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POSTDOCTORAL STUDIES

Megan A. Carter

AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.Sc. (Epidemiology)

GRADE / DEGREE

Department of Epidemiology and Community Medicine

FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Obesity and academic performance of Canadian school children: a prospective study using the first five waves of the National Longitudinal Survey of Children and Youth

TITRE DE LA THÈSE / TITLE OF THESIS

Lise Dubois

DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

Tim Ramsay

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

EXAMINATEURS (EXAMINATRICES) DE LA THÈSE / THESIS EXAMINERS

Bernard Choi

Yang Mao

Gary W. Slater

Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

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Megan A. Carter

Thesis submitted to Faculty of Graduate and Postdoctoral Studies in partial fulfilment of the requirements for the MSc degree in Epidemiology

Epidemiology and Community Medicine,
Faculty of Medicine,
University of Ottawa



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Abstract

Obesity has become a worldwide epidemic in children. It may have both short- and long-term negative effects including poor performance in academics.

Using multivariate linear regression methods and the National Longitudinal Survey of Children and Youth, this study prospectively examined the effect of obesity status during the primary school years (2-5 y to 8-11 y) on standardized math test scores, while adjusting for confounders.

Results indicate that children who grew out of obesity performed significantly better in math than children who were never obese. However, children who were always obese and those that developed obesity performed no differently than children who were never obese.

Childhood obesity was not found to be negatively associated with an objective measure of academic performance. Being obese early in childhood and normal weight later on was associated with improved academic performance. However, further studies are needed to substantiate this finding.

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CHAPTER 1: Introduction

Childhood obesity has become an epidemic in Canada and in many other developing and developed countries (1). The increasing prevalence of childhood obesity in Canada is a cause for concern first, because of the adverse health and psychosocial effects obese children could potentially suffer, and second, because of possible economic consequences to Canada both in the long and short term. Decreased academic performance could be an unappreciated negative correlate of childhood obesity. In this chapter, childhood obesity is defined and Canadian prevalence estimates are given, followed by a brief description of the more well-known negative effects of childhood obesity. The rationale behind testing for a relationship between childhood obesity and academic performance is then described.

1.1 Background

1.1.1 Definition & Aetiology

Obesity is defined as a condition of excessive adipose tissue (2). Childhood obesity is a complex multi-factorial condition with interacting genetic, behavioural and environmental components. The exact nature of the causal mechanism of childhood obesity likely differs from person to person, inevitably however, it is a result of an energy intake that is more than energy expenditure.

1.1.2 Classification

Ideally classification of childhood obesity should be related to future morbidity risk and be based on direct measures of body fat such as underwater weighing or bioelectric impedance analysis, but these types of measures are expensive and not suitable for many epidemiological studies. Body mass index (BMI: kg/m^2) is therefore

considered to provide the most useful population-level measure of obesity in children when taking into account age and sex (3). Definitions of childhood overweight (the state of being at risk for obesity) and obesity, based on BMI, vary from study to study. The most common definitions used are those developed by the International Obesity Task Force (IOTF) and those based on the 85th and 95th percentiles of a national reference distribution, e.g. 2000 Centers for Disease Control and Prevention/National Center for Health Statistics Revised Growth Charts (CDC).

The IOTF cut-off points for overweight and obesity by sex and age in children aged 2 - 18 y were developed by Cole et al (2000) based on six large nationally representative cross-sectional surveys conducted in Brazil, Great Britain, Hong Kong, the Netherlands, Singapore and the US. This approach used the World Health Organization adult definitions of overweight and obesity, BMI of 25 kg/m² and 30 kg/m² respectively, and extrapolated back to equivalent BMI percentiles in children. These cut-offs represent increased disease risk in adults, but the authors state that the health consequences for children above the cut-off points may differ from those in adults (4).

In contrast, the revised CDC growth charts were developed after recommendations were made by an expert committee convened by the US government in 1998. This committee recommended the use of the 85th and 95th percentiles for age and sex to define at risk for overweight and overweight (including obesity) respectively, based on national BMI reference data (5). It was determined that children at or above the 95th percentile tend to remain overweight and have greater risk for the development of

adverse health problems both in the short term and long term. The committee recommended that children and adolescents having BMIs at or above the 85th percentile, but below the 95th percentile, be assessed as at risk for overweight and evaluated accordingly. The CDC revised growth charts for US children and adolescents include BMI-for-age charts for males and females aged 2-20 y which can be used clinically or epidemiologically (6). For the purpose of this study, the CDC definition of overweight (including obesity) will simply be referred to as obesity.

Compared to the IOTF cut-off, the use of the CDC obesity definition gives a greater prevalence of obesity (7). There are many reasons for using an obesity definition based on a national reference distribution instead of the IOTF cut-offs (8). For example, studies examining children younger than two years cannot use the IOTF definitions as there are only cut-offs for children 2-18 y. Some studies require BMI to be used as a continuous measure (z-scores required). The IOTF cut-off BMI values cannot be converted to z-scores. Finally, the IOTF cut-offs define overweight and obesity only; some studies may require other categories such as underweight or extreme obesity. Regardless of the pitfalls of the IOTF cut-offs, it is recommended that prevalences based on IOTF cut-offs be given in addition to those based on national reference data, to facilitate cross-study and international comparisons (8).

1.1.3 Canadian Prevalence Estimates

From the 1981 Canada Fitness Survey to the 1996 National Longitudinal Survey of Children and Youth (NLSCY) the prevalence of overweight in Canadian children aged 7-13 y has risen from 11% to 33% in boys and 13% to 27% in girls (9). In terms of

obesity, the increase has been much more dramatic, where obesity in both boys and girls has increased almost five-fold from a baseline prevalence of 2% in 1981, to 10% and 9% respectively in 1996 (9). These estimates were based on the IOTF definition of overweight and obesity, and measured and parent-reported heights and weights.

More recent changes in the prevalence of overweight and obesity are estimated based on the 1978/79 Canada Health Survey and the 2004 Canadian Community Health Survey, using the IOTF definition of overweight/obesity and directly measured heights and weights (10). In 2004, the prevalence estimates for overweight and obesity were 15% and 6% for children aged 2-5 years, 18% and 8% for 6-11 year olds, and 20% and 9% for 12-17 year olds. From 1978/79 to 2004 overweight (including obesity) remained the same for 2-5 year olds. Overweight (including obesity) increased significantly for both the 6-11 y (13% to 26%) and 12-17 y (14% to 29%) age groups.

1.1.4 Negative Effects

In children, obesity is associated with the development of gallbladder disease, asthma, obstructive sleep apnoea, physical limitations, type 2 diabetes, cardiovascular disease risk factors such as hypertension and dyslipidaemia, and even the metabolic syndrome (11-13). Psychosocial problems such as depression, low self-esteem, and anxiety disorders are also more likely to occur in obese children (13;14). Not surprisingly then, the overall quality of life of obese children tends to be lower than that of their non-obese peers (15). Perhaps as a result of these aforementioned correlates of obesity, and because more and more children are becoming obese, the number of children presenting to health care with obesity-related conditions has risen dramatically (16). Childhood obesity also has long-term effects such as adult obesity and mortality (17;18).

Therefore, considering both the short and long-term effects of childhood obesity, the potential negative effects on the economy, and the health and social systems could be large and long lasting.

In addition to these well known effects of obesity, a recent study conducted by Diano et al (2006), has found evidence that ghrelin, a hormone secreted by the stomach when the stomach is empty, may directly control the higher brain functions of spatial learning and memory. The researchers determined that ghrelin produced peripherally can enter the hippocampus, a higher brain region, and bind with hippocampal neurons, promoting dendritic spine synapse formation and generation of long-term potentiation in mice (19). They then found that these ghrelin-induced changes in neuronal circuitry in the hippocampus were accompanied by enhanced spatial learning and memory in rats. Similarly, when the gene that encodes ghrelin was disrupted in mice, a marked decrease in the number of spine synapses in the hippocampus resulted, paralleled by impaired performance in behavioural memory tests. With administration of exogenous ghrelin, however, both of these impairments were reversed (19). Obesity has been found to be associated with low ghrelin levels in humans (20;21).

1.2 Rationale

A very small body of literature has uncovered a modest link between weight status in childhood and decreased academic performance (22). Diano et al (2006) posit that they have discovered a link between metabolic status and higher brain functioning. This is one possible causal pathway to link obesity with poor academic performance. Another is that obesity may cause psychosocial difficulties and/or decreased quality of

life, leading to lowered academic performance. The link may also lie with socioeconomic status (SES). Low socioeconomic status may be related to poor academic performance and to obesity. Perhaps then, obesity is a factor between poverty and academic performance.

The Program for International Student Assessment (PISA) is a collaborative enterprise among member countries of the Organisational Economic Co-operation Development (OECD). PISA was developed to measure 15 year olds' skills in mathematical, reading, and scientific literacy once every three years to determine factors that contribute to successful students, schools and education systems (23). Based on the 2000 and 2003 assessments in the science domain, performance of Canadian school-children decreased significantly over the three years. Reading performance appeared to stay the same and differences in overall mathematics performance could not be determined due to changes in the content areas of the assessment from 2000 to 2003 (23). Can this decline in the academic performance of Canadian school children therefore be explained by the current obesity epidemic?

An opportunity exists using the National Longitudinal Survey of Children and Youth (NLSCY) to determine whether obese Canadian school children do worse on measures of academic performance than their non-obese peers, while controlling for confounders such as socioeconomic status (SES). The future success of the Canadian economy depends largely on well-educated and creative workers who are highly adaptable to the changing economic climate. If childhood obesity is negatively associated with academic performance, the current obesity epidemic could then lead to a

resulting decline in the academic performance of Canada's school children. In turn, this could negatively impact on the nation's economy and social structure as these children age into adulthood. These children will be less able to attain high levels of education and skill development and thus create a national workforce that cannot compete in a global market (24). In addition, children who grow up doing poorly in school may have financial difficulty in adulthood. People of low socioeconomic status tend to have worse overall health and a lower quality of life (25), which then strains the country's health and social systems.

CHAPTER 2: Literature Review

This chapter investigates what is currently known about the relationship between childhood obesity and academic performance. The first section details the correlates that are common to both childhood obesity and academic performance and goes on to describe how each correlate relates separately to academic performance and to childhood obesity. The second section describes the critical appraisal of the published literature investigating the link between academic performance and obesity.

2.1 Common correlates of academic performance and obesity

Cognitive development and obesity in childhood share many common factors which have been identified in the literature (please see Table 1). To correctly determine the effect of obesity on academic performance, other possible explanations of the variation in academic performance must be accounted for when developing statistical models. Known confounders of this relationship, therefore, should be controlled for in prediction models. In epidemiological studies confounders are those variables that are correlated with the predictor and the outcome but are not an intermediate step in the proposed causal pathway of the exposure (obesity) and the outcome (academic performance).

2.1.1 Socioeconomic Status Variables

It is well known that socioeconomic status (SES) plays a large role in child development, and cognitive development in particular. Social position has been found to be an important predictor of childhood intelligence (26). Lawlor, Batty, Morton, et al (2005) examined this relationship in a cohort of people born in Scotland between 1950

and 1956 (n = 12,150). They found, after adjusting for confounders, that social class at birth (five categories based on the father’s occupation) had a graded positive linear association across the distribution with intelligence scores at age seven (assessed using the Moray House picture intelligence test numbers one or two). Children in the lowest social class category scored on average 14 (95% CI: -15.16, -12.70) points lower than children in the highest two categories. In addition, parental education level (27-30) and family income (28-31) have consistently been found to be directly correlated with children’s academic performance and intelligence. The nature of this relationship is not surprising as SES largely contributes to the quality of the child’s home environment and the willingness or capability of parents to invest time in their children.

Table 1: Factors associated with academic performance and obesity that have been identified in the literature – nature of the relationship

Factor	Academic Performance	Obesity
SES	Positive	Negative
Physical Activity	Positive	Negative
Sleep	Positive	Negative
Birth weight	Positive	Positive or U-shaped
Smoking during pregnancy	Negative	Positive
Breastfeeding	Positive	Negative
Parent-child interaction	Positive	Negative
Chronic health conditions	Negative	Positive

Socioeconomic status has also been found to play a role in the development of childhood obesity. Some studies have found a relationship between low parental education level and obesity, where the association appears to be stronger for younger children (32). Researchers have also found that childhood obesity is significantly related

to a lower family income or to poverty (32-35). Strauss & Knight (1999) examined the relationship of family income with the development of obesity in 2,913 US children aged 0-8 y over a six year period. Obesity was defined as BMI > 95th percentile for age and sex based on combined data from the first and second National Health and Nutrition Examination Surveys. Family income was categorized as low, medium or high based on the nationally weighted 15th and 85th percentiles of total family income of the entire cohort. After adjustment for covariates, the risk for developing obesity was 1.84 times greater (95% CI: 1.01- 3.34) for middle income children and 2.84 times greater (95% CI: 1.39-5.78) for low income children compared to children in the high income category. In addition, area-level factors of SES, such as a very high unemployment rate (> 9.0%), a very high prevalence of adult residents with less than a high school education (>35.4%) and a low average employment income based on the head of the household (<\$25,610) have been shown to increase the odds of childhood obesity (36).

SES, therefore, appears to be important in terms of children's physical as well as cognitive development.

2.1.2 Physical Activity Variables

While it is generally agreed upon that physical activity is beneficial to the health and well-being of students, it is less clear if regular physical activity can improve student's academic performance. Howard Taras (2005) recently conducted a review on physical activity and student performance at school. Only peer-reviewed articles, published after 1984, that examined school-aged children (5-18 y) were included. From the 14 studies included in the review, Taras found that overall, physical activity appeared to be positively related to student performance, but noted that the association was very

weak. Most of these studies had small sample sizes and Taras concluded that the beneficial effects of child physical activity levels may be subtle and detectable only when extremely large populations are studied, when physical activity programs are sufficiently aerobic, or when children have been exercising or been physically active for a sufficient length of time. It is clear that more evidence from studies with large sample sizes is needed to determine how physical activity or lack of physical activity is related to academic performance in children (37).

Physical activity and childhood obesity on the other hand, have been shown to be consistently and negatively correlated in the published literature. One large cross-sectional study (n = 7,216) found that 7-11 y old Canadian children who participated in unorganized sports had a 42% (95% CI: 0.48, 0.69) reduced odds for becoming obese after controlling for age, sex and SES (38). A meta-analysis of exercise training programs, lasting at least three weeks to treat childhood obesity (n =1,058), found that across all included study designs (randomized controlled trials, controlled trials and trials with no controls) exercise was efficacious for reducing selected body composition variables in children and adolescents (39). Specifically, the pre- to post decrease in body mass index was 0.76 kg/m^2 (95% CI: 0.24, 1.7) for those children being treated (39). Another small but rigorous prospective cohort study found that being physically active for at least 30 minutes a day had a major protective effect for the development of obesity in Greek elementary school-children over a one year time period ($P<0.05$)(40).

2.1.3 Total Daily Sleep, Sleep Quality and Sleep Patterns during Childhood

Sleep has been linked to academic performance in the literature. This is not surprising since intuitively it is well known that more sleep is better than less sleep in terms of efficiently conducting everyday tasks. A study of 713 Greek children aged 15-18 years found that the Athens Insomnia Scale score (AIS)¹ was inversely correlated with academic performance (categorized as 0 – 5; 0 = bad, 5 = excellent student) where AIS decreased 0.390 ± 0.114 points per 1 point increase in teacher rated student achievement ($P=0.001$) (41). Wolfson and Carskadon (2003) conducted a critical appraisal of the literature, which resulted in 14 relevant studies being reviewed. They concluded that self-reported shortened sleep time, erratic sleep/wake schedules, late bed and rise times, and poor sleep quality were negatively associated with academic performance in adolescents (42).

A possible mechanism for this relationship is child nocturnal arterial oxygen saturation. Urschitz et al (2005) recorded overnight motion-resistant new-generation pulse oximeter saturation in 995 primary school children and compared this to academic performance in mathematics based on the last school report. They found, after controlling for relevant confounders, that mild hypoxemia increased impaired mathematics performance by 65% (95% CI: 1.06, 2.56) and moderate hypoxemia increased the odds over 2-fold (OR: 2.28; 95% CI: 1.30, 4.01) (43).

¹ Instrument to assesses subjective complaints with sleep induction, nocturnal awakenings, final awakening, total sleep time and sleep quality in a four-point Likert-type scale. The scale has been validated against the ICD-10 diagnosis of insomnia, yielding sensitivity and specificity of 93% and 85% respectively

In terms of sleep and academic performance, the temporal relationship appears to be poor sleep then poor school performance. However, the temporal relationship between obesity and sleep is not clear. One cross-sectional study conducted in Texas (n = 383) found that obese adolescents aged 11-16 y experienced less sleep than their non-obese peers, and for each hour of sleep gained, the odds of obesity decreased by 80% (95% CI: 0.11, 0.34) (44). Obesity has also been found to be related to sleep-disordered breathing in children 2-18 y in an American case-control study (45). Children with a family history of sleep apnoea (n =273), and neighbourhood controls (n = 126) were assessed using overnight multi-channel monitoring. The odds ratio for obesity related to obstructive sleep apnoea (apnoea/hypopnoea index > 10) was 4.69 (95% CI: 1.58, 13.33) after controlling for SES and demographic factors (45). According to Deane & Thompson (2006), children with obstructive sleep apnoea can have drastically interrupted sleep with many episodes of obstruction and awakening that can result in daytime sleepiness, morning headaches and vomiting, poor school performance, and quality of life (46). Although some studies give plausibility to the argument that sleep debt could be a cause of obesity, it is also possible that low sleep quality follows as a result of the subjects being obese and having obstructive sleep apnoea (44).

