievement, independent of other lifestyle behaviours, is consistent with findings from Ickovics et al (2014) and Martinez-Gomez et al (2012), but inconsistent with those of our team's previous work in Nova Scotia, Canada, which found a null relationship between physical activity and academic achievement once other lifestyle behaviours were considered [20-22].

The findings from the present study about diet are largely congruent with previous findings about the relationship between diet and academic achievement. Consumption of vegetables and fruit has consistently had a positive association with academic achievement [35,36] and junk foods, including beverages and snacks high in sugar and fat and frequent consumption of fast foods, have a similar negative association with academic achievement [37,38]. In addition, breakfast consumption has been highly studied in its relationship with academic achievement; the present findings about Healthy Eating Habits, which comprise regular breakfast consumption, are consistent with the positive findings of previous work [39,40]. However, although regular consumption of meals with the family has been shown to be

beneficial for children's diet and reduce likelihood of overweight and obesity [41,42], few studies have considered this in relation to academic achievement. In the present study, of all measures of diet included in this study (Vegetables, Pulses, and Fruit, Healthy Eating Habits, and Junk Foods and Beverages), Healthy Eating Habits, which include regularly consuming breakfast and dinner, and doing so in the presence of family, had the strongest positive relationship (50% increased odds with more frequent healthy habits) with academic achievement when considered simultaneously with other aspects of the diet, similar to findings from Ickovics et al (2014) who also looked at diet, physical activity, sleep, screen time and body weight status with academic achievement in a sample of urban American youth [21]. Frequently eating meals in the presence of family is associated with better psychosocial well-being among children which may be a contributing factor to better academic success [43].

Not meeting recommendations for sleep and high levels of screen time during free time were negatively associated with academic achievement in youth. These findings are consistent with previous literature [8,44-47]. Because increased screen time has been shown to negatively affect sleep as well as academic achievement [46,48], it is possible that negative relationships between poor sleep and academic achievement are actually attributed to increased screen time [22]. However, the present findings demonstrate that poor sleep and elevated screen time have independent, negative effects on academic achievement. The relationship between screen time and academic achievement was not linear. Students who reported screen time use in their free time for 2-4 hours per day had increased odds of being in a higher academic grade group compared to students who met the 2 hours per day recommendation, while students who reported 4-7 hours of time had no significant difference in academic achievement compared to students who met recommendations. The majority of students reported using screens in their free time

more than 7 hours per day, which was associated with substantially lower odds of being in a higher academic grading group compared to students meeting recommendations. It is possible that students with lower usage may be using their screen time for homework, while higher usage may be associated with detrimental activities, but this suggestion needs to be substantiated in future research.

Overweight and obesity had strong, significant relationships with academic achievement independent of lifestyle behaviours. Although there are many studies investigating the relationship between body weight status and academic achievement, there are few that have taken the lifestyle behaviours that contribute to both weight status and academic achievement into account [12,49]. Of the existing studies [20,22,50], all found that overweight or obesity no longer had an association with academic achievement following the inclusion of lifestyle behaviours into an associative model. The results from the present study are inconsistent with the findings of these three studies [20,22,51]. The present study used self-reported measures of academic achievement and body weight status, while the work of Martinez-Gomez et al. (2012) used self-reported grades and measured body weight status [20]. The studies by Wang et al. (2008) and Faught et al. (2017) used both objectively measured academic achievement and body weight status [22,51]. The present study categorized body weight status using the WHO Growth Reference standards [28], while the other three studies used the International Obesity Task Force (IOTF) reference standards [20,22,51,52]. The distinction between these two methods is significant – the WHO Growth Reference standards are generated in reference to an international cohort raised in strictly controlled, idealistic conditions, while the IOTF is meant to be representative of how an international cohort of children and youth grow under average circumstances [28,52,53]. Using a nationally representative sample of Canadian children and

youth, Shields et al (2010) calculated childhood obesity rates using both IOTF and WHO reference cutoffs, and found that the WHO estimates of overweight and obesity were consistently and substantially higher than IOTF estimates. For boys 6-11, estimates of overweight including obesity using the WHO references were 14.0% higher than estimates using the IOTF cutpoints [53]. Results from the comparisons conducted by Shields et al and those from the present study are indicative that the use of different cutpoints across studies of the same objective may contribute to different results. Consideration must be taken in deciding which cutpoints to employ and how this choice may affect results and comparisons with existing literature. Regardless, the health promotion messages remain the same: the academic achievement of students of any body weight status will benefit from more frequent physical activity, a better diet, adequate sleep, and reduced screen time.

Being a girl and having higher levels of socioeconomic status had the strongest positive associations with academic achievement. Girls had 50% increased odds of being in a higher grade group compared to boys.The 2015 Program for International Student Assessment (PISA) found that compared to the 71 other participating countries, Canada had one of the lowest performance gaps between boys and girls [54]. There is almost no performance gap between boys and girls in the sciences and mathematics, and girls appear to have the advantage in reading, which may provide some explanation into these findings that are not subject-specific [54]. In addition, poverty is a well-understood hindrance to academic success [55], drawing attention to the need to implement equitable interventions across the spectrum of socioeconomic inequalities.

The present study's strengths include a large, representative sample of Canadian children and youth with extensive data on their lifestyle behaviours, academic achievement, and

socioeconomic status. Although statistical significance for small effect sizes can be found in studies using large datasets, the findings from this thesis provide compelling evidence of a strong relationship between lifestyle behaviours and academic achievement. However, this study is cross-sectional in nature so no statement of causality can be made from these results, although they are supported by a wide array of prospective study designs. These data are also entirely self-reported. While measures are validated, the questions are brief to reduce participant burden and do not provide the depth of information that more intensive measurement would provide for each item. Although self-reported student grades are commonly used in the literature, these data are considered to be valid for high-achieving students but may not be valid for lower-achieving students [56].

The present study contributes to the literature investigating the relationship among lifestyle behaviours, body weight status, and academic achievement. Findings from this study, and in the context of other studies with a similar objective, indicate that healthier lifestyle behaviours, regardless of body weight status, SES, and gender, contribute to better academic achievement. As such, equitable, accessible interventions to improve lifestyle behaviours to improve academic achievement and reduce the likelihood of adverse subsequent health outcomes are needed. The Ottawa Charter for Health Promotion (1986) states that, "health is created and lived by people within the context of their everyday life; where they learn, work, play and love [57]." In light of the present study's findings, health promoting interventions within children and youth's key settings, like schools and family environments, are an opportunity to support both health and academic achievement among children and early adolescents.

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5 The combined impact of diet, physical activity, screen time, and sleep on academic achievement: a prospective study of grade 5 students in Nova Scotia, Canada.

Faught EL, Ekwaru JP, Gleddie D, Storey KE, Asbridge M, Veugelers PJ. The combined impact of diet, physical activity, sleep, and screen time on academic achievement: a prospective study of grade 5 students in Nova Scotia, Canada. *International Journal of Behavioral Nutrition and Physical Activity.* 2017;14(29). doi:10.1186/s12966-017-0476-0

5.1 Introduction

It is established that academic success in childhood and adolescence is a strong predictor of future wealth, productivity and health (1,2). Provided this, attention to children's academic achievement must be taken into consideration by public health decision makers aiming to prevent chronic diseases and improve health across the lifespan. This includes not only the resources devoted to educational attainment, but an understanding of the indirect lifestyle factors the help to shape childhood and adolescent academic success.

Healthy diets, sufficient physical activity and sleep, and minimal screen time constitute a healthy lifestyle and are crucial to children's healthy development, including the optimal development and maintenance of cognition (3-9). Findings from studies investigating the relationship between individual lifestyle behaviors and academic achievement have demonstrated that children with healthy lifestyle behaviors perform better academically (10-14). In particular, reductions in children's time spent in physical education has motivated substantial study of the relationship between physical activity and academic achievement (15). However, few studies have investigated the independent association of multiple lifestyle behaviors with academic achievement; particular the potential confounding in the observed relationship given the strong correlation between lifestyle factors (16-19). For example, levels of sleep are

associated with academic achievement, yet screen time has been shown to be associated with both sleep and academic achievement (12,20,21). If screen time is not taken into consideration when evaluating the association between sleep and academic achievement, the observed relationship may, in part, have contributed to the effects of screen time.

Some scholars have hypothesized that healthy lifestyle behaviors do not act in isolation in their relationship with academic achievement, and that the effects of exhibiting multiple healthy lifestyle behaviors may be greater than the sum of their individual effects (16,22,23). To our knowledge, only two studies have investigated this hypothesis, and both have found convincing evidence in support of it (16,24). Using self-reported data in a cohort of Spanish adolescents, Martinez-Gomez et al found that meeting recommendations for 3-4 lifestyle behaviours was associated with higher odds achieving passing grades in Language and Literature and Math, in girls only (16). In American children in a low-income urban distract, Ickovics et al found that children with exhibiting the largest number of healthy lifestyle behaviours, including a healthy body weight, were more than twice as likely to meet goal on standardized exams compared to those with the fewest (24). Further investigation of this hypothesis is merited to inform effective health promotion in children, particularly school-based initiatives. Many health promotion initiatives in schools focus on singular components of a healthy lifestyle; addressing multiple behaviors simultaneously may produce cumulative effects that impact both health and academic outcomes.

Our aim is to investigate the independent and combined effects of lifestyle behaviors, as well as body weight status, on children's academic achievement on standardized exams using a large, population-based sample of grade 5 students from Nova Scotia, Canada. We evaluate children's lifestyle behaviors by their adherence to established health recommendations from

Health Canada, the United States Departments of Health and Human Services and Agriculture, and the World Health Organization (WHO) for each behavior in order to improve interpretability and applicability of results for public health decision makers. We hypothesize that each lifestyle behavior of interest (diet, physical activity, screen time and sleep) will have an independent effect on academic achievement. We also hypothesize that the combined effect of multiple healthy lifestyle behaviors will have a greater effect on academic achievement than their respective individual effects.

5.2 Methods

The 2011 Children's Lifestyle And School performance Study (CLASS) is a population-based survey examining lifestyle behaviors, weight status, and academic achievement of grade 5 (mostly 10-11 years old) students in Nova Scotia, Canada. All grade 5 students in Nova Scotia, their parents or guardians, and school administrators were invited to participate in the study. Of all schools that had grade 5 classes in the province, principals in 269 of 286 (94.1%) schools provided consent for participation. Following consent from the principal, home packages, including consent forms, were sent home to all parents and guardians of grade 5 children in the school. Parental consent to participate in the survey was provided for 6591 students out of 8736 that were distributed, resulting in an average response rate of 75.4% per school. Of these, 1169 (17.7%) were absent the day of the survey, did not complete the survey, or had caloric intakes <500 kcal or >5000 kcal as these values are considered unrealistic (25), and as such were excluded from analysis, leaving 5,422 eligible students. Of remaining students, 4,253 (78%) could be successfully linked with their achievement on grade 6 standardized exams in Reading, Writing and Mathematics that were written one full year following the lifestyle behaviour

assessment; the resulting overall completion rate was 64.5%. Further information and the survey used can be found at www.nsclass.ca.

Data Collection

Trained research assistants travelled to participating schools to administer surveys during classroom time. Students completed two surveys. The student survey contained questions about habitual physical activity and personal perceptions about diet. Students also completed the Harvard Food Frequency Questionnaire for Youth/Adolescents (YAQ), a 147-item validated questionnaire adapted for Canadian use that measures habitual intake over the past 12 months (26). Research assistants measured students' heights to the nearest 0.1 centimeter and weights to the nearest 0.1 gram using calibrated stadiometers and scales as per standard protocol (27). Parents completed a home survey reporting on children's sleep habits and screen time usage, as well questions on household income and parental level of education.

Exposures

Diet

We employed the Harvard Food Frequency Questionnaire YAQ to evaluate students dietary consumption. The YAQ contains 147 questions, 135 of which are regarding specific food items and 11 of which relate to food habits (eating in front of the TV, etc), about the frequency of consuming items over the past year (26). Nutrient information was derived using the Canadian Nutrient File (CNF) (28), a Canadian nutrient composition database for commonly consumed foods in Canada. Students' consumption was evaluated with respect to meeting age-specific recommendations from Health Canada's *Eating Well with Canada's Food Guide* (29). This includes recommendations for daily servings of vegetables and fruit (6 servings), grain products

(6 servings), milk and alternatives (3-4 servings) and meat and alternatives (2 servings). The Canadian Food Guide does not have specific recommendations for saturated fat and free sugar intake. Instead we used recommendations developed for American youth for saturated fat intake (<10% of total energy intake) (30), and for free sugars consumption – representing sugars that are added during food processing, not naturally occurring sugars such as lactose – we followed 2015 World Health Organization recommendations (<10% of total energy intake) (31). We calculated energy intake using responses from the YAQ.

Physical Activity

The student survey contained the Physical Activity Questionnaire for Children (PAQ-C) instrument, a self-administered, 10-item physical activity recall instrument (32). The questionnaire has been validated to measure general physical activity in children aged 8-14 (32,33). A score between 0-5 was calculated from responses for each student, with higher scores indicating higher levels of physical activity. Cutoff values indicating adequate physical activity for the PAQ-C have been established for children: 2.7 for girls and 2.9 for boys (34). As such, meeting recommendations for physical activity were assessed using these cutoff values.

