The Burden of Obesity and Physical Inactivity Across the Lifespan, with a Focus on Health-Related Quality of Life

by

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ABSTRACT

Obesity and physical inactivity are major risk factors for numerous chronic diseases, conditions, and early mortality. Healthy body weight and physical activity (PA) are also positively associated with health-related quality of life (HRQL). However, obesity and physical inactivity levels in Canadian youth and adults are high. This thesis comprises five studies exploring the burden of obesity and physical inactivity, focusing on HRQL.

The *first study* assessed PA research productivity in Canada from 1990-2005. Canada produced approximately 5% of global PA research, 50% originating from Ontario, the biomedical and clinical areas accounting for 40% each; however, research in population health and health services was lacking.

The *second study* used data from the Physical Activity Longitudinal Study (PALS), the 22-year follow-up of the 1981 Canada Fitness Survey, to assess PA and obesity tracking from youth to adulthood. Over 80% of overweight/obese youth became overweight/obese adults, while the majority of overweight/obese adults had not been overweight/obese youth; almost all healthy weight adults had been healthy weight youth. PA did not track over 22 years.

The *third study* used the PALS data to examine the long-term effect of youth BMI and PA on adult HRQL (SF-36), using dichotomized outcomes based on Canadian norms. Contrary to expectations, overweight youth were *more* likely than healthy weight youth to score at/above the norm in adult HRQL, especially in the mental health domains. Youth PA was not associated with adult HRQL.

The *fourth study* used the same data to explore the youth BMI-adult HRQL relationship using continuous outcomes, by sex. Youth BMI was positively

associated with mental HRQL in adult females only; no negative impacts emerged.

The *fifth study* used the Canadian Community Health Survey (CCHS) Cycle 3.1 data to investigate the combined association of PA and BMI to HRQL among Canadian adults, including self-rated health, participation/activity limitation, and total disability days, by age and sex. Inactive individuals had increased odds of adverse HRQL, regardless of weight status; underweight, overweight, and obesity were of little consequence for active individuals.

Collectively, these results help to better understand the health burdens created by the current epidemics of obesity and physical inactivity in Canadians throughout their lifespans.

Keywords: obesity, physical activity, body mass index, population health, tracking, quality of life, self-rated health, disability days, activity limitation, body weight, weight status, children, youth, adolescence, adult, older adults, chronic disease, risk factors, longitudinal studies, cross-sectional studies, public health, Canada.

CO-AUTHORSHIP

The manuscripts presented in this thesis are the work of Katya M. Herman, in collaboration with her co-authors. Katya Herman was responsible for formulating and developing the research questions, completing the data analysis, interpreting the results, and writing the manuscripts, in consultation with the co-authors. The co-authors include: Peter T. Katzmarzyk, PhD (manuscripts 1 and 2), Chris I. Ardern, PhD (manuscript 1), Caitlin Mason, PhD (manuscript 1), Susan E. Brien, PhD (manuscript 1), Cora L. Craig, MSc (manuscripts 2, 3 and 4), Lise Gauvin, PhD (manuscript 2), Wilma M. Hopman, MA (manuscripts 3, 4 and 5), Elizabeth Van Den Kerkhof, PhD (manuscript 5), and Mark W. Rosenberg, PhD (manuscript 5).

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The departure of my initial supervisor presented some tough challenges, but in hindsight many positives resulted: I learned to network to find the expertise I needed and people with whom to collaborate; I learned to formulate and refine my own research questions; and I developed a greater ownership of my work. I have become a much stronger and more independent researcher, and through all my graduate studies I have benefited from working with a large number of researchers across different departments and disciplines. These skills and abilities will be of great benefit as I move forward in my life and career.

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Finally, over the past 5 years, I have strived to balance academics with athletics, representing Canada on the national rowing team, and competing for Queen's each fall season. It would be simply false to say that this wasn't often a huge (and exhausting) challenge: Training 3 to 5 hours a day, 6 days a week, frequent travel for competition, and extended absences of many months to train and compete, sustaining this "double life" and succeeding in both would not have been possible without support. Indeed, many were not supportive and advised that I would not succeed. I thank all those who *did* believe it possible, who supported and even encouraged me to continue to follow my passions outside of academics, and who facilitated this endeavour: SKHS faculty, staff and students; my rowing team-mates near and far; friends across the country; and family. Special mention to Dr. Jane Rumball, my inspiring role model who proved it was possible before me, and to John Armitage for putting up with me all these years.

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LIST OF ABBREVIATIONS

BMI	Body Mass Index
UW	Underweight
HW	Healthy Weight
OW	Overweight
OB	Obese
BRFSS	Behavioral Risk Factor Surveillance System (U.S.)
CCHS	Canadian Community Health Survey
CDC	Centers for Disease Control and Prevention (U.S.)
CFS	Canada Fitness Survey
CHD	Coronary Heart Disease
CHMS	Canadian Health Measures Survey
CI	Confidence Interval
CSWB	Campbell's Survey of Well-Being
CVD	Cardiovascular Disease
DALY	Disability Adjusted Life Year
HRQL	Health-Related Quality of Life
IOTF	International Obesity Task Force
MLTPAQ	Minnesota Leisure Time Physical Activity Questionnaire
OR	Odds Ratio
PA	Physical Activity
PAL	Participation & Activity Limitation
PALS	Physical Activity Longitudinal Study
PAR	Population Attributable Risk

RR	Relative Risk
SD	Standard Deviation
SF-36	Medical Outcomes Study Short Form 36
PF	Physical Functioning
RP	Role Physical
BP	Bodily Pain
GH	General Health
VT	Vitality
SF	Social Functioning
RE	Role Emotional
MH	Mental Health
PCS	Physical Component Score
MCS	Mental Component Score
SRH	Self-Rated Health
SGR	Surgeon General's Report
TDD	Total Disability Days (Physical + Mental)
WHO	World Health Organization

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Obesity and physical inactivity are major modifiable risk factors for numerous chronic diseases and conditions in adulthood, including premature mortality.[1-4] The immediate health outcomes of physical inactivity and obesity in childhood appear similar to those in adulthood; however, most youth do not progress to chronic disease until adulthood.[5, 6]

Despite large-scale efforts to publicize the health benefits of physical activity, [7, 8] only 51% of Canadian adults are sufficiently physically active during their leisure time to benefit their health.[9] Further, recent data indicate that only 9% of Canadian youth aged 5 to 19 years accumulate 16,500 or more steps per day, reflecting Canadian guidelines for children and youth.[10] As well, the prevalence of overweight and obesity in Canada has increased over the past several decades;[11] currently, 61% of adults and 26% of youth aged 2 to 18 years are overweight or obese.[9, 12]

Continued research into the burden created on the population by increased prevalences of physical inactivity and obesity across the lifespan is important in the development of public health policy, and in the identification of appropriate targets for public health programs concerned with the lifelong health of the population.

1.1.1 Definitions and concepts

Physical activity refers to "any bodily movement produced by skeletal muscles that results in caloric expenditure",[13] while *physical fitness* comprises "a set of outcomes or traits that relate to the ability to perform physical activity".[13] Physical activity is a behaviour, while physical fitness is an attribute which includes cardiorespiratory fitness, muscular endurance, muscular strength, body composition, and flexibility. Physical activity levels below those required to induce fitness gains are known to produce health gains, but both physical activity and cardiorespiratory fitness are related to health promotion and disease prevention in adulthood.

Obesity can be considered a component of health-related fitness, and refers to "a condition of excessive fat accumulation that may impair health", reflecting a "continued positive energy balance, which is accompanied by weight gain".[14] The *body mass index* (BMI), calculated as weight (kg) / height (m^2), is the most commonly used measure of weight status in population studies.

Tracking of risk factors or behaviours refers to "the tendency of individuals to maintain their relative rank or position within a group over time".[15-17] In assessing the importance of childhood and adolescent physical activity and healthy body weight, the desired belief is that this healthy lifestyle will continue into adulthood, thus benefiting the health of the individual and the population.

Health-related quality of life (HRQL) has been defined by the US Centers for Disease Control and Prevention (CDC) as "an individual's or group's perceived physical and mental health over time".[18] The Medical Outcomes Study

Short Form 36 (SF-36) [19, 20] is one of the most widely used and accepted measures of functional health and well-being, for the purpose of documenting and comparing disease burden and treatment benefits. This instrument is comprised of 36 questions, assessing 8 physical and mental health domains, from which a physical and a mental component summary score are then also calculated. Higher SF-36 scores reflect better HRQL, while poorer scores reflect impaired HRQL. Further, from a population health perspective, the CDC has also identified four valid and reliable core surveillance measures for HRQL: Self-rated health, number of recent Physically unhealthy days, number of recent Mentally unhealthy days, and number of recent Activity Limitation days due to physical or mental health.[18]

1.1.2 What is known – What is needed

Physical activity and obesity research have been ongoing in Canada over many decades. A study by Sokar-Todd and Sharma [21] evaluated Canadian obesity research through three decades from 1970 onwards, determining the most prominent research areas and provinces of highest productivity. They found that the majority of published Canadian obesity literature originated in the basic sciences, with a lack of research in the community and population health realms. There is little documentation of this nature regarding research on other key cardiovascular health and disease risk factors, including no true idea of the scope and breadth of Canadian physical activity research, both descriptively within Canada and relative to global research.

A growing body of evidence has shown moderate to moderately strong tracking of overweight and obesity from youth to adulthood.[22-26] In contrast, tracking of physical activity through childhood and adolescence and into adulthood tends to be much weaker.[16, 17, 27-30] Given the alarming prevalence of youth obesity and physical inactivity in Canada, tracking of these risk factors into adulthood would create a poor outlook for the future health of the population. However, physical activity and obesity tracking studies with follow-up over longer time-spans from childhood/adolescence all the way into adulthood are limited.

Research examining the links between obesity, physical inactivity and HRQL in healthy general population samples has only recently begun to evolve. In adults, higher physical activity levels are positively related to physical and mental HRQL,[31] and obesity is generally associated with significant impairments in HRQL, with greater impairments associated with greater degrees of obesity, and weight loss leading to improved HRQL.[32] More limited research exists linking youth obesity to poorer youth HRQL, including effects on self-reported health, self-esteem, and physical and social health and functioning.[33-35] Interestingly, when surveyed, over 90% of pediatricians believed that youth overweight could affect future HRQL,[36] while in fact, no studies to date have actually explored the long-term effects of youth obesity and/or physical activity on HRQL in adulthood.

In terms of all-cause and cardiovascular disease (CVD) mortality and cardiovascular health risk factors, while not eliminating the risk associated with excess body weight or abdominal fat, several studies have shown that physical activity or fitness is beneficial regardless of weight status: mortality and health risk in lean but inactive/unfit persons has often approached or sometimes eclipsed that of obese but active/fit persons.[37-42] Regular physical activity participation has also been associated with better HRQOL regardless of weight status; in fact, similar to the literature for mortality and health risk, indicators of HRQL have been shown to be similar in obese-active persons and healthy weight-inactive persons.[43] It is not clear how these associations might vary by sex and age, into older adulthood, or how underweight status might factor in with physical activity in predicting HRQL outcomes.

In general, much of the literature examining and documenting the health impacts of physical inactivity and obesity has come from U.S. population studies, with contributions from several European countries. There is a need to add to the literature information based on representative Canadian data specifically applicable to the Canadian population.

1.2 Overview & Overall Objectives

As obesity and physical inactivity become increasingly prevalent, reaching epidemic levels in Canada across all age groups – from children and youth, to adults, to older adults – the burden these health risks will place on the population is of growing concern, not merely in terms of biomedical outcomes and mortality, but also in terms of quality of life. The *overall objective* of the research contained within this thesis was *to explore the impact of obesity and physical inactivity in*

Canadians across the lifespan, using both longitudinal and cross-sectional data, with a particular focus on health-related quality of life outcomes.

This thesis is presented in manuscript format. A general review of the literature sets the stage for the five manuscripts at the heart of this thesis. The manuscripts are followed by a general discussion of key findings, public health implications, strengths and limitations of the thesis, and future directions, as well as a final summary including overall conclusions.

1.2.1 Specific Objectives

Study 1

1) To assess the current state of physical activity research in Canada as a proportion of global physical activity research;
2) To determine trends over time; and
3) To identify research areas of greater or lesser representation.

Rationale: The results would allow physical activity researchers to better target their research programs to areas of need, and allow researchers and funding agencies to better align themselves on priorities and future opportunities. A previously published report had provided a similar assessment of *obesity* research in Canada.

Study 2

1) To investigate the tracking of body mass index and leisure time physical activity over 22 years from youth to adulthood in a Canadian population-based sample.

Rationale: There had previously been a dearth of long term tracking studies with follow-up from childhood and adolescence all the way into adulthood.

Study 3

1) To investigate the relationship of youth body mass index and leisure time physical activity to adult physical and mental health-related quality of life 22 years later, in a Canadian population-based sample, using dichotomous outcomes and previously published Canadian population norms as a basis for comparison.

Rationale: No previous studies to date had explored the long-term effects of youth obesity and physical activity on health-related quality of life in adulthood.

Study 4

1) Using the same data/sample as the third study, to expand on the initial results, using continuous outcomes (absolute scores) to further investigate the relationship of youth body mass index to adult physical and mental health-related quality of life; and
2) To examine sex differences in the relationship of youth BMI to adult health-related quality of life.

Rationale: As no previous literature existed addressing this topic, it was important to expand on initial results (study 3) to add to the sparse knowledge in this area.

Study 5

1) To explore the combined association of physical activity and body mass index on health-related quality of life (including self-rated health, participation and activity limitation, and total disability days) in the Canadian adult and older adult population;
2) To include analysis by sex and age groups;
3) To include the underweight group; and
4) To validate our results based on self-reported BMI with a sub-sample having measured BMI data.

Rationale: This would extend recently published research on the U.S. population, which had not included analysis by sex and age, and not included older adults nor the underweight group.

1.3 Main Hypotheses

Study 1

Hypothesis 1: Canadian physical activity research will have increased in volume over the past 15 years, but still comprise a rather small proportion of Global physical activity research.

Hypothesis 2: The majority of Canadian physical activity research will be biomedical and clinical in nature, with a paucity of research in the population health realm.

Study 2

Hypothesis 1: Overweight/obesity will track strongly from youth to adulthood.

Hypothesis 2: Physical activity will also track from youth to adulthood.

Study 3

Hypothesis 1: Overweight/obesity in youth will have a long-term negative impact on HRQL in adulthood, using Canadian norms for comparison.

Hypothesis 2: Physical inactivity in youth will have a long-term negative impact on HRQL in adulthood.

Study 4

Hypothesis 1: Overweight/obesity in youth will have a long term positive impact on mental HRQL in adulthood (note: now knowing the results from Study 3).

Hypothesis 2: This effect may be more pronounced in females.

Study 5

Hypothesis 1: PA will be of greater importance than BMI, such that PA is beneficial at all BMI levels, and active-obese individuals will show similar or better HRQL compared to inactive-healthy weight individuals.

Hypothesis 2: Overweight will present less of a risk in males and in older adults, while underweight will present more of a risk in males and in older adults.

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CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction: Physical Activity, Healthy Body Weight, & Life-Long Health

The importance of physical activity in early life may arise not only from its concurrent relationships with obesity, other chronic disease risk factors, and immediate health outcomes – risk factors and health outcomes which may carry forward into adulthood – but also from its possible influence on future adult participation in physical activity, which would also impact risk factors and health outcomes in adulthood. Similarly, childhood and adolescent obesity have both immediate short-term effects during youth, and long-term consequences in adulthood.

A well-known model conceptualizing the inter-relationships between physical activity and health throughout the lifespan is depicted in **Figure 1**.[1] The model shows that youth physical activity might affect adult health directly, but also indirectly through improved child and adolescent health, increased likelihood of adulthood physical activity (tracking), or a combination of these mechanisms. A similar concept is envisioned for youth obesity, with a combination of direct effects on health outcomes both immediately in childhood and adolescence, and longer-term into adulthood, and indirect effects through longitudinal tracking of obesity and overall health status. The concept of disease prevention implies the acquisition of behaviours and traits in childhood which would subsequently reduce the risk of disease in adulthood, such that those benefitting most would be those who adopt physically active, fit, healthy weight lifestyles in early life which are subsequently sustained through adult life.

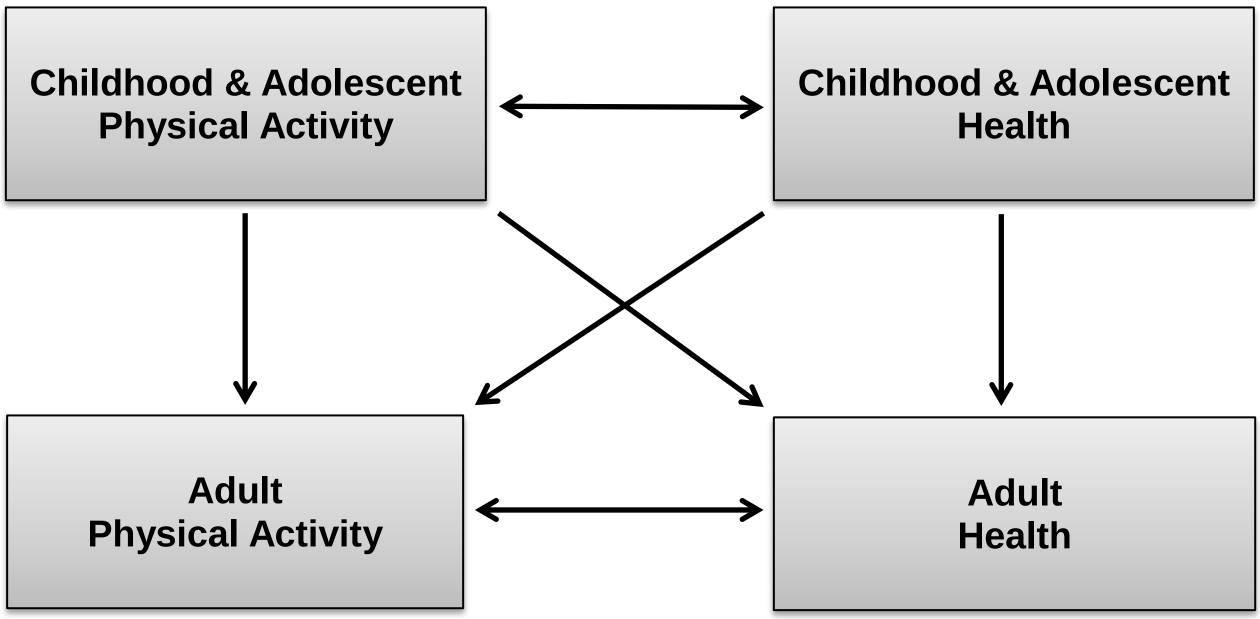

Figure 1. Conceptual model illustrating the potential relationships between physical activity and health, from youth to adulthood. A similar model can be applied to the relationships between obesity and health. (Adapted from Blair et al.,1989 [1])

This chapter sets the stage for the five manuscripts that follow, through a comprehensive review of related literature and background information. First, an overview of the epidemiology of physical activity and obesity in Canada is provided, followed by an in depth review of the literature on physical activity and obesity tracking from youth to adulthood. Next, the links between physical activity, obesity and health outcomes are discussed, including methods of assessment for physical activity and weight status. Thirdly, current knowledge relating to health-related quality of life (HRQL), and associations with physical activity and weight status, is outlined. Finally, the public health burden created by the current obesity and physical inactivity epidemics is described, in terms of both health and economic impacts.