2.1.4 Perinatal Variables

2.1.4.1 Birth weight

Birth weight may be the strongest confounder of the potential causal relationship between obesity and poor academic performance in children. In a meta-analysis that analyzed 15 matched case-control studies, Bhutta et al (2002) found that school age children who were born premature had significantly lower cognitive scores than control

children. Mean cognitive scores of both the pre-term cases and term-born controls increased as birth weight increased ($P < 0.001$). Within the low birth weight group, children who were born lighter performed less well than those born heavier, and overall, children who had a low birth weight performed less well than children who had a normal birth weight (47). One meta-analysis of six studies including children with low, normal and high birth weights that did not specifically focus on high risk infants such as those born pre-term or $< 2,500$ g, found that, after adjustment for confounders, the association between birth weight and cognitive scores was small but still positive, statistically significant, and consistent across studies (48). The effect size difference between the lightest and heaviest groups was approximately 10 IQ points, but the authors did not statistically synthesize the data of the six studies due to methodological heterogeneity (48).

In contrast, high birth weight has been found to predict childhood obesity (49-51). According to a review conducted by Oken & Gillman (2003) of over two dozen studies, almost all studies found direct, positive associations between birth weight and BMI; some of the small studies found no association; and no study found an inverse association. One large and recent prospective cohort study ($n = 2,934$) found that an increasing birth weight was significantly predictive of being overweight or obese at age five and at age 14 (RR 2.10; 95% CI: 1.50, 2.94) (50). Another recent, large prospective cohort study ($n = 1,430$) had similar findings in that, after adjustment for confounders in linear regression, birth weight was positively associated with BMI at age eight ($P = 0.001$) (51). However, the relationship between birth weight and obesity may not be linear as the evidence here

suggests. The association may actually be U-shaped as a very low birth weight has been found to predict central obesity, insulin resistance and metabolic syndrome later in life (49).

2.1.4.2 Maternal smoking during pregnancy

Smoking during pregnancy may have negative long-term effects on children that are independent of low birth weight. Cigarette smoke is a teratogen that contains many chemical compounds, a high proportion of which have been shown to cross the placental barrier (Jones et al 1989 as reported in Martin et al 2006). In terms of academic performance, smoking during pregnancy may affect foetal brain development leading to certain minimal types of brain damage such as learning difficulties, hyperkinetic impulse behaviour, and neurological soft signs (52). One recent prospective cohort study conducted in Finland found that, after adjustment for covariates, mean school grades at age 12 decreased as the number of cigarettes per day during pregnancy increased ($P < 0.01$), indicating a possible dose-response relationship (53). Another prospective study conducted on a Dutch birth cohort found that, after adjustment for confounders, problems with mathematics and spelling, assessed at ages 5.5 – 11 y, were directly proportional to the number of cigarettes mothers smoked during pregnancy (54).

Observational studies have also found that maternal prenatal smoking increases the odds for becoming obese later in life (55-58). A large Australian prospective cohort study ($n = 3,253$) found that at age 14, after controlling for confounders such as sex, SES, fast food consumption, amount of time spent watching television and participating in physical activities, children of mothers who smoked during pregnancy had a 40%

increased odds for being obese compared to children of mothers who had never smoked (95% CI: 1.01, 1.94) (56). One prospective cohort study conducted in Britain assessed obesity status at ages seven, 11, 16, 23 and 33 in relation to prenatal maternal smoking (58). The authors found that at every age, smoking in pregnancy was significantly and positively associated with obesity, where the strength of the association increased with age. At age 33, after adjustment for early life factors, childhood circumstances and adult factors, the odds for becoming obese among children whose mothers smoked during pregnancy were 55% (95% CI: 1.19, 2.00) and 45% (95% CI: 1.13, 1.87) higher than children of mothers who did not smoke, in males and females respectively (58). In addition, there is evidence of a dose-response relationship between maternal prenatal smoking and obesity development. A study conducted in Germany found that the prevalence of obesity at age 5 - 6.99 y increased as the number of cigarettes smoked daily increased (57).

2.1.4.3 Breast feeding

There is a vast literature on the health effects of breast feeding. From relevant studies, it appears that breast feeding is an important factor in child cognitive development. One large study of 2,734 sibling pairs from the 1994 wave of the National Longitudinal Study of Adolescent Health found that only cognition, as measured by the Peabody Picture Vocabulary Test (PPVT), remained significantly correlated with months of breast feeding in 'with-in family' comparisons after controlling for with-in family correlations (59). For every one month increase in breast feeding, the authors found that PPVT scores of children assessed in adolescence (~15 y) increased by 0.16 of a percentile point (95% CI: 0.003, 0.317). The association remained significant even when

the breast feeding exposure was simply termed 'yes or no'. This study used sibling comparisons to reduce sample selection bias that is common in observational studies, which the authors feel, provides persuasive evidence of a causal connection between breast feeding and intelligence (59). Another study of 1,401 Australian infants delivered to term found, after adjustment for confounders, that those who were breast fed for greater than six months had mean PPVT scores, assessed at age six years, that were 3.56 points higher than those children who were never breast fed (F test for linearity $P = 0.0003$) (60). To avoid residual confounding, one study investigated this relationship in a population where breast feeding was inversely related to socioeconomic advantages and healthy maternal behaviours ($n \sim 2,000$)(61). The authors found that, after adjustment for confounding, cognitive scores, as assessed by the Philippines Non-verbal Intelligence Test at 8.5 years, were higher for children of normal birth weight and low birth weight who breast fed for 12 to less than 18 months versus those who breast fed for less than six months (61). This relationship remained at 11.5 y, but was attenuated.

Observational studies also suggest that breast feeding may reduce the risk of overweight and obesity in later life. A meta-analysis that included nine studies (cohort, cross-sectional and case control study designs) which controlled for at least three pre-stated confounding or interacting variables (birth weight, parental overweight, parental smoking, dietary factors, physical activity and SES), and assessed the outcome between the ages of 5- 18 y, found that breast feeding significantly reduced the chance of developing of obesity (adjusted odds ratio in the fixed effect model = 0.78, 95%CI: 0.71, 0.85 where $n = 69,000$) (62). Sub group analysis showed no significant differences

between study types, age groups, definition of breast feeding or obesity and number of confounding variables controlled for. A longer duration of breast feeding has also been found to be associated, dose dependently, with a decrease in risk of overweight later in life. One recently conducted meta-analysis included 17 studies that examined the odds for overweight in relation to the duration of breast feeding by comparing breast fed infants to exclusively formula fed infants (63). The authors found that, after conducting meta-regression, the duration of breast feeding was inversely associated with the risk of overweight, and the dose-dependent relationship was confirmed after categorical analysis (63).

2.1.5 Parent-child interaction

The way in which parents interact with their children has been shown to impact on children's academic achievement, academic adjustment, memory processes and self-esteem (64-66). A longitudinal study conducted on 6,357 children aged 14-18 y who attended nine high schools in the US found that an authoritative parenting style (high acceptance, supervision, and psychological autonomy granting), defined using a composite score based on children's responses to a standardized questionnaire, was positively associated with self-reported grade-point-average and school engagement (64). Pallock & Lamborn (2006) studied 104 African-American adolescents aged 14 and 15 y to determine if the parenting dimensions: acceptance (warm, loving and supportive relationship between adolescents and their parents), behavioural control (regulation of adolescents' behaviour through consistent monitoring and supervision) and psychological control (shaping behaviours through guilt, causing anxiety, and withdrawing love) predicted children's grade point average, school values, teacher bonding and work

orientation (pride in task completion). The parenting dimensions were based on subscale scores of the 30-item version of the Child's Report of Parental Behaviour Inventory, and all of the outcomes (except GPA) were scaled based on responses to specific questions to form continuous variables. After controlling for sex and parents' education, adolescents' perceptions of acceptance were positively associated with school values, teacher bonding and work orientation. Behavioural control was positively associated with work orientation, and psychological control was negatively associated with work orientation. In addition, the type of attachment young children experience with their caregivers has been shown to impact children's mental development (66;67). Secure attachment is characterized by children who feel that they can trust and depend on their caregiver, largely as a result of sensitive and dependable behaviours exhibited by the caregiver (66). Secure attachment positively impacts children's self-esteem, advanced memory processes, conscience and emotional development, and even children's ability to develop meaningful relationships with teachers and friends (66;67).

In terms of child obesity, there is a small amount of literature that has examined the relationship between parent-child relations and weight status of the child. One recent study set out to determine the relationship between four parenting styles (authoritative, authoritarian, permissive, and neglectful), assessed when children were 54 months of age, and overweight status in first grade among 872 American children (68). Parenting styles were constructed with two scales: 1) maternal sensitivity to the child's needs and 2) maternal expectations for self-control. Maternal sensitivity to the child's needs was calculated as a composite score based on a standardized interaction task involving the

child and mother. Maternal expectations for self-control scale scores were based on maternal responses to a 32-item survey. Each scale was dichotomized and combined such that mothers scoring high on both scales were defined as authoritative (respectful of child's opinions, but maintains clear boundaries); mothers with low expectations for self-control but high sensitivity were defined as permissive (indulgent, without discipline); mothers with high expectations for self-control but low sensitivity were defined as authoritarian (strict disciplinarian); and mothers who were low on both scales were termed neglectful (emotionally uninvolved and does not set rules). Overweight was defined as BMI \geq 95th percentile for age and sex based on the CDC growth curves. After controlling for potential confounders, the authors found that children of authoritarian parents had five times the odds of being overweight compared to children of authoritative parents (95% CI: 2.15-11.10; $P < 0.001$). Also in comparison to authoritative parents, the odds for overweight in children of permissive parents was 2.84 times higher (95%CI: 1.10 – 7.35; $P = 0.03$), and the odds for children with neglectful parents was 2.67 times higher (95% CI: 1.12-6.38; $P = 0.03$). From this study, it appears that a parenting style that is not authoritative increases the child's risk for becoming overweight. Another study, conducted by Strauss and Knight (1999) on 2,913 American children, found after controlling for potential confounders, that children raised in environments with low and average cognitive stimulation (based on the Home Observation for Measurement of the Environment Short Form), had a 2.3- (95% CI: 1.10-4.72) to 2.7-fold (95% CI: 1.43 – 4.97) increased risk of developing obesity compared to children with high levels of cognitive stimulation (34). Obesity was defined as a BMI $>$ 95th percentile for age and

sex based on combined data from the first and second National Health and Nutrition Examination Surveys.

Evidence from the literature, therefore reveals the potential benefits of a stimulating and interactive home environment on children's weight status.

2.1.6 Chronic health conditions

Chronic health conditions in childhood may be associated with academic performance, as health conditions generally increase school absenteeism and decrease overall quality of life (69;70). Intuitively, it is likely that this would negatively impact school functioning. For example, Moonie et al (2006) determined that in a total cross-sectional sample of 9,014 students in grades K – 12, students with asthma (as determined by the school nurse) were consistently absent more often during the 2002-2003 school year than those that did not have asthma. The authors also evaluated the relationship of asthma severity with absences due to asthma in a subset of students with asthma (n = 543). They found, after adjustment for demographic variables and days enrolled, that as asthma severity increased so did mean days absent from school (ANOVA $P= 0.007$). Students with 'mild persistent', 'moderate persistent' and 'severe persistent' asthma symptoms were absent on average 4.3 days more than those without asthma (71). In regards to absenteeism, a study assessed this in a population of 283 adolescents aged 11 to 18 y suffering from recurrent headache and found that those absent from school more than two days in the previous six months did less well in school than those children who were only absent 0-2 days (72). According to Thies (1999), children and adolescents with chronic illness experience more academic difficulty than their healthy peers. Chronic conditions and their treatments can impact the central nervous system causing

impairments in visual scanning, spatial abilities, attention and memory (69). These effects on the central nervous system lead to difficulties in reading and problem-solving which can translate into impaired academic development. Chronic conditions tend also to create social and emotional problems which add to academic difficulties (69).

In terms of obesity, it is now relatively well established that childhood obesity has adverse chronic health effects that can develop and present in childhood (73). According to a systematic review of the health consequences of childhood obesity by Reilly et al (2003), obese children are more likely to experience psychosocial problems such as low self-esteem and behavioural problems, than their non-obese peers. Obese girls tend to experience these effects more often than obese boys and the prevalence of these conditions increases with age. The authors' conclusions were based on five studies that were rated as low risk of bias. Additionally, several studies evaluating the health-related quality of life of obese children using validated scales has shown that they experience decreased psychosocial functioning compared to their normal weight peers (15;74-76).

In Reilly et al's (2003) systematic review, 31 high quality studies examined the association of obesity (defined most commonly using BMI) or central obesity (defined using waist circumference) with cardiovascular disease risk factors measured in childhood. It was found from this review that childhood obesity has many of the same cardiovascular disease correlates as adult obesity, including elevated blood pressure, dyslipidaemia, abnormalities in left ventricular mass and/or function, hyperinsulinaemia and/or insulin resistance. Other short term health effects of childhood obesity include asthma (13;77-79) and inflammation (13).

2.1.7 Conclusion

In summary, academic performance and childhood obesity share many correlates that generally appear to stem from the child's environment and behaviours. These variables will need to be accounted for in subsequent statistical modeling.

2.2 Critical Appraisal of the Literature

This section details the critical appraisal of the literature that was conducted to determine what is currently known about the relationship between academic performance and childhood obesity. The review was conducted prior to the initiation of the study described in this paper (November 2006) and updated upon completion of the study (May 2007).

2.2.1 Selection of Studies

Studies were included if they examined the relationship of obesity with some measure of academic achievement or intelligence such as standardized math tests, grade point average or general tests of intelligence such as the Peabody Picture Vocabulary Test. These could be measured or self-reported. To be included, the temporal sequence of the relationship examined in the study had to show that obesity occurred before or during the assessment of academic achievement or intelligence, not after. Academic performance or intelligence had to be assessed during childhood (preschool, primary or secondary school). Those studies examining obesity and academic performance or intelligence of college/university students or adults were excluded.

Obesity also had to be defined in some way. Those studies that only examined body mass index (BMI – kg/m^2) and did not specify a definition of obesity were

excluded. All definitions of obesity were acceptable as some published studies preceded the definitions developed by the IOTF and the CDC revised growth charts that are commonly used today. Studies that were published earlier than 1996 and not written in the English or French language were excluded. Given the health risks associated with childhood obesity, randomized controlled trials were excluded due to ethical reasons – likely, no studies purposely made children obese. Only cohort, case-control and cross-sectional study designs were included. Finally, studies that examined populations living in Medium or Low Human Development Countries were excluded. Human development index² was used as a criterion because underdeveloped and developing countries have lower standards and invest less in education than developed countries. These countries generally have high socioeconomic inequalities where only the rich can afford quality education. Variations in wealth also result in obesity and malnutrition coexisting. Due to these and many other confounding factors, studies conducted in high human development countries may not describe the same relationship of obesity with academic performance as those conducted in low or medium human development index countries. Studies, therefore, may not be comparable across human development index.

Five electronic databases were searched – MEDLINE, EMBASE, CINHAL, Psych Info and In-process/non-indexed MEDLINE using the Ovid version 10.2.1 interface. An observational search filter was incorporated into the search strategies for MEDLINE, EMBASE and CINHAL. These search filters were an adaptation of those developed by the Scottish Intercollegiate Guidelines Network. Please see Appendix A for the search strategy employed in MEDLINE. Search strategies for the other databases

² Human Development Index available at: http://hdr.undp.org/statistics/data/pdf/hdr05_table_2.pdf

were similar so are not reported. Only one reviewer was available to assess inclusion/exclusion criteria. After duplicates and triplicate publications were removed from the initial search, the titles and abstracts of 2,865 potential studies were screened for inclusion. Full articles of the 21 remaining studies were obtained to more completely assess inclusion and exclusion criteria. Nine studies have consequently been included in this review. The reference lists of these nine articles were scanned for potentially relevant articles, but none were found.