Screen Time

Parents were asked: On average, about how many hours per day does your Grade 5 child spend watching TV not including school hours? Possible responses were: Less than 1 hour a day, 1-2 hours per day, 3-4 hours per day, or 5 or more hours per day. Children were described as meeting sedentary behavior recommendations if total screen time from television watching was less than 2 hours per day as per the Canadian Sedentary Behavior Guidelines (35).

Sleep

Parents reported habitual wake up and bed times for children on usual weekdays and weekends. Parents were asked: At what time does your child usually wake up during a) the week (Monday to Friday) and b) the weekend (Saturday and Sunday)? Possible responses were before 6:30 am, 6:30 – 7:00 am, 7:00 – 7:30 am, 7:30 – 8:00 am, 8:00 – 8:30 am, 8:30 – 9:00 am and after 9:00 am. Parents were also asked: At what time does your child usually go to bed during a) the week (Sunday to Thursday) and b) the weekend (Friday and Saturday)? Possible responses were before 8:00 pm, 8:00 – 8:30 pm, 8:30 – 9:00 pm, 9:00 – 9:30 pm, 9:30 – 10:00 pm, 10:00 – 10:30 pm, and after 10:30 pm. Finally, sleep duration was calculated based on usual bed and wake up times with usual time to fall asleep subtracted for each of weekday and weekend days. Average nightly sleep duration for a typical week was calculated from the mean sleep duration of five weekdays and two weekend days. Students were described as meeting sleep duration recommendations if average duration was between 9-11 hours, as recommended by the National Sleep Foundation (36).

Body Weight Status

Children's body mass index (BMI) was calculated using measured heights and weights. Body weight status was assessed using the International Obesity Task Force (IOTF) age- and gender-specific BMI cutoffs for overweight and obesity (37).

Potential Confounders

Analyses were adjusted for child's gender, parental education, and household income as assessed by categorical questions in the parental home survey as well as region of residence (urban or rural) determined by postal code. Energy intake was included in analyses that included YAQ data as is recommended (25).

Outcome

Academic Achievement

The Nova Scotia Department of Early Education and Childhood Development provided results for standardized provincial exams written by participants in grade 6 (2012), approximately one year following the measurement of other variables, in the subjects of Mathematics, Reading, and Writing. Results were provided as dichotomous values of 'meeting expectations' and 'not meeting expectations'. The Nova Scotia Department of Early Education and Childhood Development, who administers the exams, provides standardized rubrics for the exams to determine of children are meeting and not meeting expectations. Teachers from across the province are invited to assist in the marking of assessments. Further information about this process can be found at https://plans.ednet.ns.ca/about-plans.

Analysis

All analyses were weighted for non-response to represent provincial estimates of the grade 5 student population of Nova Scotia. Demographics of participants of the CLASS II survey were compared to Canadian census data using postal-codes provided by parents in the Home Survey. It was determined that response rates were lower in the lowest income deciles and weights were calculated and applied to overcome this nonresponse bias (38). We applied mixed effects models due to the clustering of students within schools. Univariable logistic regression

was first used to assess the associations between each individual student's lifestyle behaviors, dichotomized into meeting and not meeting recommendations for each, and their academic achievement. Next, we used multivariable models (Model 1) to adjust for potential confounders and body weight status. Finally, we considered all lifestyle behaviors simultaneously in a full model (Model 2) to assess independent associations between meeting each lifestyle behavior recommendation, body weight status, and academic achievement.

To assess combined effects of meeting each lifestyle behavior recommendation, we also considered the effect of the number of recommendations met up to 9 (vegetables and fruit, grain products, milk and alternatives, meat and alternatives, saturated fat, free sugars, physical activity, sleep, and screen time). As with assessing independent associations, univariable and multivariable regression models were employed treating the score as both categorical and continuous to assess the cumulative impact of meeting lifestyle behavior recommendations and academic achievement. This analysis was conducted treating the score as a continuous variable and by splitting scores into three categories, low (meeting 1-3 recommendations), medium (meeting 4-6 recommendations) and high (meeting 7-9 recommendations). All analyses were conducted using Stata version 14.1 IC (StataCorp, Texas, USA).

5.3 Results

Table 1 shows that 87.4% of students met expectations for reading, 89.1% met expectations for writing, and 70.6% met expectations for mathematics. The percentage of children meeting selected lifestyle behaviour recommendations was: 32.2% for Vegetables and Fruits, 20.8% for Grain Products, 56.0 for Milk and Alternatives, 86.4 for Meat and Alternatives, 54.3% for saturated fat intake, 62.6% for free sugars intake, 76.7% for physical activity as per

the PAQ-C, 91.1% for sleep duration, and 77.8% for screen time. Meeting recommendations for milk and alternatives, meat and alternatives, free sugars, sleep, and screen time all had significant univariate associations with meeting expectations for mathematics (Table 2, Column 1), while vegetables and fruit, grain products, milk and alternatives, meat and alternatives, saturated fat, and free sugars all had significant univariate associations with meeting expectations for reading (Table 3, Column 1). Meeting recommendations for vegetables and fruit, meat and alternatives, free sugars, physical activity, sleep and screen time all had significant univariate associations with meeting expectations for writing. Parental level of education, household income, and gender were all significantly associated with the likelihood of meeting expectations for each subject, while obesity only had a significant univariate association with meeting expectations in mathematics.

After adjusting for potential confounders, meeting recommendations for milk and alternatives, meat and alternatives, and free sugars continued to have significant positive associations with meeting recommendations for mathematics (Table 2, Model 1). Where meeting expectations for reading was the outcome, meeting recommendations for vegetables and fruit, grain products, milk and alternatives, meat and alternatives, saturated fat and free sugars were all associated with increased likelihood of meeting expectations (Table 3, Model 1). Finally, meeting recommendations for sleep, screen time, meat and alternatives, and free sugars were all associated with increased likelihood of meeting expectations for writing (Table 4, Model 1). Body weight status did not have an association with any outcome in these models.

When considering all lifestyle behaviors simultaneously, only meeting recommendations for milk and alternatives, and meat and alternatives remained significantly associated with meeting expectations for mathematics; meeting recommendations for free sugars was borderline

significant (Table 2, Model 2: OR: 1.20 [95%CI: 0.99, 1.45]). Meeting expectations for grain products, milk and alternatives, meat and alternatives, saturated fat and free sugars were all positively associated with meeting expectations for reading (Table 3, Model 2). Meeting recommendations for meat and alternatives, free sugars, sleep and television had significant, positive associations with meeting expectations for writing (Table 4, Model 2). Neither overweight nor obesity demonstrated any association with meeting expectations for any subject.

Considering the combined effect of the nine criteria, for each additional criterion met, the odds of meeting the expectations for mathematics was 1.13 times higher (OR: 1.13 [95%CI: 1.06, 1.20]). Table 5 shows that each additional criterion met also increased odds of meeting recommendations for reading by 1.26 times, (OR: 1.26 [95% CI: 1.17, 1.35]), and by 1.21 times for meeting recommendations in writing (OR: 1.21 [95%CI: 1.11, 1.32]).

The criteria were also considered in groups representing low, medium, and high compliance. Respectively, 7.9%, 64.6%, and 27.4% were in the low, medium and high categories. Compared to the lowest category, children who were in the highest category had 1.47 times the odds of meeting expectations for mathematics (Table 5: OR: 1.47 [95% CI: 1.04, 2.06]), and 3.07 and 2.77 times the odds for meeting expectations in reading and writing respectively (Table 5: OR: 3.07, [95% CI: 2.09, 4.51], OR: 2.77 [95% CI: 1.83, 4.20]).

5.4 Discussion

We observed that meeting recommendations for diet, sleep and screen time had independent, positive effects for children's academic achievement. No association was found between meeting physical activity cutoffs and academic achievement. The findings from this

study also indicated that the combined effects of meeting multiple lifestyle behavior recommendations had a stronger impact on academic achievement than the individual effects of lifestyle behaviors, particularly for reading and writing. We chose to evaluate lifestyle behaviors based on established recommendations that are widely accepted. Substantial efforts and resources go into the development and promotion of these recommendations, and findings from this study reveal that more efforts are needed to achieve compliance not only for the benefit of health, but for education.

The associations between dietary behaviours and academic achievement are supported by previous literature (6,7,39-45). However, the majority of studies linking diet and academic achievement have tended to focus on breakfast consumption and whole diet, and few studies have evaluated the relationship between established dietary recommendations and academic achievement (7). In particular, no study has evaluated the relationship between meeting newly released guidelines for free sugar recommendations, which exhibited a strong positive association with each of the three subjects. The lack of association between vegetables and fruit and academic achievement in this study seems inconsistent with much of the literature investigating the association between diet and academic achievement (19,46). In previous studies, servings of vegetables and fruit have been assessed as a continuous variable, with more servings being positively associated with academic achievement. In this study, very few children met the recommendation for vegetables and fruit. As such, there may not have been sufficient power to detect any positive effect of meeting recommendations for vegetables and fruit. We conducted additional analyses treating servings of vegetables and fruit as a continuous variable, however, and no significant effect on academic achievement was observed. Milk and alternatives, meat and alternatives, and sugars consumption were more consistent predictors of

higher academic achievement. This may be a reflection of a higher income household that is more likely to access and purchase products within these groups more regularly (47).

The observation that meeting designated cutoffs for physical activity levels is not significantly associated with higher academic achievement complements existing findings in the literature investigating the relationship of physical activity with children's school performance. Much of the literature has concluded that the inclusion of more physical activity and physical education relative to other subjects in a school day does not negatively affect school performance (15,48). Many studies have found a relationship between children's physical activity levels and their academic achievement or cognitive development, though few studies have aimed to investigate its importance independent of other lifestyle behaviours (11,49-51). Another study found that the relationship between physical activity and academic achievement to be curvilinear, suggesting that children who are athletes may have many extra-curricular activities that displace time spent on academics (52). Though cutoff values are useful in identifying sufficient levels of physical activity for physical health benefits, they may not be the most appropriate way to assess the association between physical activity and academic achievement as this relationship appears to be more complex. An analysis was conducted using PAQ-C score as a continuous variable (results not shown) and physical activity continued to have no effect on academic achievement. However, though the PAQ-C is a well-used and validated questionnaire, it's intent is to provide a broad overview of children's physical activity levels and it does not provide detailed information about intensity and frequency of physical activities or the physiological benefits children gain from regular physical activity that would contribute to their academic achievement, among other contributors. In addition, there was a time lag (one year) between physical activity assessment and exam writing which may have introduced error. As

such, this lack of association may be due to the limitations of the measure used, and further investigation using a more detailed means of measurement of children's physical activity is needed.

Sleep and screen time have been previously associated with academic achievement (12,13,53). This is the second study, to our knowledge, to demonstrate the independent importance of meeting sleep recommendations for these behaviors for academic achievement (16). In this study, sleep was found to only be associated with performance on writing exams. Sleep has been shown to be crucial for creativity and insight, key determinants of strong writing skills (54).This study is also among the first to evaluate sleep duration and academic achievement using the National Sleep Foundation guideline (36). Sleep is recommended within a range of hours, not as a minimum number of hours, and this study highlights the importance of both meeting the minimum requirements of sleep while not exceeding the maximum recommended number of hours (36,55).

Few studies have investigated the association of body weight status and lifestyle behaviors simultaneously to determine their independent associations. Those that have, provide indication that it is not weight status that drives academic achievement, but that both academic achievement and body weight status are a result of long-term lifestyle behaviors (16,17). This study complements this important work and indicates that promoting healthy lifestyles and values, rather than focusing on obesity prevention and reduction, is most effective in supporting optimal health, holistic wellness and academic achievement (22,56-58).

Finally, the findings that the combined effects of lifestyle behaviors result in substantially higher likelihood of meeting expectations in all subjects is an important contribution to the

literature. Ickovics et al. noted similar results in a sample of low-income American children of the same age – children with higher levels of 'health assets' including indicators of healthy diet, physical activity, screen time and sleep, were 2.2 times more likely to meet goals in mathematics, reading and writing compared to those who had the fewest health assets (24). A Spanish study with the objective of investigating the combined effects of meeting recommendations for diet, physical activity, screen time and sleep on the self-reported grades of adolescents had similar findings for girls (16). The present study complements and expands on these important findings drawing on a large, population-based sample of children. Collectively, these studies speak to the value of school-based health promotion initiatives that are more comprehensive in their approach compared to initiatives that address only singular aspects of health. Successful models of a comprehensive school health approach that show improvement in the healthfulness of children's lifestyle behaviours have been well-evaluated (27,59). Interventions that aim to improve multiple lifestyle behaviors may have a greater impact on academic achievement than those that focus on single behaviors.

Of note is girls' strong, positive association with the likelihood of meeting expectations for reading and writing. There was no gender effect for meeting expectations in mathematics. These results are consistent with other investigations about the school performance of girls and boys (60). Stratified analyses by gender revealed no substantial differences between effects of individual lifestyle behaviors and academic achievement across gender (results not shown). Children's test scores are influenced by a multitude of factors, and differential influences between girls and boys, including self-confidence and parental support for specific career streams, are among them (60). Further investigation is merited to determine the cause of the substantial gender differences in academic achievement in this population.