2.2 Epidemiology of Physical Activity & Obesity in Canada

2.2.1 Physical Activity in Adults

Data from the Canadian Community Health Survey (CCHS 2005) indicate that only 27% of Canadians aged 12 and over (30% males, 24% females) are leisure-time physically “active” enough to benefit their health (≥ 3.0 kcal/kg/day, equivalent to walking at least 60 minutes per day); another 25% (25% males, 26% females) are “moderately active” (1.5-2.9 kcal/kg/day, equivalent to walking at least 30 minutes per day), while 48% (45% males, 50% females), or 12.7 million Canadians, are sedentary (< 1.5 kcalkg/day).[5] Men are more active than women, especially at younger and older ages, and physical activity levels drop off with age following adolescence – from 51% of 12-17 year olds considered active, to less than 20% of adults ≥ 65. Prevalence of physical activity is lower in lower income groups and in immigrants, as well as for those living in larger centres. The most popular leisure-time activity for Canadians is walking, reported by 64% of men and 76% of women. Geographically, an east-to-west gradient is evident: residents of British Columbia, the Yukon, Alberta, and Ontario tend to be more active than the national average, while residents of the Prairie provinces, Quebec, and the Maritime provinces tend to be less active than the national average. Multiple studies have examined secular trends in leisure-time physical activity among Canadians, showing that the prevalence of adults participating in at least the equivalent of 30 minutes of walking per day has in fact increased over the past several decades,[5-9] notably from approximately 43% in 1996/97 to 52% in 2005.[5]

A recent paper sought to determine the proportion of Canadian adults aged 18-55 years who met the guidelines for moderate and vigorous physical activity set out in Canada's Physical Activity Guide to Healthy Active Living (30-60 minutes of moderate-effort activity at least 4 days/week, or 20-30 minutes of vigorous-effort activity at least 4 days/week).[10] Sixty-five percent of adults met the guidelines in 2007 (up from 54% in 1994-95), and fewer than 10% of adult reported no leisure-time physical activity.[11] Men, younger adults, those with a higher income, and those with a lower BMI were more likely to meet the guidelines, and the guidelines were most often met through participation in moderate-intensity activity.

Recently released data from the 2007-2009 Canada Health Measures Survey (CHMS) indicates that aerobic fitness decreases with age in adults aged 20-69 years. While approximately one quarter of Canadians aged 20-29 exhibit very good or excellent fitness, this drops to 10% for males and <5% for females by age 60-69, a decrease partly attributed to a drop in physical activity levels.[12] Using accelerometers, the CHMS has collected objectively measured physical activity data from all ambulatory participants, with results due to be released later in 2010.

2.2.2 Obesity in Adults

With close to 50% of Canadian adults physically inactive in their leisure time, the prevalence of overweight and obesity has increased substantially over the past several decades.[13, 14] The most up-to-date objectively measured data on weight status of Canadians were recently released from the 2007-2009 CHMS.[12] For ages 20-39 years, 37% of males and 23% of females are overweight, while 19% and 21% respectively are obese. For ages 40-59 years, 52% of males and 31% of females are overweight, while 27% and 24% respectively are obese. And for ages 60-69 years, 39% of males and 37% of females are overweight, while 34% and 33% respectively are obese.

The proportion of obese persons in Canada has approximately doubled since 1981 for males and females aged 40 and above, tripled for males aged 20-39, and increased fivefold for females aged 20-39. Mean BMI, which in 1981 was in the “normal weight” range for all sex and age groups, has since increased by about 2 units in males of all age groups and in middle-aged females, and by 3 units in younger and older females, such that it is now in the overweight range for all groups.[12]

2.2.3 Physical Activity in Children & Adolescents

The *2010 Active Healthy Kids Canada Report Card on Physical Activity for Children and Youth* [15] has published a grade of “F” for physical activity levels of Canadian children and adolescents, for the fourth consecutive year. Overall, objectively measured data (pedometers) indicate that only 12% of Canadian children are meeting the Canadian physical activity guideline of 90 minutes of physical activity per day (=16,500 steps/day), ranging from 7-10% in the Maritime provinces and Quebec (10%), and from 11-15% in the rest of Canada (BC and NWT at 15%). This figure represents a slight increase from 9% in 2007, and 10% in 2008, but a minor decrease from 13% in 2009, indicating little progress overall. The Canadian average is 11,698 steps per day, representing less than 60 minutes of physical activity daily, a threshold that only 31% of children and youth are achieving. Important sex differences exist: while 20% of boys aged 5-10 years and 15% of boys aged 11-14 years are meeting the guidelines, only 5% of adolescent girls are engaging in adequate physical activity. The *Report Card* also states that less than half of Canadian children under the age of five are getting regular physical activity as part of their daily routines.

Previous self-reported data from the CCHS (2004) have indicated that 16% of Canadian children aged 6-11 are physically active < 7 hours per week (on average less than 1 hour per day), 41% are active 7-13 hours per week, 32% 14-20 hours per week, and 10% > 21 hours per week.[16] In terms of energy expenditure (CCHS 2005), 48% of adolescents aged 12-19 were classified as active (≥3.0 kcal/kg/day), adolescent boys being much more likely to be physically active than girls (54% vs. 41%), activity levels decreasing with age, and the gender gap increasing with age.[17] The WHO's 2005-2006 *Health Behaviour in School-Aged Children* survey (HBSC) reported that only 26%, 16%, and 13% of girls, and 36%, 31%, and 27% of boys, aged 11, 13, and 15 years, respectively, reported engaging in at least 60 minutes of physical activity per day.[18] In general, physical activity levels tend to increase from age 5-6 years into early to mid-adolescence, before declining through adolescence and into adulthood.[19] It is estimated that the proportion of the population that is moderately or vigorously active declines by about 10-20% between the ages of 20-40 years.

The 2007-2009 CHMS also shows that fitness levels of Canadian children and youth of all ages have declined “significantly and meaningfully” over the past 3 decades, with fitness declining as individuals transition through adolescence into adulthood.[20] The objectively measured physical activity data from this new survey will provide additional insight into these trends.

2.2.4 Obesity in Children & Adolescents

In general, BMI rises steeply in early life, peaking at 9 months, then declining until about 6 years of age, before rising again into adulthood.[21] In growing children, anthropometric cut-offs must be adjusted for age, as well as maturation in adolescence.[21]

Alongside the high prevalence of physical inactivity, the prevalence of overweight and obesity in Canadian youth has also increased substantially over the past several decades.[13] The objectively measured 2007-2009 CHMS data indicate that 14% of boys and 10% of girls aged 15-19 are currently classified as obese, while 17% and 16% respectively are classified as overweight.[20] Thus, over 31% of boys and 26% of girls in that age range are overweight or obese, compared to approximately 14% for both sexes in 1981. While mean BMI has increased for all ages 7-19, the increase has been most pronounced in 15-19 year olds, with a 2 unit increase in boys, and a 1.5 unit increase in girls.[20] Geographically, the prevalence of youth overweight and obesity is highest in the Prairie provinces, and in the Maritimes.[15]

Previously, data from the CCHS (2004) indicated that 26% of Canadian children and adolescents aged 2-18 were considered overweight (18%) or obese (8%), representing approximately 1.6 million children, compared to 15% overweight or obese in 1978-1979.[22] Among the youngest children, 15% and 6% of 2-5 year olds were classified as overweight and obese, respectively.

2.3 Tracking of Physical Activity & Obesity

2.3.1 Tracking of Physical Activity

Several studies have assessed the tracking of physical activity, although time-frames have generally been short, and results inconsistent. In young children aged 3-4 years at baseline, Pate et al. [23] reported correlation coefficients of 0.57-0.66 for the 3-year tracking of physical activity (% time HR ≥ 50% of resting HR), indicating maintenance of relative rank at early ages. In the *Minnesota Heart Health Program*, both physical activity score and hours of exercise per week tracked over 6 years in students from grade 6 to 12, especially when comparing extreme groups.[24] Another study reported tracking correlations of 0.50-0.53 for VO_2max, and 0.18-0.37 for physical activity, with no significant gender differences for youth followed from ages 8 to 16.[25]

In the *Cardiovascular Risk in Young Finns Study*, significant tracking of a physical activity index was observed over 6 years in subjects aged 12, 15, and 18 years at baseline (r=0.18-0.43 in males, 0.17-0.37 in females).[26] Tracking was highest after 3 years (0.35-0.54 in males, 0.33-0.39 in females). After 6 years, 57% of inactive subjects at baseline remained inactive, while 44% of active subjects remained active. A subsequent report described tracking coefficients over 3-year intervals (ages 9-30) of 0.50-0.80 for boys and 0.42-0.61 for girls for a multi-component physical activity index, increasing with age, and decreasing at longer time-intervals.[27] The strongest individual tracking was for sports club training (0.28-0.64 for girls, 0.40-0.78 for boys).

In the *Amsterdam Growth and Health Study*, moderate tracking (r=0.36 M, 0.46 F) of VO_2max was reported after 8 years for participants aged 13 years at baseline, the stronger tracking for girls in contrast to findings from the *Young Finns Study*.[28] After 14 years of follow-up (age 13-27 years), tracking correlations were 0.31 and 0.34 for VO_2max and daily physical activity, respectively, and the odds of being inactive at follow-up were 3.6 times greater for those inactive at baseline, compared to their active counterparts.[29]

Three reports using Canadian data have been published. In the *Trois-Rivieres Growth and Development Study*, significant but weak associations (r=0.12-0.20) were found between the weekly duration of total, intense, light organized, and non-organized physical activity at ages 10-12 years and physical activity frequency at age 35 years.[30] Childhood participation in organized physical activity predicted current adulthood weekly physical activity in males only. In the *Quebec Family* Study, controlling for length of follow-up and baseline age, partial correlations for submaximal aerobic fitness adjusted for body weight were 0.24 and 0.46 for males and females respectively, aged 13 years at baseline and 25 years at follow-up; in terms of physical activity, only inactivity in males tracked significantly.[31]

In the *Campbell's Survey* (1988), representing the 7-year follow-up of the *Canada Fitness Survey* (1981), greater stability was reported for musculoskeletal fitness than for physical activity, in participants aged 11-69 at baseline.[32] Significant tracking of physical activity occurred only within adulthood, while musculoskeletal fitness showed moderate-to-high tracking throughout the lifespan, though generally higher stability in adulthood. About 36-68% of participants remained in the extreme quintiles of musculoskeletal fitness measures over 7 years; only 30-34% remained in the extreme quintiles of physical activity. Activity energy expenditure in adulthood tracked better in males than females; however, the opposite pattern occurred for time spent on activity.

An early review of participation in organized school athletics as a precursor for physical activity in adulthood concluded that the strongest support came from the *Harvard Alumni Study*, which suggested that those who participated in varsity and intramural sports in college (1916-1950) were more likely to continue beneficial physical activity patterns through their adult years (1962-1966).[33] Another study found that physically active men aged 23-25 had significantly higher childhood (ages 10-11, and 15-18) 600 yard run scores than did the inactive men: 42% of men who scored in the lowest 20% were physically inactive as adults, compared to 25% of men who scored in the upper 80%.[34]

There are few data available on the tracking of physical activity from childhood and adolescence into later adulthood and old-age. One study found that retrospective recall of childhood and adolescent frequency and enjoyment of physical activity experiences did not correlate with current physical activity habits in men 32-62 years of age.[35] However, self-reported physical activity skill levels and participation in team sports in early to mid-adolescence were weakly correlated to adult physical activity habits (r=0.16-0.17), while being forced or encouraged to exercise in adolescence were negatively related to adult habits.

To summarize, larger studies consistently show moderately high correlations spanning 3-4 year intervals, but weaker correlations with increasing time intervals, and inconsistent sex differences.[19, 36, 37] Moderate tracking of physical activity may exist during childhood and adolescence, and lower tracking within adolescence and from adolescence into young adulthood. In adulthood, inter-age correlations are low to moderate, and weaker with longer time intervals and increasing age at baseline, the latter in contrast to child/adolescent studies. There is sparse physical activity tracking evidence for time frames from childhood/adolescence into later adulthood/old age, indicating weak associations. Results from several studies have suggested that acquisition of motor skills and sport participation in early life is important in the prediction of adulthood physical activity, and that cardiovascular and musculoskeletal fitness indicators track better than physical activity measures. The greater stability of fitness characteristics is likely partly explained by their genetic component, and greater ease of accurate measurement, while physical activity may be more stable in reality than reported due to measurement error.[32] In a review of 313 physical activity tracking correlations, 81% fell between 0.10-0.49, while 9% fell between 0.50-0.59, and only 3% exceeded 0.60.[36] The highest correlations involved sports club training, males, higher baseline age, and shorter time intervals.

2.3.2 Tracking of Obesity

There is a growing body of evidence showing a consistently positive association between youth and adulthood obesity. Several reviews have shown that childhood BMI is positively correlated with adulthood BMI (r=0.40-0.70).[21, 38, 39] Most studies have suggested that 40-70% of obese pre-pubertal children would become obese adults.[38] Once into adulthood, stability of obesity indicators is moderate to strong, inter-age correlations for BMI ranging from about 0.35-0.60 in early to mid-adulthood, and up to 0.90 at older ages.[36]

In the *Amsterdam Growth and Development Study*, for participants aged 13 years at baseline, inter-age correlations for single skinfolds ranged from 0.70-0.81 and 0.77-0.83 for males and females respectively at age 16, to 0.35-0.54 and 0.31-0.48 at age 29. For trunk-extremity skinfold ratios, correlations ranged from 0.60-0.66 and 0.80-0.81 for males and females respectively at age 16, to 0.43-0.53 and 0.53-0.58 at age 29. In a further study, a stability coefficient of 0.63 was reported for the tracking of the sum of four skinfolds from age 13 to 27 years.[29] Youth who were above a defined “at risk” sum-of-skinfolds threshold were almost 18 times more likely to become obese adults compared to those below the threshold.

In a sample of U.S. children, 69% of 6-9 years olds and 83% of 10-14 year olds with a BMI > 95th percentile became "obese" (BMI ≥27.8 M, ≥27.3 F) at age 21-29 (OR 18.5 and 44.3 compared to BMI < 85th percentile).[40] The probability of obesity in adulthood increased with increasing baseline age and degree of obesity, with no significant gender differences. After controlling for parental obesity, the odds of adult obesity for obese versus non-obese children increased from 1.3 for 1-2 year olds, to 17.5 for 15-17 year olds.

In a 1970 British Birth Cohort, 61% of obese (≥ 95th percentile) 16 year olds were obese as 30 year olds (≥ 28.5 kg/m^2).[41] After controlling for sex and social class, only sports participation was significant in predicting loss of BMI. Gain in BMI was predicted by ≥ 4 hours of sedentary activities per day, eating fast-food ≥ twice per week and consuming ≥ 2 carbonated drinks per day, and history of dieting.

Of 9795 U.S. adolescents enrolled in waves II (1996; age 13-20) and III (2001; age 19-26) of the *National Longitudinal Study of Adolescent Health*, 76% remained non-obese in adulthood, 12.7% became obese in the transition to adulthood, and 9.4% remained obese.[42] Only 1.6% of obese adolescents became non-obese adults.

In the *Fels Longitudinal Study*, among children aged 3-18 at baseline and followed up at age 35, tracking strength increased with increasing baseline age, from r ≤ 0.3 for males under 9 and females under 4 years of age, up to 0.6 and 0.7 in males and females, respectively, at age 18.[43] The probability of overweight (BMI > 28 kg/m^2 for men, > 26 kg/m^2 for women) at 35 years increased with baseline age (1-18): from 0.15-0.37 for a childhood BMI at the 75th percentile, and from 0.20-0.78 for a childhood BMI at the 95th percentile. For children at the 85th percentile, the probability of overweight at age 35 ranged from 20-30% for boys < 7 and girls < 10 years of age, to 40-80% for boys at age 18 and girls > 16 years of age. At the 95th percentile, the probability of overweight at 35 years was 40-80% after the age of 9-10 years for both boys and girls. In a subsequent analysis, using the CDC-developed BMI-for-age growth charts, the probability of adult obesity for youth at the 85th percentile was ≤ 20% for males < 17 years of age, and 20-40% for females up to 18 years of age.[44] The probability rose to 60% in both sexes beyond these ages, and beyond 60% for a youth BMI at the 95th percentile. Probabilities of adult obesity were generally higher in males. Probabilities for overweight were even higher, reaching ≥ 80% for both the 85th and 95th BMI percentiles at older ages in both sexes.