2.2.2 Results and Discussion

Please see Table 2 for articles found and reviewed. Four of these studies were conducted in the US, two in Finland, one in Australia, one in Sweden and one in Iceland. Excluding the Swedish study, all had very large sample sizes of at least 666 subjects. A large sample size improves the power of a study to detect significant differences between those exposed and not exposed, in this case, differences in academic performance between obese versus non- obese children. All studies, except one, were conducted on adolescents (80). Three studies had a prospective cohort design (80-82), one was a case-control study (83) and five were cross-sectional studies (84-88). Of the three cohort studies, two assessed academic performance as the primary outcome, defined obesity and adjusted for relevant confounders. In the third cohort study, this was not the main intent of the authors, therefore, the association of obesity with academic performance was explored in crude preliminary analysis only (82). In the case-control study, academic performance was not the primary outcome nor was it defined, and no adjustment was made for confounding. For all five cross-sectional studies, academic performance was one of the main outcomes. One of these cross-sectional studies, however, compared non-

Table 2: Published research studies that examined the association of childhood obesity with academic performance in childhood and adolescence

Study	Design	Sample (total N and age)	Obesity Definition	Outcome Definition	Statistical Method	Statistical Adjustments	Main Effect of Obesity
Datar & Sturm, 2006 (80)	Prospective cohort	N = ~ 7,000 owing to differential missing data on various outcomes Followed from kindergarten to grade 3.	BMI (based on measured height and weight) $\geq 95^{\text{th}}$ percentile for sex and age using the CDC growth charts. Height and weight were measured at each data collection point. Constructed key predictor variable: categorical variable that equals 0 if child is never obese, equals 1 if not obese at baseline but obese in grade 3, and equals 2 if always obese. Children obese at baseline and not obese in grade 3 were dropped from the analysis (n=139)	Individually administered math and reading assessments to compute item response theory scale scores for each participant on each test. Assessments were conducted at each data collection point.	Hierarchical linear regression	Race, age, SES, school-level factors, urbanicity, physical activity, parent-child interaction, hours of TV watching, birth weight and stratified by gender	**Reference category is never obese** <u>Math test scores:</u> Girls who became obese -1.623 \pm 0.753; p < 0.05 <u>Reading test scores:</u> Girls who became obese -2.541 \pm 0.924; p < 0.01
Huang et al, 2006(87)	Cross-sectional	N = 666 11-14 y	BMI (based on measured height and weight) $\geq 85^{\text{th}}$ percentile for sex and age using the CDC growth charts. Compared to normal weight children defined as those with a BMI < 85 th percentile but $\geq 5^{\text{th}}$ percentile.	-Self-reported grades in the last year on a 4-point scale (0, mostly Fs to 4, mostly As) -Actual, measured grade-point average from the previous year (4-point scale)	Linear mixed models	Gender, race, age, physical activity	**Reference category is normal weight** <u>Self-reported GPA</u> -0.21 \pm 0.08; p \leq 0.01 <u>Measured GPA</u> -0.05 \pm 0.07; NS

Table 2: Published research studies that examined the association of childhood obesity with academic performance in childhood and adolescence

Study	Design	Sample (total N and age)	Obesity Definition	Outcome Definition	Statistical Method	Statistical Adjustments	Main Effect of Obesity
Sigfusdottir et al, 2006 (86)	Cross-sectional	N = 5810 14-15 y (9 and 10 th graders)	BMI (based on self-reported height and weight) > 85 th percentile was considered overweight. Did not use a reference population or mention if age and sex specific. Overweight was compared to not overweight.	A scale ranging from 0 to 28 derived from self-reported average grades in Icelandic, Mathematics, English and Danish (or Norwegian or Swedish) Grades in Iceland range from 0 – 10 with < 5 = failing grade. Response categories for each of the subjects ranged from 0 – 7 where 0 = a grade of under 4, 1 = about 4, 2= about 5 and so on.	Student's t-test	None	Mean grade scale score for > 85 th %ile = 15.16 (SD=5.69) Mean grade scale score for ≤ 85 th %ile = 16.86 (SD=5.70) t = -1.70 p<0.01
Lawlor et al, 2005 (88)	Cross-sectional	N = 5172 14 y	BMI (based on measured height and weight) > 22.62 kg/m ² for boys and > 23.34 kg/m ² for girls – this is based on the IOTF obesity definition. The variable was binary: obese versus not-obese	Cognitive function assessed by two tests (both dichotomized into ≤ 25 th percentile and > 25 th percentile): 1) Raven's standard progressive matrices 2) Wide Range Achievements Test version 3 (WRAT3)	Chi-square test	None	<u>Raven's (% obese)</u> ≤ 25 th 25.3 >25 th 20.7 p = 0.003 <u>WRAT3 (% obese)</u> ≤ 25 th 25.3 >25 th 20.7 p = 0.003

Table 2: Published research studies that examined the association of childhood obesity with academic performance in childhood and adolescence

Study	Design	Sample (total N and age)	Obesity Definition	Outcome Definition	Statistical Method	Statistical Adjustments	Main Effect of Obesity
Crosnoe & Muller, 2004 (81)	Prospective cohort	N = 11,658 Mean age = 15.8 y (followed for one year)	BMI (based on self-reported height and weight at Wave I) $\geq 85^{\text{th}}$ percentile for sex and age using the CDC growth charts. The variable was binary - At Risk of Obesity (overweight) compared to Not at Risk (not overweight)	Self-reported grades for four subjects (math, science, English and social studies). These responses ranging from 1(D or F) to 4 (A) were averaged across subjects and then converted to a standard four point grade point average	Hierarchical linear modelling	Race, age, gender, SES, athletic status	Risk of obesity (SE) (unadjusted for baseline academic performance) -0.05 (0.02) $p < 0.001$ (adjusted) -0.01 (0.01) NS
Laitinen et al, 2002 (82)	Prospective cohort	N = 9,754 Followed from age 14 to 16	BMI (based on self-reported height and weight at age 14) $\geq 95^{\text{th}}$ percentile at age 14 and by sex. (23.7 kg/m ² for males and 23.8 kg/m ² for females – percentiles based on the internal population) Obese compared to overweight (85 th – 95 th percentile) and normal weight (<85 th percentile)	School marks at age 16 from national registers. Mean scores of all subjects were calculated from school reports at the end of compulsory primary school and categorized as low, moderate and good	Pearson's Chi-squared test	None	Males (% not reported) χ^2 for obesity and school performance $p = 0.025$ Females (% not reported) χ^2 for obesity and school performance $p = 0.033$
Mikkilä et al, 2002 (84)	Cross-sectional	N = 60,252 14-16 y	Relative weight > 120% (Relative weight expressed as a percentage of the mean weight for sex and height	Divided adolescents into tertiles of school performance based on calculated mean value of the marks on their	Logistic regression	Stratified by gender and adjusted for socioeconomic and health	**Lowest tertile is reference. Odds ratio (95% confidence interval) ** <u>Middle Tertile</u>

overweight to overweight adolescents in the preliminary stages of the study and did not adjust for confounding factors (86). The primary intent of the authors was to investigate mean BMI with academic performance using linear regression. Another cross-sectional study assessed the association of cognitive function with overweight in the preliminary stages of analysis and also did not control for confounders (88). The main intent of this study was to investigate clustering of cardiovascular risk factors with low cognitive scores. Of the three cross-sectional studies that assessed academic performance as the primary outcome and controlled for relevant confounders, all found significant negative effects of obesity on academic performance. However, only one uncovered this relationship using actual student grades (84). The other two reported a significant association of obesity with self-reported grades or self-reports of being a poor student (85;87).

The most recent study of childhood obesity and academic performance was the only study of the nine reviewed here that examined the link between *change* in obesity status and academic performance (80). Height and weight were directly measured and used to calculate BMI. Measured height and weight is much more accurate in determining obesity status than self or parent-reported height and weight. Results of this study showed that females who were not obese in kindergarten and became obese sometime between kindergarten and the start of third grade, did worse academically than females who were never obese during the same time period. No significant differences were found for females who were always obese or for males who became obese or were always obese compared to never obese. A potential source of bias in this study is the

response rate, as the study authors did not report this. It may be that participation was mandatory and all children originally sampled did in fact participate. However, if this was not the case and those that did not respond were somehow different from responders in terms of a variable that was related to the exposure and outcome, a bias in the study may have resulted. Similarly, if participation was not mandatory, bias could have resulted from losses to follow-up. The authors did not report any losses, however, if there were and the reasons for them were related to the exposure and outcome, the study results would be biased. As well, the authors did not state that outcome assessment was made blind to exposure status. If this study was an analysis of secondary data, blinding would not have been an issue, however, the reader cannot be sure of this. Failing to blind researchers, who measure or record outcomes, to exposure status may introduce bias into the results of the study. Finally, the authors controlled for relevant confounders in this study but may have over-controlled in terms of socioeconomic factors. They did not check for the presence of multicollinearity in the prediction models. If present, this may have inflated the standard errors around parameter estimates so that associations that were shown to be non-significant may actually have been statistically significant.

The second longitudinal study that specifically examined the relationship of obesity with academic performance took into account obesity status at only one point in time – at baseline, and only used self-reported height and weight (81). Academic performance was measured both at baseline and at the last data collection point and was also self-reported. After controlling for socio-demographic factors and subjects' athletic status, risk of obesity (overweight) was negatively associated with academic performance

measured one year later. This association did not stay significant when baseline academic performance was added to the model indicating that being overweight was not associated with worsening or improving academic performance over time (one year). A third model revealed significant interactions of risk of obesity with two school-level factors: percentage of athletic participation and mean student romantic activity. This indicates that the negative association of risk of obesity with academic performance is weaker in schools in which there is a high percentage of students participating in athletics and stronger in schools with a high percentage of students involved in romantic activities. Due to the design of this study, subjects were considered always overweight or never overweight, when it is possible that they changed categories after the first data collection point. This may have resulted in a certain degree of misclassification of overweight, here referring to the potential underestimation of overweight, as intuitively it would seem more likely for normal weight individuals to become overweight than for overweight individuals to become normal weight, especially in a US population where the childhood prevalence of overweight and obesity increase with age (89). As well, the follow-up time was very short, only one year. The exposure time, therefore, may not have been sufficient to determine the full effect of overweight on academic performance. In addition to the short follow-up time, health factors/outcomes tend not to be as strongly correlated with overweight as they are with obesity. More significant associations of higher magnitude may have resulted if the authors had chosen to use obesity as their exposure variable instead of overweight. Finally, as in the previous study, the authors do not mention that outcome assessment was blinded to exposure status.

From the limited data provided in this review, it appears that obese children may be more likely to do poorly in school, where this relationship is stronger in girls than boys, and in adolescents compared to children. However, of these studies, only two were longitudinal and assessed academic performance as part of the primary objective. The remaining seven studies were either cross-sectional or case-control and/or did not plan to assess the association of obesity with academic performance as the primary objective. Therefore, based on this weak body of literature it is not possible to conclusively determine if the association between childhood obesity and academic performance is likely causal.

2.2.3 Limitations

One limitation of this review is that the literature search was restricted to the published literature only. This could have introduced publication bias as studies that had found a null effect for the relationships examined in this review may not have been published and therefore, not included here. Another limitation is that only one person assessed articles for inclusion. This may have introduced bias into the review as relevant studies may have been missed; interpretation of inclusion criteria may have been wrong or inconsistent; or the reviewer may have subconsciously included certain studies over others. It is inherently less biased for two or more people to review studies for inclusion criteria. Therefore, important studies may have been missed that could have contributed useful information to this review. Studies were also not systematically assessed for quality. Thus, it is unknown which studies may need to be interpreted with caution. However, in this review, studies that: 1) had a prospective design, 2) controlled for

confounders, 3) examined the association between obesity and academic performance as the primary objective, and 4) used actual grades or directly measured academic performance (i.e. a math test administered by the researcher), were considered of higher quality compared to studies missing these characteristics. Finally, included studies were restricted to the English and French languages. This may have missed important studies conducted in Scandinavia, Europe and Japan.

CHAPTER 3: Study Objectives and Conceptualizing Variable Relationships

3.1 Goal

The overarching aim of this project is to analyse the effect of childhood obesity on academic performance.

3.2 Objective

The objective of this study is to determine whether obesity during childhood is related to academic performance, independently of other factors, using a large representative sample of Canadian children (National Longitudinal Survey of Children and Youth).

3.3 Hypotheses

***Hypothesis 1 (general):** obesity is related to lower academic performance, independently of other factors;*

***Hypothesis 2:** children who are obese for all or most of their childhood will have significantly lower math scores than children who are never obese;*

***Hypothesis 3:** children who develop obesity will have significantly lower math scores than children who are never obese;*

***Hypothesis:** children who grow out of obesity will have significantly lower math scores than children who are never obese*

3.4 Conceptualizing Variable Relationships

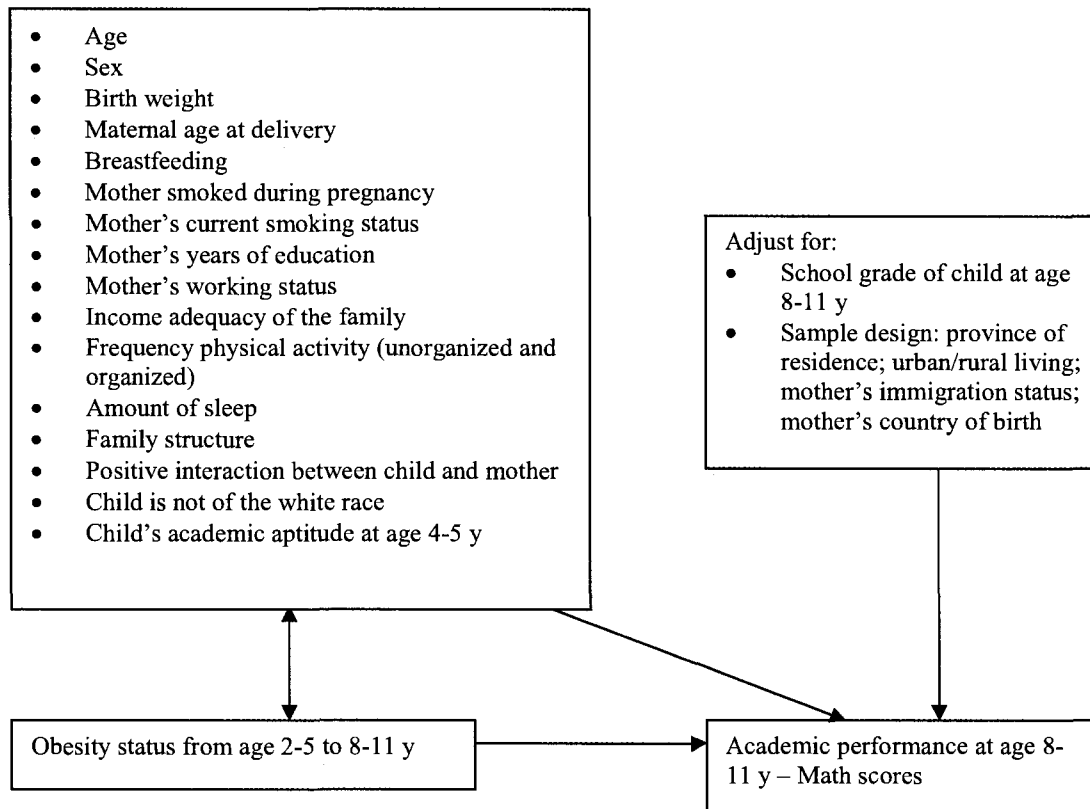
The data dictionary of the National Longitudinal Survey of Children and Youth (NLSCY) was reviewed following the literature search presented in the previous chapter (section 2.1), to determine similar variables that should be added during model development to control for confounding. These variables are presented in Table 3.

Table 3: Potential confounders identified in the NLSCY

Socio-demographic/economic	Behavioural	Early environment and health	Related to sample design of NLSCY
<ul style="list-style-type: none"> ▪ Age 	<ul style="list-style-type: none"> ▪ Amount of sleep 	<ul style="list-style-type: none"> ▪ Birth weight 	<ul style="list-style-type: none"> ▪ Province of residence
<ul style="list-style-type: none"> ▪ Sex 	<ul style="list-style-type: none"> ▪ Positive interaction of child and mother 	<ul style="list-style-type: none"> ▪ Maternal age at delivery of child 	<ul style="list-style-type: none"> ▪ Urban/rural living
<ul style="list-style-type: none"> ▪ Race (white vs not white) 	<ul style="list-style-type: none"> ▪ Frequency of physical activity 	<ul style="list-style-type: none"> ▪ Maternal smoking during pregnancy 	<ul style="list-style-type: none"> ▪ Mother's immigration status
<ul style="list-style-type: none"> ▪ Income adequacy 		<ul style="list-style-type: none"> ▪ Maternal smoking status during childhood 	<ul style="list-style-type: none"> ▪ Mother's country of birth
<ul style="list-style-type: none"> ▪ Family structure 		<ul style="list-style-type: none"> ▪ Breastfeeding 	
<ul style="list-style-type: none"> ▪ Mother's working status 		<ul style="list-style-type: none"> ▪ Early academic aptitude of the child 	
<ul style="list-style-type: none"> ▪ Mother's years of education 		<ul style="list-style-type: none"> ▪ Child's chronic condition status 	
<ul style="list-style-type: none"> ▪ School grade 			

From this, a simplistic framework was developed to conceptualize the complex relationship of obesity with academic performance in the context of the NLSCY. Please see Figure 1 for this framework (next page).

Figure 1: Conceptual Framework



CHAPTER 4: Methods

4.1 Data source: The National Longitudinal Survey of Children and Youth

This study was conducted with data from the National Longitudinal Survey of Children and Youth (NLSCY). The NLSCY is a nationally representative, prospective longitudinal study of Canadian children (90). It began in 1994 and was designed to follow children aged newborn to 11 years into adulthood, with data collection occurring at two-year intervals. It is the biggest national survey assessing the development and well-being of Canadian children as they grow from infancy to adulthood. So far, the data from six cycles (last being 2004/2005) are available for analysis at Research Data Centres across Canada.

For the longitudinal cohort, in terms of sampling children for the NLSCY, the starting point was the household (90). Households that were currently or had recently participated in Statistics Canada's Labour Force Survey (LFS), and contained children 0-11 years, became the household sample for the NLSCY. The LFS is conducted monthly on a representative sample of the Canadian population and employs a stratified, multi-stage probability sample design based on an area frame in which residences are the sampling units (90). Approximately 12,900 households with children 0-11 years were selected for inclusion into the NLSCY. Children living in the Yukon, North West Territories, on Indian Reserves, or in institutions were not sampled as the LFS excludes these populations from its sampling frame.