This study has several key strengths. First, it is a very large, population-based sample of children who are representative of an entire Canadian province. This study evaluated lifestyle behaviors with respect to established recommendations, which allows for easier interpretation and specific targets for health promotion initiatives. Non-response weighting was employed in order to account for non-response of students residing in lower-income neighbourhoods in Nova Scotia. This study also used results from standardized exams from several different subjects, both eliminating bias from self-reported grades and illustrating that lifestyle behaviors may have differential effects for different cognitive tasks. This study used validated questionnaires to assess lifestyle behaviors as well as directly measured heights and weights. Limitations of the study were the self-reported nature of lifestyle behaviors that can be prone to bias. The time lag between measurement of lifestyle behaviours and the writing of standardized exams may have introduced error to estimates of association. In the case of screen time, only TV watching was captured in this analysis and other forms of screen-based media which may be widely used were not included. In addition, questions used to assess sleep and screen time where not validated. Though a validated questionnaire was used to assess physical activity levels, the PAQ-C does not provided information about duration or intensity of physical activity, which is thought to be important in terms of its influence on academic achievement and relationship with meeting recommendations. As such, a lack of association may be due to the limited information provided by the tool used. Provided the large scope of this study, objective measurements of lifestyle behaviors were not feasible. Finally, standardized tests are only one means by which to evaluate children's academic success and their value has been disputed (61). Investigations of the relationship between healthy lifestyle behaviors and other measures of academic success including enjoyment of school, psycho-social well-being, and sense of belonging are important

complements to consider. There is also possibility of residual confounding by unmeasured variables including IQ and measures of mental health.

5.5 Conclusions

This study demonstrates that individual lifestyle behaviors have independent, positive effects on academic achievement, and that cumulative effects of multiple healthy lifestyle behaviours has a stronger positive effect for academic outcomes than any individual effect. These findings suggest that school-based health promotion approaches that address multiple lifestyle behaviours instead of single behaviours may have more benefit for academic achievement. Future studies investigating a longitudinal link between lifestyle behaviors, body weight and academic achievement are important to strengthen the prospective findings of this study and others similar to it.

5.6 References

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5.7 Tables

Table 5.1 Sample characteristics of grade 5 students participating in the CLASS II Project in Nova Scotia, Canada

Characteristics	**n = 4,253**
Age, mean (SD), years	11.0 (0.4)
Proportion Male (sex), %	47.2
Overweight or obese, %	34.7
Energy Intake, mean (SD), kcal	1849.9 (808.1)
Percentage of children who are meeting lifestyle behavior recommendations, %	%
Vegetables and Fruits (6 servings)	32.2
Grain Products (6 servings)	20.8
Milk and Alternatives (3-4 servings)	56.0
Meat and Alternatives (1-2 servings)	86.4
Saturated Fat Intake (<10% total energy)	54.3
Free Sugars (<10% total energy)	62.6
Physical Activity (PAQ-C Score >=2.7 for girls, >=2.9 for boys)	76.7
Sleep Duration (9-11 hours)	91.1
Screen Time (<=2h day of television)	77.8
Percentage of children meeting multiple lifestyle behaviour recommendations, %	
Low (1-3)	7.9
Medium (4-6)	64.7
High (7-9)	27.5
Academic Achievement, % meeting expectations	%
Reading	87.4
Writing	89.1
Mathematics	70.6
Parental Education, %	%
Secondary or Less	17.3
College Diploma	38.4
University or Graduate degree	36.3
Missing/Prefer not to answer	8.0
Household Income (CAN$), %	%
<=20,000	20.3
20,001 - 40,000	13.3
40,001 - 60,000	24.1
>= 60,001	19.8
Missing/Prefer not to answer	22.5
Region of Residence, %	%
Urban	69.7
Rural	30.3

Table 5.2 The associations between adherence to lifestyle behaviour recommendations and meeting expectations on standardized tests in Mathematics

	Academic Achievement in Mathematics					
	Univariable		**Model 1**		**Model 2**	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Vegetables and Fruits						
No (reference)	-	-	-	-	-	-
Yes	1.13 (0.95, 1.35)	0.18	1.06 (0.90, 1.27)	0.48	1.04 (0.86, 1.27)	0.66
Grain Products						
No (reference)	-	-	-	-	-	-
Yes	1.02 (0.86, 1.22)	0.81	1.00 (0.83, 1.20)	0.99	0.99 (0.82, 1.20)	0.92
Milk and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	**1.34 (1.15, 1.57)**	**<0.001**	**1.27 (1.09, 1.49)**	**0.002**	**1.33 (1.11, 1.59)**	**0.002**
Meat and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	**1.56 (1.27, 1.90)**	**<0.001**	**1.56 (1.28, 1.91)**	**<0.001**	**1.59 (1.27, 1.99)**	**<0.001**
Saturated Fat						
No (reference)	-	-	-	-	-	-
Yes	0.97 (0.82, 1.14)	0.71	0.94 (0.79, 1.12)	0.49	1.00 (0.83, 1.21)	0.99
Free Sugars <10%						
No (reference)	-	-	-	-	-	-
Yes	**1.63 (1.38, 1.93)**	**<0.001**	**1.33 (1.12, 1.57)**	**0.001**	1.20 (0.99, 1.45)	0.06
Physical Activity						
No (reference)	-	-	-	-	-	-
Yes	1.14 (0.96, 1.35)	0.12	1.10 (0.92, 1.30)	0.30	1.12 (0.94, 1.33)	0.21
Sleep						
No (reference)	-	-	-	-	-	-
Yes	**1.44 (1.01, 2.02)**	**0.04**	1.26 (0.88, 1.80)	0.20	1.42 (0.97, 2.07)	0.71
Screen (TV)						
No (reference)	-	-	-	-	-	-
Yes	**1.33 (1.11, 1.60)**	**0.002**	1.11 (0.92, 1.35)	0.28	1.02 (0.83, 1.25)	0.86
Body Weight Status						
Normal weight (reference)	-	-	-	-	-	-
Overweight or Obese	0.95 (0.79, 1.13)	0.533	1.00 (0.84, 1.20)	0.97	0.98 (0.82, 1.17)	0.81
Gender						
Girl (reference)	-	-	-	-	-	-
Boy	1.09 (0.93, 1.28)	0.27	1.08 (0.92, 1.27)	-	1.11 (0.94, 1.30)	0.22
Parental Education						
Secondary or Less (ref)	-	-	-	-	-	-
College Diploma	**1.50 (1.20, 1.86)**	**<0.001**	**1.32 (1.07, 1.63)**	**0.01**	**1.32 (1.06, 1.65)**	**0.01**
University or Graduate Degree	**3.28 (2.65, 4.06)**	**<0.001**	**2.38 (1.91, 2.97)**	**<0.001**	**2.45 (1.96, 3.07)**	**<0.001**
Household Income (CAN$)						
<=20,000 (reference)	-	-	-	-	-	-
20,001 – 40,000	**1.61 (1.30, 2.01)**	**<0.001**	**1.43 (1.15, 1.79)**	**0.002**	**1.42 (1.13, 1.79)**	**0.003**
40,001 – 60,000	**2.03 (1.63, 2.53)**	**<0.001**	**1.49 (1.21, 1.85)**	**<0.001**	**1.44 (1.15, 1.80)**	**0.001**
>= 60,001	**3.43 (2.71, 4.35)**	**<0.001**	**2.05 (1.58, 2.65)**	**<0.001**	**2.03 (1.56, 2.63)**	**<0.001**
Region of Residence						
Rural (reference)	-	-	-	-	-	-

Urban	0.82 (0.66, 1.04)	0.10	**0.70 (0.59, 0.84)**	**<0.001**	**0.72 (0.58, 0.89)**	**0.002**

*Model 1 adjusted for gender, parental education, household income, and region of residence

*Model 2 adjusted for above, weight status and all lifestyle behaviors.

Table 5.3 The associations between adherence to lifestyle behaviour recommendations and meeting expectations on standardized tests in Reading

	Academic Achievement in Reading					
	Univariable		**Model 1**		**Model 2**	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Meets Vegetables and Fruits						
No (reference)	-	-	-	-	-	-
Yes	**1.44 (1.13, 1.83)**	**0.003**	**1.30 (1.02, 1.66)**	**0.03**	1.19 (0.91, 1.56)	0.20
Meets Grain Products						
No (reference)	-	-	-	-	-	-
Yes	**1.49 (1.13, 1.97)**	**0.005**	**1.49 (1.12, 1.98)**	**0.006**	**1.57 (1.16, 2.14)**	**0.004**
Meets Milk and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	**1.25 (1.02, 1.53)**	**0.03**	**1.24 (1.00, 1.53)**	**0.045**	**1.46 (1.16, 1.84)**	**0.001**
Meets Meat and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	**1.55 (1.20, 2.01)**	**0.001**	**1.55 (1.19, 2.01)**	**0.001**	**1.56 (1.18, 2.08)**	**0.04**
Meets Saturated Fat						
No (reference)	-	-	-	-	-	-
Yes	**1.36 (1.13, 1.65)**	**0.001**	**1.28 (1.06, 1.56)**	**0.01**	**1.28 (1.01, 1.62)**	**0.04**
Meets Free Sugars <10%						
No (reference)	-	-	-	-	-	-
Yes	**1.91 (1.57, 2.32)**	**<0.001**	**1.56 (1.28, 1.90)**	**<0.001**	**1.29 (1.02, 1.62)**	**0.03**
Meets Physical Activity						
No (reference)	-	-	-	-	-	-
Yes	1.14 (0.90, 1.45)	0.28	1.05 (0.82, 1.34)	0.70	1.05 (0.82, 1.36)	0.66
Meets Sleep						
No (reference)	-	-	-	-	-	-
Yes	1.33 (0.89, 2.00)	0.16	1.21 (0.79, 1.88)	0.38	1.39 (0.90, 2.13)	0.14
Meets Screen Time						
No (reference)	-	-	-	-	-	-
Yes	1.17 (0.94, 1.46)	0.16	1.03 (0.82, 1.31)	0.77	0.96 (0.75, 1.23)	0.74
Body Weight Status						
Normal weight (reference)	-	-	-	-	-	-
Overweight or Obese	1.01 (0.81, 1.26)	0.92	1.09 (0.86, 1.37)	0.48	1.03 (0.82, 1.31)	0.79
Gender						
Girl (reference)	-	-	-	-	-	-
Boy	**0.56 (0.46, 0.67)**	**<0.001**	**0.57 (0.46, 0.69)**	**<0.001**	**0.57 (0.47, 0.70)**	**<0.001**
Parental Education						
Secondary or Less (ref)	-	-	-	-	-	-
College Diploma	**1.42 (1.09, 1.84)**	**0.008**	**1.33 (1.02, 1.73)**	**0.04**	1.24 (0.93, 1.66)	0.14
University or Graduate Degree	**2.56 (1.92, 3.41)**	**<0.001**	**1.89 (1.40, 2.55)**	**<0.001**	**1.89 (1.37, 2.60)**	**<0.001**
Household Income (CAN$)						
<=20,000 (reference)	-	-	-	-	-	-
20,001 – 40,000	1.31 (0.97, 1.77)	0.78	1.20 (0.90, 1.62)	0.22	1.23 (0.89, 1.70)	0.21
40,001 – 60,000	**1.68 (1.20, 2.34)**	**0.002**	1.32 (0.95, 1.84)	0.10	1.33 (0.94, 1.88)	0.11
>= 60,001	**3.10 (2.13, 4.51)**	**<0.001**	**1.95 (1.33, 2.87)**	**0.001**	**2.06 (1.37, 3.08)**	**<0.001**

Region of Residence						
Rural (reference)	-	-	-	-	-	-
Urban	1.23 (0.96, 1.57)	0.11	1.03 (0.84, 1.25)	0.81	1.11 (0.87, 1.41)	0.41

*Model 1 adjusted for gender, parental education, household income, and region of residence

*Model 2 adjusted for above, weight status and all lifestyle behaviors.