In the *Bogalusa Heart Study,* among overweight children (BMI for age ≥ 95th percentile) aged 5-14 years at baseline and followed for 8-24 years, 65% of white girls and 84% of black girls became obese adults (BMI ≥ 30 kg/m^2), while 71% of white boys and 82% of black boys became obese adults.[45] Of children examined ≥ three times before age 15, only 9% with a BMI < 85th percentile at all exams became obese adults, while 68% of those with a BMI ≥ 85th percentile at all exams became obese adults. Of obese adults, 71% had a childhood BMI ≥ 85th percentile. In another report, tracking of overweight (childhood BMI ≥ 85th percentile; adulthood BMI ≥ 25 kg/m^2) from 9-11 years to 19-35 years was demonstrated by moderately strong correlations (r=0.66), and > 60% of those in the highest BMI quartile in childhood remained in that quartile in adulthood.[46]

Two reports using Canadian data have been published. In the *Campbell's Survey* (1988), representing the 7-year follow-up of the *Canada Fitness Survey* (1981), inter-age correlations in participants aged 7-69 ranged from 0.53-0.91 for BMI, -0.09-0.72 for sum of five skinfolds, 0.24-0.89 for waist circumference, 0.23-0.73 for trunk to extremity skinfold ratio, and 0.18-0.77 for waist circumference adjusted for BMI.[47] The percentage of participants remaining in the extreme quintiles of the BMI distribution ranged from 38-62% and 49-67% for the upper and lower quintiles respectively in males, and 49-65% and 47-58% in females. Similarly, in the *Quebec Family Study*, 12-year inter-age correlations for males and females aged 8-18 years at baseline were 0.65 and 0.59 for BMI, 0.59 and 0.64 for fat mass, 0.65 and 0.57 for fat-free mass, 0.50 and 0.57 for body fat percentage, 0.66 and 0.44 for sum of six skinfolds, and 0.40 and 0.47 for trunk-to-extremity skinfold ratio, controlling for initial age and follow-up length.[48]

A comprehensive review spanning 1970-1992 reported a consistently positive association between childhood and adulthood obesity, finding that 26-41% of obese pre-schoolers were obese as adults, while 42-63% of obese school-age children were obese as adults.[39] Correlation magnitude was positively associated with age and degree of obesity, inversely associated with length of follow-up, and tended to be stronger in males. The RR of adult obesity was 2-6.5 times higher for obese versus non-obese children; however, only 5-44% of obese adults had been obese as children, and population attributable risk estimates indicated that < 50% of adult obesity was attributable to childhood obesity. A later review spanning 1985-1996 reported consistent evidence that more overweight children were more likely to be obese later in life, with 20-90%

of obese children remaining obese as adults; however, ≥ 70% of obese adults were not overweight in adolescence or childhood, again indicating only poor to moderate prediction of adult obesity.[21] Associations with adulthood obesity were stronger with increasing childhood age, inter-age correlations ranging from 0.46-0.91 for males and 0.60-0.78 for females from ages 13-14 to 25-36 years.

In summary, predictive values of childhood overweight for adult obesity have generally ranged from 40-70%. Higher values from more recent studies may reflect secular increases in adult obesity as well as differences in BMI cut-off points used, while older studies likely underestimate the strength of tracking given the current obesity epidemic.[38, 45] The large ranges in estimates reported by different studies can also be attributed to differences in methodology, definitions, ages, time intervals, and cultural or temporal differences.[39]

2.4 Physical Activity, Obesity & Health

2.4.1 Physical Activity & Health in Adults

Beginning with the seminal work of the late Jeremy Morris in the early 1950s, reporting lower rates of coronary heart disease (CHD) in double-decker bus conductors, who spent most of the day on their feet and climbing stairs to collect bus fares, as compared to bus drivers, who spent most of the day sitting,[49] and further ground-breaking work by Paffenbarger and colleagues in the 1970s,[50] research over more than five decades has shown unequivocally that physical inactivity and low cardiorespiratory fitness are associated with increased chronic disease incidence and mortality, with historically the greatest research focus on cardiovascular disease (CVD). Towards the end of the 1980s, a comprehensive review and a more rigorous meta-analysis determined an approximate doubling of the relative risk of both CHD incidence and death for sedentary versus active groups, a risk that remained unaltered in magnitude and significance after multivariate adjustment.[51, 52]

In the early 1990s, physical inactivity was elevated to the status of a major independent modifiable risk factor for CVD by both the American Heart Association and the Heart and Stroke Foundation of Canada.[53, 54] In 1996, *Physical Activity and Health: A Report of the Surgeon General* (SGR) [55] was released, representing the first large-scale document summarizing and providing the most influential support to date for the health benefits of physical activity. The SGR concluded unequivocally that regular, moderate physical activity provides health benefits at all ages, with additional benefits garnered from additional activity. *Canada's Physical Activity Guide to Healthy Active Living* was released shortly thereafter.[10]

In the 21st century, the health benefits of physical activity and risks of inactivity are well established and irrefutable. There is incontrovertible evidence that participation in regular physical activity plays a vital role in the primary, secondary and tertiary prevention of a multitude of chronic diseases and conditions. These include: CHD; stroke; type 2 diabetes; obesity; hypertension; dyslipidemia; muscle, bone and joint conditions (e.g. sarcopenia, osteoporosis, osteoarthritis); colon and breast cancers; respiratory disease; mental health conditions; and overall risk of premature mortality.[56-59] Primary prevention employs physical activity within strategies aimed at avoiding the development of disease, thus reducing the risk and incidence of chronic diseases, conditions, and early mortality. Secondary prevention stresses the importance of engaging in physical activity to reverse or slow already established disease processes in their early stages, prior to the onset of significant morbidity: incidence of premature death from all-causes and CVD is reduced, and conditions such as diabetes (improved glucose homeostasis and reduced death rates) and osteoporosis (maintenance of bone health) are better managed.[58, 59] Tertiary prevention uses physical activity to reduce the negative impacts of established disease by restoring function and reducing disease-related complications, such as with cardiac and stroke rehabilitation programs.

There is a dose-response relationship between physical activity and health status, whereby the most active people tend to exhibit the lowest risk; however, even slight increases in physical activity lead to significant reductions in health risks, and the greatest health improvements are seen when an individual transitions from being sedentary to beginning some level of activity.[58-60]

There exist several known and potential mechanisms for the beneficial effects of physical activity on chronic disease risk, including both modification of other known risk factors, as well as direct effects of physical activity. Biological mechanisms include: improved body composition; enhanced lipid profiles; improved glucose homeostasis and insulin sensitivity; reduced blood pressure; reduced systemic inflammation; decreased blood coagulation; improved coronary blood flow; improved cardiac and endothelial function; and improved psychological well-being.[58, 59]

2.4.2 Obesity & Health in Adults

Similar to their earlier acknowledgement of physical inactivity, the American Heart Association added obesity to the list of major independent CVD risk factors in 1998.[61] Obesity, often related to physical inactivity, is an important risk factor for numerous diseases and conditions including: CHD; stroke; hypertension; type 2 diabetes; dyslipidemia; colon, breast, kidney, oesophageal, prostate and endometrial cancers; gall bladder disease; respiratory conditions; osteoarthritis; mental health conditions; and premature mortality.[57, 62] Abdominal, or visceral, obesity is known to be especially hazardous to metabolic and cardiovascular health.[63, 64] While the relationship between weight status and morbidity or mortality generally follows a J-shaped curve,[65] there is evidence that a BMI in the “overweight” range is less harmful in adults over the age of 65, and in fact may be protective.[66-68] Hypotheses explaining these effects may include: selective survival, whereby individuals more susceptible to the negative effects of elevated BMI may be previously deceased; a lesser importance of excess body fat in older adults, when additional competing risk factors emerge with a greater influence on health; weakened relationships among BMI, body fat and fat distribution in older adults compared to their younger counterparts; benefits of nutritional reserves provided by both lean and fat mass, which may become important during illness especially in older age when incidence and severity of illness and disease increase; and the effects of age-related weight-loss secondary to disease or illness, which may confound the association of BMI to health risk.[67, 68]

2.4.3 Relationship Between Physical Activity & Obesity

The relationship between physical activity and obesity is a complex one. It is true that active individuals are less likely to be overweight or obese, and overweight or obese individuals tend to be less active.[57] As well, increasing levels of physical activity energy expenditure have been shown to lead to reductions in total adiposity in a dose-response manner.[69] However, physical activity alone often leads to unsuccessful weight loss efforts.[70, 71] As such, the main importance of physical activity to body weight may be in maintenance, rather than in significant weight loss.[62, 71]

The key pathways between physical activity, obesity and chronic diseases are illustrated in **Figure 2**.[72] Several studies over the past decade have attempted to tease out the relative importance of physical activity and weight status on health outcomes. In terms of all-cause and CVD mortality and CVD risk factors, while not eliminating the risk associated with excess body weight or abdominal fat, several studies have shown that physical activity or fitness is beneficial at all BMI or waist circumference levels: mortality and health risk in lean but inactive/unfit persons has often approached or sometimes eclipsed that of obese but active/fit persons.[73-78] In the Aerobics Centre Longitudinal Study (ACLS), a mortality follow-up of over 25,000 men showed that low

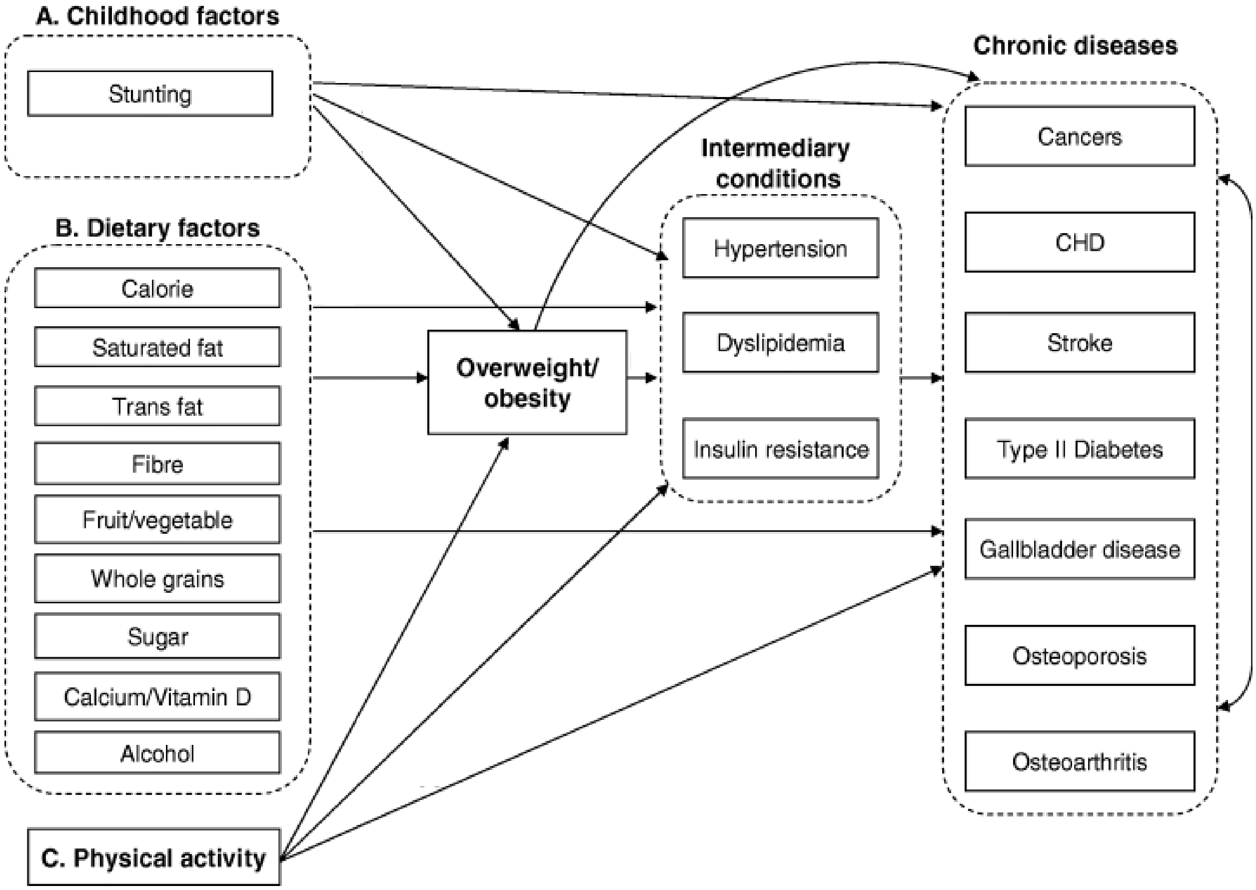

Figure 2. Key pathways from physical activity and obesity to chronic disease. (From: Popkin et al., Obes Rev, 2006 [72])

fitness was a strong independent predictor of CVD and all-cause mortality in all BMI groups, whereas men who were overweight or obese, but fit, did not have greater risk of mortality compared to their healthy weight fit counterparts.[73] Also in the ACLS sample, the health benefits of "leanness", whether measured by BMI, waist circumference, or fat/fat-free mass, were limited to those men who were fit, and fitness reduced the hazards otherwise associated with obesity. Unfit, lean men had double the risk of all-cause and CVD mortality of fit, lean men; however, they also had a higher risk of mortality than fit, obese men, while the latter had no greater risk of mortality than fit, lean men.[74]

Other studies, including follow-up of a large sample of women, have only partially supported this hypothesis, finding that being fit/active indeed reduced, but did not completely eliminate, the increased risks associated with obesity, but likewise, that being of healthy weight did not eliminate the increased risk associated with being unfit/inactive.[75, 76] A recent systematic review aimed to answer the question "Which is a greater health risk, poor cardio-respiratory fitness (or physical inactivity) in normal weight people, or obesity in individuals with good cardiorespiratory fitness (or high physical activity)?" by examining the evidence published over the past 2 decades.[78] The review concluded that the risk for all-cause and CVD mortality was lower in high-BMI fit individuals, compared with normal-BMI unfit individuals; however, the evidence was inconclusive for physical activity and BMI with respect to all-cause and CVD mortality. As well, having a high BMI even if physically active was a greater risk for type 2 diabetes, as well as CVD and diabetes risk factors, compared to those with normal BMI and inactive.

In summary, while physical activity and weight status are clearly linked, it is also clear that physical activity is important regardless of weight status, with health benefits over and above weight loss or maintenance.

2.4.4 Physical Activity, Obesity & Health in Children & Adolescents

Childhood and adolescent physical activity is associated with numerous health outcomes, similar to those of adulthood, including: obesity; hypertension; type 2 diabetes; dyslipidemia; respiratory conditions; and mental health conditions.[79, 80] As in adults, a negative dose-response gradient is also found in children and adolescents between physical activity level and several metabolic risk factors.[79] Positive effects of physical activity are also evident on academic performance, musculoskeletal health and fitness, and bone mineral density.[80]

Obesity in childhood has been associated with a greater likelihood of psychological problems, adverse levels of cardiovascular risk factors and risk factor clustering, asthma, diabetes, and low-grade systemic inflammation.[38, 81] Longer term, childhood obesity is associated with lower income and educational attainment in adulthood, persistence of obesity into adulthood (thereby increasing the risk of known adult comorbidities), and increased adult morbidity and premature mortality including adverse cardiovascular risk profiles, even after adjustment for adulthood BMI.[21, 38, 81]

In general, more active youth are less overweight than less active youth.[80] In the Framingham Children's Study, children in the highest tertile of objectively-measured physical activity from ages 4 to 11 had smaller gains in BMI and skinfolds by early adolescence (age 11).[82] In Canadian children, both organized and unorganized sport and physical activity are negatively associated with overweight and obesity.[83] However, increases in obesity prevalence have continued unabated, despite physical activity promotion efforts. A recent prospective cohort study examining the relationship between objectively measured physical activity (accelerometers) and body fat percentage in children aged 7 to 10 years, in fact found that a higher body fat percentage predicted a relative decrease in physical activity level, but that physical activity did not predict a relative decrease in body fat percentage.[84] A systematic review of treatment interventions in overweight youth concluded that, based on the limited number of short-term randomized trials available, 155-180 minutes of moderate intensity aerobic exercise per week was effective at reducing body fat in overweight children and adolescents, although effects on body weight and abdominal obesity were inconclusive.[85]

2.4.5 Physical Activity Measurement

The characterization and quantification of complex physical activity behaviour presents inherent methodological challenges. Leisure time physical activity is most commonly measured via self-report questionnaire. Estimated levels of activity in adults are often quantified in terms of time spent in activity, frequency and/or intensity of activity, an activity “score”, or energy expenditure in light or moderate-to-vigorous activities.[19]

Commonly in Canada, leisure time physical activity energy expenditure (AEE) over 12 months has been assessed using an adaptation of the Minnesota Leisure Time Physical Activity Questionnaire (MLTPAQ).[86] Referring to a list of 24 physical activities plus 3 volunteered activities, participants indicate which activities they have undertaken over the past year, the frequency, and the average time spent. Average daily AEE is then calculated as follows:

$$AEE\ (kcal \cdot kg^{-1} \cdot day^{-1}) = \Sigma\ (N_i \times D_i \times METs_i / 365)$$

where N is the number of times the activity (i) was performed in the past 12 months, D is the average duration in hours, and METs [87] is the estimated energy cost (kcal·kg^{-1}·hr^{-1}). Established cut-points are 1.5 KKD, or 90 MET-minutes, reflecting, on average, the equivalent of 30 minutes of moderate intensity activity daily, and 3.0 KKD, or 180 MET-minutes, reflecting, on average, the equivalent of 60 minutes of moderate intensity activity daily [88] as recommended by public health guidelines in Canada [89] and the U.S.[90] Using these cut-points, Canadians are classified as inactive (< 1.5 KKD), moderately active (1.5 – 3.0 KKD), or active (> 3.0 KKD).