Children of each economic family were then selected at random up to a maximum of four children per household (91). Due to response burden, the maximum number of children that could be sampled within the household was dropped to two in cycle 2 and beyond. Approximately 69% of the sample responded in all five cycles (see Table 4) (91).

Table 4: Total number of children followed longitudinally in the NLSCY that were 0-3 years of age in cycle 1

Cycle	Age	Number of Respondents
1	0-3	6,968
2	2-5	6,402
3	4-7	6,223
4	6-9	5,566
5	8-11	5,386
All 5 cycles	0-3 to 8-11	4,801

The main respondent in the NLSCY was the person in the household most knowledgeable (PMK) of the child; usually this was the mother but could be a father, step-parent or adoptive parent. The PMK provided information about her/himself, her/his partner, the selected child(ren) and household members through a telephone or personal interview (91). Children who were 10-11 in cycle 5 also filled out a paper self-complete questionnaire which addressed various aspects of the child's life. For the sake of simplicity, PMK will be referred to as the mother as the proportion of mothers responding as the PMK was approximately 90% for all five cycles.

4.2 Sample

Statistics Canada's Research Data Centre in Ottawa was used to access the master files for cycles 1 -5 of the NLSCY to develop a statistical model that tested for the effects

of obesity status in childhood on academic performance at 8-11 y of age. The sample was limited to children: 1) 0-3 years in cycle 1; 2) 8-11 years in cycle 5; and 3) responded in all five cycles (funnel survey weight > 0). Limiting the sample to those children who responded in all five cycles was necessary as some relevant covariates were measured in different cycles. The largest possible sample size for the present study was therefore 4,801 (see Table 4). Those children that were flagged as having moved out of the country or deceased were deleted from the final sample. Of the entire longitudinal cohort at cycle 5 (aged 8 – 15y) only eight children had died, and 72 had moved permanently out of the country (91). A breakdown for only the 8-11 y olds was not possible due to Statistics Canada's confidentiality policies.

4.3 Measures

Univariate analysis was carried out on all considered variables to assess their distributions. Continuous variables, in particular, were assessed for the presence of outliers. All continuous variables were found to have approximately symmetrical distributions. Considering that this is an analysis of secondary data, it is assumed that the assessment of the outcome was blinded to exposure status and vice versa as the exposure was not conceptualized at the time of data collection.

4.3.1 Outcome

The outcome variable is a measure of academic achievement - a mathematics test administered directly by NLSCY interviewers to the responding children. The test is a shortened version of the Mathematics Computation Test of the Standardized Canadian Achievement Tests: Second Edition (CAT/2) and is considered to be an objective measure of children's academic performance in mathematics (91). It consists of 20

questions designed to test a child's ability to do addition, subtraction, and multiplication and division operations on whole numbers, decimals, fractions, negatives and exponents where the level of complexity depends on the grade of the child. The raw scores of the CAT/2 were not used as the outcome variable of interest. Rather, a scaled math score derived using item response theory (IRT) was used, as this provides for more precision in the estimates of test performance (91). All scores were adjusted for grade level by subtracting the within grade mean IRT math score from each child's original IRT math score.

Other measures of academic performance available in the NLSCY were mother-reported. These variables were based on the mother's opinion of her child's performance in math, reading, writing, and overall school performance, and included the response categories very poor, poor, average, well and very well. These variables were not used as outcomes in the analysis due to their high subjectivity.

4.3.2 Main Predictor

The predictor of interest in this relationship is obesity status throughout early childhood. The presence of obesity was assessed at each cycle except cycle 1, as the cohort was too young, and was based on body mass index (BMI – kg/m^2) derived from mother-reported height and weight of the child. Both the CDC and IOTF definitions of childhood obesity were used in order to rule out bias due to using one obesity definition over the other. For the CDC definition, children were considered obese if their BMI was $\geq 95^{\text{th}}$ percentile for age and sex based on the 2000 CDC BMI-for-age-and-sex growth charts (92). In terms of the IOTF definition, children were considered obese if their BMI

was \geq the age- and sex-specific obesity cut-off BMI provided by Cole et al (4). A categorical variable for each obesity definition was then created to capture the change of obesity status over time. Since many respondents did not report height, weight or both for all four cycles (cycle 2 -5) only cycles 2 and 5 were used in constructing the categorical 'obesity status' variable. This reduced the percentage of missing observations from approximately 50% to 25%. The categorical obesity status variable was created as follows:

1. Not obese in cycle 2 or cycle 5
2. **Obese** in cycle 2; **not** obese in cycle 5
3. **Not** obese in cycle 2; **obese** in cycle 5
4. Obese in cycle 2 and cycle 5

For the sake of simplicity, category one will be referred to as 'never obese', category two as 'grew out of obesity', three as 'developed obesity', and four as 'always obese'.

4.3.3 Covariates

Those variables identified in the literature and available in the NLSCY were considered for inclusion in the final statistical model. All continuous covariates were assessed for linearity with the outcome through residual analysis - if the bivariate relationship was non-linear the covariate was categorized.

4.3.3.1 Socio-demographic/economic variables

a) Income adequacy: The original variable in the NLSCY had five categories (90).

Categories one and two had to be collapsed for this analysis due to small cell counts (see Table 5).

Table 5: Income adequacy categories and their definitions

Category Name	Definition
Lowest	Household income is < 10,000 and household size is 1-4 persons; or household income is < 15,000 and household size is 5 or more persons
Lower-middle	Household income is 10,000-14,999 and household size is 3-4 persons; or household income is 15,000-29,999 and household size is 5 or more persons
Middle	Household income is 15,000-29,999 and household size is 1-2 persons; or household income is 20,000-39,999 and household size is 3-4 persons; or household income is 30,000 to 59,999 and household size is 5 or more persons
Upper-middle	Household income is 30,000-59,999 and household size is 1-2 persons; or household income is 40,000-79,999 and household size is 3-4 persons; or household income is 60,000-79,999 and household size is 5 or more persons
Highest	Household income is 60,000 or more and household size is 1-2 persons; or household income is 80,000 or more and household size is 3 or more persons

b) Number of years of education the mother has received: continuous

c) Mother's working status: dichotomous – 1) mother currently working; 2) mother not currently working.

d) Family structure: dichotomous - 1) child lives in a two-parent family; 2) child lives in a one-parent or 'other' type of family (i.e. child not living with a parent).

e) Age of the child in cycle 5: categorical

f) Child's race: dichotomous – 1) white; 2) not white

g) Sex of the child: dichotomous – 1) male; 2) female

4.3.3.2 Behavioural Variables

a) Average daily hours child sleeps in cycle 5: Originally this variable was continuous but was found to have a curvilinear rather than a linear relationship with the standardized

IRT math scores. Subsequently, it was categorized based on tertiles of the continuous distribution.

Table 6: Tertiles of average daily hours child sleeps in cycle 5

	Category Name	Definition
1.	Low	4-9 hours/day
2.	Moderate	> 9 -10 hours/day
3.	High	>10-13 hours/day

b) Positive interaction scale score (mother with the child): this scale was designed to measure the positive interaction, ineffectiveness and consistency of the parenting of the child. The score is based on factor analysis and ranges from 0 to 20 (Cronbach's Alpha of 0.778) where 20 indicates high positive interaction between mother and child. Questions that make up the scale were provided by Dr. M. Boyle of the Chedoke-McMaster Hospital, McMaster University, and based on the work of Dr. Ken Dodge, Vanderbilt University, and an adaptation of the Parent Practices Scale of Strayhorn and Weidman (91). When the standardized IRT score was regressed on the positive interaction scale score, the relationship did not appear to be linear or homoscedastic, so it was dichotomized based on the 50th percentile into 1) low positive interaction (score of 0 to 12) and 2) high positive interaction (score of 13 to 20).

c) Physical activity levels

1) Child's frequency of participation in organized sports (i.e. with a coach or instructor) in cycle 5;

2) *Child's frequency of participation in unorganized sports (i.e. without a coach or instructor) in cycle 5*

For the 8-9 year olds, both of these variables were reported by the mother. However, for the 10-11 year olds they were self-reported. This presented a problem as not only were two different points of view being combined, measuring two potentially different things, but also the variables were not exactly coded the same in the survey (Table 7).

Table 7: Example of differences in PA variables between 8-9 and 10-11 y olds - unorganized sports*

	8-9 y olds, mother-reported	10-11 y olds, self-reported
Question wording	'In the past 12 months, outside of school hours, how often has this child taken part in unorganized sports or physical activities without a coach or instructor?'	'During the past 12 months, how often have you played sports or done physical activities WITHOUT a coach or instructor (biking, skateboarding etc)'
Response categories	1. Most days 2. A few times a week 3. About once a week 4. About once a month 5. Almost never	1. Never 2. Less than once a week 3. 1 to 3 times a week 4. 4 or more times a week
*response categories are the same for organized sports		

For the 8-9 y old group, the PA variables were dichotomized into *frequent* and *infrequent* participation, where frequent included 'most days', 'a few times a week' and 'about once a week', and infrequent included 'about once a month' and 'almost never'. For the 10-11 y old group the PA variables were also dichotomized into *frequent* and *infrequent*. However, the frequent group contained the categories '1 to 3 times a week' and '4 or more times a week', and the infrequent group consisted of 'less than once a week' and 'never'. In order to determine if it was appropriate to combine the four

variables into two that could be used in a statistical model, the distributions of the two variables were compared across age groups and then compared again in terms of their effect on the standardized IRT math score – see Tables 8 and 9.

For both variables, the univariate distributions appeared to be similar across age groups. In terms of the standardized IRT math score, there does not appear to be significant differences between group means across the two age groups as confidence intervals overlap (i.e. mean for 8-9 y olds who are frequent unorganized sports players is 0.5 (95% CI: -2.2, 3.2) versus -0.2 (95% CI: -3.6, 3.4) for 10-11 y olds).

Table 8: Frequency of PA participation by age group

	Frequent (%)	Infrequent (%)	Total N
Organized sports			
8-9 y	62.3	37.7	2302
10-11 y	65.7	34.3	1829
Unorganized sports			
8-9 y	73.5	26.5	2295
10-11 y	76.7	23.3	1843

Clearly it is questionable, even when no differences are found, to go ahead and combine the two age groups. However, the main purpose of this project is to determine the effect of obesity status on academic performance. Since physical activity is not the main predictor and has been found to be a confounder of this relationship in the literature, it was thought that using these two combined variables to control for physical activity was better than not controlling for physical activity at all.

Table 9: Comparison of math scores by PA variable across age group

Standardized Math Score	Unorganized sports		Organized Sports	
	Frequent	Infrequent	Frequent	Infrequent
<i>8-9 y olds</i>				
Mean	0.5	-0.2	-1.5	3.1
95% CI	-2.2 to 3.2	-5.4 to 5.0	-4.2 to 1.2	-1.3 to 7.5
N	1436	523	1258	708
<i>10-11 y olds</i>				
Mean	-0.2	-0.3	1.5	-3.45
95% CI	-3.6 to 3.4	-7.1 to 6.5	-2.0 to 5.0	-9.9 to 3.0
N	1323	406	1131	585

4.3.3.3 Early Environment and Health Variables

a) Child's birth weight: continuous and measured in grams.

b) Mother's age at birth of the child: continuous.

c) Mother's smoking status: This was a dichotomous variable with 1) daily or occasional smoker 2) non-smoker. Smoking during pregnancy could not be totally measured in this sample because this question was only asked of mothers of 0 -1 y olds in cycle 1 (8-9 y in cycle 5).

d) Standardized Peabody Score: This was a continuous variable that measured academic aptitude – and is based on the Peabody Picture Vocabulary Test (PPVT-R). This test was administered to the sample when they were four or five years old to assess receptive vocabulary achievement and verbal ability. It is used as an indicator of linguistic and cognitive development (93). The purpose of controlling for academic aptitude is that changes in obesity status can be related to changes in academic performance, which helps to eliminate the influence of unobserved confounders that are fixed over time (80).

However, to ultimately control for changes in academic performance (in this case, math

scores) and eliminate unobserved confounders, we should be controlling instead using scores from the same or a similar math test administered to children when they first started school. Children entering school, however, generally cannot do math.

Nonetheless, vocabulary is a strong predictor of school success and in this context, the PPVT-R can be used as an initial screening device for pre-school children who may have high or low academic ability (93).

e) Child's chronic health condition status: This was a dichotomous variable with a yes/no response. A chronic condition could include food or digestive allergies, respiratory allergies, 'other' allergies, bronchitis, heart condition or heart disease, epilepsy, cerebral palsy, kidney condition or disease, mental handicap, learning disability, attention deficit disorder (with or without hyperactivity), or emotional, psychological or nervous difficulties, all of which have been diagnosed by a health care professional (94).

4.4 Statistical Analysis

All analysis was conducted using child funnel weights provided by Statistics Canada using SAS v 9.1. Each unit (child) in the sample represents a number of units in the population. The funnel weight is a longitudinal weight calculated for children who *have data collected in all five cycles*. The longitudinal weighting of all-cycle respondents represents the original population at the time of selection (91). All weights were re-scaled to the un-weighted sample size by dividing an observation's funnel weight by the mean for the entire sample. Since the standard errors from any weighted analysis underestimate the true variance, boot-strap estimates of variance were calculated using a SAS program provided by Statistics Canada and 1000 bootstrap replicates. All statistical tests were two-tailed where the level of significance was set at $P \leq 0.05$.

4.4.1 Preliminary Analysis

Bivariate analysis was conducted to assess crude associations between the outcome and main predictor, between the outcome and covariates and between the main predictor and covariates using simple linear regression, the two sample t-test, and the Chi-squared test of independence.

As well, a few covariates had the potential to change over time where their values early in the child's life may have been important in addition to their values in cycle 5. These included: income adequacy, mother's total years of education, mother's working status, mother's smoking status, child's chronic health condition status, family structure and positive interaction. Values for these variables were examined in each of the five cycles and categorical variables constructed to determine if the differences between early life and cycle 5 values warranted further exploration.

4.4.2 Model Specification

Multivariate linear regression was used to test for the effect of obesity status over time on academic performance, while controlling for important confounders. Model specification involved building two separate models – one with the obesity predictor based on the CDC definition of obesity and the other with the obesity predictor based on the IOTF definition. The same model building steps occurred in each of these models and included both continuous and categorical confounders. Each categorical variable was dummied and the reference category left out of the model. The first step involved forcing all covariates and obesity status into the model. From this full model, the betas of each of the obesity categories (grew out of obesity, became obese, always obese) were compared to those same betas when one covariate was taken out of the full model. If any of the

betas changed by 20% or more, the covariate was deemed a confounder and left in the final model. Each model also tested for the presence of interaction of sex with obesity status. Four covariates were forced into the model regardless of whether they had an effect on the obesity betas. These were:

- Child's province of residence in cycle 1;
- Size of the population child lived in at cycle 1 - rural, small city, or large city living;
- Mother's immigration status in cycle 1 - new immigrant of < 10 years versus not a new immigrant;
- And mother's country of birth – Canada/US versus other.

A similar previous study using the NLSCY included these variables because they were strongly related to the NLSCY sample design, which is based on geography, immigration and other socio-demographic variables (95). A model without these variables may be misspecified or ill-fitting (95).

Since many of the covariates had the potential to be highly related to one another, the final models were examined for evidence of multicollinearity using variance inflation factors (*VIFs*). Multicollinearity was considered to be present if betas had *VIFs* of 10 or more.

4.4.3 Influence Analysis

A problem with NLSCY survey weights arises because the distribution of weights is highly skewed, where very few children have high survey weights. If a regression model is less than perfect, these few observations with high survey weights can have a

large influence on model parameters (95). Because of this, it is recommended that one conduct an influence and fit analysis to determine the effect of survey weights on model parameters (95). A detailed influence analysis was therefore carried out on the final weighted and un-weighted models. Studentized residuals (*rstudents*) from each of the models and one summary measure of influence, *Cook's D*, were examined in detail.

An observation's residual by itself sometimes hides the fact that it is highly influential and therefore, is not a great tool for diagnosing influence. The reason for this is that an outlier with high leverage usually causes the fitted line to be shifted towards it which reduces the magnitude of the residual. The *rstudent*, however, is sensitive both to an observation's distance from the fitted line *and* to its degree of leverage (96).

Essentially, the *rstudent* is a type of standardized residual adjusted for the observation's leverage, where large values of *rstudent* will occur when observations have large residuals or high leverage, and especially high values when an observation has both (96). The distribution of *rstudents* was examined in both the weighted and un-weighted models to detect outliers and to determine model fit.

Cook's Distance (D_i) measures the extent to which the regression coefficients change when the i^{th} observation is deleted. D_i may be large either because the observation has a large *rstudent* or because the observation has high leverage, or both (97). A scatter plot of D_i for all observations was constructed to identify extreme values relative to the sample. Criteria for defining influential values can be based on external scaling, internal scaling and noticeable gaps in the distribution of the influence statistic (98). External scaling provides absolute cut-off values to determine extreme values and is based on statistical theory. According to Dupont (2002) a $D_i > 1$ is considered large

(99). Hamilton (1992) suggests a cut-off of $D_i > 4/n$ (100). Absolute cut-offs, however, are based on assumptions about the distribution of the residuals and may risk missing relatively influential data (95). Internal scaling involves specifying cut-offs based on examination of the influence statistic's distribution and/or graphical analysis (98). Highly influential observations are immediately detected because extreme influence statistics stand out relative to the sample. Therefore, scatter bubble plots of *rstudents* by predicted value of the standardized IRT math score were also created for both weighted and un-weighted models to visually examine the fit of the final models and to detect influential observations. The bubbles in the plot represent the D_i of each observation where the larger the bubble, the larger the D_i . In addition, the *rstudents* of the weighted and un-weighted models were compared before and after deletion of the influential observations.