Table 5.4 The associations between adherence to lifestyle behaviour recommendations and meeting expectations on a standardized test in Writing

	Academic Achievement in Writing					
	Univariable		**Model 1**		**Model 2**	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Meets Vegetables and Fruits						
No (reference)	-	-	-	-	-	-
Yes	**1.35 (1.06, 1.71)**	**0.02**	1.20 (0.93, 1.54)	0.16	1.08 (0.81, 1.43)	0.61
Meets Grain Products						
No (reference)	-	-	-	-	-	-
Yes	1.05 (0.79, 1.40)	0.72	1.09 (0.82, 1.44)	0.57	1.00 (0.74, 1.37)	0.96
Meets Milk and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	1.15 (0.91, 1.45)	0.25	1.08 (0.85, 1.37)	0.54	1.10 (0.85, 1.43)	0.46
Meets Meat and Alternatives						
No (reference)	-	-	-	-	-	-
Yes	**1.46 (1.08, 1.99)**	**0.01**	**1.40 (1.04, 1.90)**	**0.03**	**1.39 (1.01, 1.91)**	**0.04**
Meets Saturated Fat						
No (reference)	-	-	-	-	-	-
Yes	1.23 (0.99, 1.52)	0.06	1.18 (0.95, 1.48)	0.141	1.16 (0.90, 1.49)	0.25
Meets Free Sugars <10%						
No (reference)	-	-	-	-	-	-
Yes	**1.66 (1.35, 2.04)**	**<0.001**	**1.43 (1.16, 1.77)**	**0.001**	**1.41 (1.13, 1.49)**	**0.002**
Meets Physical Activty						
No (reference)	-		-	-	-	-
Yes	**1.32 (1.05, 1.66)**	**0.02**	1.19 (0.94, 1.49)	0.14	1.12 (0.88, 1.43)	0.36
Meets Sleep						
No (reference)	-	-	-	-	-	-
Yes	**1.50 (1.05, 2.14)**	**0.03**	**1.56 (1.05, 2.29)**	**0.03**	**1.56 (1.03, 2.34)**	**0.03**
Meets Screen Time						
No (reference)	-	-	-	-	-	-
Yes	**1.47 (1.16, 1.88)**	**0.002**	**1.43 (1.12, 1.83)**	**0.004**	**1.35 (1.04, 1.75)**	**0.03**
Body Weight Status						
Normal Weight (reference)	-	-	-	-	-	-
Overweight or Obese	0.80 (0.63, 1.03)	0.08	0. 84 (0.65, 1.08)	0.17	0.82 (0.64, 1.06)	0.14
Gender						
Girl (reference)	-	-	-	-	-	-
Boy	**0.44 (0.36, 0.55)**	**<0.001**	**0.42 (0.34, 0.52)**	**<0.001**	**0.45 (0.36, 0.56)**	**<0.001**
Parental Education						
Secondary or Less (ref)	-	-	-	-	-	-
College Diploma	1.20 (0.89, 1.63)	0.24	**1.33 (1.07, 1.65)**	**0.01**	1.16 (0.84, 1.61)	0.36
University or Graduate Degree	**1.82 (1.34, 2.46)**	**<0.001**	**2.42 (1.94, 3.03)**	**<0.001**	1.37 (0.96, 1.94)	0.08
Household Income (CAN$)						
<=20,000 (reference)	-	-	-	-	-	-
20,001 – 40,000	**1.50 (1.07, 2.11)**	**0.02**	**1.46 (1.17, 1.83)**	**0.01**	**1.44 (1.01, 2.06)**	**0.045**
40,001 – 60,000	**1.65 (1.18, 2.30)**	**0.003**	**1.53 (1.23, 1.90)**	**<0.001**	**1.51 (1.03, 2.21)**	**0.04**

>= 60,001	**2.66 (1.80, 3.93)**	**<0.001**	**2.42 (1.94, 3.03)**	**<0.001**	**2.10 (1.31, 3.36)**	**0.002**
Region of Residence						
Rural (reference)	-	-	-	-	-	-
Urban	0.97 (0.74, 1.26)	0.80	**0.70 (0.57, 0.85)**	**<0.001**	0.86 (0.65. 1.12)	0.264

*Model 1 adjusted for gender, parental education, household income, and region of residence
*Model 2 adjusted for above, weight status and all lifestyle behaviors.

Table 5.5 Mixed effects logistic regression models of the relationship between children's combined adherence to multiple lifestyle behavior recommendations and the odds meeting expectations on a standardized Mathematics, Reading and Writing

		Academic Achievement					
		Mathematics		**Reading**		**Writing**	
		OR (95% CI)*	p-value	OR (95% CI)*	p-value	OR (95% CI)*	p-value
Per recommendation met**		**1.13 (1.06, 1.20)**	**<0.001**	**1.26 (1.17, 1.35)**	**<0.001**	**1.21 (1.11, 1.32)**	**<0.001**
No. of Recommendations Met**	Prevalence (%)	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
3 or less	7.9	-	-	-	-	-	-
4-6	64.6	1.12 (0.81, 1.54)	0.50	**1.85 (1.32, 2.59)**	**<0.001**	**1.98 (1.38, 2.84)**	**<0.001**
7-9	27.5	**1.47 (1.04, 2.06)**	**0.03**	**3.07 (2.09, 4.51)**	**<0.001**	**2.77 (1.83, 4.20)**	**<0.001**

*Adjusted for body weight status, gender, parental education, parental income, region of residence and energy intake.
**Includes meeting recommendations for vegetables and fruit, grain products, milk and alternatives, meat and alternatives, saturated fat, free sugars, physical activity cutoffs, sleep, and screen time.

6 Brief Communication: Revisiting the relationship between physical activity and academic achievement: is it in shape? Considerations for methodological approaches and health promotion messaging

6.1 Brief Communication

The relationship between physical activity and fitness, cognitive development, and academic achievement has received significant attention in the literature. Although the importance of physical activity for the health and well-being of children is well established, physical activity has declined over the years in school environments in favor of more time spent on academic pursuits. Given the epidemic of physical inactivity presently afflicting today's youth and the resultant health risks associated (1), evidence to justify increased physical activity in the predominantly sedentary school environment is necessary.

In 2000, when investigations of physical activity and academic achievement were fewer than they are today, Tremblay et al (2000) found a trivial, negative relationship of physical activity with academic achievement in a sample of grade 6 students in New Brunswick, Canada (2). In discussing study limitations, they proposed that it may be that physical activity is beneficial for academic achievement until a certain, optimal level, but time spent on physical activity more than this may detract from academic pursuits (2). Since 2000, numerous systematic reviews have been conducted to summarize the plethora of studies that have aimed to elucidate this relationship. Most studies support either a positive or neutral effect of physical activity on academic achievement (3-7). However, a percentage of studies have reported negative or inverse-U shaped relationships (2,8-10).

Despite this lack of clarity in the shape of this relationship, health promotion messaging about physical activity for schoolchildren in Canada has consistently continued to take a 'meet or

exceed' approach, where the present recommendation for children and youth being 'at least 60 minutes of moderate-to-vigorous physical activity' each day (11), or approximately 12,000 steps per day (12). Recently, Canada moved to an integrated recommendation system that amalgamated recommendations for 'Sweat, Step, Sleep, and Sit' – representing recommendations for moderate-to-vigorous physical activity (MVPA), light physical activity (steps), sleep, and sedentary behaviour. This is in acknowledgment that 'behaviours among the movement continuum (i.e., physical activity, sedentary behaviour, sleep) cluster and interact, such that their combined effects extend beyond the individual contributions of each behaviour (Tremblay et al, 2016) (11).' This approach acknowledges the interrelatedness of these behaviours and the need to balance them to yield maximum benefits to children's health. However, as has been previously suggested, should there indeed be an optimal level of physical activity for academic achievement, after which physical activity pursuits may detract from opportunities to focus on studies, or to 'sit' in order to complete homework activities, recommendations that focus only on minimum levels of physical activity and subsequent messaging that encourages accruing 'at least' an amount of time being active may not support the balance between health and academic success.

With respect to the inconsistency in findings between physical activity and academic achievement, reviews point to heterogeneity in methods used to assess physical activity, aspects of physical activity measured (e.g.: MVPA, total physical activity, school day vs. non-school day, participation in sports), measurement of academic achievement, and the inability to account for important covariates (i.e.: socioeconomic status, variation by age and gender) as reasons for the inconsistency in findings between studies. I agree that these are crucial points for consideration. Here, I present additional recommendations for those who conduct future analyses

with the aim of elucidating the relationship between physical activity and academic achievement among children and youth in light of a possible curvilinear relationship that would correspond with an 'optimal' level of physical activity for children's academic achievement. These considerations have not been previously discussed in any review investigating the relationship between physical activity and academic achievement despite findings of an inverse-U shaped relationship.

Because one expects a dose-response positive relationship between physical activity and academic achievement, analyses are frequently conducted using linear regression or other analytical methods that use an assumption of linearity. However, null relationships between physical activity and academic achievement are observed almost as frequently as positive relationships are observed (4). Of interest to the present communication are the studies that have observed inverse-U shaped, curvilinear relationships (2,8,9), supporting the supposition by Tremblay et al (2000) that there may be an optimal level of physical activity that yields maximum benefit to academic achievement. If data is analyzed using a method that assumes linearity when in fact the relationship is curvilinear, several outcomes are possible. If the sample of children used in the analyses represent all of low, medium, and high levels of physical activity, the findings may be null as the inverse-U shaped curvilinear relationship, assumed to be linear, will be nullified. Alternatively, the results will be positive or negative in the direction of where data is most frequent: if a sample consists predominantly of students who are low-active, the relationship will be positive, and in a sample consisting of high-active students may be negative. Which leads to the question: how could one test if the relationship is curvilinear between physical activity and academic achievement? Simple analytical methods can be used to

assess whether the relationship is linear or non-linear and from there, assess which methods are most appropriate for analysis.

To demonstrate, below are the results of an analysis of 525 grade 5 children (10-11 years old) participating in a comprehensive school health program in 33 schools called the Alberta Project Promotion active Living and healthy Eating Schools (APPLE Schools) in Alberta, Canada. Students' physical activity was measured using both objective and subjective measures of physical activity. Students wore time-stamped pedometers over a nine-day period and were included when they met inclusion criteria of at least 8 hours of wear time on two week days and one weekend day (13). Steps taken on days with adequate wear-time were used to calculated the average daily step-counts which were weighted to represent a typical week of five weekdays and two weekend days (13). In order to have meaningful coefficients, step counts were divided by 1000 so potential relationships between physical activity and academic achievement could be interpreted as changes in academic achievement for every 1000 additional steps rather than for every additional step. Students also completed the Physical Activity Questionnaire for Children (PAQ-C), a validated, self-reported measure of MVPA over the most recent seven-day period (14). The PAQ-C generates a score between 0-5, with higher scores being indicating higher levels of regular MVPA. Parents reported their education level and household income. Data were linked to children's academic achievement on standardized provincial exams in Math and Language arts written in grade 6. These scores were collapsed into a single average percent grade. Table 1 provides descriptive statistics of this sample.

Figures 6.1 and 6.2 represent the locally weighted scatterplot smoothing (LOWESS) line, linear regression line, and polynomial regression line of the unadjusted relationship for physical activity in steps, or light physical activity (Fig. 6.1), and PAQ-C score representing MVPA (Fig.

6.2) with academic achievement. Reference lines representing the recommended number of steps per day (12,000) and PAQ-C cutoffs that correspond with minimum physical activity levels for cardiovascular health (15) (2.7 for boys, 2.9 for girls) are included. From these figures, it can be clearly seen that the polynomial regression, for both steps and PAQ-C score, more closely represents the relationship with academic achievement. In this sample, students appear to be substantially more active than other Canadian children, where 70.1% of students met the recommendation of 12,000 steps/day, whereas only 7% of 5-19 year olds were found to be meeting this recommendation in Canada in 2014 (16). In Figure 6.1, using both the LOWESS and polynomial prediction line, it can be seen that higher levels of physical activity are associated with higher levels of academic achievement until approximately 15,000 steps. This association is sustained until approximately 21,000 steps. Step counts higher than 21,000 are associated with declining levels of academic achievement. Provided this, the optimal range of step counts per day for academic achievement appears to be 15,000 – 21,000 steps per day, well above the recommended 12,000 steps per day. For MVPA represented by PAQ-C score, the optimal range of the PAQ-C score for academic test scores is 2.7-3.5. This is again above the minimum PAQ-C scores that correspond with optimal cardiovascular health among children (15). However, a limitation of the PAQ-C score is that there is not a clear translation from the PAQ-C score to a specific amount of physical activity.

Table 2 describes the results of unadjusted and adjusted linear regression models using both pedometer-measured and self-reported measures of physical activity. Because children are nested in schools, random effects were applied to account for potential lack of independence between students. Results are provided for unadjusted models and models that are adjusted for parental education level and household income. While gender was also considered as a

confounder, it was dropped in the final models due to non-significance. To illustrate the potential difference in findings by treating the relationship as linear and curvilinear, step counts and PAQ-C scores were analysed as continuous variables using linear regression, and as squared terms in a polynomial regression approach. We found that when step counts were treated as a continuous variable, there was no relationship with academic achievement. Results for step counts are nonsignificant and coefficients were close to zero in both the unadjusted and the adjusted models. By comparison, results analyzing steps in a polynomial model in remained non-significant, but coefficients had substantially smaller p-values. Though this relationship is not statistically significant, the figure suggests that this model may be a more accurate fit for the data. Results for the relationship between PAQ-C score as a continuous variable are negative, though non-significant. In an unadjusted polynomial regression analysis, results for continuous PAQ-C score and its squared polynomial form are both statistically significant, providing evidence for an inverse-U relationship. These results were not statistically significant in the adjusted model. Likelihood ratio tests were performed for the fitted polynomial models compared to an intercept-only model in order to assess the statistical significance of including both the x (steps or PAQ-C score) and x^2 (steps^2 and PAQ-C^2) values. These values were only significant for the unadjusted PAQ-C polynomial model.

Findings from this analyses and others support the suggestion of Tremblay et al (2000) that there may be a limit to the benefits of physical activity for academic achievement until engagement in physical activity may displace time spent on other important tasks, like homework or learning. In the movement towards new integrated, balanced health promotion messaging, it is important to consider how high-active students may experience imbalance in other healthy behaviours. In addition to consequences for academic achievement, it has also been

shown that children who report engaging in more extracurricular activities also report getting less sleep (17), while a Swiss study found an inverse-U relationship between weekly sport practice and well-being among adolescents (18). Though it is natural to assume that the relationship between physical activity and academic achievement is a positive dose-response relationship, as it is between physical activity and physiological health benefits, this assumption may not provide accurate results from analyses of physical activity and academic achievement. To date, I have only found one study that has considered this a priori and adjusted their analysis accordingly (19).