The original MLTPAQ was comprised a list of activities and their intensity codes based predominantly on experience in middle-aged, middleclass American men, and thus might not fully cover the activities of women and children.[86] The format was deemed useful in populations, except in young children and the elderly, with the caveat that activities might have to be added or deleted, and intensity codes altered. Initial validation showed a significant association between objectively measured aerobic exercise endpoints and energy expenditures estimated by the MLTPAQ in middle-aged men, especially with respect to heavy activity levels, and effective discrimination of energy expenditures in female athletes compared to non-athletes, including agreement with caloric intake based on food diaries.[86] However, the original authors did note that high intensity leisure activities might be reported with more accuracy than moderate or light activities, and also that the lack of information on occupational activity might lead to poor capture of overall daily activity level for individuals with high-activity occupations.[86] Test-retest reliability coefficients for adult men and women were later reported in the range of r=.79-0.88 for total activity, and 0.69-0.86 for light, moderate and heavy intensity activity sub-categories.[91]

A comprehensive evaluation of the MLTPAQ in men and women 20-59 years of age showed weak to moderate associations with body fat percentage (r=-0.24) and maximal aerobic capacity (r=0.47), and weak association with accelerometer readings (r=0.23).[92] Also reported were a strong association with a 4-week version of the questionnaire, and moderate association with total and heavy activities from 48-hour activity records, but no association with light and moderate activities. Test-retest reliability for total activity was 0.92 and 0.69 for 1-month and 1-year intervals respectively, with higher reliability for heavy compared to moderate and light activities. It was pointed out that several common types of LTPA were either under-represented or not included in the MLTPAQ.

Only one validation of the MLTPAQ in younger persons has been reported, whereby a significant association (r=0.49) was found with total energy expenditure measured by the doubly labelled water technique in 15-year old adolescents, the questionnaire underestimating energy expenditure in almost all individuals.[93] In a validation of a 1-year moderate-to-vigorous physical activity recall in 8-11 year old girls, a correlation of r=0.47 was reported with 2-week energy expenditure measured by doubly labelled water.[94]

The Physical Activity Monitor is a Canadian adaptation of the MLTPAQ, notably used in the Physical Activity Longitudinal Study, the 22-year follow-up of the 1981 Canada Fitness Survey.[95] This adaptation has demonstrated good 1 month test-retest reliability (r=0.91) in a group of 512 men and women aged 18 and older, and moderate criterion validity (r=0.30-0.45) in 148 men and women aged 18-69 years, although agreement between individual activity level and predicted aerobic capacity was low.[95]

The advantages of collecting physical activity data via self-report methods include low costs when administered in large scale surveys, ease of use and modification, and breadth of information gathered. Limitations include over-reporting due to perceived social desirability,[96] errors stemming from misinterpretation of terminology, the generalization of questions and activities across all gender, age, race/ethnic, and socioeconomic groups, the reliance on recall of often lengthy time periods, the use of standardized MET values when in reality energy expenditure for any given activity can vary greatly between individuals and situations, and the exclusion of activities of daily living, occupational activity, and various unstructured or non-purposeful exercise which may occur over the course of the day.

Notably, the use of self-report physical activity measures in children may be problematic. Frequency, intensity, time, and type of activity may be less appropriate for describing childhood activity, which tends to be more sporadic and spontaneous in nature. Methods used to quantify physical activity in adults may be inappropriate for describing this type of activity,[19] which may be more influenced by physiologic, environmental, and psychological and sociodemographic factors [97] and vary by gender, maturational status, and socioeconomic status, along with daily, seasonal, and “life transition” variations.[19, 98] By contrast, in adulthood physical activity behaviours tend to be of a more consistent nature with fewer sources of variation. As well, physical activity levels determined from questionnaires such as the MLTPAQ are based on activity energy expenditures of adults [87], and children may undertake similar activities with different intensities which might be far from the mean MET level references used.

Kohl et al.[99] reviewed 17 reliability studies of self-report physical activity assessment methods in children and adolescents ranging in age from 6-19 years, finding a wide range in test-retest reliability (r=0.20-0.99), with higher coefficients in older children and adolescents, and over shorter re-testing time-frames (as expected due to lack of long-term consistency of youth physical activity behaviours). The authors similarly reviewed 37 validation studies in children and adolescents ranging in age from 3-18 years, finding that most studies reported non-significant validation coefficients in children under 10 years of age; among older children, validation coefficients using monitoring devices ranged from 0.03-0.88 (majority 0.30-0.50) for monitoring devices, 0.46-0.88 for direct observation (although 2 studies showed no association), and 0.47 for doubly labelled water on 1-yr PA recall. The authors concluded that the validity of self-report measures of physical activity in children and adolescents was variable, but generally low-to-moderate; however, these measures are unlikely to be measuring what they are intending to measure among children younger than 10 years of age, and hence are not advised for physical activity assessment in this age group.

2.4.6 Body Mass Index

The body mass index (BMI), calculated as weight (kg) / height (m^2), is the most commonly used measure of weight status in population studies. According to Canadian [100] and WHO [101] guidelines, a healthy ("normal") adult body weight is defined as a BMI of 18.5-24.9 kg/m^2, underweight as < 18.5 kg/m^2, overweight as 25-29.9 kg/m^2, and obese as ≥ 30.0 kg/m^2.

Ideally, height and weight are directly measured, providing the most accurate and reliable BMI figures. However, as with physical activity, self-reported height and weight continue to be most commonly used in large-scale surveys. The resultant BMI tends to be underestimated in both men and women, although the degree and patterns of variability in under-reporting differ between the sexes, with increasing age and BMI, and between studies, in addition to a great deal of individual variability in reporting.[102-104]

Average under-reporting of weight is approximately 2 kg, with females under-reporting their weight to a greater extent than males.[105] Under-reporting of weight increases with increasing BMI, and is particularly high among obese persons (up to 4-5 kg); however, underweight males tend over-report their weight by significant margins (> 6 kg). Further, on average, males over-report their height by 1.0 cm and females by 0.5 cm. The tendency to over-report height increases with age, and is more pronounced among seniors (up to 3 cm), for the shortest individuals and for overweight/obese individuals (over 2 cm).

As a result of misreported height and weight, overall underestimation of BMI averages approximately 1 kg/m^2. It is slightly greater in females versus males, with the degree of underestimation increasing with increasing BMI (up to 4-5 kg/m^2 for the extremely obese); conversely, BMI tends to be overestimated in underweight males.[105]

In terms of correct classification into BMI categories, sensitivity is very high for those individuals who are at a healthy weight, indicating that a majority will correctly place themselves in this category based on self-report.[105] However, sensitivity falls to < 70% for those who are overweight, and further yet with increasing levels of obesity; note that sensitivity is lowest for underweight males (40%). For the obese category, specificity is > 95%, with very few people classifying themselves as obese who are not obese, while sensitivity is much lower (60%), indicating that many people who are obese do not place themselves in this category through self-report.

These inaccuracies inherent in self-reported BMI lead to underestimation of the prevalence of overweight/obesity,[105] and could lead to underestimation and/or differing patterns of BMI tracking and obesity persistence over time. Finally, if many obese individuals are misclassified as merely overweight (and overweight individuals as healthy weight), the obese category becomes comprised of a falsely elevated proportion of extremely obese individuals, the overweight category comprised of a large proportion of obese individuals, and the healthy weight category contains many overweight individuals. The negative impacts of overweight and obesity on health outcomes may then be *overestimated*.[105]

The categorization of children and adolescents as overweight or obese must take into account age and sex, and various methods are available. The approach developed by the International Obesity Task Force (IOTF) uses age- (by 6-month interval) and gender-specific BMI cut-offs, derived from a large international dataset including nationally representative samples of children variously collected from 1973 to 1993 from the U.S., Brazil, Great Britain, Hong Kong, the Netherlands, and Singapore, and associated with the predicted health-related BMI cut-offs of 25 and 30 kg/m^2 at age 18,[106] which are the WHO-defined adult cut-offs for overweight and obesity.[101] Alternatively, the CDC developed age- (by 1-month interval) and sex-specific BMI thresholds (via growth curves), based on five nationally representative U.S. surveys conducted from 1963 to 1994, whereby the 85^{th} and 95^{th} percentiles denote overweight and obesity respectively.[107] Both the IOTF and CDC approaches to classifying youth overweight and obesity were released in the year 2000.

Examining the utility of childhood BMI in the prediction of adulthood disease, Janssen et al.[108] found that both the CDC and IOTF references had a low sensitivity and high specificity for predicting obesity and metabolic disorders in young adulthood, with only minimal differences: overweight and obesity classified by the CDC growth curves were slightly more sensitive and slightly less specific than the corresponding values classified by the IOTF cut-offs. In other words, only a small percentage of low-risk young adults had been overweight or obese as children, while many participants developed obesity and metabolic disorders in young adulthood despite having had a healthy BMI as children. A slightly higher percentage of children were classified as overweight based on the IOTF reference compared to the CDC reference, while a slightly smaller percentage of children were classified as obese based on the IOTF reference compared with the CDC reference; notably, a larger percentage of children who were obese based on the IOTF reference remained obese 14-24 years later in comparison with those who were obese as children based on the CDC reference.

While these differences were deemed to have significant impact in clinical practice settings, the impact on statistical findings in research settings was deemed to be negligible.

In 2006, the WHO released a new international growth standard for children aged 0-5 years,[109] including BMI-for-age growth charts, based on a multi-national cohort of children raised from 1997 to 2003 under deliberate exposure to optimal growth and development conditions and considered to represent the "gold standard" in childhood growth. This was followed in 2007 by the release of WHO growth references for 5 to 19 year olds,[110] the curves based on U.S. data and constructed to form a smooth transition from the WHO standard for 0-5 year olds. By the WHO approach, children whose BMI is more than two standard deviations above the mean are classified as obese, while those with a BMI between one and two standard deviations above the mean are classified as overweight,[110] approximating the 97.7th and 84th percentile, respectively.[111] At 19 years of age the youth cut-points align closely with the adult cut-points for overweight and obesity.

A recent comparison of Canadian youth obesity prevalence estimates, based on all three now available methods of classification, found a higher prevalence of the combined overweight/obese category (35%) when based on the WHO reference, compared to the IOTF (26%) or CDC (28%) references.[111] Prevalence of obesity alone was similar when based on either the WHO or CDC references (13%), but, similar to above-mentioned findings of Janssen et al.,[108] lower when based on the IOTF reference (8%). At all ages, the IOTF cut-points for obesity were higher than the WHO cut-points, by up to three BMI units; the

CDC cut-points were closer to the WHO cut-points, either slightly below or slightly above depending on age and sex. Differences were smaller for the overweight category, with both the CDC and IOTF cut-points exceeding the WHO cut-points except in 4-5 year old girls.

Released just prior to the release of the WHO youth reference, the Canadian Clinical Practice Guidelines on the Management and Prevention of Obesity recommend using the CDC growth curves for screening of children and adolescents for overweight and obesity in clinical practice.[112] However, for population surveillance, the Guidelines recommend using the IOTF cut-offs to classify children and adolescents as overweight and obese.[112] The goal of the WHO was for all countries to base prevalence estimates of childhood and adolescent overweight and obesity on the WHO reference by 2010;[110] however, the Canadian Guidelines to date have not yet been updated to reflect this intention.

2.5 Health-Related Quality of Life

Research into the links between obesity, physical inactivity and health-related quality-of-life (HRQL) in healthy general population samples has only recently begun to evolve. In general, greater levels of physical activity have been shown to be positively related to physical and mental HRQL[113] and obesity associated with significant impairments in HRQL, with greater impairments associated with greater degrees of obesity, and weight loss leading to improved HRQL.[114]

2.5.1 Physical Activity & HRQL

Using the SF-36 instrument, whereby higher scores reflect better HRQL and less pain, several adult studies have reported significant positive associations between current physical activity level and most SF-36 domains in healthy general populations for both genders and across all age groups,[115-118] indicating the importance of regular physical activity for HRQL as well as for objective health measures and disease prevention.[118] Notably, a randomized controlled trial has shown that while participation in a physical activity program led to improvements in both physical and mental HRQL, these improvements were maintained only if exercise participation continued.[119] Hence it is possible that only *current* physical activity levels impact HRQL, similar to past findings relating to maintenance of overall health benefits.[4]

Using the four CDC HRQL measures, Brown et al.[120] were the first to describe the benefits of physical activity on HRQL in a large adult population sample (N=175,850), using data from the 2001 U.S. Behavioral Risk Factor Surveillance System (BRFSS). The proportions of adults and likelihood of reporting fair or poor self-rated health, or ≥ 14 unhealthy days (physical or mental) in the past month, were significantly lower among those meeting public health recommendations for physical activity compared to their inactive counterparts, a relationship which held across age and sex groups in adults and older adults, illustrating the public health impact in terms of adult productivity. This relationship was j-shaped, in that participation in very short (< 20 min/day) or extended (≥ 90 min/day) physical activity sessions was associated with poorer HRQL (possibly due to adverse immune response reactions, respiratory tract infections, mood disturbances, risk of musculoskeletal injuries).[121] Others have reported a higher prevalence and odds of poor or very poor self-rated health with increasing physical activity level, in both healthy individuals and those with physical impairments or chronic conditions,[122] and a greater likelihood of good self-rated health in sufficiently or highly active compared to insufficiently active individuals, regardless of age, sex, income and education.[123] An earlier systematic review had concluded that physical function and well-being were related to higher levels of physical activity in older adults, but that randomized intervention studies did not always support this relationship.[124]

2.5.2 Obesity & HRQL

Using the SF-36 instrument to examine the relationship of obesity to HRQL, several studies of adult population samples have reported poorer scores (reflecting impaired HRQL) on the SF-36 physical domains with increasing levels of overweight and obesity,[125, 126] or in overweight or obese compared to healthy-weight individuals.[127-130] Moreover, excess weight may have a greater negative effect on physical HRQL with increasing age,[127] possibly indicating a greater importance of current versus past weight status.

Associations of adult obesity with the SF-36 mental domains have been weaker and less clear than for the physical domains.[125, 126, 128, 129] In some cases, poorer emotional well-being among obese individuals was due to the presence of obesity-related comorbidities rather than to obesity itself.[125] Others have reported a positive association between adult obesity and the SF-36 mental domains: obesity in older men was associated with higher scores on the SF-36 mental health scales, a result not explained by lifestyle or comorbidities,[130] and obese (not overweight) women scored higher on MH and MCS, and obese and overweight men higher on MH, compared to healthy weight persons.[128] Another study reported that overweight and obese women had better mental health, including lower anxiety, depression, and negative affect, while overweight and obese men had lower depression and negative affect, compared to healthy weight participants, after controlling for physical ill-health.[131] The authors concluded that "reducing obesity in the population was unlikely to have any direct effect on mental health or emotional well-being".

Using the four CDC HRQL indicators and the 1996 BRFSS data, Ford et al. [132] reported that underweight, overweight and obese persons had increased odds of fair or poor self-rated health, while underweight and obese persons fared worse in terms of unhealthy days, and activity limitation days. Patterns were similar across age groups and for males and females, although there was a greater impact of underweight in males, and little effect of overweight in males who in fact reported fewer unhealthy days than normal weight men. Similarly, using the 2000 BRFSS data, it was reported that the proportion of individuals with fair or poor self-rated health increased with increasing BMI for overweight, obese, and severely obese compared to non-overweight individuals, while obese and severely obese (but not overweight) individuals had greater odds of experiencing > 14 physical/mental unhealthy days, or > 14 activity limitation days, over the past month.[133] This analysis did not include underweight individuals, nor stratify by age or gender. Using the 3rd NHANES data, it was reported that the proportion of healthy individuals free of chronic disease reporting excellent health decreased with increasing BMI; however, overweight did not lead to greater odds of reduced self-rated health.[134]

More recently, Imai et al. [135] examined the association of BMI with self-rated health and functional status in U.S. adults and older adults, by age and sex, reporting a consistent association of underweight and severe obesity with increased disability and poorer health status. However, associations for overweight and moderate obesity varied by age and sex, suggesting that a single "ideal body weight category" might not apply to all ages or all health outcomes in both men and women. In men, the odds of impaired HRQL were lowest among the overweight, especially for ages ≥ 45, and moderately obese men had increased risk of disability for ages 18–44 but lower risk for ages ≥ 65. In women, the odds of impaired HRQL were lowest among the normal-weight, especially for ages ≤ 45, while overweight women aged ≥ 65 had a lower risk of disability but elevated risk of fair or poor self-rated health compared to normal-weight women.

2.5.3 Physical Activity, Weight Status, and HRQL

In a recent study of the U.S. adult population, Kruger et al. [136] showed that participation in regular physical activity was associated with better HRQL regardless of BMI; in fact, similar to studies examining mortality outcomes, the prevalence of fair or poor general health, ≥ 14 physically or mentally unhealthy days, or ≥ 14 days with activity limitations was similar in obese active persons and healthy weight inactive persons. Further, in overweight and obese U.S. adults, Heath & Brown [137] recently showed that, similar to their healthy-weight counterparts, those who met public health recommendations for physical activity had better self-rated health and lower odds of ≥ 14 unhealthy days than inactive adults across all age-sex strata; indeed, active-obese individuals had better self-rated health and fewer unhealthy days versus inactive-healthy weight individuals (overweight similar to healthy weight, for all physical activity categories), highlighting the role of regular physical activity on HRQL in overweight and obese persons despite their excess weight.

2.5.4 HRQL in Children & Adolescents

More limited research also exists linking youth physical activity to better youth HRQL, and youth obesity to poorer youth HRQL, including effects on self-reported health, as well as physical, emotional, and social health and functioning.[138-142] Youth physical activity has been linked to better self-esteem, and reduced anxiety and depression.[80, 143] As well, studies have shown that overweight and obese adolescents have significantly worse self-reported health, are more likely to report physical function limitations, and have decreased psychosocial functioning and self-esteem, compared to healthy weight adolescents.[138, 141] However, while some studies have linked youth overweight and obesity to poorer self-esteem [143] and bullying,[144] others have shown relatively little effect of adolescent overweight on depression, self-esteem, and emotional and school functioning.[141, 142] While adolescent obese girls may show greater dissatisfaction with their body weight and shape than their healthy weight counterparts, this may not lead to greater incidence of anxiety or depression.[145]

The long-term effects of youth obesity and physical inactivity on HRQL in adulthood have not yet been studied, though the plausibility for long-term consequences exists. Youth obesity and physical activity may affect physical growth and development into adulthood.[80, 81] In addition, it is conceivable that effects on outcomes reported above could carry negative implications into adulthood. For example, these outcomes could affect social, psychological, and cognitive development, creating the potential for long-term effects on both physical and mental HRQL, with ramifications at both the individual and population levels, especially as youth obesity and physical inactivity reach alarming levels. However, while more active children may report better HRQL than sedentary children,[140] one short-term follow-up study found that weekly physical activity hours at age 15-16 years were only weakly associated with mental health just 3 years later in boys, and no association for girls.[139] On the other hand, when surveyed, over 90% of pediatricians believed that youth overweight could affect future HRQL,[146] despite there being no evidence to date to substantiate this belief.