CHAPTER 5: Results

5.1 Descriptive

The total sample of children used in this analysis was 4,664, representing 67% of the original cohort sampled in cycle 1 and 97% (4664/4801) of 'all cycle respondents'. Since, the IRT math scores were standardized based on grade level (grades 2 -6), a few children could not be used in constructing the final models because they were either in grade one or grade seven at the time of cycle 5 (n =17). The effective sample size then was reduced to 4,647. These 17 children, however, were included in the preliminary analysis not involving the outcome. In cycle 2 when children were 2-5 y of age, 24.7% were obese (IOTF), whereas in cycle 5 when children were 8-11 y, only 10.5% were obese. The same trend occurred using the CDC definition where the corresponding values were 34.2% and 15.1% respectively. The IOTF prevalence estimates are comparable to a similar study using the NLSCY (101). The larger difference between the CDC and IOTF estimates in cycle 2 may be due to the fact that IOTF reference values tend to give lower estimates for young children and higher estimates for older children (7).

Figure 2, shows the percentages of children within each obesity status category using cycle 2 and cycle 5 data. Approximately 26% of children did not have height, weight or both recorded for one or both cycles and thus were not included in the construction of this variable and the final models. In terms of BMI, Table 10 shows mean BMI by obesity status group in cycle 2 and cycle 5 using the IOTF definition of obesity. Estimates for the CDC definition are similar so are not shown here.

Figure 2: Obesity status category percentages for the CDC and IOTF definitions

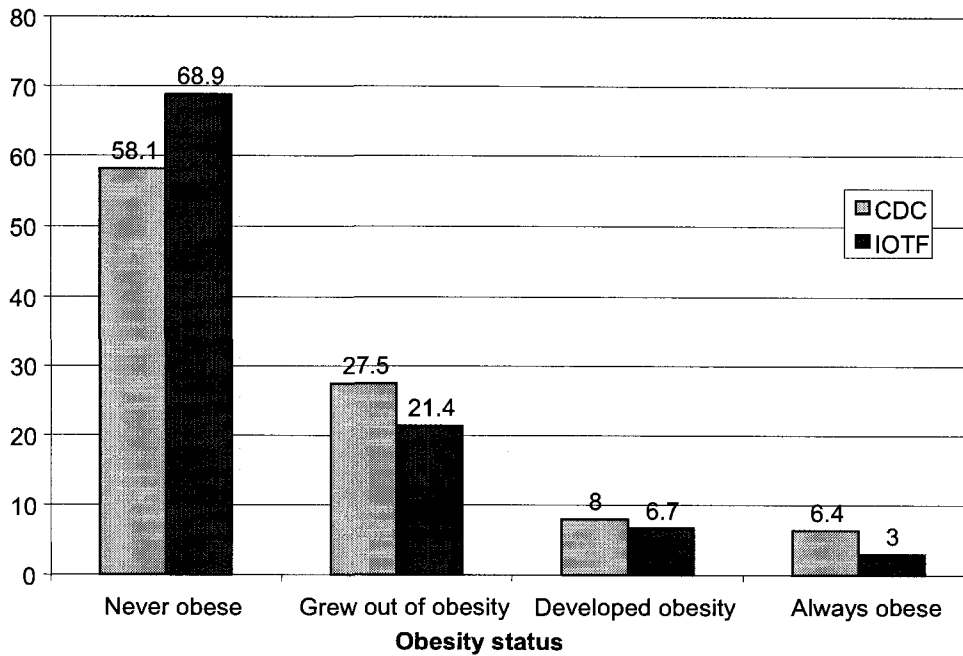


Table 10: Mean BMI by obesity status in cycle 2 and cycle 5

Obesity status (based on IOTF)	Mean BMI (95%CI)	
	Cycle 2: Children aged 2-5 y	Cycle 5: Children aged 8-11 y
Never obese	15.8 (15.7 – 15.9)	17.4 (17.2-17.6)
Grew out of obesity	23.2 (22.8 – 23.6)	17.9 (17.5-18.3)
Developed obesity	16.3 (15.9 – 16.7)	26.6 (25.9 – 27.2)
Always obese	24.0 (22.9 – 25.0)	26.7 (25.8 -27.7)

The within grade means for the IRT math scores are shown in Table 11. After standardization, the mean of the IRT math scores was 0.0 (95%CI: -1.9, 1.9), the median was -3.4 and scores ranged from -114 to 131. The distribution of the standardized IRT math scores was approximately symmetric, reducing the likelihood of some observations being highly influential in further analysis as a symmetrical distribution indicates few or no major outliers. Standardization of the math scores was based on the entire sample (n = 4,647).

Grade	Mean IRT Math Score
2	313.3
3	334.2
4	370.3
5	400.4
6	452.0

Table 12 shows the demographic, economic, behavioural, health, early environmental factors and survey-specific variables (measured in cycle 1) for the total sample in cycle 5, as well as for those with and without height and weight data. Very few children lived in families in the two lowest income adequacy categories and few children were not white. More children without height and weight data, however, were not white and had mothers who were new immigrants and were born outside of Canada/US, compared to children with height and weight data for cycles 2 and 5.

Table 13 shows the means and standard errors of the academic aptitude score (from the PPVT-R) and standardized IRT math score by obesity status. For both scores

Table 12: Sample Characteristics

	Have height and weight data	Missing height and/or weight data	Total Sample	
	Means (SE) and Percentages		Means (SE) and Percentages	N
Male	51.3	49.1	50.7	4664
Age:				4664
8	23.3	28.2	24.6	
9	24.7	26.3	25.1	
10	25.7	25.5	25.6	
11	26.3	20.1	24.7	
Child is not white	7.0	19.7	10.3	4659
Income adequacy:				4664
Lowest/lower middle	7.2	11.9	8.4	
Middle	21.7	26.4	23.0	
Upper Middle	35.4	32.2	34.5	
Highest	35.7	29.6	34.1	
Child does not live in a two-parent family	18.2	22.8	19.4	4664
Years of education mother has received	13.8 (0.06)	13.6 (0.13)	13.8 (0.05)	4598
Mother is not currently working	21.9	25.1	22.8	4591
Child participates in unorganized sports <i>infrequently</i>	23.8	28.8	25.1	4138
Child participates in organized sports <i>infrequently</i>	34.0	42.3	36.2	4130
Mother's age at birth of child (y)	29.1 (0.14)	28.6 (0.27)	29.0 (0.13)	4600
Child's birth weight (g)	3416.2 (18.4)	3351.2 (34.2)	3399.2 (16.8)	4525
Positive interaction score (out of 20 where 20 = high positive interaction)	12.4 (0.08)	12.1 (0.14)	12.3 (0.07)	4574
Mother is a daily or occasional smoker	26.1	24.6	25.7	4572
Child has a chronic condition	30.7	27.7	29.9	4632
Avg daily amount of sleep (h)	9.6 (0.02)	9.6 (0.06)	9.6 (0.02)	4613
Academic aptitude (PPVT-R at age 4/5)	100.1 (0.44)	95.3 (0.87)	98.9 (0.41)	4065
Standardized Math IRT Score	-1.3 (1.1)	3.5 (1.8)	0.0 (0.97)	4647
Population density where child lived in cycle 1:				4664
Rural (no count given)	17.9	17.2	17.7	
Small city (< 100,000)	20.1	19.7	20.0	
Large city (\geq 100,000)	62.0	63.2	62.3	
Mother born outside Canada/USA	12.8	24.4	15.8	4654
Mother was a new immigrant (< 10 years) in cycle 1	5.1	15.5	7.8	4653

there does not appear to be any significant differences between the obesity groups and the never obese group for both definitions of obesity, save one; for the IOTF definition of obesity, children who were always obese had a significantly lower mean academic aptitude score compared to children who were never obese ($P = 0.0001$). Since the math scores were standardized based on the entire sample and approximately 26% of children did not have BMI data, the math scores (after being weighted) in Table 13 do not add to zero. The mean math score for children who did not have BMI data was 3.5 (SE = 1.8).

Table 13: Bivariate analysis of baseline academic aptitude and standardized IRT math score by obesity status using the CDC and IOTF definitions of childhood obesity

	Never obese			Grew out of obesity			Developed obesity			Always obese		
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
CDC: BMI \geq 95th %ile for age/sex												
Academic aptitude score	100.7	0.6	1764	99.8	0.8	819	98.9	1.4	236	97.4	2.1	196
Standardized IRT math score	-0.7	1.5	1738	-1.1	1.9	815	-5.6	3.1	225	-1.9	3.8	179
IOTF: BMI \geq the equivalent of 30 kg/m² for age/sex												
Academic aptitude score	100.2	0.5	2094	100.8	1.0	631	99.2	1.4	200	93.7*	1.6	90
Standardized IRT math score	-1.8	1.4	2061	2.1	2.4	633	-5.2	3.8	183	-5.8	4.6	82

* denotes significantly different from the 'never obese' group at the 1% level based on a two-tailed t-test

5.2 Relationship of obesity status with covariates

A Chi-squared analysis of independence for all the categorical covariates showed that sex ($P = 0.001$), 'mother is a daily or occasional smoker' ($P = 0.02$), 'child does not live in a two-parent family' ($P = 0.05$), and population density ($P = 0.02$) were all

significantly related to the obesity status predictor based on the CDC obesity definition. Conversely, using the IOTF definition, age ($P = 0.01$), 'mother is a daily or occasional smoker' ($P = 0.03$), and population density ($P = 0.04$) were significantly related to the obesity status predictor. Please see Table 14 for actual group percentages.

Table 14: Covariates that were significantly related to obesity status - group percentages

	Never obese	Grew out of obesity	Developed obesity	Always obese
<i>Obesity status- CDC</i>				
Sex				
Female	52.0	48.2	35.6	37.7
Male	48.0	51.8	64.4	62.3
Mother smokes daily or occasionally				
No	77.2	68.8	69.0	72.6
Yes	22.8	31.2	31.0	27.4
Child lives in a one-parent or 'other' family type				
No	84.6	78.1	75.8	79.3
Yes	15.4	21.9	24.2	20.7
Population Density				
Large city	64.3	61.3	54.8	54.0
Small city	20.0	19.8	19.4	23.1
Rural	15.7	18.9	25.8	22.9
<i>Obesity status- IOTF</i>				
Age:				
8 yrs	21.3	26.2	27.4	42.6
9 yrs	25.7	19.5	28.9	28.0
10 yrs	26.1	27.0	21.0	16.3
11 yrs	26.9	27.3	22.7	13.1
Mother smokes daily or occasionally				
No	76.1	68.5	73.4	63.3
Yes	23.9	31.5	26.6	36.7
Population Density				
Large city	63.4	62.5	54.9	43.8
Small city	19.7	19.7	21.4	29.3
Rural	17.0	17.8	23.7	26.9

To assess associations between the continuous covariates and obesity status, t-tests were conducted. Based on the CDC definition, the 'always obese' group had mothers with significantly fewer years of education ($P = 0.01$) than the mothers of the 'never obese' group. In addition, all of the obesity groups (grew out of, became and always) had mothers who were significantly younger in age at the time of their birth than the never obese group (all probabilities were ≤ 0.005). Similar associations were seen using the IOTF definition: the 'always obese' group had mothers with significantly fewer years of education ($P = 0.0001$) than the 'never obese' group; and all obesity groups (grew out of, became and always) had mothers who were significantly younger in age at the time of their birth than the never obese group (all probabilities were ≤ 0.02).

5.3 Relationship of math scores with covariates

To further assess associations and potential confounders, the outcome was regressed on continuous covariates. Mothers' age at birth (0.58, 95%CI: 0.25 to 0.91), years of schooling mother had received (1.85, 95%CI: 0.95 to 2.75), and academic aptitude score (0.23, 95%CI: 0.083 to 0.38) were all positively and significantly associated with the outcome (all probabilities were ≤ 0.0025). T-tests were conducted to assess associations between math scores and the categorical covariates. Smoking, income adequacy, child's chronic condition status, child's race, 'mother was a new immigrant in cycle 1', 'mother is foreign born', and rural living were all significantly related to math scores. Children whose mother smoked in cycle 5 had significantly lower standardized math scores than children of mothers who never smoked ($P = 0.0009$). Compared to the highest income adequacy group, the lowest/lower middle, middle, and upper middle

groups had significantly lower standardized math scores with $P = 0.046$, $P = 0.038$ and $P = 0.001$ respectively. Children who had a chronic condition in cycle 5 had significantly lower standardized math scores than children who did not have a chronic condition ($P=0.043$). Math scores, however, were significantly higher for children who were not white compared to white children ($P= 0.027$). Similarly, children of mothers who were new immigrants in cycle 1 or of mothers who were not born in Canada/USA had significantly higher math scores with p-values for both of 0.007. Finally, those children who lived in a rural area in cycle 1 had significantly lower math scores than those children who lived in a large city ($P = 0.046$).

5.4 Assessing the effect of changing covariates

There were a few variables that had the potential to change overtime where the definition of the variable remained constant from cycle 1 to cycle 5, and therefore, could be accounted for during model building. Income adequacy increased over the 10 year period where 48% of children experienced an increase, 41% stayed the same and only 11% decreased. The highest income adequacy category increased by almost 21% whereas the percentages of all the lower categories decreased. However, children whose income adequacy increased or decreased did not score any differently on the math test than children whose income adequacy stayed the same. In addition, change in income adequacy was not significantly related to obesity status.

Mother's smoking status also changed slightly where 4.4% fewer mothers smoked daily or occasionally in cycle 5 than in cycle 1. Most of the smokers in cycle 5 (80%)

had smoked since cycle 1. Even though some mothers quit smoking, this did not have a significant effect on math scores. For those mothers who smoked in cycle 1 and cycle 5, it did not matter if they were categorized as 'always smoker' (versus 'never smoker') or 'daily or occasional smoker in cycle 5' (versus 'non smoker') as both were significantly related to math scores. Similarly, both were significantly related to obesity status in the unadjusted analysis. Therefore, the change in smoking status was similar to the effect of current or cycle 5 smoking status on both the outcome and predictor.

In terms of working status, 28% of mothers did not work when their children were very young (0-3 y) but worked later on (when their children were aged 8-11 y). The majority of mothers (49%) always worked and very few gave up working when their children got older (7%). The change in mother's working status, however, was not associated with math scores or obesity status.

The frequency of children not living in a two-parent family increased approximately 6% over the 10 year period. Twelve percent of children began life in a two-parent family but experienced a change in their family structure requiring adjustment to living in a one parent or no parent family environment. This change, however, was not associated with math scores or obesity status.

Children also experienced changes in their chronic health condition status. Most (64%) never had a chronic condition, while 20% had developed some sort of a condition by cycle 5; only 6% had grown out of the condition and 10% always had a condition.

Children who had a chronic health condition in cycle 5 scored significantly lower on the math test than children who did not. However, when taking into account the change categories (developed, grew out of and always) and comparing them to 'never having a chronic condition' in terms of math scores, only the 'grew out of the condition' group scored significantly lower ($P= 0.04$). This association could be due to random error or highlight important consequences of having a chronic health condition early in life. Intuitively, however, children who have had a chronic condition all along would be more likely to be affected cognitively and psychosocially. In addition, change in chronic condition status was not significantly related to obesity status.

In terms of the continuous covariates that had the potential to change over time, from cycle 1 to cycle 5, the number of years of education mothers had received increased on average by only one year, and the positive interaction score of the mother with the child changed from being highly skewed in cycle 1, where most children had high positive interaction with their mothers, to being symmetrically distributed in cycle 5.

Since the categorical change variables did not appear to be important confounders, and the level of mother's education did not increase substantially from cycle 1 to cycle 5, as well as the fact that the highly skewed distribution of positive interaction scores in early cycles would not likely be all that discriminative, only cycle 5 values for the above mentioned variables were used in model building.