The present analysis shows a positive, linear association between average daily steps taken and academic achievement until approximately 15,000 steps. Between 15,000 and 21,000 average daily steps, academic achievement appears to be the highest and relatively stable, and thus this range represents an optimal range of average daily steps for academic achievement. Above 21,000 steps per day, there is a negative linear relationship between steps taken and academic achievement, where children with 30,000 steps scoring on average 3% less than children with 15,000-21,000 steps. Fortunately, this optimal range is well above the recommended 12,000 steps per day. There is a gain of almost 5% on academic exams between students in the sample with the lowest average step counts and those who achieve the recommended 12,000 steps per day. The most recent assessment of Canadian students' physical activity demonstrated that only 7% of students were meeting this recommendation (15), so at the population level, this indicates that very few students are at risk of experiencing detriment to their academic achievement due to high levels of physical activity. However, for the small percentage of students with high levels of physical activity, there appears to be a trade-off between the health benefits of higher levels of physical activity and academic achievement.

While these findings may have only a limited impact at the population level, they do suggest that the small percentage of individuals with very high levels of physical activity may have to consider whether the benefits of their physical activity levels outweigh the potential cost to their academic achievement.

For future scientific analyses, I would like to make two recommendations moving forward. The first is to check the assumption of linearity using simple explanatory data analysis methods prior to conducting analyses to ensure the most appropriate statistical methods are applied. Fitting linear and polynomial models and plotting the relationship compared to the LOWESS provides a valuable visualization of how the plotted relationship fits the data. The second is to consider findings not only in the context of age, gender, socioeconomic status, region, etc., but also based on the distribution of physical activity levels exhibited by the participants. Although the present analysis demonstrates that increasing the physical activity of low-to-moderately active children would be beneficial for academic achievement, children who are very active may be experiencing superior health, but not be benefitting academically from their high activity level. Future systematic reviews may consider organizing studies by low-active, high-active, or samples that span all activity levels and considering results within those subgroups.

With regards to health promotion messaging, I acknowledge that the vast majority of children in Canada are far from being sufficiently active (16), and stand to benefit from increases in physical activity both in terms of health and academic achievement. The movement towards integrated recommendations that encourage both sufficiency and balance between interrelated health behaviours is a progressive step towards recommendations that capture the complexity of achieving overall wellness for school-aged children. Given the few children that are achieving

sufficient or high levels of physical activity in Canada, I agree with, and the present evidence supports, the assessment that 'the benefits of following these guidelines far exceed potential risks', as cited on the 24-Hour Movement Guidelines (11). As such, I continue to support the wide promotion of these guidelines. However, given the evidence that high levels of physical activity may be detrimental to the academic achievement, sleep, and well-being of school-aged children, I encourage further consideration for high-active children to ensure that their high levels of healthy physical activity do not cause an imbalance towards other, healthy behaviours.

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6.3 Figures

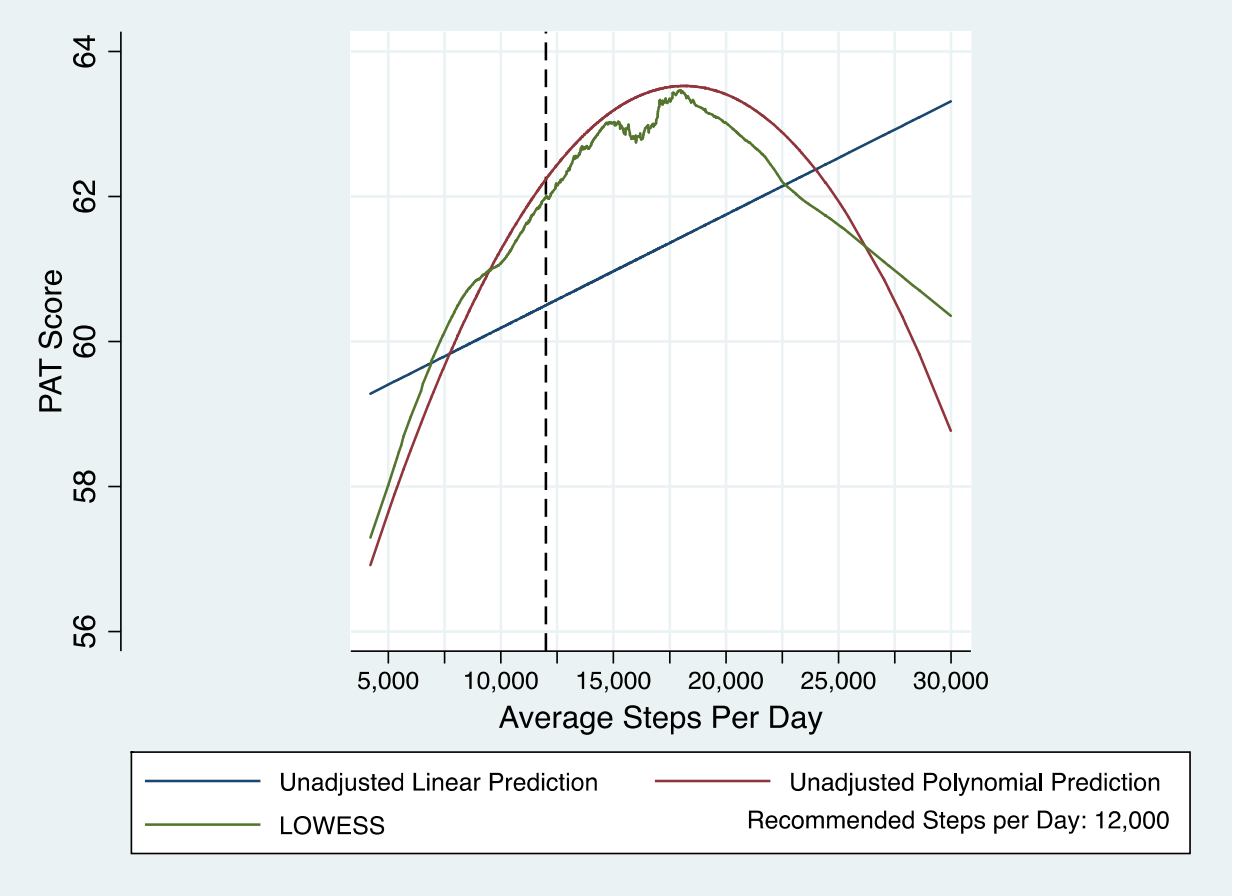

Fig. 6.1: Visualization of LOWESS, Unadjusted Linear Prediction, and Unadjusted Polynomial Prediction of the relationship between pedometer-measured daily steps counts and Provincial Achievement Test (PAT) Score in elementary school students from Alberta, Canada

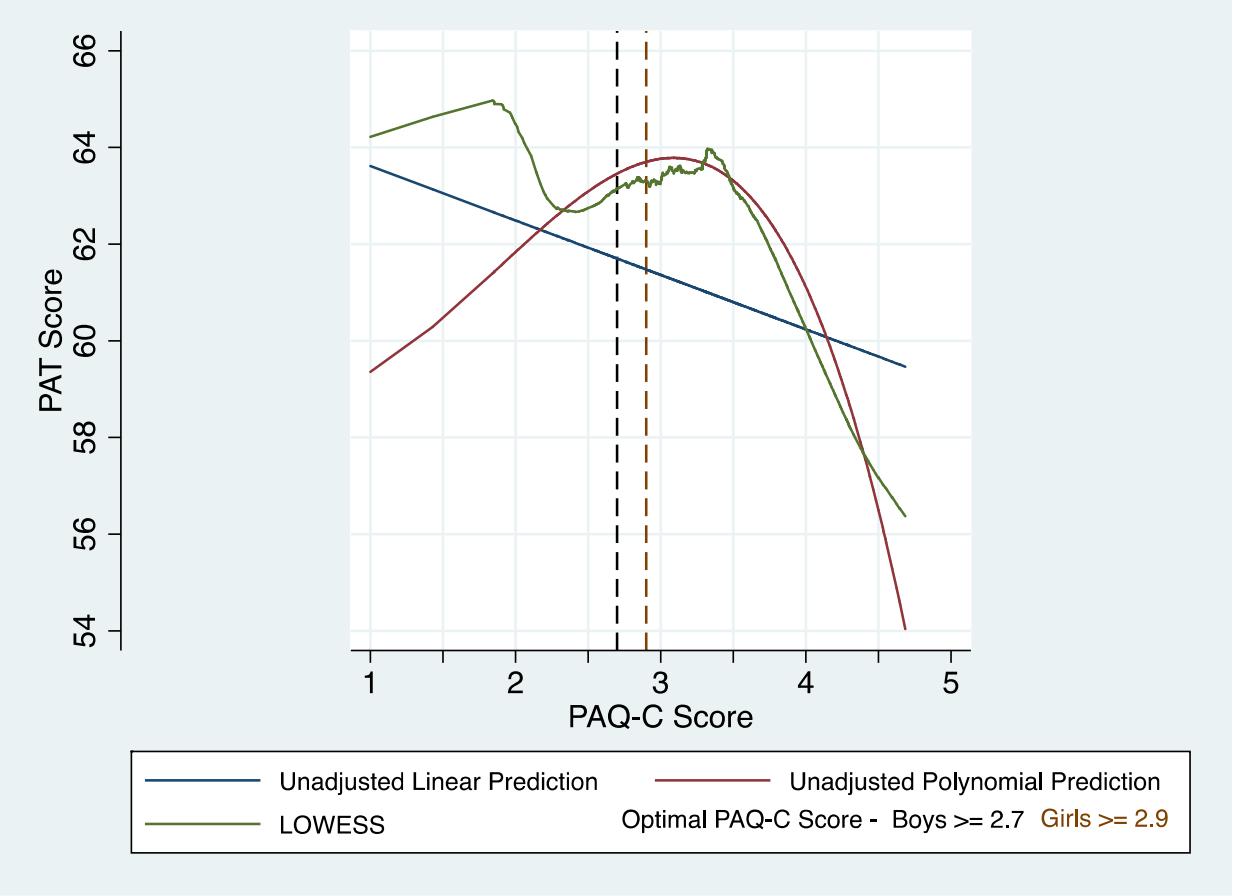

Fig. 6.2: Visualization of LOWESS, Unadjusted Linear Prediction, and Unadjusted Polynomial Prediction of the relationship between self-reported moderate-to-vigorous physical activity (as PAQ-C score) and Provincial Achievement Test (PAT) Score in elementary school students from Alberta, Canada

6.4 Tables

Table 6.1: Descriptive statistics of 525 students participating in the APPLE Schools program in Alberta, Canada, in 2012	
Gender, %	
Girl	54.9
Boy	45.1
Age, mean (range)	10.9 (9.2, 12.4)
Academic Achievement, mean (SD)	62.4 (14.6)
Average Steps per Day, median (range)	14,523 (4,204 – 29,989)
Achieving Step Recommendations (12,000 steps per day), %	70.1
Average PAQ-C Score, mean (range)	3.3 (1.0 – 4.7)
Household Income (CAD $), %	
<50,000	18.0
50,001 – 75,000	9.6
75,001 – 100,000	9.9
>100,001	37.3
Don't Know/Prefer not to answer	25.3
Parental Level of Education, %	
Secondary or Less	22.6
College	39.6
University or Graduate	34.8
Prefer not to answer	3.0

Table 6.2: The relationship between objectively and subjectively measured physical activity and children's academic achievement				
	Unadjusted		**Adjusted***	
	β (95% CI)	**p-value**	**β (95% CI)**	**p-value**
Steps (continuous)/1000	0.16 (-0.10, 0.41)	0.23	0.08 (-0.17, 0.33)	0.55
Steps (polynomial)				
Steps	0.94 (-0.34, 2.22)	0.15	0.53 (-0.74, 1.80)	0.41
$Steps^2$	-0.02 (-0.06, 0.01)	0.22	-0.01 (-0.05, 0.02)	0.47
	**Combined p = 0.23		**Combined p = 0.64	
PAQ-C Continuous	-1.13 (-2.96, 0.71)	0.23	-1.05 (-3.34, 1.25)	0.16
PAQ-C (polynomial)				
PAQ-C	**15.79 (1.73, 29.84)**	**0.03**	11.71 (-2.22, 25.64)	0.10
$PAQ\text{-}C^2$	**-2.61 (-4.76, -0.46)**	**0.02**	-2.00 (-4.14, 0.13)	0.07
	****Combined p = 0.03**		**Combined p = 0.07	

*adjusted for household income and parental level of education (gender was dropped due to non-significance)

**results of likelihood ratio test comparing polynomial model to intercept-only model (in unadjusted column) and intercept- and confounders- only model (adjusted column).