2.6 Public Health Burden of Physical Inactivity & Obesity

Chronic diseases are the leading cause of mortality and disease burden globally, in both developed and developing countries.[2] Of the 58 million global deaths in 2005, 35 million (60%) resulted from chronic diseases (17.5M from CVD). The global toll is projected to increase by 17% by the year 2015, with an enormous economic impact. CVD is the leading cause of death in Canada, as well as the leading economic burden.[147] Although CVD deaths have declined by more than 50% over the last half century, mortality rates remain high, comprising 36% of all deaths in Canada (1999 data). Approximately 5% of the population reports having diagnosed heart disease, of whom 14% (men) to 21% (women) report mobility difficulties, six times higher than in the population without CVD. A total of 4.5 years of life expectancy and 2.8 years of healthy life expectancy are lost due to CVD. Direct costs (hospital, physician, institutional care; drugs) and indirect costs (relating to mortality, lost wages, short- and long-term disability) amount to $6.8 and $11.6 billion respectively. In addition to CVD, 28% of deaths occur from cancer, 10% from respiratory diseases, and 3% from diabetes.[147]

The WHO report *Preventing Chronic Disease: A Vital* Investment [2] presents the goal of a 2% yearly reduction in chronic disease death rates worldwide to 2015, preventing 36 million premature deaths and leading to substantial economic gains for all countries. The report stresses that the major chronic disease causes are known, and if all risk factors were eliminated, at least 80% of all heart disease, stroke and type 2 diabetes, and 40% of cancer, would be prevented. The following statistics are listed:

> *"Each year at least:*
> *7.1 million people die as a result of raised blood pressure;*
> *4.9 million people die as a result of tobacco use;*
> *4.4 million people die as a result of raised total cholesterol levels;*
> *2.7 million people die as a result of low fruit and vegetable consumption;*
> *2.6 million people die as a result of being overweight or obese;*
> *1.9 million people die as a result of physical inactivity."*
>
> (From: WHO. Preventing Chronic Disease: A Vital Investment. 2005) [2]

While the health benefits of physical activity have been well publicized through the *U.S. Surgeon General's Report on Physical Activity and Health*,[55] and *Canada's Physical Activity Guide to Healthy Active Living*,[10] a large proportion of North Americans remain insufficiently active to benefit their health. In Canada, it has been estimated that 21,000 lives are prematurely lost each year due to physical inactivity,[148] and that physical inactivity reduces life expectancy by over 10 months (0.65 y M, 1.0 y F).[149]

Burden of disease is defined by the WHO as "a measurement of the gap between a population's current health and the optimal state where all people attain full life expectancy without suffering major ill-health."[150] Assessing burden of disease and major risk factors is important for planning health policy, programs and interventions, and resource allocation, for assessing cost-effectiveness of programs and interventions, and for setting health research priorities. The

WHO's *Global Burden of Disease Study* included physical inactivity as one of the most important risk factors threatening global health.[151]

The *Global Strategy on Physical Activity and Health* [152] also recognizes the "heavy and growing burden of non-communicable diseases" globally, and addresses diet and physical inactivity as two of the main risk factors for these conditions. The Global Strategy stresses the population approach to prevention, as even modest risk reduction across the population "cumulatively yields sustainable benefits, which exceeds the impact of interventions restricted to high-risk individuals".

The *Integrated Pan-Canadian Healthy Living Strategy* [153] strives for an integrated approach to "reducing non-communicable diseases by addressing their common risk factors and underlying conditions in society". The Canadian Strategy states that more than two-thirds of deaths annually in Canada are attributed to CVD, cancer, type 2 diabetes, and respiratory diseases – diseases which share common preventable risk factors including physical inactivity and obesity – with the estimated total cost of illness, morbidity, and mortality from chronic diseases in Canada at over $80 billion per year.

In measuring public health burden, while *prevalence* statistics provide basic information about disease, illness, and risk factors (i.e. physical inactivity and obesity) in a population, they ignore the severity of disease or illness. Therefore, there might appear to be a higher burden from mild but common diseases. As well, mortality rates and crude death counts do not account for the morbidity associated with many chronic conditions prior to death, nor the impact on health-related quality of life.[154] A longer life is not necessarily favourable if the additional years are lived in poor health. As physical inactivity and obesity are not direct “causes” of death, other measures are needed to determine the proportion of deaths from other causes attributable to these risk factors.

2.6.1 Population Attributable Risk

The *Population Attributable Risk* (PAR) expresses the proportion of a disease attributable to a particular risk factor. PAR estimates for physical inactivity with respect to CHD have generally ranged from 23% - 46%.[155] PAR is a function of both the prevalence of the risk factor in the population, and the RR independently attributable to the risk factor for a particular disease or condition. PAR can help decipher between the apparent need to target stronger risk factors that affect fewer people, and weaker but more prevalent risk factors which may pose a greater public health burden. While hypertension creates high risk (RR 2.1) for CHD in an *individual*, the population prevalence is relatively low (14.9%); hence, it has less influence than physical inactivity and/or obesity on CHD in the *population*. PAR estimates the potential percentage reduction in disease incidence or mortality if all individuals in a population with an unhealthy risk factor converted this risk factor to healthy levels (and those at healthy levels remained healthy); it can also be used to predict disease benefits resulting from less-than-complete reduction in risk factor levels in the population. PAR is calculated as follows:

$$PAR = \frac{Prevalence_{RF} * (RR_{RF} - 1)}{Prevalence_{RF} * (RR_{RF} - 1) + 1} * 100\%$$

PAR can be multiplied by the total number of disease cases or deaths to give the absolute number of preventable cases due to a specific risk factor. It can also be multiplied by other disease burden summary measures, to estimate disease burden attributable to a risk factor, and multiple disease burdens summed to estimate overall health burden attributable to the risk factor.

The results of a prospective study examining PAR for CHD and all-cause mortality in 16,936 male Harvard Alumni are outlined in **Table 1**.[3, 4] At the individual level, the highest risk for CHD incidence was from hypertension (57%). However, physical inactivity had a much higher prevalence in the population, resulting in a PAR more than double that for hypertension. If all individuals in this population expended > 2000 kcal/week, CHD incidence might be reduced by 23%, while population efforts aimed at hypertension would have a much lesser effect on disease burden. Similarly, the highest risk of all-cause mortality in individuals was caused by smoking and hypertension. Again, the higher physically inactivity prevalence results in a PAR for physical inactivity (16.1%) second only to that for smoking (22.5%). The greatest reduction in premature all-cause mortality at the population level would be achieved by targeting smoking and physical inactivity.

Powell and Blair [156] estimated the PAR for physical inactivity in the U.S. at 35% for CHD, 32% for colon cancer, and 35% for type 2 diabetes, describing the preventable proportion of deaths (1988 mortality statistics) from these conditions if all persons met current physical activity recommendations (Surgeon General's Report). The largest drop in PAR (from 35% to 25%) would have been achieved if 50% of people in each of four physical activity categories moved up to the next

Table 1. Population Attributable Risk of (a) first CHD attack fatal or non-fatal (1962-1972) and (b) Death from all-causes (1962-1978) among 16,936 male Harvard Alumni by selected risk factors.

(a) Risk Factor	Prevalence	RR of CHD Incidence	p-value	PAR (%)
Sedentary	61	1.49	<0.001	23
Hypertension	9	2.34	0.008	10
Cigarette Smoking	52	1.30	0.005	13
Obese	38	1.32	<0.001	11
History of Parental CHD	39	1.28	0.012	10

(b) Risk Factor	Prevalence	RR of All-Cause Death	p-value	PAR (%)
Sedentary	62.0	1.31	0.0001	16.1
Hypertension	94	1.73	<0.0001	6.4
Cigarette Smoking	38.2	1.76	<0.0001	22.5
Weight gain	35.1	1.33	0.0001	10.3
Early parental death	33.3	1.15	0.0248	4.8

Sedentary = < 2000 kcal/wk energy expenditure walking, stair climbing, sports play; Hypertension = physician diagnosed; Cigarette Smoking = Any amount; Obese = BMI ≥ 36; History of Parental CHD = Either or both parents; Weight Gain = More than 7kg (15lb); Early Parental Death = Either or both parents before age 65.
(Adapted from: Paffenbarger et al., JAMA, 1984 (a)[3], Paffenbager et al., NEJM, 1986 (b)[4])

more active category. Under this scenario, deaths from CHD would be reduced by 11.4%, colon cancer 10.1%, type 2 diabetes 7.8%, and the three conditions combined 11.0%; total mortality would be reduced by 3.0%, preventing 66,000 premature deaths in 1988. Some years later, Colditz [154] reported that the largest PARs for physical activity were for CHD, gall bladder disease, and colon cancer, at 22% each, and osteoporotic fractures at 18%. For obesity (BMI ≥ 30), the largest burdens were from type 2 diabetes (69%) and CHD (40%).

In Canada, Katzmarzyk and Janssen [57] used the population physical activity prevalence of 53.5% (CCHS 2000/2001) and RR estimates from their own meta-analysis to determine PARs for physical inactivity as follows: stroke and osteoporosis each 24%, type 2 diabetes 21%, CAD 19%, colon cancer 18%, and hypertension and breast cancer each 14%. For obesity (self-reported population prevalence 14.7%), hypertension had the highest PAR at 34%, followed by type 2 diabetes (29%), gall bladder disease (26%), CAD (15%), and osteoarthritis (13%).

While it is assumed in the calculation of PAR that the prevalence of other risk factors remains constant, realistically other risk factors would likely change when physical activity changes, hence PAR would underestimate the probable change in health outcome.[155] PAR can also overestimate the benefit of eliminating one risk factor on mortality, since those at risk often have more than one risk factor: eliminating physical inactivity in someone with only that risk factor may reduce risk more than eliminating the same risk factor in someone with multiple risk factors. Further, since PAR estimates for a given condition exceed 100% due to overlap between risk factors, the rank order and relative difference in magnitude of these estimates is more important than the absolute percentages. Simply summing PARs will overestimate the effect achieved on a single disease if more than one risk factor were removed from the situation simultaneously, but miss the fact that any risk factor reduction would reduce the burden of multiple conditions in the population at once.

2.6.2 Disability Adjusted Life Years

Disability Adjusted Life Years (DALYs) are a summary measure of *total* burden of disease, representing the gap between current health and a hypothetical ideal health achieving maximum life expectancy free of disease and disability.[151] One DALY is equal to the loss of one year of healthy life to a particular disease, condition or risk factor, including both disability and death. DALYs incorporate both the age at which death occurs and the duration and severity of disability, giving importance to both length and quality of life, and include age-weighting. The *Global Burden of Disease Study* [151] reported that the most significant global risk factors in 1990 were childhood malnutrition (15.9% of total DALYs), and sanitation and hygiene (6.8%). Smoking, hypertension, and physical inactivity contributed 2.6%, 1.4%, and 1.0% of global DALYs respectively; however, in developed countries, physical inactivity contributed 4.0% of DALYs, while smoking contributed 12.1%, and hypertension 4.7%.

The *WHO World Health Report* [157] states that 60% of all deaths and 47% of global DALYs are accounted for by mortality, morbidity and disability attributed to chronic disease, figures predicted to rise to 73% and 60% respectively by the year 2020. The Report estimated that physical inactivity caused 1.9 million deaths and 19 million DALYs globally, or 10–16% of cases each of breast cancer, colon and rectal cancers and diabetes mellitus globally, and 22% of CHD. In North America and Europe, the proportion of deaths attributable to physical inactivity was estimated at 5–8%. The Report also stated that 58% of type 2 diabetes, 21% of CHD and 8–42% of certain cancers globally were attributable to a BMI > 21, accounting for 9–10% of deaths and 8-15% of DALYs in North America and Western Europe.

2.6.3 Economic Burden

A final important measure of public health burden involves the description of *economic costs*, determined by multiplying the PAR for a given condition or risk factor by known medical and social costs. Some conditions with a high PAR may be cheaper to effectively treat (or have high immediate mortality), while others may involve more expensive treatment or require treatment over a longer term. *Direct costs* reflect “the values of goods and services for which payment was made and resources were used in treatment, care, and rehabilitation related to illness or injury” (e.g. hospital stay, nursing home, medications, and physician visits).[57] *Indirect costs* reflect “the value of economic output lost because of illness, injury-related work disability, or premature death”.[57] This includes the value of lost productivity (e.g. wages lost due to inability to work, future earnings lost due to premature mortality), early retirement and increased risk of disability pensions, money spent on commercial weight loss programs, reduced quality of life and lower earnings, and greater use of social services.

In the U.S., the total annual direct health care delivery economic costs of physical inactivity were conservatively estimated at $24 billion (1995 USD), or 2.4% of U.S. healthcare expenditures, and potentially as high as $37.2 billion USD (3.7% of direct health care costs) using higher available physical inactivity prevalence estimates.[154] The largest proportion of physical inactivity costs were from CHD and type 2 diabetes, at $8.9 and $6.4 billion (1995) respectively. For obesity (BMI ≥ 30), the direct health care costs were $70 billion, or 7% of total health care costs, with the largest burden created by type 2 diabetes ($36.6B) and CHD ($16.2B). It was concluded that costs of physical inactivity and obesity were similar to those of smoking ($47 B). Moreover, a cross-sectional analysis of the 1987 U.S. National Medical Expenditures Survey (N=35,000) revealed a difference of $1000 annually in direct medical costs for active (30 min moderate/strenuous activity ≥ 3x/wk) versus inactive adults, controlling for age, sex, and smoking status: if all persons in the US became physically active, an annual direct medical cost savings of $29.2 billion (1987 USD; = $76.6 billion in 2000 USD) could be realized.[158] Finally, based on an analysis of seven states, including medical care costs, worker's compensation claims, and productivity loss (absenteeism, short-term disability, time on job but not fully functioning), it was estimated that physical inactivity costs for the entire U.S. amounted to $251 billion, while costs of overweight and obesity amounted to $256.5 billion (some overlap).[159]

In Canada, Katzmarzyk and Janssen [57] estimated the annual economic burden of physical inactivity and obesity at $5.3 billion in health care costs (2.6% of total health care costs in Canada; 2001 dollars), including $1.6 billion in direct medical costs and $3.7 billion (two-thirds of total) in indirect costs. The most costly conditions related to physical inactivity were CAD, stroke, and osteoporosis, each accounting for 20% of the total cost of treating the seven diseases included in the analysis. The corresponding cost associated with obesity was $4.3 billion ($1.5 B direct + $2.7 B indirect), or 2.2% of total health care costs in Canada. The most expensive obesity-related conditions were CAD, hypertension, and osteoarthritis.

2.7 Summary

The current epidemics of obesity and physical inactivity in Canada are cause for growing concern, both in terms of the predicted burden on the health of the population, and the consequent strain on the health care system. Especially concerning are the increasing levels of childhood and adolescent obesity and inactivity, not only in terms of the immediate health of the country's youth, but also with a view to the health and productivity of the future adult population. Long-term tracking studies of obesity and physical activity are few, and as the prevalence of youth obesity and inactivity increases, it becomes increasingly essential to understand the long-term consequences in terms of adult obesity and inactivity prevalence, as well as impact on various adult health outcomes. The links between obesity and physical activity and a host of chronic diseases, conditions, and early mortality are well established; however, research relating these risks to HRQL is still in its infancy. While physical activity and obesity have been found to impact HRQL in adulthood, and possibly within childhood, potential longitudinal relationships have not previously been examined. Similarly, while physical activity is more important than weight status with respect to biomedical outcomes in adults and older adults, research examining HRQL outcomes in this light has only very recently begun. The research presented in this thesis aims to quantify the long-term tracking of overweight and physical activity from youth to adulthood, the long-term impact of youth weight status and physical activity on adult health-related quality of life, and the relationships between weight status, physical activity, and health-related quality of life in adults and older adults, all within the Canadian context.

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CHAPTER 3

MANUSCRIPT 1

Trends in Physical Activity Research in Canada

This manuscript has been published in *Applied Physiology, Nutrition, and Metabolism* (2007, 32(3): 400-408), and is presented in a format consistent with journal requirements.

Abstract

Objective: To assess Canada's physical activity research productivity by 1) assessing Canada's contribution to global physical activity research, 2) determining trends over time, and 3) identifying research areas of greater or lesser representation. **Research Design and Methods:** A Medline search was performed to identify physical activity research published between 1990 and 2005 from Canadian institutions or using Canadian data. Trends over time were plotted and compared to global physical activity research patterns. Original and review articles were sorted based on subject characteristics, nature of physical activity contribution, province and institution of origin, and research area or "pillar". **Results:** A total of 5302 Canadian physical activity articles were identified for the period 1990-2005, representing 4.9% of global physical activity research. Following manual sorting of abstracts, 3829 relevant articles were included for further analysis. A majority of Canada's physical activity research has come from Ontario (49%), followed by Quebec (21%), and Alberta and British Columbia (10% each). Where physical activity was the primary research focus, the Biomedical and Clinical pillars each accounted for 39% of Canadian research, with lesser contributions from Population Health (14%) and Health Services (2%). **Conclusions:** Physical activity research productivity in Canada has paralleled global trends over the last 15 years. There is currently less physical activity research being conducted in population health and health services than in the biomedical and clinical areas; however, these areas play an important role in the development of public health policy and programs targeted reducing the burden of physical inactivity and obesity in Canada.

Key Words: *Citation Analysis, Canadian Institutes of Health Research, Medline, PubMed, Exercise.*

Introduction

Physical inactivity is a major modifiable risk factor for several chronic diseases, including coronary artery disease, stroke, hypertension, type 2 diabetes, colon cancer, breast cancer, osteoporosis, and increased overall risk of premature mortality (Bouchard et al. 1994b). It has been estimated that about 21,000 lives are prematurely lost each year in Canada due to physical inactivity (Katzmarzyk et al. 2000). The total annual economic burden of physical inactivity, including direct costs plus the indirect costs of lost productivity due to premature death and disability, is estimated at $5.3 billion. This represents about 20% of the total costs of treating the above-mentioned diseases, or 2.6% of total healthcare costs in Canada (Katzmarzyk and Janssen 2004). The health benefits of physical activity have been well publicized through the *1996 U.S. Surgeon General's Report on Physical Activity and Health* (U.S. Dept. Health & Human Services 1996), and the 1998 *Canada's Physical Activity Guide to Healthy Active Living* (Health Canada 1998). Therefore it is troubling that 51% of Canadians age 12 and up remain insufficiently physically active to benefit their health (defined as expending ≥ 1.5 kcal/kg/day) (Statistics Canada 2006).