5.5 Final model

Table 15 shows the multivariate linear regression estimates of the relationship between change in obesity status and academic performance for both definitions of obesity, before influence analysis. The two final models were only slightly different in that race and child's chronic health condition status were significant confounders in the IOTF but not the CDC model, and birth weight was a significant confounder in the CDC model and not the IOTF model. All other covariates were the same. Both physical activity variables and mother's working status in cycle 5 were not significant confounders in either model so were not included in the final models. None of the obesity status groups (grew out of obesity, developed or always) based on the CDC definition of obesity were significantly different than the 'never obese' group in terms of the outcome, and no interactions of sex with obesity status groups were significant. For the IOTF definition, however, children who grew out of obesity had significantly higher math scores than children who were never obese. The only statistically significant interaction of sex with obesity status was with the developed obesity group where it appears that males who developed obesity scored significantly higher on the math test than girls who were never obese. Due to missing data, the effective sample size for the CDC model was 2,565 and 2,601 for the IOTF model. The corresponding adjusted R^2 s were **0.0951** and **0.1007** respectively

Table 15: Multivariate linear regression parameters of change in obesity status on standardized IRT math scores with relevant covariates

Independent Variables	CDC: BMI \geq 95 th %ile for age/sex			IOTF: BMI \geq the equivalent of 30 kg/m ² for age/sex		
	Beta	SE	P-value	Beta	SE	P-value
Obesity status *						
Grew out of obesity	2.86	2.39	0.2314	6.86	2.78	0.0138
Developed obesity	-4.72	3.50	0.1778	-10.76	5.23	0.0396
Always obese	2.07	4.84	0.6684	3.06	5.62	0.5861
Interaction of sex with 'developed obesity'	<i>Not included in final model</i>			16.42	7.95	0.0388
Covariates						
Male sex	4.47	2.27	0.0492	3.32	2.21	0.1337
Population density [§]						
Rural living	1.62	2.53	0.5226	1.01	2.49	0.6841
Small city living	4.38	2.67	0.1012	3.82	2.63	0.1466
Mother foreign born	3.78	4.98	0.4479	2.05	5.22	0.6920
Mother new immigrant in C1 (< 10 y)	2.04	8.58	0.8123	0.49	8.47	0.9536
Age*						
Eight yrs old	-1.59	3.38	0.6376	-1.53	3.32	0.6453
Nine yrs old	4.64	3.54	0.1895	4.44	3.51	0.2053
Ten yrs old	-2.64	3.07	0.3895	-2.53	2.97	0.3946
Child is not white	<i>Not included in final model</i>			3.0	7.02	0.6693
Income adequacy ^f						
Upper –middle	-7.26	2.74	0.0079	-7.15	2.70	0.0080
Middle	-6.24	3.43	0.0690	-4.84	3.40	0.1545
Lowest/Lower middle	-9.15	4.86	0.0600	-8.14	4.76	0.0874
Not living in a two-parent family	3.38	3.38	0.3184	2.59	3.35	0.4389
Mother years of education	0.72	0.65	0.2662	0.92	0.65	0.1571
Child has a chronic health condition	<i>Not included in final model</i>			-4.09	2.30	0.0748
Child's birthweight	-0.0028	0.0020	0.1553	<i>Not included in final model</i>		
Mother's age at birth of the child	0.37	0.23	0.1084	0.38	0.23	0.1018
Mother smokes daily or occasionally	-6.24	3.22	0.0524	-5.42	3.10	0.0805
Child's ppvt score at age 4/5	0.32	0.09	0.0003	0.30	0.09	0.0008
High positive interaction score (child and mother)	1.12	2.29	0.6240	0.65	2.26	0.7726
Average h of daily sleep **						
Child sleeps >9-10 h a day	-1.84	2.71	0.4976	-1.92	2.67	0.4733
Child sleeps >10-13 h a day	-5.17	3.0	0.0854	-4.79	2.99	0.1084

Note: * Reference is never obese [§] Reference is large city living ^v Reference is 11 year olds ^f Reference is highest income adequacy
 ** Reference is child sleeps 4-9 h a day. Model also controlled for province of residence

A standard criterion was developed to diagnose highly influential observations based on graphical analysis of Cook's D for both CDC and IOTF weighted and un-weighted models. For both models, observations with a Cooks D of > 0.02 were considered extreme and deleted (Appendix B-E). Bubble plots of un-weighted and weighted models were constructed to illustrate how the survey weights influenced model fit - please refer to Appendix F-I. For both definitions of obesity, extreme observations in the weighted model have much larger bubbles (larger Cooks D) than their corresponding values in the un-weighted model. The weighted model also has observations with much larger studentized residuals, i.e. the largest *rstudent* in the un-weighted CDC model is not quite four but is nine in the corresponding weighted model. In terms of model fit, the studentized residuals for both weighted models appear to be homoscedastic and normally distributed, indicating adequate model fit. The *VIFs* of the model parameters in the two models were all < 10 indicating that multicollinearity was not large enough to lead to unstable variance estimates. Based on the definition derived from graphical analysis of Cooks D, 18 observations were deleted from the CDC model and 19 were deleted from the IOTF model. Sixteen of these observations were common to both models. Please see Table 16 for the adjusted multivariate linear regression estimates for both models (influential observations dropped).

For both models (CDC and IOTF), the betas of many variables changed after dropping the influential observations. In both adjusted models, the only obesity group that was significantly different from the 'never obese group' was the 'grew out of obesity' group. The original models may have underestimated this relationship, as the difference in math scores between the two groups jumped from 2.86 (95%CI: -1.82, 7.54)

Table 16: Multivariate linear regression parameters of change in obesity status on standardized IRT math scores with relevant covariates - influential observations dropped

Independent Variables	CDC: BMI \geq 95 th %ile for age/sex			IOTF: BMI \geq the equivalent of 30 kg/m ² for age/sex		
	Beta	SE	P-value	Beta	SE	P-value
Obesity status *						
Grew out of obesity	6.09	2.0	0.0024	11.23	2.27	0.0000
Developed obesity	-4.49	3.07	0.1439	-4.06	3.56	0.2540
Always obese	5.29	4.37	0.2260	4.80	5.50	0.3832
Covariates						
Male sex	2.35	1.33	0.1945	2.68	1.74	0.1226
Population density [§] :						
Rural living	1.72	1.83	0.4396	1.24	2.19	0.5709
Small city living	3.90	1.69	0.0949	3.48	2.33	0.1345
Mother foreign born	1.84	2.60	0.6326	0.35	3.71	0.9240
Mother new immigrant in C1 (< 10 y)	2.12	4.15	0.7384	5.36	7.11	0.4512
Age [¶] :						
Eight yrs old	-3.18	1.95	0.2363	-2.63	2.67	0.3247
Nine yrs old	1.44	1.88	0.5887	1.22	2.65	0.6444
Ten yrs old	-4.37	1.81	0.0656	-4.23	2.35	0.0712
Child is not white	<i>Not included in final model</i>			-5.35	5.39	0.3207
Income adequacy [¶] :						
Upper -middle	-4.38	2.18	0.0448	-3.64	2.15	0.0892
Middle	-5.32	3.0	0.0760	-3.51	2.96	0.2359
Lowest/Lower middle	-9.26	4.02	0.0214	-8.28	3.97	0.0368
Not living in a two-parent family	2.82	3.06	0.3570	2.21	2.94	0.4529
Mother years of education	1.62	0.50	0.0013	1.73	0.51	0.0007
Child has a chronic health condition	<i>Not included in final model</i>			-1.73	1.88	0.3578
Child's birthweight	-0.0019	0.0018	0.2895	<i>Not included in final model</i>		
Mother's age at birth of the child	0.09	0.19	0.6157	0.13	0.19	0.4839
Mother smokes daily or occasionally	-3.53	2.36	0.1350	-3.31	2.24	0.1392
Child's ppvt score at age 4/5	0.39	0.07	0.0000	0.31	0.07	0.0000
High positive interaction score (child and mother)	-0.54	1.84	0.7706	-0.56	1.82	0.7600
Average h of daily sleep ^{**} :						
Child sleeps >9-10 h a day	-1.28	2.10	0.5437	-1.73	2.03	0.3952
Child sleeps >10-13 h a day	-4.16	2.82	0.1395	-3.21	2.68	0.2302

Note: * Reference is never obese [§] Reference is large city living [¶] Reference is 11 year olds [¶] Reference is highest income adequacy
 ** Reference is child sleeps 4-9 h a day. Model also controlled for province of residence

to 6.09 (95%CI: 2.17, 10.01) in the CDC model, and 6.86 (95%CI: 1.41, 12.31) to 11.23 (95%CI: 6.78, 15.68) in the IOTF model. Interaction of sex with the 'developed obesity' group also became non-significant in the IOTF adjusted model (removed from the final adjusted model). In terms of covariates, both of the original models may also have overestimated the effect of income adequacy on math scores, particularly in the higher income adequacy categories, and underestimated the effect of the number of years of education the mother had in cycle 5, where the betas increased in magnitude and changed from being statistically non-significant to highly significant. The original CDC model also estimated a higher sex effect, as the fitted sex effect changed from being statistically significant to non-significant in the adjusted model.

Individual values of the descriptive variables could not be reported for each of these dropped influential observations due to confidentiality reasons. However, all had exceptionally high survey weights (all above the 90th percentile) and either lived in a large urban centre, a large province (Quebec, Ontario or British Columbia) or both. For the weighted CDC model, the largest absolute studentized residual dropped from almost nine (18 observations kept) to 4.3 (18 observations dropped). This same analysis was carried out on the un-weighted CDC model where the largest absolute *rstudent* changed only slightly from 3.85 to 3.92. Similarly, the largest weighted absolute *rstudent* in the IOTF model decreased from 8.7 (19 observations kept) to 4.3 (19 observations dropped), and the largest un-weighted absolute *rstudent* increased trivially from 3.85 to 3.91 after dropping the same 19 observations. The impact of removing the influential observations was far greater in the weighted model than the un-weighted model, which supports the

argument that the survey weights likely caused observations to become highly influential rather than unusual covariate values. Dropping these observations also slightly increased model efficiency as the adjusted R²s increased from 0.0951 and 0.1007 to 0.1128 and 0.1175, for the CDC and IOTF models respectively.

5.6 Assessing non-response

The main predictor and outcome had the highest number of missing responses. Twenty-six percent (n = 1225) of the sample was missing values for obesity status (both definitions), 13% (n = 627) did not complete the math test and 3% (n = 155) were missing both. Table 17 shows math response status by obesity status. There were no significant differences between responders and non-responders in terms of obesity status.

Table 17: Math responder status by obesity status					
	Never obese (%)	Grew out of obesity (%)	Developed obesity (%)	Always obese (%)	Total (n)
CDC: BMI \geq 95th %ile for age/sex					
Math non-responders	53.1	27.6	10.9	8.5	471
Math responders	58.9	27.5	7.6	6.0	2968
Total	58.1	27.5	8.0	6.4	3439
<i>P</i> = 0.30					
IOTF: BMI \geq the equivalent of 30 kg/m² for age/sex					
Math non-responders	63.5	22.1	10.0	4.4	471
Math responders	69.8	21.3	6.2	2.8	2968
Total	68.9	21.4	6.7	3.0	3439
<i>P</i> = 0.22					

Examination of the differences between math non-responders and responders on selected covariates (Table 18) revealed that math non-response was significantly related to mother's current working status, child's chronic health condition status and participation in organized sports. More mothers were not currently working in the math

non-responder group compared to the responder group. In the non-responder group, the proportion of children with a chronic condition was higher and the frequency of participation in organized sports was lower compared to responders. Mother's working status and physical activity were not significant confounders of the relationship between obesity status and academic performance and were subsequently left out of the final models. The child's chronic condition status was added to the IOTF model but was not a significant predictor in the final model.

Table 18: Selected characteristics of math non-responders versus math responders

Descriptive Variable	Math non-responders	Math responders	Total	p-value
Male sex	54.1	50.2	50.7	0.27
Age:				
8	27.5	24.2	24.6	0.26
9	28.3	24.6	25.1	
10	23.4	26.0	25.6	
11	20.9	25.2	24.7	
Income adequacy:				
Highest	30.6	34.7	34.1	0.39
Upper-middle	34.0	34.6	34.5	
Middle	24.5	22.7	23.0	
Lowest/Lower- middle	10.9	8.0	8.4	
Mother is not currently working	29.7	21.8	22.8	0.02*
Child is not white	11.9	10.1	10.3	0.56
Mother years of education (SE)	13.5 (0.14)	13.8 (0.06)	13.8 (0.05)	0.06
Mother born outside Canada/US	15.7	15.9	15.8	0.96
Mother new immigrant in cycle 1 (< 10 y)	6.3	8.0	7.8	0.40
Child has a chronic health condition	38.8	28.7	29.9	0.004**
Child participates infrequently in organized sports	43.9	35.3	36.2	0.03*
Academic aptitude - PPVT-R (SE)	97.4 (0.93)	99.1 (0.44)	98.9 (0.41)	0.11

Chi-square test for proportions and T-test for means

*Denotes significantly different at the 5% level; **Denotes significantly different at the 1% level

Interestingly, those children that were missing height, weight or both in cycle 2, cycle 5 or both, had a higher mean standardized IRT math score compared to children not missing this data (Table 19). At the other extreme, however, these children had significantly lower academic aptitude scores (assessed at ages 4 or 5) than children not missing height and weight data. Height and weight non-response decreased significantly as age of the child increased and as income adequacy increased. Whether the child was white or not, significantly affected height and weight response. Similarly, twice as many children in the missing group had mothers who were born outside of Canada or the US compared to children with valid height and weight data, and three times as many children in the missing group had mothers who were new immigrants in cycle 1. Participation in organized sports was also significantly related to height and weight non-response where the proportion of children participating infrequently in organized sports was much higher in the missing height and weight data group compared to the non-missing group.

Table 19: Selected characteristics of children with height and weight data in cycles 2 and 5 versus children missing this data

Descriptive Variable	Missing height and/or weight for cycle 2 and 5	Height and weight data for cycle 2 and 5	Total	p-value
Male sex	49.1	51.2	50.7	0.47
Age:				
8	28.2	23.3	24.6	0.04*
9	26.3	24.7	25.1	
10	25.5	25.7	25.6	
11	20.1	26.3	24.7	
Income adequacy:				
Highest	29.6	35.7	34.1	0.012*
Upper-middle	32.2	35.4	34.5	
Middle	26.4	21.7	23.0	
Lowest/lower middle	11.9	7.2	8.4	
Mother is not currently working	25.1	21.9	22.8	0.27
Child is not white	19.7	7.0	10.3	0.0002**
Mother's years of education (SE)	13.6 (0.13)	13.8 (0.06)	13.8 (0.05)	0.16
Mother born outside Canada/US	24.5	12.8	15.8	0.0003**
Mother new immigrant in cycle 1 (< 10 y)	15.5	5.1	7.8	0.0001**
Child has a chronic condition	27.7	30.7	29.9	0.26
Child participates infrequently in organized sports	42.3	34.0	36.2	0.007**
Academic aptitude - PPVT-R score (SE)	95.3 (0.87)	100.1 (0.44)	98.9 (0.41)	0.000**
Standardized math score (SE)	3.5 (1.8)	-1.3 (1.1)	0.0 (0.97)	0.025*

Chi-square test for proportions and T-test for means

*Denotes significantly different at the 5% level; **Denotes significantly different at the 1% level

CHAPTER 6: Discussion

6.1 Summary

To our knowledge this is the first study to investigate the association between obesity status and measured academic performance in a representative sample of Canadian children. In this sample, the prevalence of obesity declined as children grew older. This may be because rates of overweight and obesity tend to be overestimated when parents report their child's height and weight at younger ages (2-5 y) versus at older ages (6-11 y) (102).

It was found, using two different definitions of obesity, that children who were obese when they were 2-5 y but grew out of obesity by the time they were 8-11 y, scored significantly higher on the CAT/2 math test than their peers who did not experience obesity at any point in their lives. This difference was adjusted for grade level and independent of sex, age and many other covariates known to affect weight status and academic performance both in early life and throughout childhood. The effect was much more pronounced when using the IOTF definition of obesity compared to the CDC definition. Nonetheless, in both models, this relationship was highly significant. Using the CDC definition of obesity, children who grew out of obesity scored on average 6 points higher on the math test than children who were never obese. Whereas using the IOTF definition these children scored approximately 11 points higher. This finding, however, runs contrary to the original hypothesis where it was thought that obesity early in life would impact negatively on children's cognitive development and subsequent

academic performance. In terms of the main and secondary hypotheses in this study, results were found to be null; children who were always obese in early childhood did not score any differently on the math test than children who were never obese, and children who developed obesity by the time they were 8-11 y but who were not obese in early life did not score any differently than children who were never obese. For all obesity status indicators, the results were the same for both boys and girls as no interaction with sex was found to be significant. Finally, low income adequacy, educational attainment of the mother and children's academic aptitude, measured at age 4 or 5, were all found to be important covariates in the obesity status/academic performance relationship.

In terms of non-response, math non-responders and responders were not substantially different on most characteristics analyzed. Height and weight non-responders appeared to come from a lower socioeconomic background based on a lower income adequacy, a higher proportion of non-white children, higher proportion of children of mothers born outside of Canada or the US, higher proportion of children of mothers who were new immigrants in cycle 1, and less organized sports participation, compared to responders. Since SES has been found to be inversely related to obesity in children, it is possible that these children may be more likely to be obese. However, it is difficult to determine the effect of the missing data on obesity status as four pieces of data were required (height and weight at cycles 2 and 5) to calculate obesity at two time periods and then categorize into obesity groups. Some children may have only been missing height or weight or both. Since there is such a wide variation in what measurements children could be missing at the two time points, it is unlikely that having

missing data for height, weight or both for cycle 2, cycle 5 or both is related to obesity status. For instance, 50% of the sample was missing height, weight or both in at least one cycle from cycles 2-5.

Math test scores were significantly higher in the height and weight non-responder group compared to responders yet academic aptitude scores were significantly lower. A possible explanation for this is that more non-responders had mothers who were new immigrants and were born outside of Canada or the US. The academic aptitude test is based on the English or French language; children new to Canada may not have had a good grasp of the language at the time the test was administered and thus did not score well. On the other hand, immigration status has been found to be positively related to school performance at the grade three level. Thus, after learning English or French and the Canadian culture, children of immigrant parents may have placed themselves at an equal advantage in terms of academic achievement compared to children of parents born in Canada, and were able to score at their true potential on the math test. However, both immigration status and being born outside of Canada or the US were not statistically significant in the final models. Therefore, if these children were included with valid height and weight data, they likely would not significantly change the results.