7 Discussion

7.1 Summary of key findings

The relationship between children's lifestyle behaviours and academic achievement is important to understand to inform best approaches for improving children's well-being during childhood, and to set them on a trajectory of success and health throughout their lifetime (1-4). Diet, physical activity, sleep, and sedentary behaviour are all important determinants of children's health and disease risk (5-8). Schools are an important setting for children's development, and a setting that can be altered to successfully support healthful improvements in children's lifestyle behaviours (9-12). The recent rise in the prevalence of childhood obesity (13), and resultant search for appropriate, effective, and wide-reaching interventions to both reduce and prevent childhood obesity has lead to extensive research of the design, implementation, and evaluation of school-based health promotion initiatives (14-16). Programs that take a comprehensive, environmental, culture shifting approach to promoting health and wellness have been shown to be equitable and effective in improving diet and physical activity, and to a lesser extent sleep and screen time, resulting in decreases in the prevalence of obesity (14,15,17-22). Evidence to support the broader benefits of effective school-based health promotion initiatives, like benefits to academic achievement, is crucial in order to engage important stakeholders in supporting the development and implementation of these initiatives (10,23-25). Downward trends in lifestyle behaviours hinder efforts to improve academic achievement, and because academic achievement is associated with health across the lifespan, investments in these behaviours by health actors to support both health and academic achievement are merited (2,26,27). There are few studies in a Canadian context linking lifestyle behaviours with academic achievement (28-32). Several existing studies have investigated the

relationship between diet or physical activity and academic achievement (28,30-32), and only one has taken into consideration both diet and physical activity in relation to academic achievement (29). None have considered sleep or screen time in relation to academic achievement. There are also only two previous studies in the literature that take into consideration all of diet, physical activity, sleep, screen time, body weight status, and socioeconomic status in independent relation to academic achievement (33,34). The studies in this thesis provide novel contributions by employing large, representative sample sizes in varying age groups. While Martinez-Gomez et al. (2012) also assessed lifestyle behaviours in relation to adherence to recommendations, they were only able to assess diet using fruit intake as an indicator. The studies in this thesis include a broad range of dietary recommendation indicators that have been demonstrated to be strongly associated with academic achievement. This evidence is important in order to inform the development of school-based health promotion initiatives that effectively support both healthier lifestyle behaviours and academic achievement among children.

This discussion will first provide an overview of key findings in relation to the four objectives of this thesis. Following that summary, these findings will be positioned within the current literature. Methodological considerations and strengths and limitations of the thesis will next be discussed, and the discussion will conclude with implications and recommendations for public health and suggestions for future research.

7.1.1 Objective 1

The first objective of this thesis was **to determine if adherence to established recommendations for healthful lifestyle behaviours has benefits to academic achievement,**

with special consideration for vulnerable populations. This objective was addressed by research question 1, 2, 3, and 4 (chapters 2, 3, 4, and 5). In these papers, students' adherence to recommendations for food group servings from the Eating Well with Canada's Food Guide (35), saturated fat intake as per the Dietary Guidelines for Americans 2010 (36), free sugars (sugars added during the processing phase of food production) intake as per the World Health Organization Guidelines: Sugars Intake for Adults and Children (37), and physical activity, sleep, and screen usage as per the Canadian 24-Hour Movement Guidelines (38). Previously in Canada, physical activity, sleep, and screen usage were represented by three separate guidelines (39-41), but recognizing the interrelatedness of these three behaviours and the importance for children's health of maintaining a balance between them, they have since been amalgamated into a single guideline (38).

Throughout the present thesis, adherence to guidelines for free sugars intake was most consistently and strongly associated with academic achievement. In chapter 2, boys in Alberta who adhered to free sugars recommendations scored almost 6% better on their exams than boys who did not, while students in Nova Scotia who met free sugars in chapters 3 and 5 had a 30-40% increase in the odds of meeting expectations on their reading and writing exams. Although the brevity of the dietary assessment tool used in chapter 4 did not allow for the assessment of adherence to these guidelines, students who consumed higher levels of junk foods, including high sugar items, were 25% less likely to achieve at a higher academic grading level. The relationship between adherence to food group recommendations from the Eating Well with Canada's Food Guide and to saturated fat recommendations from the Dietary Guidelines for Americans 2010 was inconsistent throughout the thesis chapters. Although all analyses did reveal positive relationships between various aspects of adherence to these recommendations

with academic achievement, there was a difference in which aspects had significant relationships. In chapter 2, only adherence to recommended servings of milk and alternatives had significant associations with academic achievement, while in chapter 5, all of adherence to recommendations for milk and alternatives, grain products, meat and alternatives, and saturated fat all had significant, positive associations with academic achievement. Contrary to what I hypothesized, and what earlier research suggested, adherence to recommendations for vegetables and fruit intake did not have significant associations with academic achievement in any chapter where it was considered. However, in chapter 4, increases in the frequency of consumption for vegetables and fruit lead to increased likelihood of achieving at a higher grade group for early adolescents.

The relationship between meeting physical activity recommendations in the Canadian 24-Hour Movement Guidelines and academic achievement was assessed in chapter 4. Not meeting recommendations for physical activity (60 minutes per day of moderate-to-vigorous physical activity) resulted in 13-33% lower odds of achieving at a higher academic grading group. Because of the measurement of physical activity used in chapters 2, 3, and 5, adequate physical activity was not able to be assessed according to the established guidelines. It was instead assessed using cut-offs developed for the method used that best correspond to cardiorespiratory fitness for children (42). However, no significant association was found between meeting these cutoffs and academic achievement in any analysis.

Adherence to sleep recommendations was consistently and positively associated with academic achievement throughout this thesis. In chapters 3 and 5, adherence to sleep recommendations in Nova Scotian children was associated with an almost 60% increase in odds

of meeting expectations on writing exams. In chapter 4, not adhering to sleep recommendations was associated with 13% reduced odds of being in a higher academic grading group.

Adherence to recommendations for screen usage had inconsistent associations with academic achievement. In chapters 3 and 5, schoolchildren in Nova Scotia who adhered to recommendations for screen usage (<2 hours per day) had an approximately 30% increase in likelihood of meeting expectations on exams in writing. In chapter 4, Canadian early adolescents who had 2-4 hours of screen usage per day had 20% increased odds of achieving at a higher grading level than those who met the recommendation, while youth who used screens for more than 7 hours per day had 24% reduced odds of achieving at a higher grade group compared to children who met the recommendation.

In chapter 3, consideration of recommendations for free sugars, saturated fat, sleep, and screen time, as well as cutoffs for physical activity for cardiorespiratory fitness, were considered in relation to academic achievement while also considering children in Nova Scotia's household food security status. Although consideration of food security status did not meaningfully change estimates for the relationship between these recommendations and academic achievement, children experiencing very low household food security (6.7% of students) had approximately 40% reduced odds of meeting expectations on academic exams. This indicates that adherence to healthful lifestyle behaviour recommendations is positively associated with academic achievement regardless of household food security status, but adherence to these recommendations is not sufficient to reduce achievement gaps between students from food secure and insecure households.

Findings from this thesis support the hypothesis that adherence to lifestyle behaviour recommendations, most consistently those with respect to sugar consumption and sleep, is supportive of academic achievement, and that meeting these recommendations are appropriate and meaningful targets for school-based health promotion initiatives. Although the relationship between adherence to these recommendations and academic achievement is not influenced by household food security status, these results demonstrate that more needs to be done to support children in food insecure households to succeed in school.

7.1.2 Objective 2

The second objective of this thesis was **to determine the independent associations of diet, physical activity, sleep, screen usage, and body weight status with academic achievement.** This objective was addressed by research question 3 and 4 (chapters 4 and 5). In Nova Scotian schoolchildren, aspects of diet, screen usage, and sleep were independently associated with academic achievement, while body weight status exhibited no significant relationship with academic achievement. In Canadian early adolescents, we found that all of diet, physical activity, sleep, screen usage, and body weight status exhibited strong, independent relationships with academic achievement. In both studies, measurement of all variables of interest was done using different methods, which may contribute to the differences in outcomes. For lifestyle behaviours, both of these studies provide compelling evidence that more healthful lifestyle behaviours have positive relationships with academic achievement. However, these findings are in conflict in terms of whether body weight status has a relationship with academic achievement independently of the lifestyle behaviours that contribute to both weight status and academic achievement. Although the Canadian study had a very large sample size, I am have more confidence about the results from the Nova Scotian study as heights and weights were

objectively measured rather than self-reported, which is known to be prone to bias (43). These findings provide support for approaches to school health that have a primary, rather than secondary, prevention approach – rather than focusing on school-aged children who are overweight or obese, all children benefit in terms of academic achievement from more healthful lifestyle behaviours.

7.1.3 Objective 3

The third objective of this thesis was **to determine the combined association of diet, physical activity, sleep, and screen usage with academic achievement.** This objective was addressed by research question 4 (chapter 5). Nova Scotian grade 5 students were given a score between 0-9 based on how many lifestyle behaviour recommendations they were adhering to: the four food group recommendations from the Eating Well with Canada's Food Guide, the saturated fat guideline from the Dietary Guidelines for Americans 2010, the WHO free sugars intake guidelines, and the physical activity, sleep, and screen usage recommendations from the Canadian 24-Hour Movement Guidelines. Students who met the most recommendations had 1.46, 3.07, and 2.77 times the odds of meeting expectations on exams in Math, Reading, and Writing, respectively, relative to students who met the lowest number of expectations. These effect sizes are substantial and indicative of the strong, synergistic effect of adhering to recommendations for all lifestyle behaviours of interest. These findings speak to the importance of balance and a holistic view of wellness – though each of these individual behaviours appear to have positive relationships with academic achievement, the strength of their combined effects is stronger than the addition of the individual effects.

7.1.4 Objective 4

The fourth objective of this thesis was **to discuss methodological considerations for investigating the relationship between lifestyle behaviours and academic achievement.** This objective was addressed by research question 5 (chapter 6). The present literature investigating the relationship is inconsistent, with most findings suggesting either a positive or neutral effect (44-46). I discussed the potential inappropriateness of employing analytical techniques that have an assumption of linearity as the true relationship between physical activity and academic achievement may be curvilinear, or have an inverse-U shape (32,47,48). Using an example of a sub-sample of schoolchildren in Alberta who wore pedometers and self-reported their physical activity, I generated an illustrative example of the potential inverse-U shaped relationship between physical activity and academic achievement. Using traditional linear assessment methods, the relationship was null, but using a polynomial regression method provided a better fit to the true, inverse-U shaped relationship between physical activity and academic achievement in the sample. Provided this findings, we made recommendations for methodological approaches that may more appropriately assess curvilinear relationships between physical activity and academic achievement, and that special consideration for high-active children must be made to ensure that increased participation in physical activity does not cause imbalance in other healthy behaviours.

Beyond the associations of the exposures of interest, other covariates that were considered in this thesis had substantial effects on academic achievement. Consistently, parental level of education and household income had strong, positive relationships with academic achievement, as I expected (49). However, what I did not expect was for female gender to consistently come through as having the strongest, positive relationship of any variable considered throughout this thesis. In Nova Scotian students, females had almost twice the odds

of meeting expectations in Reading and Writing compared to boys. Although effect modification by gender was seen in the smallest study in this thesis (chapter 2), gender did not appear to be an effect modifier throughout larger analyses. Further literature supports that girls tend to achieve more highly in school, particularly in reading and writing, than boys, regardless of socioeconomic status (50). This appears to be the case in Nova Scotia and efforts to improve the achievement in boys in these subject areas is merited.

7.2 Positioning findings in existing literature

Investigations of the relationship between diet and academic achievement have been focused predominantly on particular nutrients, especially in circumstances of malnutrition, individual food items, and on breakfast consumption (51-54). Our analyses provide a unique contribution to the literature by evaluating diet based on established, widely used and recognized dietary recommendations, and the standards by which we consider diets to be adequate from the health perspective. Our findings are thus easy to comprehend by knowledge users and are easily translated for application in health promotion. Our analysis is also the first to investigate the wider benefits of adhering to the recently released WHO Guidelines: Sugars Intake for Adults and Children (37), and provide evidence of a strong association between reduced free sugars intake and academic achievement, particularly for boys. Although sugar intake has been previously linked to academic achievement (55-58), our findings are the first to assess this questions with respect to adherence to sugar consumption guidelines. While earlier reviews concluded that the anecdotal relationship between sugar and behavioural issues did not have sufficient evidence to be substantiated (59), recent studies and reviews are revisiting this question and new evidence is coming to support it (60). However, this is a topic that continues to be debated and mechanisms for this relationship –whether physiological or due to dietary

patterns associated with socioeconomic status- continue to be discussed (61). In chapter 4, we found that healthy eating behaviours, such as eating breakfast frequently and sharing meals with family, had stronger positive associations with academic achievement than consumption of fruits and vegetables, similar to existing findings in urban American children that considered both dietary aspects (33). This observation is important when considering targets for health promotion to improve nutrition and ultimately academic achievement – more frequent breakfast consumption and consumption of meals with family may both improve diet quality as well as provide other benefits to student well-being such as reduced stress and opportunities to learn from familial role models (62-66).

Food insecurity has previously been demonstrated to have a negative effect on children's development and academic achievement (67-71). While there are many studies in the United States eliciting this relationship (69,72), most studies investigating this question take place in underdeveloped countries where poverty, nutrient deficiency, and consequent poor development are far more prevalent (71,73,74). Studies to investigate this relationship are lacking in Canada (67), and none have simultaneously considered children's diet quality in order to understand the magnitude of the negative association of food insecurity and academic achievement above and beyond its action through poor diet (69,75,76). We found that children living in households experiencing very low food security had substantially (30-40%) lower odds of meeting academic expectations, above and beyond the effects of diet and income. This provides further support for the need for a strategy to address food insecurity beyond food provision and income support programs, of which none presently exists in Canada (67).