In October 2005 the *Integrated Pan-Canadian Healthy Living Strategy* was released by the country's Federal, Provincial, and Territorial Ministers of Health (Secretariat for the Intersectoral Healthy Living Network 2005). Targets set out by this strategy call for a 20% increase by the year 2015 in the proportion of Canadians who are physically active – defined as participating in regular physical activity based on 30 minutes per day of moderate to vigorous activity – such that about 60% of Canadians would be physically active by 2015. In light of the high prevalence of physical inactivity and current population health targets, physical activity research has been identified as a priority in Canada (Secretariat for the Intersectoral Healthy Living Network 2005). However, currently very little is known about the amount and type of research being conducted in this area.

The Canadian Institutes of Health Research (CIHR) is Canada's major health research funding agency, created by the Canadian government in June 2000 as a program for health research funding to replace the Medical Research Council (MRC). CIHR currently supports approximately 250 research institutions and over 9,000 researchers (CIHR 2005). Its mandate is "to excel according to international levels of scientific excellence, in the creation of new knowledge and its translation into improved health for Canadians, more effective health services and products, and a strengthened health care system" (CIHR 2001). CIHR allocates its funding to four key areas ("pillars") of health research: Biomedical, Clinical, Health Services, and Population Health. However, it is currently unknown how much physical activity research is conducted across these four pillars.

The purpose of this study was to 1) assess the current state of physical activity research in Canada as a proportion of global physical activity research, 2) determine trends over time, and 3) identify research areas of greater or lesser representation. It is anticipated that the results will allow researchers to better target their research programs to areas of need, and will allow researchers and funding agencies to better align themselves on priorities and future opportunities.

Materials and methods

Medline Search. The National Library of Medicine PubMed database contains information on scientific articles indexed in Medline and published between 1966 and today. The database has evolved over the years. In the early years only the title and author's names were provided in many cases, and the MESH (medical subject headings) terms were limited. Journals have been added to the database over the years, and more complete abstract and author information has been provided. Given these early-year limitations and to ensure consistency of the information available for classification, this analysis was limited to papers published between 1990 and 2005.

The PubMed database was searched on February 1, 2006 and abstracts retrieved for the period January 1990 to December 2005. Search terms used were ("physical activity" or "exercise" or "fitness") to assess global research, with the addition of ("Canada" or "Canadian" or "Canad*") to determine Canadian research (* = "wild card"). Physical activity can be defined as any bodily movement produced by the skeletal muscles that increases energy expenditure over resting levels, whereas exercise is a form of leisure-time physical activity that is performed on a repeated basis over an extended period of time (Bouchard and Shephard 1994a). Physical fitness, on the other hand, is an attained state that is related to numerous factors, including physical activity and inherent biological traits (Bouchard and Shephard 1994a).

Papers were aggregated by single-year as well as by 5-year brackets. To avoid overlap or duplication caused by the advent of "epub" (year 2000), papers were counted only in the year published in hard copy.

Manual Sort. All Canadian abstracts retrieved from the years 1990-2005 were printed and manually sorted and categorized. The initial set of papers was reduced according to predetermined inclusion criteria: a) original research or review articles; b) physical activity-related, defined as any research having to do with physical activity, fitness or exercise be it as the primary focus or peripheral influence, and ultimately applicable to humans; c) Canadian research, defined as research by authors with Canadian affiliations, or involving Canadian data.

The data gathered included the type of article (original/review), province and institution (largely universities, but also hospitals and other research centres) of origin, human vs. animal research, sex and age of human subjects, and the role of physical activity in the publication. Animal studies that were strictly related to animal health or function that were i) not typical models of disease relevant to humans, and ii) made no explicit mention of the study implications for humans, were considered 'not relevant to humans' and were excluded. Physical activity was defined as the 'primary focus' if it had a central role in the study (e.g. research question could not be addressed without physical activity, exercise, or fitness), 'among factors' if physical activity was included as a component along with other risk factors, predictors, or factors (e.g. risk of heart attack in obese individuals, after adjusting for the influence of physical activity pattern), or a 'peripheral/contributing' concept if it was peripherally related (e.g. treadmill testing as a baseline measurement in a pharmaceutical intervention in a clinical population). If the sex of the subjects was not specifically stated in the abstract but could be discerned (either by topic area or characteristics of sample) then assumptions were permitted. If papers overlapped more than one age group they were placed in the age category most represented (generally adult). The child/adolescent and elderly categories were reserved for research focusing solely on those populations (≤ 18 y or ≥ 65 y). Only if research specifically compared or encompassed the entirety of two age categories was it deemed to be “multiple ages” – overall this was not a common occurrence.

Abstracts were categorized according to the four “pillars” encompassing and guiding health research, as identified by CIHR at its conception: *Biomedical* research seeks to understand normal and abnormal human functioning at the molecular, cellular, organ system and whole body level, including the development of tools and techniques for this purpose; *Clinical* research seeks to improve the diagnosis and treatment (including rehabilitation) of disease and injury in patients; *Health Services* research evaluates health services practice and policy with the goal of improving the efficiency and effectiveness of health professionals and the health care system; *Population Health* research investigates the social, economic and environmental factors affecting the health of the Canadian population or defined sub-populations. If more than one pillar seemed to apply, the “best fit” was used. A fifth category, *Other – Performance*, was added to encompass those papers in which the physical activity pertained to sport/athlete-specific or occupation-specific training with the goal of enhancing performance in that sport/occupation, and having no bearing on or immediate relevance to overall human health.

The categorization of abstracts was undertaken by four researchers. This introduces a potential source of error into the study. However it was not feasible for a single individual to sort over 5000 abstracts in a short time frame. Several steps were taken to minimize the potential variability among researchers. First, an initial categorization of 50 abstracts was performed in a group setting to align the individuals' sorting processes. Further, throughout the manual sorting process, where a researcher was unsure of any aspect of an abstract, it was later reviewed by one of more of the other researchers for consensus. Upon completion of sorting, the lead author did a full check through the sorted abstracts, and any abstract pulled for uncertainty around the categorization was sent back to one or more members of the group for review. Finally, the use of a spreadsheet for data entry and analysis allowed possible categorization errors to be identified and re-checked where categories within an individual research article did not align in a probable sense.

If any of the desired information was unavailable from the abstract, the internet and library were used to seek out the information, either reviewing the full article or accessing the primary author's research, location, etc.

Analysis. Canada's contribution as a proportion of global physical activity research, and trends over the past 15 years were plotted based on the overall Medline searches. While these searches would include many papers ultimately not applicable by way of either subject area and type of article, this "error" would likely be similar in proportion in both the global and Canadian counts, thus relative proportions and trends would not be affected.

Categorized counts obtained from the manual sort were used to describe the physical activity research taking place in Canada during 1990-2005, the distribution of this research by province, institution and CIHR health research pillar, trends over time, and ultimately to illustrate areas of areas of greater and lesser representation.

Results

Medline Search/Global Comparison. The Medline search (1990-2005) identified 108,335 global abstracts, of which 5,302 were Canadian (4.9%). Plotting the number of papers over time, a relatively consistent increase in research is seen over the course of the past 15 years, with Canada's trend more-or-less mirroring that of global research activity (Figure 1a). Over the 15-year period, Canada contributed approximately 4.9% of the world's physical activity research on average (Figure 1b); most recently in 2001-2005, Canada contributed 5.0% of global physical activity research.

Descriptive Analysis. A total of 5,302 "Canadian" abstracts were retrieved in the Medline search for the years 1990-2005. The manual sort according to the inclusion criteria reduced this number to 3,829. The excluded abstracts included 1098 non-physical activity (or not applicable to humans), 138 non-Canadian, and 237 publications classified as other than original research or review article.

A descriptive analysis of the physical activity research in Canada (1990-2005) is found in Table 1. A total of 80% of the papers were classified as original research and the remainder as review articles. The trend over time appears to be toward an increasing proportion of review articles pertaining to physical activity (16% in 1990-1995, increasing to 22% by 2001-2005). Approximately two-thirds of included papers involved physical activity as their primary focus, while 19%

involved it as one of several factors examined. In the remaining 14% physical activity played only a peripheral or minor contributing role. A total of 91% of papers reported studies using human subjects, with the remainder reporting animal and cell (less than 1%) research. Of those papers reporting on human subjects, 18% reported on males only, 11% on females only, and 49% on both sexes. Twenty two percent of the abstracts did not indicate or imply the sex of the study population in any way. In those publications for which the sex of the subjects was apparent, the trend over time shows an increased research focus on females and/or subjects of both sexes, and less focus on “males only”: sex-specific studies are approximately equal in the 2001-2005 period. Of the human-subject papers, 91% reported on adults over the age of 18, including 5% focusing exclusively on the elderly (≥ 65 y). Only 8% of human-subject papers focused exclusively on children/adolescents (≤ 18 y). Over time an increased focus specifically on children/adolescents and the elderly is seen (Table 1).

Provincial Breakdown. A total of 98% of included physical activity papers were published from Canada. Of the remaining 2%, the majority were published from the United States, while 10 papers were published from various other countries (in each case, using Canadian data).

The percentage of physical activity papers from Ontario has varied from 48% in 1990-95, to 52% in 1996-2000, and back to 48% in 2001-05. Productivity in physical activity research appears to be decreasing in Quebec from 26% in 1990-95 to 18% in 2001-05, while contributions from Alberta have increased from

7% in 1990-95 to 14% in 2001-05. The contribution from the Atlantic provinces has also increased, from 3% in 1990-95 to 5% in 2001-05. (Figure 2)

Institutional Breakdown. Over 80% of Canadian physical activity research, 1990-2005, was identified on the abstract as originating from Canada's universities. In fact, 12 schools consistently contributed two-thirds of all physical activity research (Table 2). While McMaster University, University of Toronto, and Université Laval were ranked highly for research contributions on physical activity during 1990-2005, their contribution has decreased in recent years. Notably, Université Laval produced 9.6% of Canada's physical activity research in 1990-1995 and 4.9% of the research in 2001-2005. In contrast, research contributions from University of Alberta have increased from 3.3% to 9.0%, and Queen's University has increased from 2.2% to 4.4% over the 15 year period.

While the majority of physical activity research was affiliated with Canada's universities, 18% of papers were not identified on their abstracts as university-affiliated. The majority of this group was listed as hospital or medical research centre-affiliated, and many of these centres are known to be university-affiliated; however the authors chose not to report the university affiliation in these cases. Key contributors included Toronto General Hospital, Montreal Heart Institute, Hospital for Sick Children (Toronto), University Health Network, and Hôpital Laval. Other affiliations included government (eg. Defense Research and Development Canada – formerly Defense and Civil Institute of Environmental Medicine; Statistics Canada; Health Canada), cancer agencies, and various public health departments, among others.

CIHR Pillars. In 2001-2005, Canada's physical activity research has centred in the Clinical (45%) and Biomedical (31%) pillars, with lesser contributions from Population Health (18%) and Health Services (2%) research (Figure 3a). Additionally, 145 papers (4%) were placed in the "*Other - Performance*" category. The observed current distribution between the Biomedical and Clinical pillars represents a shift when compared to earlier years (pre-CIHR): in 1996-2000 approximately equal proportions of Canadian physical activity research fell under each of these 2 pillars (39% and 41% respectively), while in 1990-1995, 51% of physical activity research was classified as Biomedical and only 29% as Clinical. The proportion of physical activity research classified as Population Health has undergone a minor increase (from 14% to 18%), while the proportion falling under Health Services research has remained relatively unchanged over time.

Looking only at those papers that had physical activity as the primary focus (as assessed in this study) gives a more equal distribution between the Biomedical and Clinical pillars: for 2001-2005, 39% of papers were classified in each, with 14% falling under Population Health, 2% under Health Services, and 6% classified as Performance-related (Figure 3b). However, even this represents a shift: in 1996-2000, primary focus physical activity research was 51% Biomedical/32% Clinical, and in 1990-1995, primary focus physical activity research was 62% Biomedical/20% Clinical. Analyzing by article type, physical activity research classified as Biomedical during 2001-2005 included somewhat more original articles (vs. review) than did the research classified as Clinical (84% and 73% original articles respectively).

Discussion

The purpose of this paper was to assess the current state of physical activity research in Canada, determine trends over time, and identify areas of greater or lesser representation. The results show that over the past 15 years Canada's productivity in physical activity research has increased in a similar fashion to that of the rest of the world, that Canada currently accounts for approximately 5% of global physical activity research, and that the majority of this research has been clinical and biomedical in nature.

Compared to research being conducted on other major chronic disease risk factors, Canada's contribution (5%) to global physical activity research during 2001-2005 is similar to or greater than its contribution to global research involving smoking, obesity, hypertension, cholesterol and diabetes (Figure 4). Among the major chronic disease risk factors, physical inactivity has a higher population prevalence (51%) (Statistics Canada 2006) than smoking (22%) (Statistics Canada 2006), obesity (24%) (Statistics Canada 2006), hypertension (15%) (Statistics Canada 2006), high cholesterol (34%) (Connolly et al. 1992) and diabetes (4.9 %) (Statistics Canada 2006), and is thus arguably the greatest target for modification. Further, physical inactivity, smoking, hypertension and high cholesterol carry similar relative risks for all-cause mortality (Paffenbarger et al. 1986), suggesting that, at least for some diseases, the population attributable risk for physical inactivity is higher. This information provides some rationale for investing in physical activity research in Canada.

The distribution of Canadian physical activity research by province and institution seems relatively well aligned with current overall CIHR funding distributions, available through CIHR annual reports (CIHR 2005a) and the agency's online searchable funding database (CIHR 2006), while differences are apparent among the CIHR pillars. For the years 2001-2005, the results of this study showed that 48% of physical activity research came from Ontario, 18% from Quebec, and 14% from Alberta (Figure 2). Similarly, Ontario has been the top-funded province in terms of *total* CIHR research funding: its share has been about 40%, while Quebec and Alberta have received 30% and 12% of total CIHR funding respectively (BC also at 12%). These differences are not entirely unexpected given Canada's population distribution, the number of institutions per province, and the sizes of the universities. The specific Canadian universities are similar when comparing the most prominent physical activity research institutions (Table 2) to the distribution of *total* CIHR research funding. From 2000/01 to 2004/05, University of Toronto, University of British Columbia, McGill University, and University of Alberta were the top funded academic institutions, followed by University of Calgary, Université Montreal, McMaster University, Université Laval, University of Manitoba, and University of Western Ontario. It would be expected that some institutions which produce a large amount of *total* health research might not always place a priority on physical activity research, and vice versa.

For the years 2001-2005, this study found that 45% of Canadian physical activity research was Clinical, 31% was Biomedical, 18% was Population Health, and 2% was Health Services. In contrast, only 14% of total CIHR funding was directed to Clinical research, while 72% went to Biomedical research, 8% to Population Health, and 5% to Health Services. This may reflect the nature of physical activity research versus the broader scope of overall health research;

however, CIHR has recently established a Clinical Research Initiative to close the gap between biomedical advances and clinical applications, strengthening Canada's clinical research capacity and establishing it as world leader in clinical research by 2010 (CIHR 2005b). The results of this study suggest that Canada's physical activity researchers may be bridging this gap, as the percentage of physical activity research classified as "clinical" has increased steadily over the 15 year period. Although few attempts have been made to summarize Canadian research on other chronic disease risk factors, a study by Sokar-Todd and Sharma (2004) recently evaluated Canadian obesity research. Similar to the current study on physical activity, the majority of the published Canadian studies on obesity are also clinical and biomedical in nature.

The research pillars described by CIHR do not necessarily follow academic disciplinary boundaries. Upon closer examination of the physical activity research within the four pillars, several themes emerged. For example, close to 50% of the Biomedical research was focused on exercise and/or muscle metabolism/physiology. Other much smaller but key areas included immune function, thermoregulation, and lung/respiratory diseases. Over 20% of Clinical research was focused on cardiovascular disease and cardiology, while other major contributors included lung/respiratory diseases, various aspects of disability/injury/surgery, cancer, obesity/weight issues, and diabetes. Health Services research was largely focused on cardiovascular disease/cardiology and health/physical activity promotion/programs (30% each). Finally, 17% of Population Health research was focused on determinants of health, physical activity and other health behaviours, while other prominent themes included behavioural issues, cancer, obesity/weight issues, cardiovascular disease, and health/physical activity promotion. Among the performance-related research, the research themes included elite athlete training methods (34%), sport/occupation-specific physiology (26%) and ergogenic methods (18%).

There are several limitations to this study that should be discussed. Medline was the only database searched, inevitably resulting in some relevant published academic research being missed. Other relevant databases include PsychInfo, SportDiscus, CINAHL, etc. However, for the purpose of this study it was not feasible to search multiple databases as many are run on separate platforms (PubMed, Ovid, ScholarsPortal, etc), the ability to accurately replicate identical searches using keywords was doubtful, and the elimination of overlap/duplication when research is indexed in multiple databases would have been problematic. Therefore, it is assumed that some areas of research, in particular studies of sociological and behavioural aspects of physical activity, may have been missed to a greater degree by this investigation. By the same token, it is important to note that Canadian population health research conducted by the Federal Government (eg. Statistics Canada), Provincial/Territorial Health Ministries, and national research agencies (eg. Canadian Fitness and Lifestyle Research Institute – CFLRI) is often published as reports, without publication in academic journals: the proportion of population heath research reported here is likely somewhat lower than the Canadian reality, however across several thousand papers, the difference created by this unpublished research is arguably small.

The initial intent of this study was to include research from earlier years (1966 –) to examine historical trends. However, not only are many journals missing from Medline in the early years, but many early abstracts are missing the required information for proper sorting which would cause many Canadian abstracts to be missed altogether (author affiliation missing, MESH terms limited). With the level of possible error in these years, it would be impossible to distinguish between true trend patterns and artifact resulting from the evolution of the database.