6.2 Interpretation

The literature linking obesity to academic performance is weak at best. The finding here that chronic obesity (i.e. obese at 2-5y and at 8-11 y) is not associated with academic performance coincides with the findings of Datar & Sturm (2006) and a study conducted in Thailand, where changes in BMI status (becoming thinner, becoming overweight and stable overweight) had no significant effect on GPA for children in

grades 3-6 after adjustment for gender, age group, school and grade (103). The only other prospective study that examined this relationship (Crosnoe & Muller, 2004) found that obesity negatively affected academic performance when there was a high level of romantic activity or a low level of athletic participation in a school (81). It was not possible to assess the effect of school level factors in the present study owing to the design of the NLSCY; however, Crosnoe & Muller (2004) used baseline weight status which assumed no change in weight status over time. Perhaps, the negative academic effects of chronic obesity present later in childhood either because the exposure to obesity takes time to accrue before any damaging affects to academic performance can be detected, or simply because the effects of obesity are much stronger in older ages. The age group analyzed in this study (and in Datar & Sturm, 2006) was significantly younger than the age groups examined in previous studies where significant associations were found (81;84;85;87). Strauss found that obesity in 9-10 y olds was not significantly related to global self-esteem scores. However, global self-esteem scores significantly decreased over four years in obese Hispanic and obese white females compared to non-obese Hispanic females and non-obese white females. Similar trends were seen in boys but did not reach statistical significance. This longitudinal study of self-esteem showed that obesity was a factor at ages 13-14 but not 9-10 y (104). Mustillo et al conducted a similar study relating obesity trajectories of children starting at 9-13 y and ending at 16, with psychiatric disorders at age 16. The four trajectory groups were similar to the ones in the present study. They found that chronically obese children were more likely to have an oppositional defiance disorder compared to never/rarely obese children and chronically obese boys were more likely to experience depression at age 16 compared to

never/rarely obese boys (14). This study was conducted on older children compared to the present study and measured obesity at each age rather than just two points in time, so that trajectories could be used to accurately predict which obesity group a child fit into. Perhaps the present study would have found a significant negative effect of chronic obesity on academic performance if older children had been studied instead and if obesity had been measured at each age. It should be noted that originally, obesity was going to be measured at each age since respondents are asked to report their height and weight in each cycle. However, it was decided not to do this due to large amounts of missing data. Future studies need to ensure that valid heights and weights, preferably measured, are recorded at every age when following cohorts of children.

Children, who developed obesity in this sample, were also no different in terms of math scores than children who were never obese. Datar & Sturm (2006) found only a significant effect in girls, not boys who developed obesity, and this association was small in comparison to other confounders like race, income and mother's education. In the study by Mo-suwan et al (1999), the negative effects of developing obesity were seen only in grades 7-9 and not those in grades 3-6 lending credence to the hypothesis that the effects of obesity are much stronger in later childhood. This could be partly due to the fact that adolescence is a critical period in a child's psychosocial development where peers are highly influential (104). This is in contrast to preadolescence where family interaction and support is most important (104). In our study, one cannot determine exactly when the child developed obesity. If the period in childhood was not a factor

perhaps there is a difference between those who recently developed obesity and those who were obese for a longer period of time.

There are a few possible explanations as to why children who grew out of obesity scored significantly higher than those children who were never obese. The first is based on the hypothesis that 'fatness during late foetal development and on through the first five years of life is a key determinant of optimal brain development in humans, where the 'fattest (infants) become, mentally, the fittest adults' (105). This coincides with the consensus that the first five years of life are crucial for children's cognitive, social and emotional development (66). Compared to other mammals, humans are born with the highest proportion of body fat (~15%) (106) and have the highest brain to body weight ratio (105). They experience peak adiposity at early infancy (~25% at 6-9 months), and a later decline to a comparably leaner childhood by age five (106). Humans, in contrast to other primates, are born relatively under-developed where brain growth occurs well into early childhood (Martin, 1990; Rosenberg, 1992 as reviewed by Leonard, 2003). As a result, the infant human brain requires a substantial percentage of total metabolic expenditure for development compared to adulthood (105;107). In times of feeding disruptions such as parturition, breastfeeding, weaning, and lapses between feedings, the body does not disrupt the flow of nutrients to the brain unlike other organs and tissues (107). A possible solution, developed as humans evolved, may have been to have larger fat stores and less muscle mass in the early years to provide a large energy reserve for the developing human brain and its huge energy needs (105;106). Ketone bodies, the breakdown products of fat oxidation are an essential alternative to glucose as a source of

energy for the brain when glycogen stores have been depleted. Infants, in contrast to adults however, have slightly elevated blood ketone levels at all times regardless of whether they have just been fed or not (105), and switch three to four times faster to fat oxidation from carbohydrate metabolism in times of fasting (Bier et al., 1977; Kerr et al., 1978; Saudubray et al., 1981 as reviewed by Kuzawa, 1998). The argument then is that humans are fat in early childhood to 1) provide a form of energy to sustain the high energy needs of the brain; 2) provide the building blocks for brain lipid synthesis as ketone bodies are the preferred substrate; and 3) provide a store of long chain polyunsaturated fatty acids that are needed for normal brain development (105).

Since the proportion of fat in children does not decrease substantially until after age five, perhaps those children who were obese at 2-5 y in the NLSCY had larger than normal fat stores that allowed for above-optimal brain development compared to children who were not obese at that time and did not have extra fat stores. Corbett et al (2007) found that weight gain in early infancy (birth to 9 – 24 months) was positively and significantly related to Picture Vocabulary Test scores at age 10 (31). The benefit of extra fat stores may have been lost, however, on children who remained obese after age five (always obese) as large fat stores would no longer be needed. Obesity after age five may have made null the benefit of being obese at age 2-5 y by negatively affecting cognition via a complex pathway of its interacting psychosocial, metabolic and inflammatory effects. This, however, is only a hypothesis and to test it, we would need to measure the percentage of body fat in children when they were aged 2-5 y. Greater brain development/higher cognition may not solely depend on brain size as the literature

linking the two is still contentious, however, measurements of brain size, volume and functioning as measured by anthropometric cranial measurements, positron emission tomography (PET) or functional magnetic resonance imaging (MRI) could be used, adjusted by percentage body fat at age 2-5 y, to predict math scores at age 8-11 y. If a positive and significant association were found, the effect of obesity at 2-5 y on math scores at 8-11 y would then be mediated by degree of brain development. Of course brain development in the early years is highly complex with factors such as genetics, frequency and quality of parent-child interactions, household income, physical environment, healthcare, experiences such as stress, violence etc. playing an integral part (66).

The state of being obese in early childhood and then becoming normal weight by the late primary school years may be a mediating factor through which socioeconomic factors such as family income adequacy or mother's educational attainment act upon a child's later academic performance. In the present study, both low income adequacy and years of education attained by the mother were significantly related to academic performance. It has been found that Quebec babies born with a high birth weight (> 4,000g) are more likely to be obese at age 4.5 y (35). Parents with a higher socioeconomic background (including income and education) are more likely to have children that weigh over 4,000g at birth (108). It may be that children of parents with a high level of education and subsequently a higher SES tend to have high birth weight babies who are obese in early childhood but not later on [as SES in later childhood and beyond is inversely related to obesity (34)] and do very well in school due to their early socioeconomic environment and not necessarily their weight status. Growing out of

obesity may simply be a marker and not a causal factor for high academic performance in the late primary school years.

In the study by Datar & Sturm (2006), very few children grew out of obesity ($n = 139$) and this group was subsequently dropped from the final analysis owing to insufficient statistical power to detect a significant difference. Mo-suwan et al (1999) did not find that there was a significant difference in GPA between children who grew out of obesity and those that never experienced obesity in either age group (grades 3-6 and 7-9). However, the number of children that grew out of obesity was quite small; $n = 24$ (2% of sample) and $n = 28$ (5% of sample) for grades 3-6 and 7-9 respectively, and the follow-up time very short at two years. Likely there lacked sufficient power to detect a statistical difference between the two obesity status groups. In the present study, the statistically significant difference between children who grew out of obesity and those who were never obese may be the 'true' association however there still remains the possibility of bias in the results. Misclassification of the obesity status groups is of most concern. In particular, children labelled as 'grew out of obesity' when they in fact should have been labelled as never having experienced obesity, may have created a differential bias. For example, children misclassified as 'grew out of obesity' may have had high math scores that skewed the group mean upwards. If these children had been correctly placed in the 'never obese' group, their high math scores would not have influenced the group mean to the same degree due to a much larger group n . However, the mean BMI of the 'grew out of obesity' group (based on the IOTF definition) at ages 2-5 y was 23 kg/m^2 , and the standard deviation was small at 5.5 indicating that there was very little variation in BMI

in this group. Estimates based on the CDC definition were similar. A BMI of 23 kg/m² at age 2-5 y is well above the obesity cut-offs for both the CDC and IOTF definitions. This BMI, however, was based on mother-reported height and weight. Childhood obesity based on parent-reported height and weight tends to be overestimated regardless of age, mainly due to the underestimation of height. Overestimation is much more dramatic in early ages (~14%) compared to older ages (~4%) (102).

6.3 Strengths of this study

This was a prospective study that accounted for change in obesity status over time and controlled for baseline academic aptitude. Thus, we were able to control for unobserved confounders related to academic performance and obesity status that were fixed over time. The prospective design also allowed us to determine the time-order of obesity effects on academic performance where the type of childhood obesity occurred before the outcome. Even though we cannot infer causation, this type of design provides more robust evidence for the case of causation. In addition, the study design allowed for a relatively long follow-up time compared to similar studies (80;81;103). We used an objective measure of academic performance as the outcome of interest and did not rely on self-reported or parent-reported academic performance. Self/parent reported academic performance tends to be higher than actual academic performance and relates differently to weight status (87).

We used data compiled and managed by Statistics Canada, considered to be of very high quality (109). The survey weights provided by Statistics Canada allowed us to

partially account for non-response and we were able to calculate valid estimates of variance using the bootstrap method. The unequal probability of selection in the NLSCY will result in incorrect confidence intervals if only the survey weights are used in calculations. Regardless of whether bootstrap and non-bootstrap estimates of variance are similar, the bootstrap estimate should always be reported. All estimates of variance presented in this paper are bootstrap estimates. We also adjusted the final models for highly influential observations caused by children with very high survey weights. These children had a huge, but artificial influence on model parameters, due simply to their high assigned survey weights. With such a large sample size, taking these children out of the analysis does not affect the generalizability of our results (95). Both final models were also assessed for adequacy of fit. Finally, to allow comparability between studies and rule out bias in terms of the obesity definition used, we assessed the association of obesity status with academic performance using the two most common definitions of childhood obesity used in the literature (8).

6.4 Limitations

In our study, BMI was based on mother-reported height and weight. This likely resulted in a certain degree of misclassification of the main predictor, obesity status. A recent study found that parental estimations of height and weight of children aged 3-7 y were inaccurate for classifying children into BMI categories (110). The sample size in this study was relatively small in an epidemiological context ($n = 297$) and other studies have found that parent-reported height and weight accurately classified children as overweight or obese in large epidemiological samples (111;112). The main intent of this study was to determine if chronic obesity negatively affects academic performance. For

both definitions of obesity, the number of children classified as 'always obese' was fairly small; $n = 220$ and $n = 103$ for CDC and IOTF definitions respectively. Thus the null finding in the present study may be due to lack of power to detect a statistically significant difference.

The adjusted R^2 's for the final models were 0.1128 and 0.1175, for the CDC and IOTF models respectively. These are fairly low indicating that a number of other explanatory variables likely were not accounted for. School-level factors such as those identified by Crosnoe & Muller (2004) may be important in the relationship of obesity status with academic performance. Datar & Sturm (2006) identified percent minority in the school and school size as significant confounders. A study examining grade three student achievement in Ontario found that students in urban schools, those in schools located in affluent neighbourhoods and those in schools with a high prevalence of recent immigrants scored higher on the Grade three achievement tests after adjusting for covariates (113). School-level factors, however, could not be measured in the NLSCY.

In addition, early life factors such as breast feeding and smoking during pregnancy could not be accounted for as originally planned because children who were 2-3 y in cycle 1 (10-11 y in cycle 5) were not asked these questions. Other potentially important confounders that could not be accounted for were weight status and IQ of the mother, and amount of time child spent watching television, playing video games and using the computer in cycle 5. In the NLSCY there was a question that asked how often a child participated in sedentary behaviours. This variable was initially considered for

inclusion however, like the physical activity variables, the mother reported this amount for 8-9 y olds and 10-11 y olds reported it themselves. There was a large difference between the two age groups either owing to differences in how the question was asked or actual differences in sedentary behaviours between the two groups. It was decided to leave this variable out of the analysis. The two measures of physical activity in this study were not significant confounders. Limitations of these measures have already been discussed; thus, a better measure of physical activity or degree of physical fitness in this study may have shown it to be an important confounder in the obesity status-academic performance relationship.

Finally, there is the possibility of exposure misclassification due to measuring obesity at only two points in time (cycle 2 and cycle 5) where children assumed to be obese from cycle 2 to cycle 5 may not have been. However, there is no reason to believe that this misclassification, if present, is differential. Thus, any potential bias would be towards the null, leading to the underestimation of the obesity effect. To more correctly classify children into obesity status groups, obesity should have been assessed at each cycle of the NLSCY to identify distinct developmental trajectories. As has been discussed previously, this was not possible in this study.

6.5 Conclusion

Canadian children who develop obesity or who are chronically obese in early to mid-childhood do not appear to be negatively affected in terms of their academic performance, while children who grow out of obesity seem to better than their never

obese peers. Chronic obesity has many other well-known health effects in children so even though a negative effect was not found in this study, by no means does it negate the need for obesity to be prevented or managed during childhood/ pre-adolescence.

Similarly, the result that children obese at a young age, but not later on, do significantly better in school than children who are never obese, in no way should encourage mothers to fatten their babies or young children. It does, however, strengthen the position that adequate (and above-adequate) nutrition during pregnancy and in early life is very important for child development.

The future success of the Canadian economy depends largely on well-educated and creative workers who are highly adaptable to the changing economic climate. It is our responsibility to determine factors operating in childhood that have the potential to negatively affect academic performance and later life success. The global competitiveness of our national workforce may be stifled as more and more children are less able to attain high levels of education and develop their job skills. These children may also experience financial difficulty in adulthood which then strains the country's health and social systems.

Early child weight status and later academic performance appears to be a very complex relationship that warrants further investigation. Future studies need to directly measure heights and weights at many points throughout childhood to accurately identify obesity trajectories; make use of a prospective design by following children in early childhood well into adolescence; control for all confounders identified in the literature; and compile or use existing high quality data from large epidemiological samples.

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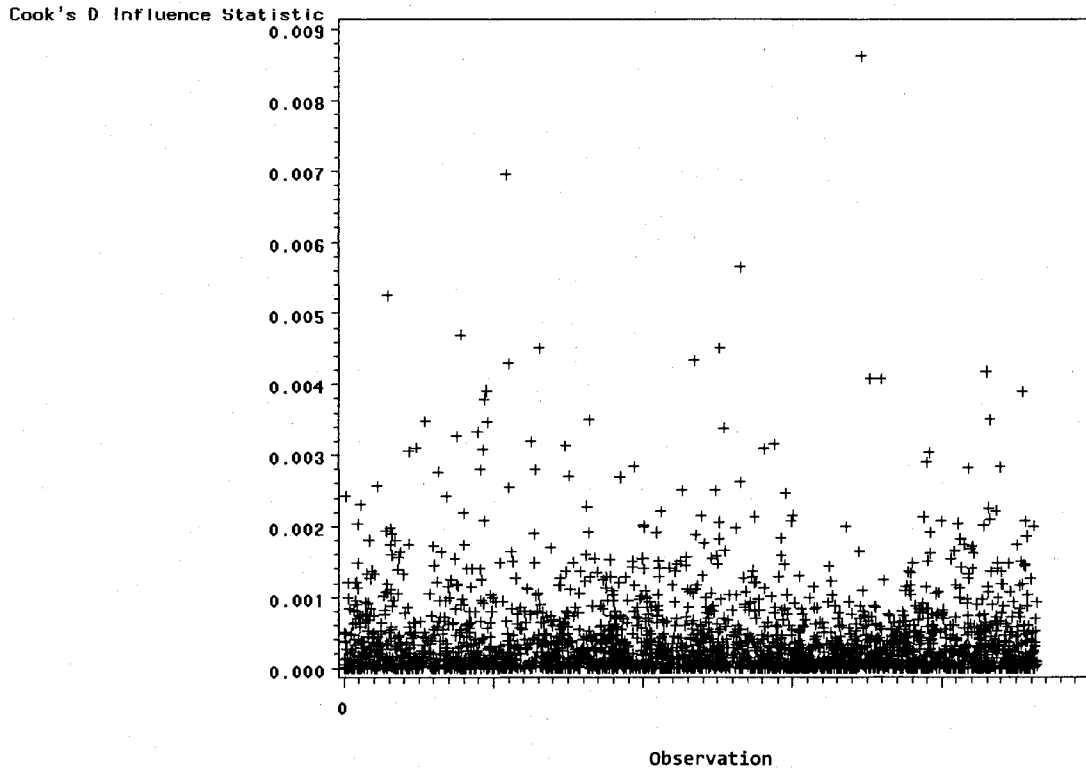
Appendices