The existing literature evaluating the relationship between physical activity and academic achievement has been inconsistent. Multiple systematic reviews have been conducted in an

attempt to formulate an overall conclusion (44-46,77). Though the literature tends to suggest a positive or neutral effect of physical activity on academic achievement, these reviews have also cited the challenge of drawing conclusions given the heterogeneity of measurement methods used for physical activity and academic achievement (44-46). They also conclude that studies using objective measures of physical activity, rather than self-report, are necessary (44-46). Two of the papers in this thesis investigated the relationship between physical activity and academic achievement independent of diet, sleep, screen time, and body weight status. In grade 5 children from Nova Scotia, we found that physical activity, represented by scores generated from a validated self-report questionnaire, the Physical Activity Questionnaire for Older Children (PAQ-C) (78,79), was not independently associated with academic achievement. However, in 11-15 year old children and adolescents across Canada, we found that more frequent days spent being adequately active was independently associated with an increased likelihood of higher academic achievement. These findings echo those of the above-mentioned systematic reviews – that physical activity has either a positive or neutral effect on academic achievement. Although these studies also utilized self-reported measures of academic achievement, they were among the few in existing literature that evaluated the effects of physical activity on academic achievement simultaneously alongside the effects of diet, screen time, sleep and body weight status (33,34). In chapter 6, we discussed some methodological issues that may be contributing to the inconsistent findings about physical activity and academic achievement both in this thesis and in the general literature. Previous findings in the literature suggest that the relationship between physical activity and academic achievement may have an inverse-U shape (32,47,48), though this suggested relationship was only discovered after conducting analyses. I have only found one other study that has analyzed this relationship with the expectation of it potentially curvilinear

(80). I discuss the possibility of an optimal level of physical activity that best supports academic achievement rather than assuming a positive dose-response relationship. This commentary is an important contribution to the literature in ensuring the health promotion messages developed about physical activity and academic achievement are accurate.

The relationship between sleep and academic achievement has been previously assessed in the literature, and findings have supported a positive relationship between longer sleep durations and academic achievement (7,81,82). In Chapter 5, we found that meeting recommendations for sleep duration had the strongest association (56% of increase in odds) of any of diet, physical activity, or screen usage with meeting expectations on exams in Writing, but not for Math or Reading. Previous research about the benefits of sleep support this relationship as adequate sleep is associated with creativity and the development of insight which are important for writing (83). In Chapter 4, we found that not meeting sleep recommendations was significantly associated with reduced likelihood of being in a higher academic grade group, again supporting the positive relationship between adequate sleep and academic achievement. Sleep is also considered to have an inverse-U shaped relationship with many health outcomes, including academic success (7,84). Sleep recommendations are provided as a range, not as a minimum duration, in order to address the notion that while short sleep duration is harmful, too much sleep is also associated with poor outcomes (84). Our work thus fills an important gap in the literature regarding the relationship between sleep duration and academic achievement – meeting but not exceeding recommendations is optimal for both academic achievement and health. Our findings that meeting sleep recommendations benefits both younger children (grade 5-6) and early adolescents (grades 6-10) is important given the changes in sleep patterns that occur in the transition from childhood to adolescents (85). The consistency in the importance in sleep

throughout childhood and adolescence, though its patterns and actions change in the transition to adolescence, is confirmed by this thesis. In addition, most studies that have focused on sleep and academic achievement in children tend to be in students who are experiencing sleep disturbances and few studies have focused on the general population of students (86). Our studies use two very large, representative samples of the population of Canadian children and youth.

In recent years, the detrimental effects of sedentary behaviour on children's health and well-being have garnered substantial interest. In particular, the rise in use of screen-based media among children is considered to be responsible for the large rise observed in school-aged children (87). Though previous research has identified negative relationships between screen-time use and academic achievement (5,88,89), the landscape of screen-based media use among school-aged children is changing rapidly, with TV and video games now being supplemented and replaced by cell phones and tablets, which are portable and easy to access in the bedroom (89). Continued monitoring of the harmful effects of screen-based media on academic achievement is crucial given the new variety of mediums that children are regularly accessing. In chapter 4, TV-watching beyond the recommended hours of screen time per day (90) was found to be negatively associated with the likelihood of meeting expectations for writing among grade 6 children. Findings from analysis of data from the HBSC survey revealed another inverse-U shaped relationship with academic achievement, which is consistent with other findings (80). A possible explanation for this relationship that children who are using a moderate amount of screen time in their free time are doing so for homework. High levels of screen time use, including video games, tablets, cell phone use outside of school hours, were strongly and negatively associated with likelihood of achieving at a higher grade level, consistent with

previous research (89). This analysis provides an up-to-date interpretation of the association between current screen devices and academic achievement.

Chapters 4 and 5 provide two further analyses that investigate the independent effects of diet, physical activity, sleep, and screen time on academic achievement. Given the interrelatedness of these behaviours and potential for confounding (62), determining the independent effects of each lifestyle behaviour on academic achievement provides a clearer understanding on how each affects children's development. The two chapters in this thesis complement only two other studies globally that have considered these independent effects (33,34), the largest sample sizes of any, and the only studies to have considered these associations in Canada. Chapter 4 also provided one of the few studies that have considered the combined impact of meeting lifestyle behaviour recommendations and academic achievement, suggesting that the more lifestyle behaviour recommendations that are met, the higher the odds are of higher academic achievement (33,34). Findings from Martinez-Gomez et al (2012) about the combined relationship of adequate lifestyle behaviours are similar in magnitude to the findings in this thesis (34). They found that Spanish adolescent girls who had the highest number of adequate lifestyle behaviours had 3.07 odds of passing their Learning and Language exams compared to girls who were adequate in the lowest number of behaviours (34), where we found that children who met the most lifestyle behaviour recommendations had 3.07 times the odds of meeting expectations on Reading exams compared to children who met the lowest. The participants in the study by Martinez-Gomez et al. were approximately 15 years old, providing evidence that the strong relationships between lifestyle behaviours and academic achievement that I observed in grade 5 and 6 children persist into adolescence.

Chapters 5 and 6 also provide two of the few existing studies that consider the relationship of lifestyle behaviours independent of body weight status. Though body weight status has been shown to be associated with academic achievement, the lack of consideration for lifestyle behaviours and socioeconomic status in these analyses has been identified as a major gap in the literature in a recent review (91). Only two other studies have considered all lifestyle behaviours considered in this thesis in relationship to academic achievement (33,34), and only one other study in Canada has considered diet, physical activity, socioeconomic status, and body weight status and academic achievement simultaneously (29). Results from the present thesis about the independent association of body weight status and academic achievement were in conflict. In Chapter 4, once all lifestyle behaviours, socioeconomic status, and other related confounders were considered, overweight and obesity did not exhibit any significant association with academic achievement. However, in analyses of HBSC data in chapter 6, both overweight and obesity were significantly, negatively, and independently associated with academic achievement. Both studies used different measures of body weight status, different cutoffs to assess body weight status (92,93), and different measures of academic achievement, demonstrating the challenges and differences and results that can occur in a field where there is a vast heterogeneity in measurement methods (94). However, all studies that have used objective measures of both body weight status and academic achievement have found that body weight status is no longer associated with academic achievement when diet, physical activity, sleep, and screen usage are included in analyses (29,34,95).

Findings from this thesis indicate that diet, physical activity, sleep, and screen time are associated with children's academic achievement. The analyses in this thesis took the unique approach of assessing the relationship of lifestyle behaviours and academic achievement by

considering lifestyle behaviours in relation to adhering to established, well-understood, and widely implemented guidelines and recommendations. This approach has two benefits: first, findings are easily described in knowledge translation initiatives and well-understood by audiences of interest including educators, policy-makers, and health promotion experts aiming to improve children's lifestyle behaviours and academic achievement. Secondly, this approach allows further understanding of the wider benefits of lifestyle behaviour recommendations and guidelines: are the recommended levels of diet, physical activity, sleep, and screen time considered to be optimal not only for health, but for other aspects of well-being? For diet and sleep this does appear to be the case. Discussion in this thesis suggests that for physical activity and screen time in school children, the way that recommendations for physical activity are presented in health promotion messages may need to be reconsidered. This thesis provides further support for newly developed guidelines about free sugar consumption and for meeting but not exceeding sleep guidelines as the range that they are, not as a minimum requirement. This approach also provides further understanding of physical activity guidelines and screen time guidelines, the relationships between these two behaviours and academic achievement may not be linear as previously thought, and optimal ranges may instead need to be considered. This thesis also presented novel findings about the independent and combined effects of lifestyle behaviours and academic achievement, indicating that a holistic approach to children's health behaviours may be the most beneficial for academic achievement. Results from this thesis demonstrate that the associations of lifestyle behaviours and academic achievement are largely consistent across the transition from childhood to adolescence. This thesis also considered important social determinants of health, and in particular highlighted how food insecurity can be detrimental to academic achievement irrespective of diet, income, other lifestyle behaviours, and

body weight status. This thesis presented comprehensive and new information using representative, population-based Canadian data that can be used to inform decision-making about health promotion initiatives to improve the lifestyle behaviours of school-aged children, particularly those that take place in schools.

7.3 Methodological considerations

Data analyzed in this thesis was collected as part of three separate, larger, on-going projects across Canada: the Raising healthy Eating and Active Living Kids Alberta evaluation (REAL Kids) (17), the Children's Lifestyle and School-performance Study (CLASS) (18), and the Health Behaviours of School-aged Children (HBSC) Survey (96). The 2012 iteration of the REAL Kids Alberta survey and the 2011 CLASS results were linked with children's academic achievement data with the explicit purpose of investigating the relationship between lifestyle behaviours and academic achievement, while the HBSC aims to collect a vast breadth of information and the research question answered within this thesis represents a secondary data analysis. Because this data was collected prior to the beginning of this thesis and I was not a part of the decision-making team that decided on the tools used in each of these studies, the reasoning behind these decisions will not be discussed in this thesis. However, strengths and limitations of the measures used will be discussed in the subsequent section. This section will discuss methodological choices and analytical considerations made for the purposes of the analyses that comprise this thesis.

Where possible, lifestyle behaviour variables were assessed against well-established recommendations or guidelines for all constructs. Among the recommendations and guidelines assessed were the Eating Well with Canada's Food Guide (35), the WHO Sugars Intake for

Adults and Children guideline (37), the National Sleep Foundations' sleep guidelines (41), the Canadian Sedentary Behaviour Guidelines (40), and the newly-released 24-hour Movement Guidelines for Children and Youth which amalgamates recommendations for physical activity, sleep, and sedentary behaviour (38). These recommendations are well-known and widely promoted and implemented in Canadian contexts, particularly in school environments. In population-level evaluations in Canada, they are also the standards by which the adequacy of children's lifestyle behaviours are measured (97,98). Saturated fat intake was assessed using recommendations used in the Dietary Guidelines for Americans 2010 (36) as saturated fat intake was of interest to this thesis, but the Canadian dietary guidelines contain no specific cutoff for saturated fat intake.

Some tools used for data collection in REAL Kids, CLASS, and the HBSC survey did not allow for assessment of well-known lifestyle behaviour recommendations. The short food frequency questionnaire used in the HBSC survey was not comprehensive enough to determine adherence to dietary recommendations. Instead, we employed exploratory factor analysis to reduce the data into three factors and these were used in regression analyses. The Physical Activity Questionnaire for Children (PAQ-C) tool (78) used in REAL Kids and CLASS did not allow for comparisons to the 24-Hour Movement Guidelines that provide physical activity recommendations in steps and minutes per day for ease of comprehension (38). The PAQ-C instead generates a score from 0-5 that represents general levels of moderate-to-vigorous physical activity among children (78) that cannot be translated into either steps per day or minutes per day of physical activity. However, validated score cutoffs were generated that correspond with optimal cardiovascular fitness among girls and boys (42), and these were used

to assess adherence to optimal amounts of physical activity among children where the PAQ-C was used.

Because of the clustering of children within schools in all datasets used in this analysis, random effects were applied to overcome the potential lack of independence between students in the same schools. In addition, HBSC data is collected across 12 Canadian provinces, and because education is under the jurisdiction of provincial governments, provinces are also treated as a level of clustering in analysis of HBSC data. In order to achieve representativeness of the respective populations of interest in each sample used for this thesis, a variety of weights were applied. Sampling weights were applied to the REAL Kids data in order to accommodate the sampling methodology of the evaluation. REAL Kids used a one-stage stratified sampling design in which the province was stratified into three regions (metropolitan, urban, and rural) and schools were randomly selected within the strata (17). Each student is given a sample weight in order to achieve representativeness within the strata. Sample weights were calculated by accessing Alberta Education enrollment data to understand the number of grade 5 students enrolled in schools within each strata. In the CLASS evaluation, every school comprising a grade 5 class and every student were invited to participate in the evaluation, and a high participation rate ensued (18). However, upon analysis of postal code data provided by parents and comparison to neighbourhood income-level estimates available from the Canadian census in both participants and non-participants, it was determined that non-response was somewhat higher among residents in low-income neighbourhoods in Nova Scotia (18). Because all grade 5 students in the province were invited to participate in the survey, response weighting could be applied to analyses. Finally, survey weights were applied to the HBSC dataset in order to achieve representativeness of the Canadian population.