In categorizing the physical activity research into CIHR pillars, it was often questionable as to which pillar a piece of research belonged: often research appeared to overlap between areas, in which case it was placed in the category of “best fit”. While this perceived overlap and interconnectedness is a concept that is built into the very nature of the CIHR pillars, CIHR itself tracks its funding allocation history according to the individual pillars. For the purpose of this study all physical activity research was “forced” into the CIHR pillars because of fit “by definition”. However, it is recognized that much of the physical activity research retrieved and discussed in this study might in fact not be funded by CIHR, but rather by more relevant funding agencies such as the National Science and Engineering Research Council (NSERC), and the Social Sciences and Humanities Research Council (SSHRC), among others.

In conclusion, the volume of physical activity research in Canada has been increasing over the last 15 years. From 2001-2005, the majority of this research has been clinical and biomedical in nature, with lesser contributions of population health and health services research. However, these latter areas play an important role in the development and evaluation of public health policy and programs targeted at reducing physical inactivity and obesity in the population.

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TABLE 1. Descriptive analysis of Canadian physical activity research based on abstracts retrieved by Medline search, by 5-year intervals, 1990-2005.

	Number (%) of articles			
	1990-1995	**1996-2000**	**2001-2005**	**Total 1990-2005**
Total articles retrieved	**1496**	**1559**	**2247**	**5302**
Included Articles	**1109 (74.1)**	**1101 (70.6)**	**1619 (72.0)**	**3829 (72.2)**
Article Type – Original	935 (84.3)	897 (81.5)	1260 (77.8)	3092 (80.8)
Review	174 (15.7)	204 (18.5)	359 (22.2)	737 (19.2)
PA – Primary Focus	786 (70.9)	725 (65.8)	1045 (64.5)	2556 (66.8)
Among Factors	187 (16.9)	214 (19.4)	320 (19.8)	721 (18.8)
Peripheral/Contributing	136 (12.3)	162 (14.7)	254 (15.7)	552 (14.4)
Sex – Male	215 (19.4)	201 (18.3)	209 (12.9)	625 (16.3)
Female	78 (7.0)	107 (9.7)	202 (12.5)	387 (10.1)
Male + Female	413 (37.2)	501 (45.5)	789 (48.7)	1702 (44.5)
Human - Unspecified	279 (25.2)	211 (19.2)	269 (16.6)	759 (19.8)
Animal Studies	118 (10.6)	73 (6.6)	123 (7.6)	314 (8.2)
Human + Animal	1 (0.1)	5 (0.5)	4 (0.2)	10 (0.3)
In Vitro/Cell-based	5 (0.5)	3 (0.3)	17 (1.1)	26 (0.7)
Other	0	0	6 (0.4)	6 (0.2)
Age – Adult (can incl. 65+)	897 (80.9)	867 (78.7)	1208 (74.6)	2971 (77.6)
Child/Adolescent	57 (5.1)	85 (7.7)	143 (8.8)	285 (7.4)
Elderly (65+ only)	25 (2.3)	47 (4.3)	104 (6.4)	176 (4.6)
Multiple/All Age	7 (0.6)	26 (2.4)	19 (1.2)	52 (1.4)
N/A (Animal/In Vitro)	123 (11.1)	76 (6.9)	145 (9.0)	345 (9.0)
Excluded Articles – Total	**387 (25.9)**	**458 (29.4)**	**628 (28.0)**	**1473 (27.8)**
Non-Physical Activity	292 (75.5)	339 (74.0)	467 (74.4)	1098 (74.5)
Non-Canadian	33 (8.5)	46 (10.0)	59 (9.4)	138 (9.4)
Non-Original/Review *	62 (16.0)	73 (15.9)	102 (16.2)	237 (16.1)

PA=physical activity; * Non-original/review included case reports, letters, comments, guidelines, editorials, symposium proceedings, etc.

Table 2. Top 12 contributing universities to physical activity research in Canada by 5-year intervals, 1990-2005.

	% Canadian Physical Activity Research			
University	**1990-1995**	**1996-2000**	**2001-2005**	**Total 1990-2005**
McMaster University	9.0	9.9	7.8	**8.7**
University of Toronto	8.9	9.1	8.1	**8.6**
Université Laval	9.6	7.7	4.9	**7.1**
University of British Columbia	6.0	6.3	7.2	**6.6**
University of Alberta	3.3	6.2	9.0	**6.5**
University of Waterloo	6.6	6.6	4.3	**5.6**
University of Western Ontario	4.9	5.4	4.3	**4.8**
McGill University	4.8	5.5	3.6	**4.5**
Université de Montreal	4.8	3.3	4.3	**4.2**
Queen's University	2.2	3.3	4.4	**3.4**
University of Guelph	2.6	3.4	2.7	**2.9**
University of Ottawa	2.9	1.5	3.2	**2.6**
Total	**65.6**	**68.2**	**63.8**	**65.6**

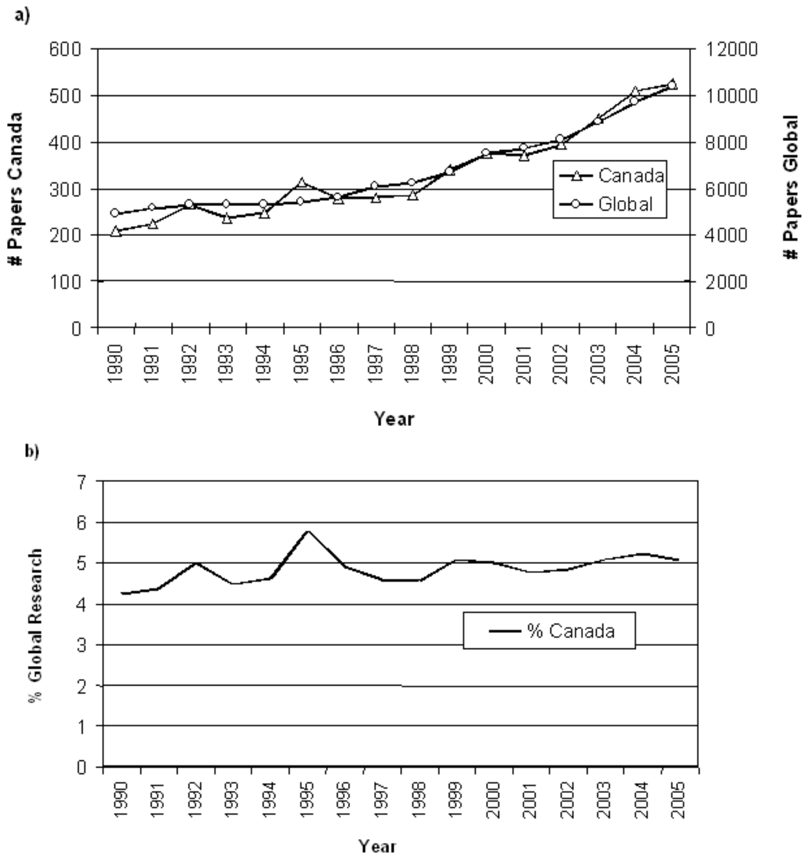
FIGURE CAPTIONS

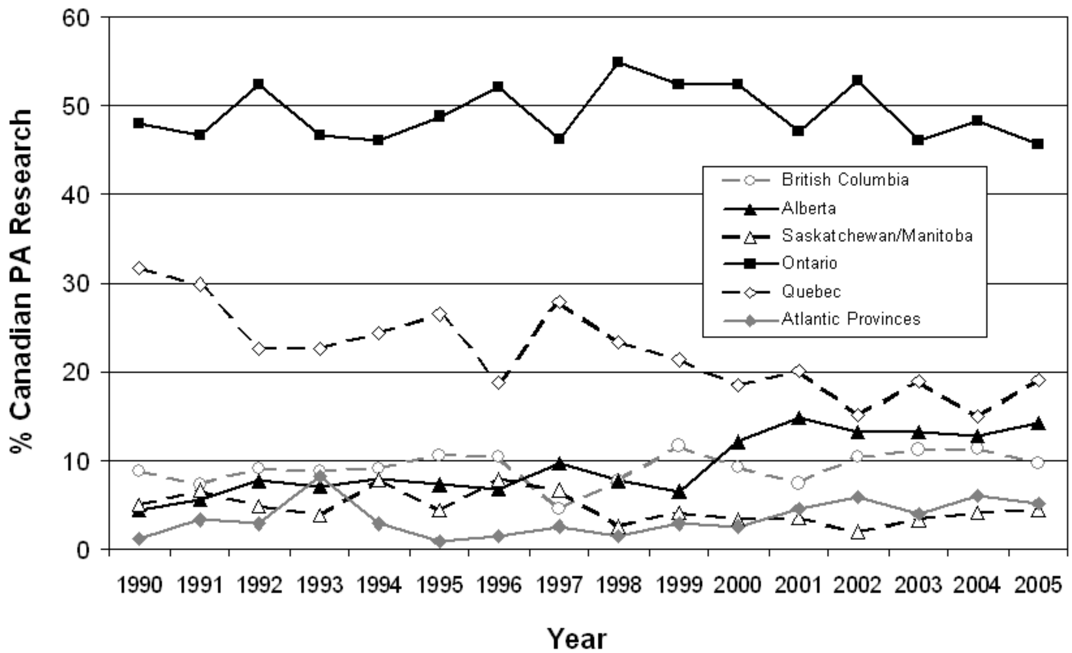
Figure 1. a) Physical activity research trends, Canada and Global, 1990-2005; b) Canada's proportion of Global physical activity research, 1990-2005. PA=physical activity.

Figure 2. Canadian physical activity research by Province, 1990-2005.
* Atlantic Provinces include Nova Scotia, New Brunswick, Prince Edward Island, Newfoundland. PA=physical activity.

Figure 3. Physical activity research in Canada, 2001-2005, by CIHR pillars of strength: a) All physical activity research; b) Physical activity as the primary research focus.

Figure 4. Canada's contribution to Global research 2001-2005: Physical activity vs. other chronic disease risk factors*.
* Medline search was performed for the years 2001-2005, using the terms "cigarette", "obes*", "hypertens*", "cholesterol", and "diabet*" (*=wildcard).


a)
Papers Canada
Papers Global
Canada
Global
Year
b)
% Global Research
% Canada
Year



60
50
40
30
20
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% Canadian PA Research
1990
1991
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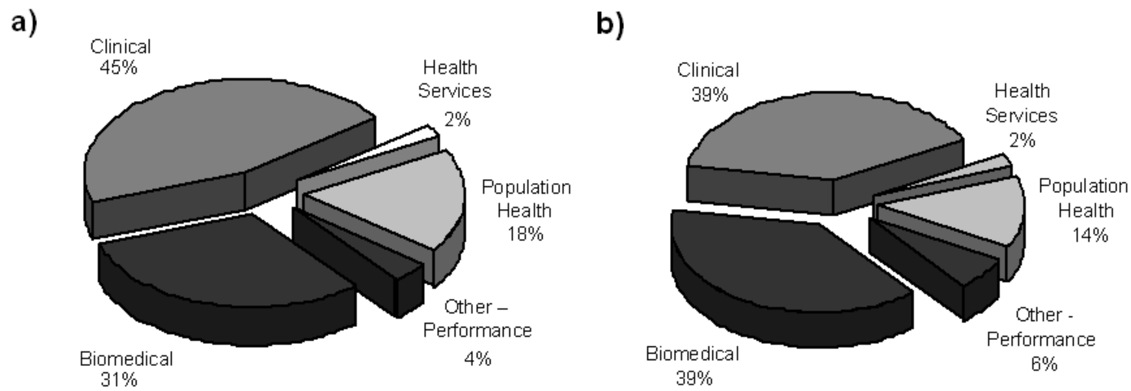
Year
British Columbia
Alberta
Saskatchewan/Manitoba
Ontario
Quebec
Atlantic Provinces


a)
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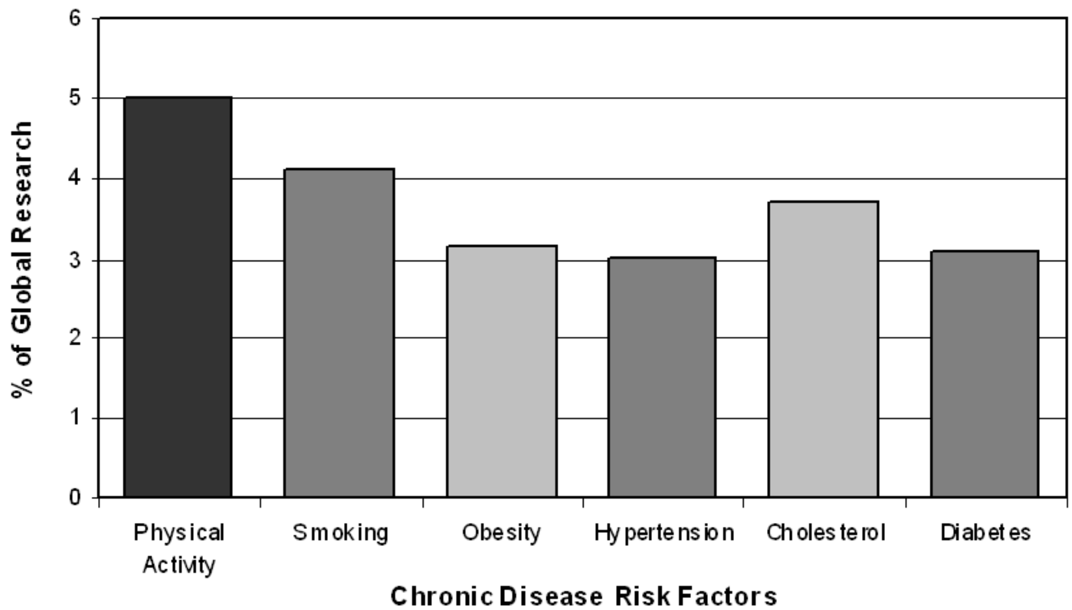
Health
Services
2%
Population
Health
18%
Other –
Performance
4%
Biomedical
31%
b)
Clinical
39%
Health
Services
2%
Population
Health
14%
Other -
Performance
6%
Biomedical
39%


6
5
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% of Global Research
Physical Activity
Smoking
Obesity
Hypertension
Cholesterol
Diabetes
Chronic Disease Risk Factors

CHAPTER 4

MANUSCRIPT 2

Tracking of Obesity and Physical Activity from Childhood to Adulthood: The Physical Activity Longitudinal Study

This manuscript has been published in *International Journal of Pediatric Obesity* (2009, 4(4):281-288), and is presented in a format consistent with journal requirements.

ABSTRACT

Objective. Body mass index (BMI) has shown moderate to strong stability through childhood into adulthood, while physical activity (PA) tracks less well. Tracking studies have often had limited follow-up lengths. The aim was to investigate BMI and PA tracking over 22 y from youth to adulthood. **Methods.** Subjects included 374 participants aged 7 to 18 y in the 1981 Canada Fitness Survey, who were re-evaluated in 2002-04. The stability of BMI and leisure-time PA energy expenditure (AEE) was assessed by inter-age correlations, maintenance of extreme quintiles and BMI status, and the prediction of adult overweight from youth BMI. **Results.** BMI tracking was moderate to strong (r=0.42-0.65) in females, and moderate (r=0.29-0.53) in males. Approximately 38% and 42% of youth in the highest and lowest BMI quintiles remained in these quintiles as adults. About 83% of overweight youth remained overweight as adults, while 85% of overweight adults were not overweight youth. Almost all healthy weight adults had been healthy weight youth. The odds of being overweight in adulthood was 6.2 (95% CI: 2.2-17.2) times greater in overweight compared with healthy weight youth. PA tracking over 22 y was low and non-significant, but moderate over the final 15 y. Only 16% and 18% of youth in the highest and lowest PA quintiles remained in these quintiles as adults. **Conclusions.** BMI, but not PA, tracked well over 22 y in this sample. The majority of overweight youth remained overweight as adults; however, the majority of overweight adults were not overweight youth.

Keywords: *Adolescent, Body Mass Index, Body Weight, Child, Exercise, Leisure Activities, Longitudinal Studies, Motor Activity.*

INTRODUCTION

Physical activity is important in the prevention of several chronic diseases and conditions, often exhibiting a dose-response relationship with health outcomes in adults (1, 2). Obesity is also a major modifiable risk factor for numerous chronic diseases and conditions in adulthood (3). The immediate health outcomes of physical inactivity and obesity in childhood appear similar to those in adulthood; however, most youth do not progress to chronic disease until adulthood (4, 5). Despite large-scale efforts to publicize the health benefits of physical activity (6, 7), only 51% of Canadian adults are sufficiently physically active during their leisure time (8). Further, recent data indicate that only 9% of Canadian youth aged 5 to 19 y accumulate 16,500 or more steps per day, reflecting Canadian guidelines for children and youth (9). As well, the prevalence of overweight and obesity in Canada has increased over the past several decades (10); currently, 59% of adults and 26% of youth aged 2 to 18 y are overweight or obese (8).

Tracking refers to the tendency of individuals to maintain their relative rank or position within a group over time (11, 12). The most common method to assess tracking is by inter-age correlations: those <0.30 are interpreted as low, 0.30-0.60 as moderate, and >0.60 as moderately high (11, 12). Other approaches include assessing the maintenance of percentile rank, and assessing the odds of maintaining a particular characteristic over time (11, 12). A growing body of evidence has shown moderate to moderately strong tracking of overweight and obesity from youth to adulthood (13-17). The strength of overweight or obesity tracking increases with increasing age at baseline;

however, at all ages the stability appears substantial (18). Past research has suggested that 40-70% of obese pre-pubertal children will become obese adults (4), while tracking coefficients for childhood and adolescent BMI range from 0.40 to 0.90 (4, 17). In contrast, tracking of physical activity through childhood and adolescence and into adulthood tends to be low; correlations tend to be stronger with older age at first observation and over shorter time intervals (11, 12, 19-22). An analysis of 313 correlations from published physical activity tracking studies showed that 81% fell between 0.10 and 0.49, 9% between 0.50 and 0.59, and only 3% exceeded 0.60 (12).