Appendix A – MEDLINE search strategy

1. Obesity/
2. body mass index/
3. obes\$.tw.
4. weight.tw.
5. overweight.tw.
6. (body adj weight).tw.
7. (weight adj status).tw.
8. BMI.tw.
9. overnutrition/
10. child\$.mp.
11. adolescent/
12. child/
13. adolesc\$.mp.
14. student.mp.
15. students/
16. (school adj children).tw.
17. (school adj performance).tw.
18. Intelligence/
19. exp Intelligence Tests/
20. IQ.mp.
21. Learning/
22. cognit\$.tw.
23. grade\$.mp.
24. academic\$.mp.
25. school\$.tw.
26. (academic adj performance).tw.
27. (school adj outcomes).tw.
28. (grade adj repetition).tw.
29. (scholastic adj aptitude).tw.
30. (test adj scores\$.mp.
31. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9
32. 10 or 11 or 12 or 13 or 14 or 15 or 16
33. 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30
34. 31 and 32 and 33
35. (low adj birth adj weight).mp. [mp=title, original title, abstract, name of substance word, subject heading word]
36. 34 not 35
37. epidemiologic studies/
38. exp case control studies/
39. exp cohort studies/
40. case control.tw.
41. (cohort adj (study or studies)).tw.
42. cohort analy\$.tw.
43. (follow up adj (study or studies)).tw.
44. (observational adj (study or studies)).tw.
45. longitudinal.tw.
46. retrospective.tw.
47. cross-sectional.tw.
48. cross-sectional studies/
49. association\$.tw.
50. cross-sectional.tw.
51. 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50
52. 36 and 51
53. limit 52 to (humans and english language and "all child (0 to 18 years)" and yr="1996 - 2007" and humans)

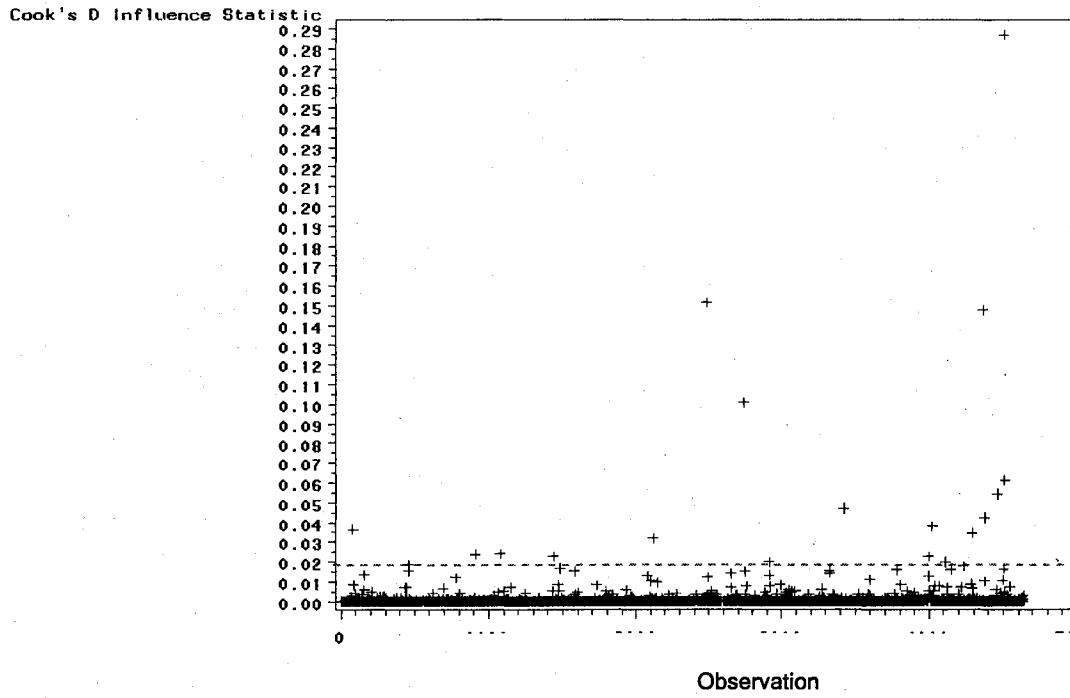
Appendix B

CDC Influence Diagnostics: Scatter plot of Cook's D by observation (un-weighted)



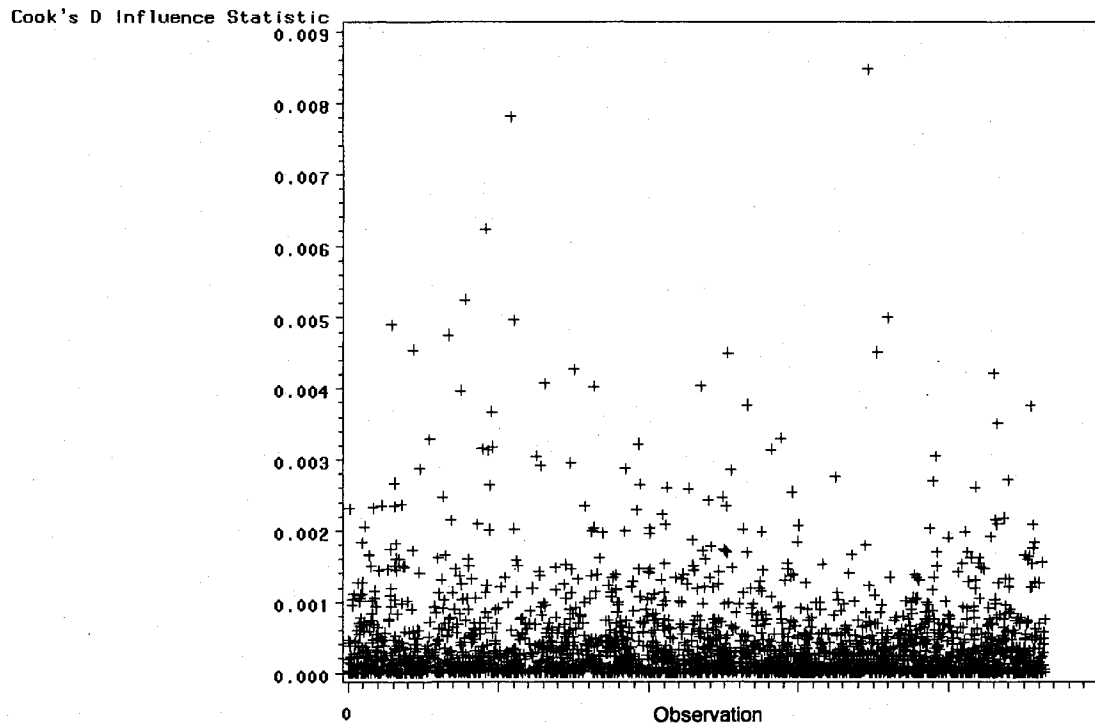
Appendix C

CDC Influence Diagnostics: Scatter plot of Cook's D by observation (weighted)



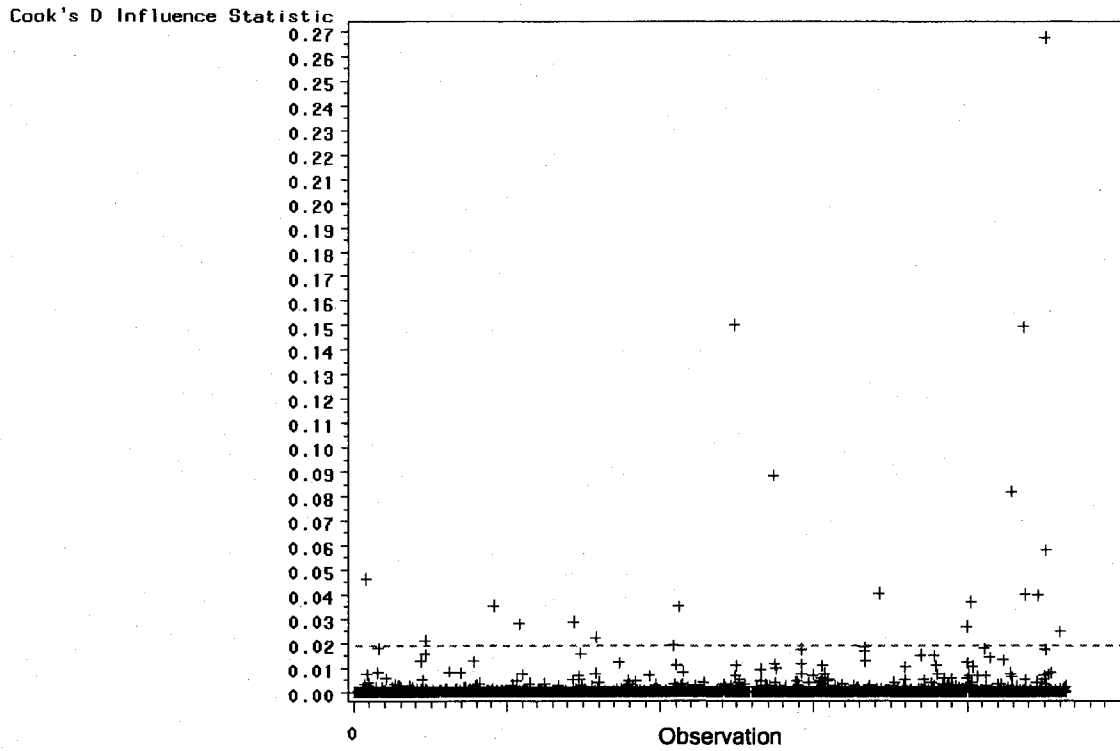
Appendix D

IOTF Influence Diagnostics: Scatter plot of Cook's D by observation (un-weighted)



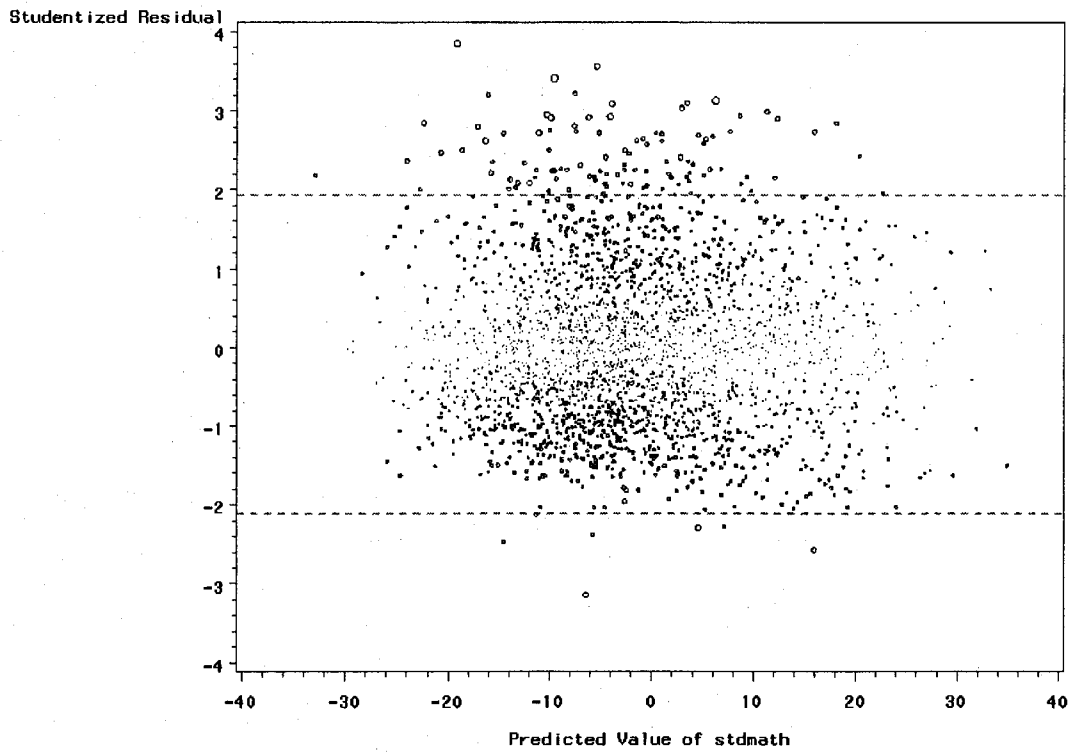
Appendix E

IOTF Influence Diagnostics: Scatter plot of Cook's D by observation (weighted)



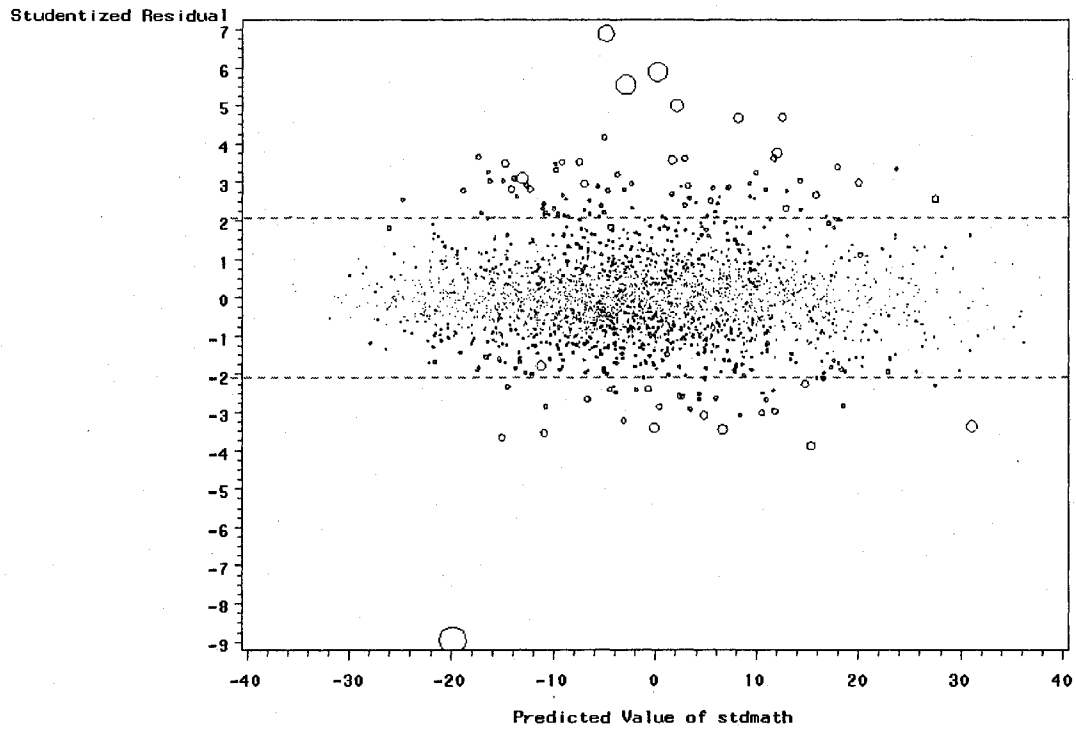
Appendix F

Final Un-weighted CDC Model: Studentized Residuals X Predicted Y



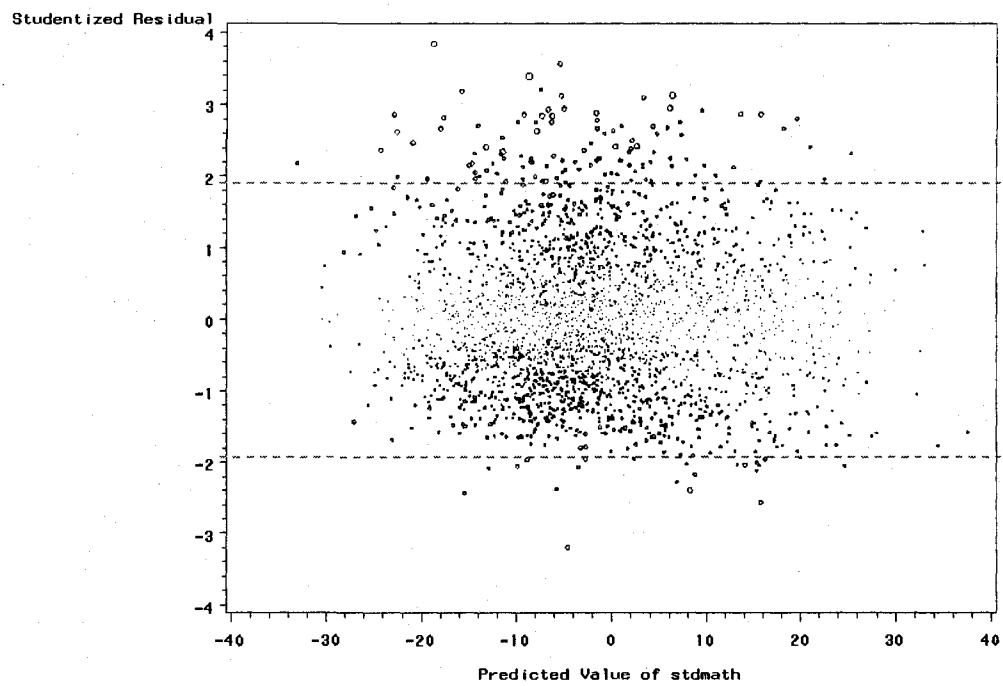
Appendix G

Final CDC Weighted Model: Studentized Residuals X Predicted Y



Appendix H

Un-weighted IOTF Final Model: Studentized Residuals X Predicted Y



Appendix I

Weighted IOTF Final Model: Studentized Residuals X Predicted Y