Potential confounding and effect modification was considered in all analyses. Potential confounders and effect modifiers were identified based on findings from existing literature, including gender (34) and socioeconomic status (99,100). Age was only considered in the HBSC analysis as there was a distribution of children's ages, while data from REAL Kids and CLASS comprise only of grade 5 (10-11 year old) students. There is the potential of residual confounding in these studies in the case that there were unknown, unmeasured confounders, or if these confounding variables that were considered were not measured accurately (101). Where food frequency data was used, analyses were adjusted for energy intake where possible as per analytical protocol (102). Where effect modification was suspected, results were stratified. Effect modification was only observed in chapter 2 where it was found that gender was contributing.

7.4 Strengths and limitations

A major strength of this thesis was the use of three, large, population-based Canadian studies to evaluate our objectives that included both children (ages 10-11) and early adolescents (11-15). Relevant weighting was applied in all analyses in order to achieve accurate representativeness of the populations of interest (17,18,103). Though self-reported measures are prone to bias (104), validated measures were used to assess diet and physical activity, and food insecurity in the REAL Kids and CLASS datasets: the widely used Harvard Food Frequency Questionnaire for Children and Youth (YAQ) (105), adapted for Canadian use (18), the Physical Activity Questionnaire for Children and Youth (PAQ-C) (78), and the short-form Household Food Security Survey Module (HFSSM) (106). Questions about screen use were adapted from the National Longitudinal Survey for Children and Youth (NLSCY) (107). Chapter 5 also integrated pedometer-measured physical activity in a sub-sample of Albertan students (108). The REAL Kids and CLASS datasets used objectively measured anthropometric measurements for

calculation of body weight status. In addition, chapters 2-5 include standardized provincial measures of academic achievement, providing an objective measure of academic performance and utilizing measures of achievement that are used by important knowledge users – educators and policy-makers in education. In addition, lifestyle behaviours were assessed using established, well-known guidelines and recommendations, resulting in findings that are easily translated for relevant knowledge users.

This thesis employed complex statistical analyses including random effects modeling to account for clustering among students, linear, logistic, and ordinal logistic regression, exploratory factor analysis, weighting, adjustment for confounders, and the use of survey data with a high participation rate for school-based research (109) .

There are also limitations to this thesis that are important to discuss. In all analyses, measures of sleep were not validated, though they are simply questions of duration, and in REAL Kids and CLASS, the questions of interest were piloted in the target population to ensure comprehension. Although objective measurements are considered to be ideal for the measurement of sleep and screen time (89,110), it has been suggested that self-report measures of screen time are superior in analyses aiming to elucidate the relationship between screen time and academic achievement because it is important to know what a child is doing while using a screen – homework that would contribute positively to academic achievement or activities that may have a negative effect on academic achievement (47). Analyses in chapter 6 did not use validated tools for any variable of interest and used self-reported anthropometric measurements, which is prone to bias in all age groups (43). Although studies 2-4 employ a prospective design where the exposures are measured at baseline and outcomes are measured one year later, there may be error introduced by the time lag between exposure measurement and outcome

measurement given the nature of the tools for the exposure. Only the YAQ measures diet over the previous year, providing a strong measure of usual intake, while all other measures assess behaviours over a recent week. This may not provide a strong enough relationship to disentangle temporality. Chapter 6 employs a cross-sectional design and again, temporality cannot be established (101). It is possible that students who have higher school achievement may then exhibit healthier behaviours. Though chapter 6 employed a self-reported measure of academic achievement, report card grades are also an important indicator of academic achievement and standardized testing has been criticized as an outcome measure. Critics against standardized testing suggest that standardized tests are not always an accurate measure of learning or cognitive ability (111). While measures of socioeconomic status were available to include in analyses for all chapters, these measures were only validated in chapter 4. Because of the strong relationship between socioeconomic status for lifestyle behaviours as well as for academic achievement, there is a likelihood that residual confounding may result in the overestimation of the relationship between lifestyle behaviours and academic achievement and underestimation of the relationship between socioeconomic status and academic achievement.

7.4 Recommendations for Health Promotion

Based on the novel contributions from this thesis, I have identified several key recommendations for health promotion.

7.5.1 Free Sugars are a Key Health Promotion Target

Results for this thesis provide compelling evidence that free sugars, in the form of sugar-sweetened beverages (SSBs) and sugary snacks, are strongly and negatively associated with academic achievement. As such, given that their contribution to children's nutrition is

predominantly in the form of excess calories, as well as their strong association with adverse health consequences (112,113), these represent sensible and key targets for health promotion to improve the well-being of children. In particular, educational jurisdictions should look to reducing consumption of free sugars among their students as an effective way to meet their organizational goals. For example, in their 2016-2019 Business Plan (114), Alberta Education aims to increase the percentage of students meeting the Acceptable and Excellent Standards on PAT exams by approximately 0.2% (89 students) per year for the next three years. Using results from this thesis, I have determined that if all students met the WHO Free Sugars Guidelines for Adults and Children, an additional 1.4% (620 students) and 0.3% (132 students) of Albertan students could meet Acceptable standards on their grade 6 PATs in Language Arts and Math, respectively. An additional 0.5% (221) students could reach the Excellent standards in both Language Arts and Math. For the average child who is presently not meeting recommendations, this would require a reduction of free sugars intake of 20g per day, or the equivalent of half of a can of regular Coke. If the reduction of free sugars intake of children was made a priority, the goals of Alberta Education to improve children's achievement could be easily attainable.

I have several recommendations to achieve a reduction in free sugars intake among Canadian children and youth. First, at this time, the Eating Well with Canada's Food Guide does not have specific recommendations about free sugars intake. At present, Health Canada is re-designing the next edition of the national dietary recommendations. I recommend the inclusion of the WHO Free Sugars Guideline for Adults and Children to provide a tangible target of free sugar intake for the population. SSB taxes have been shown to be a cost-effective intervention to reduce sugar consumption and potentially reduce the body mass index of not only school-aged children, but the wider population (115). While taxation is often considered to be an undesirable

intervention due to the inequitable burden that would be placed on lower-income segments of the population, SSBs are non-essential for dietary adequacy and if additional cost of their purchase represents a barrier for lower-income groups, they may stand to benefit the most from a cost savings and reduction of excess sugar intake. Provided the evidence from this thesis, Canadian Ministries of Education can provide their support in advocating for this intervention given the direct harm to students that excess sugar intake has been shown to cause.

Many effective school-based interventions are also available to curb the free sugars intake of students. Because free sugars are directly harmful to academic achievement, I think it is evident that SSBs, in particular, and sugary snacks, are not an appropriate item of sale in a school environment. Their removal from food service outlets in a school environment is imperative. In addition, schools do have the option of banning the presence of SSBs or 'junk food items' from entering the school environment. While I am hesitant to recommend a complete ban, I do not think it would be wrong for schools to implement them given this compelling evidence. I would expect, and have anecdotally seen, the backlash from the community that can be generated from policies of this nature. I believe that findings from this thesis could be a strong argument to appease that backlash. These kinds of recommendations are not new (12,116), but I feel that the evidence generated by this thesis provides novel and strong evidence to further support these types of interventions.

7.5.2 Healthy lifestyle behaviour recommendations for all of diet, physical activity, sleep, and screen time are an effective target for both better health and academic achievement

The findings from this thesis about the consistent and substantial benefits of adhering to healthy lifestyle behaviour recommendations supports wider promotion of these guidelines. In particular, these recommendations have an important place in school environments both in terms

of promoting awareness of them and creating environments that are supportive of achieving adherence to them. However, they are important to promote in any environment where children are present. The findings from this thesis about the benefits, beyond those to health, of adhering to these behaviours are convincing and meaningful for key end-users of this information, such as parents. For example, children who adhere to guidelines for screen time and sleep have a 56% and 35% increase in odds of meeting expectations on writing exams compared to children who do not. For parents, this is a highly motivating piece of evidence to support their child in achieving the recommended amount of screen time and sleep. These recommendations can be paired with simple, actionable suggestions to achieve them. For example, the presence of screens in the bedroom contributes to higher amounts of screen time, shorter sleep, and higher likelihood of overweight among children (117). Removing them from the bedroom can make a substantial difference in adhering to these guidelines and consequently, achieving academically at a higher level.

The findings about the combined adherence to multiple lifestyle behaviour recommendations having a strong, positive association with academic achievement is supportive of the new Canadian 24-Hour Movement Guidelines. Acknowledging the interrelatedness of lifestyle behaviours, the guidelines were developed to encourage a balance of healthy behaviours, and to create a singular resource for information about healthy behaviours rather than three. The findings from this thesis that demonstrate the independent and combined importance of all of physical activity, sleep, and sedentary behaviour for academic achievement provide further support for the wider promotion of these guidelines. Children who meet the most lifestyle behavior recommendations have more than three times the odds of meeting expectations on their Mathematics exams compared to children who meet the fewest, which is a very large

and convincing effect. For every additional lifestyle behaviour recommendation met, a child's odds of meeting expectations on their exams improves by up to 1.26 times, indicating that a child who did not meet any recommendations could potentially improve their odds of passing their exams by 8 times if they met all recommendations from Eating Well with Canada's Food Guide and the 24-hour Movement Guidelines. Achieving healthier lifestyle behaviours in children prevents a substantial and tangible opportunity to prevent exam failure among students.

7.5.3 All children would benefit academically from healthy school environments regardless of socioeconomic status or body weight status

Ultimately, the findings from this thesis demonstrate that opportunities for optimal health belong in the school environment and that health should be comprehensively embedded in the school environments and the curriculum. If the objective of public investment in education is to produce engaged, productive citizens (118), educational jurisdictions have a public duty to implement interventions that support students in their academic achievement. School-based health promotion programs that have a singular focus do present opportunities to improve health. For example, in-school food programs that provide healthy meals for children represent an opportunity to both improve nutrition and support students who may be experiencing food insecurity (67). However, in order to achieve the highest quality health for children in school environments, I recommend wider implementation of school-based health promotion initiatives that take a comprehensive school health approach. This thesis has demonstrated the independent and combined importance of diet, physical activity, sleep, and screen use for children's academic achievement, and comprehensive school health approaches have the opportunity to embed opportunities for healthful lifestyle behaviours in a school environment for the entire school population. Though previous evidence and this thesis provide evidence that socioeconomic status

is a strong determinant of academic achievement, healthy lifestyle behaviours have independent associations of a large magnitude beyond the effects of socioeconomic status. In addition, findings from this thesis and others in the literature provide evidence that unhealthy lifestyle behaviours may be confounding previous findings about the negative relationship between childhood obesity and academic achievement. I feel that these findings are convincing to refocus the objectives of school-based health promotion initiatives from 'obesity reduction' back to 'health promotion'. All children, regardless of body weight status, would benefit academically from healthy improvements in their lifestyle behaviours. Finally, comprehensive school health approaches are also positioned to, and have been shown to, support other aspects of children's well-being into the school environment, including leadership, reduction in bullying, healthy sexual practices, and discouragement of drug use (15,22). This approach shows great promise to support academic success and holistic well-being of children from a diverse range of backgrounds.

7.5 Recommendations for Future Research

The present thesis identifies several opportunities for further research. This thesis comprised of studies that were cross-sectional and prospective in nature. Longitudinal research is needed to confirm the temporality of the identified associations, given that lifestyle behaviours and academic achievement are individual constructs that are constantly occurring and developing in children. While there have been a host of studies that have considered individual behaviours with respect to academic achievement longitudinally (119-121), none have simultaneously considered all of the lifestyle behaviours considered in this thesis nor assessed them in relation to established recommendations. Our communication in chapter 6 also identified the need to assess the relationship between physical activity and academic achievement as potentially curvilinear

rather than linear. I recommend that future investigations of the relationship between physical activity and academic achievement consider testing a polynomial model as a way of assessing if the shape if the relationship between physical activity and academic achievement is curvilinear within their sample. I also recommend that authors of future systematic reviews consider organizing included studies by physical activity level exhibited by the sample in order to ensure comparability between these subgroups. Given the conflicting findings about the relationship between body weight status and academic achievement in this thesis, further study is merited to disentangle the relationship between lifestyle behaviours, body weight status, socioeconomic status, and academic achievement.

While this thesis provides compelling evidence that effective school-based health promotion initiatives focusing on the improvement of diet, physical activity, sleep, and screen time can be supportive of better academic achievement among children, trials investigating this question are necessary to provide causal evidence. Evidence is convincingly mounting in support of comprehensive approaches for improving health outcomes, but few cluster-randomized control trials consider academic achievement as an outcome (122). Studies that take into consideration socioeconomic inequalities among students, students that are older than 12 years of age, and research outside of the United States have also been pointed to as key areas in need of evidence (22). Given the challenges, with relation to time and cost, of conducting high-quality cluster randomized trials to investigate this research objective (123), findings from this thesis provide the impetus to support the development of further research programs investigating this and the provision of funding to execute them. School-based health promotion approaches provide a crucial opportunity to equitably support both health and academic achievement in children and prevent chronic disease and persistent socioeconomic inequalities throughout the

lifespan. In addition, though standardized exam performance is an important indicator of academic achievement, other aspects of academic success (e.g.: sense of belonging in school, satisfaction with performance (111)) also require attention as important educational outcomes when considering the influence of lifestyle behaviours on student success.

7.6 References

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Chapter 1

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