Given the alarming prevalence of childhood obesity and physical inactivity in Canada, tracking of these risk factors from youth into adulthood would create a poor outlook for the future health of the population. Physical activity and obesity tracking studies with long term follow-up from childhood into adulthood are limited. The purpose of this study was to investigate the tracking of BMI and leisure time physical activity over 22 y from youth to adulthood in a Canadian population-based sample.

METHODS

Sample. The 2002-2004 Physical Activity Longitudinal Study (PALS), represents the 22 y follow-up of a 20% sub-sample of participants from the nationally representative 1981 Canada Fitness Survey (CFS) (N=23,397) (23). Detailed information regarding the conceptual design and methods of PALS has previously been published – the larger PALS sample was also representative of the 1981 population (24). Baseline height and weight were measured for participants aged 7-69 y during household visits in 1981, while physical activity was assessed by questionnaire for those aged 10 y and older. Intermediary follow-up data are available for the respondents (N=4345) who also participated in the 1988 Campbell's Survey of Well-Being (CSWB)(25). At the 2002-04 assessment, self-administered questionnaire data were collected using comparable methods; however, due to budgetary constraints, height and weight were assessed by self-report rather than by direct measurement. The PALS study was approved by the Ethics Review Board of the Faculty of Medicine of the Université de Montréal; participants were given an explanation of all protocols and provided informed consent indicating their awareness of the survey requirements in 1981, 1988, and 2002-04.

The PALS sub-sample used for this analysis included 374 male (N=192) and female (N=182) participants aged 7-18 y in 1981 who returned for follow-up in 2002-2004 (aged 29-41 y), and who had BMI and/or physical activity data at both visits. This represents 45.8% of the 817 participants aged 7-18 y in 1981 who participated in 1988. Baseline and follow-up data on BMI and physical activity were available for 332 and 275 participants, respectively. Those lost to follow-up were similar to participants according to a range of key characteristics with the exception that father's education was higher for participating males and mother's education was higher for participating females.

Measures. Leisure time physical activity energy expenditure (AEE) over 12 months was assessed using an adaptation of the Minnesota Leisure Time Physical Activity Questionnaire (26). The questionnaire has reasonable criterion validity (rho = 0.30-0.45) and good 1-month retest reliability (0.91) (27). Referring to a list of 24 physical activities plus 3 volunteered activities, participants indicated which activities they had undertaken over the past year, the frequency, and the average time spent. Average daily AEE was calculated as follows:

$$\text{AEE } (\text{kcal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}) = \Sigma\ (N_i \times D_i \times \text{METs}_i / 365)$$

where N is the number of times the activity (i) was performed in the past 12 months, D is the average duration in hours, and METs is the estimated energy cost ($\text{kcal}\cdot\text{kg}^{-1}\cdot\text{hr}^{-1}$).

BMI was calculated as weight (kg)/height (m^2). Youth overweight and obesity were categorized according to the International Obesity Task Force (IOTF) age- and gender-specific BMI cut-offs, associated with the predicted health-related BMI cut-offs of 25 and 30 kg/m^2 at age 18 y (28) which are the WHO-defined adult cut-offs for overweight and obesity (29).

Statistical Analysis. Youth were divided into 3-y age groups for analysis. Analyses were initially conducted with 2-y age groups, however, the results were similar (data not shown), thus the larger age groups were retained in order to maximize sample sizes. Inter-age rank-order (Spearman) correlation coefficients were used to assess the stability of BMI and AEE. The maintenance of relative position over time was also assessed using quintiles by age group. The proportion of healthy weight and overweight/obese youth who remained classified as either healthy weight or overweight/obese in adulthood was determined, and conversely, the proportion of healthy weight and overweight/obese adults who had been healthy weight or overweight/obese youth. Finally, the prediction of adulthood overweight/obese from youth overweight/obese was assessed using logistic regression, adjusted for age and sex. Sample sizes varied from analysis to analysis due to missing values.

RESULTS

Descriptive characteristics of the sample are reported in **Table 1**. Approximately 10% of participants were overweight or obese as youth, while 52.2% (62.7% M, 40.4% F) were overweight or obese (BMI ≥ 25 kg/m^2) at follow-up. Approximately 79% and 63% of boys and girls, respectively, were physically active (≥1.5 kcal/kg/day) in childhood or adolescence; 65% and 58% of men and women, respectively, were physically active in adulthood.

BMI showed moderate to strong tracking (r=0.42-0.65) in females, and moderate tracking (r=0.29-0.53) in males **(Table 2a).** With one exception in males (16-18 y), correlations were significant; overall, inter-age correlations tended to be stronger in females. After 22 y, 37% (n=13/35) of males and 39% (12/31) of females in the highest BMI quintile at baseline remained in the highest quintile; 38% (13/34) of males and 47% (14/30) of females in the lowest BMI quintile at baseline remained in the lowest quintile at follow-up **(Tables 3a, b)**. Males appeared more likely than females to move into the higher quintiles in adulthood after being in the lowest quintile in their youth. A total of 83% (100% males, 66.6% females) of those overweight or obese as youth (n=30) remained overweight or obese as adults, while 50% (39.9% males, 61.8% females) of those healthy weight in their youth (n=302) remained healthy weight as adults **(Table 4a)**. However, 85% (86.1% males, 83.9% females) of overweight or obese adults (n=170) had been healthy weight in their youth, while 97% (100%

males, 94.7% females) of healthy weight adults (n=157) had been healthy weight in their youth **(Table 4b).** Of adults who were obese (BMI ≥ 30 kg/m^2) at follow-up (n=47), 70% (60.9% M, 79.2% F) had been at a healthy weight at baseline (data not shown). The odds of becoming an overweight or obese adult were 6.2 times greater for overweight or obese youth, compared to healthy weight youth, after adjusting for age and sex (OR=6.21; p<0.001, 95% CI 2.24-17.17). Older age was a significant independent predictor of overweight or obesity in adulthood (OR=1.08; p<0.05, 95% CI 1.01-1.16), while females had a lower risk of being overweight or obese in adulthood compared to males, independent of age and youth weight status (OR=0.37; P<0.001, 95% CI 0.23-0.58).

Twenty-two year inter-age correlations for physical activity were low and mostly non-significant in both males and females through all baseline ages **(Table 2b)**. However, significant moderate tracking of physical activity (r=0.38-0.57) was found in the two older age groups over the most recent 15 y of follow-up, reflecting ages 20-25 y in 1988 to 35-41 y in 2002-2004; the youngest age group exhibited lower tracking correlations of 0.2-0.23 but these were not significant. After 22 y, approximately 17% of males and 15% of females in the highest PA quintile at baseline remained in the highest quintile at follow-up; approximately 15% of males and 22% of females in the lowest PA quintile at baseline remained in the lowest quintile at follow-up **(Tables 3a, b)**.

DISCUSSION

This study evaluated the tracking of obesity and physical activity over 22 y from youth to adulthood in a sample of Canadians. Moderate tracking of BMI was observed in both genders, while no tracking was found for physical activity over this time span. However, moderate tracking of physical activity occurred over the most recent 15 y, from ages 20-25 y to 32-41 y. Earlier reports on this population at 7-y follow-up had shown moderate to strong tracking of BMI (15), and generally low tracking of physical activity (20), although the latter appeared more stable in adulthood than in youth (20).

In this study, 22-y BMI tracking coefficients were moderate-to-strong (r=0.42-0.65) in females, and moderate (r=0.29-0.53) in males; the pattern of increasing correlations with increasing baseline age suggested by previous literature (11, 12, 30) was not apparent. From 37-47% of this cohort in the upper and lower BMI quintiles at baseline remained in those quintiles 22 y later, also indicating moderate stability (31); however, this result should be interpreted with caution due to small sample numbers involved. Two other long-term Canadian studies have reported BMI tracking results. In the Quebec Family Study, 12-y inter-age correlations for youth aged 8-18 y at baseline were 0.65 and 0.59 for males and females respectively (13), while in the Trois-Rivières Growth and Development Study, 22-y tracking coefficients from age 10-12 y at baseline were 0.43-0.49 and 0.64-0.70 for males and females respectively and 50% of participants remained in the upper- and lower-most BMI quintiles (32). Previous studies internationally have also shown inconsistent results regarding gender differences; however, all studies report moderate-to-strong correlations over a wide range of follow-up lengths from childhood or adolescence into adulthood (14, 16, 30, 33-38). In the Bogalusa Heart Study, 62% and 54% of participants in the highest and lowest BMI quartiles respectively at age 9-11 y remained in those quartiles at age 19-35 y (14).

Persistence of overweight or obesity from youth into adulthood in this study was high – while the current study sample contained relatively few overweight or obese participants at baseline (15 females and 15 males), youth overweight or obesity was a virtual guarantee of adulthood overweight or obesity, especially for males. However, a healthy weight in childhood offered no guarantee of future healthy weight status, rather, 85% of overweight or obese adults gained the excess weight later in life. Whereas almost all healthy weight adults were healthy weight as youth, only about 50% of healthy weight youth maintained their healthy weight in adulthood – female youth appeared more likely to maintain a healthy weight into adulthood, while male youth appeared more likely to gain and become overweight or obese adults. Past research has reported about 50%-80% of overweight or obese youth becoming overweight or obese adults (18, 38-40), the proportion increasing with age at baseline (18), and when one or both parents are obese (39), while about 60-80% of obese adults have not been obese in their youth (34, 40). Finally, the odds of adulthood overweight or obesity in this study (OR=6.2) were similar to previous reports indicating about 5 to 9 times greater odds for overweight or obese youth compared with healthy weight youth (35, 37, 38).

Limited evidence exists for the long-term tracking of physical activity from childhood into adulthood. Another Canadian study reported weak physical activity correlations (r=0.12-0.20) from age 10-12 y to 35 y, and these were largely due to participation in an experimental enhanced school physical education program (22). In the Cardiovascular Risk in Young Finns Study, 21-y inter-age correlations for physical activity from baseline ages 9-18 y were moderate (0.32-0.44) and low (0.14-0.26) in males and females respectively; being continuously active in youth increased the probability of being active in adulthood, compared to being continuously inactive (21). Other research has reported inconsistent relationships of youth sport participation to adult physical activity levels (38, 41), however, youth classified as active and inactive may be more likely to remain active or inactive as adults (38). Recently, physical activity measured by accelerometry from baseline ages 8-10 y showed highly significant tracking correlations (r=0.53 boys, 0.48 girls) over 6 y, comparable in magnitude to those often reported for cardiorespiratory fitness (42). Future research should explore physical activity tracking over longer follow-ups using objective measures.

The evidence from this study and others that indicates significant long-term stability of overweight and obesity , coupled with the knowledge that greater than 1 in 4 Canadian children are currently overweight or obese (43), forecasts serious consequences for the obesity epidemic. Given the health risks associated with adulthood obesity, and the increasing prevalence of youth obesity, the notion that 80% or more of these overweight children may be remain obese as adults is cause for serious concern.

As for physical activity, the direction of instability is important to consider: active youth might not remain active, but inactive youth might also not remain inactive. The proportions of youth in this study remaining in the extreme quintiles over time were close to what would be expected by chance (31). Physical activity levels may be highly variable in both directions across the lifespan: approximately two-thirds of Canadians aged 12 y and up, including three-quarters of youth aged 12-19 y, changed their physical activity level more than once as measured every two years from 1994/95 to 2004/5 (44). Low tracking of physical activity might indicate that intervention opportunities exist if behaviours are not firmly entrenched; however, programs must also ensure that those who are active remain active.

The main strength of this study is the 22-y follow-up from childhood into adulthood in a representative Canadian population sample. This study spans a time-frame in the midst of the obesity epidemic, while several previous studies commenced prior to it. The greater tracking of BMI with an increasing baseline level of BMI suggests that a cohort assembled today might exhibit even stronger BMI tracking if followed 22 y hence.

There are several limitations to be noted. While the sample size is not large, this is not uncommon in longitudinal tracking studies, especially those spanning longer time frames (13, 22, 32, 37, 38). Inter-age correlations can be influenced by potentially important but uncontrolled covariates (11, 45) which could affect the stability of attributes and behaviours, leading to underestimation of tracking. Height and weight in the PALS follow-up were self-reported: self-reported BMI tends to be underestimated in both men and women, although the degree and patterns of variability in under-reporting differ between the sexes, with increasing age and BMI, and between studies, and a great deal of individual variability in reporting exists as well (46, 47). This could lead to both underestimation and differing patterns of BMI tracking and obesity persistence over time. Most physical activity tracking studies to date have used self-report measures, however inherent difficulties exist in validly and accurately measuring this complex behaviour via self-report, and the true stability of physical activity is likely higher than typically reported (20). Objectively measured physical fitness attributes tend to track better than physical activity (12, 19, 20, 38). However, little variation in childhood fitness is accounted for by physical activity, sex, and age (11, 12). Although the validity of self-reported physical activity in children <10 y of age is deemed very poor, it is considered somewhat better in those ≥10 y, as were the PALS participants (48). However, methods used to quantify physical activity in adults may be inappropriate for describing more sporadic and spontaneous childhood physical activity (11), which may be more influenced by physiologic, environmental, and psychological and sociodemographic factors (49) and vary by gender, maturational status, and socioeconomic status, as well as daily, seasonal, and "life transition" variations (11, 42). Hence, the greater tracking of physical activity observed over the most recent 15 y might be explained by the more consistent nature of physical activity behaviours and fewer sources of variation in adulthood. Finally, youth included in this study were representative of the overall cohort and therefore the Canadian population at baseline, however, a greater proportion of adults in this study are active above 1.5 kcal/kg/day (8), and youth overweight and obesity prevalence was lower in 1981 than in the present-day Canadian population (10% vs. 26%)(8). With this secular trend of increasing overweight and obesity among youth, in addition to the likely under-reporting of BMI/weight-gain in adults, the results may be an underestimation of the current reality: if over 80% of currently overweight or obese youth are destined to become overweight or obese adults, the health status of the adult population several decades from now appears grim.

In conclusion, BMI tracked well over 22 y in this sample of Canadian youth, while physical activity tracked only from later adolescence/early-adulthood onward. A large majority of overweight or obese youth remained overweight or obese as adults; however, the majority of overweight or obese adults were not overweight or obese youth. As the treatment of established obesity is difficult, prevention should be the preferred public health goal: more attention must be paid to youth obesity, physical activity being one aspect of the strategy. However, while overweight or obesity in youth tends to persist into adulthood, the current prevalence of adult overweight and obesity is twice that of youth: many are becoming overweight following a healthy-weight youth. The best prevention strategies will be multi-factorial and population-based, targeting obesity and physical inactivity throughout the lifespan, rather than focusing solely on overweight and inactive youth, in order to combat the overall health risks.

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Table 1. Descriptive characteristics of the Physical Activity Longitudinal Study sample aged 7-18 y at Baseline (1981) who returned for re-evaluation in 2002-04. Values are means (SD) or percentages of the total sample

	Males	**Females**
Age 7-18 y (1981)	13.0 (3.4)	12.6 (3.5)
Body Mass Index (173 males;159 females):		
Healthy Weight	90.8%	89.2%
Overweight/Obese	9.2%	10.8%
PA (kcal/kg/day) (146 males; 129 females)*	5.8 (8.4)	4.1 (4.6)
PA ≥ 1.5 kcal/kg/day	79.2%	62.9%
PA ≥ 3.0 kcal/kg/day	53.0%	43.9%
Age 29-41 y (2002-2004)	35.6 (3.4)	35.2 (3.5)
BMI (kg/m^2)	26.4 (3.5)	25.3 (4.8)
Underweight (<18.5)	1%	1.7%
Healthy Weight (18.5-24.9)	36.2%	57.8%
Overweight (25.0-29.9)	49.7%	26.0%
Obese (≥ 30.0)	13.0%	14.4%
PA (kcal/kg/day)*	4.1 (4.9)	3.0 (4.0)
PA ≥ 1.5 kcal/kg/day	65.1%	57.6%
PA ≥ 3.0 kcal/kg/day	44.4%	29.9%
Current Smoker	22.1%	23.2%
Self-Reported Health: Very Good/Excellent	50.8%	47.3%
Married	71.2%	77.5%
Employed	85.3%	54.4%
Education: ≥ 1 University Degree	38.4%	41.4%
Total Household Income: <$20,000	4.8%	6.5%
$20-60,000	30.1%	30.6%
$60-100,000	42.4%	39.4%
>$100,000	22.3%	22.5%

*physical activity assessment began at 10 y of age.

Table 2a. Inter-age correlations for BMI in the Physical Activity Longitudinal Study between 1981 and 2003 for males and females aged 7-18 y at baseline

Age in 1981	**1981-1988**		**1988-2003**		**1981-2003**	
MALES	**r**	**n**	**r**	**n**	**r**	**n**
7-9 y	0.69**	83	0.69**	34	0.53**	39
10-12 y	0.70**	82	0.37*	34	0.34**	46
13-15 y	0.69**	69	0.61**	39	0.36*	44
16-18 y	0.57**	70	0.46**	34	0.29	44
FEMALES	**r**	**n**	**r**	**n**	**r**	**n**
7-9 y	0.73**	76	0.57**	35	0.42**	41
10-12 y	0.63**	85	0.62**	34	0.65**	40
13-15 y	0.71**	62	0.62**	31	0.50**	41
16-18 y	0.73**	56	0.70**	32	0.49**	37

* p<0.05, ** p<0.01

Table 2b. Inter-age correlations for physical activity in the Physical Activity Longitudinal Study between 1981 and 2003 for males and females aged 10-18 y at baseline

Age in 1981	**1981-1988**		**1988-2003**		**1981-2003**	
MALES	**r**	**n**	**r**	**n**	**r**	**n**
10-12 y	-0.03	76	0.23	38	-0.10	47
13-15 y	0.16	79	0.38*	38	0.18	44
16-18 y	0.14	81	0.54**	42	-0.10	55
FEMALES	**r**	**n**	**r**	**n**	**r**	**n**
10-12 y	-0.04	87	0.20	41	0.10	41
13-15 y	0.02	71	0.57**	37	0.07	44
16-18 y	0.24*	77	0.54**	42	0.14	44

* p<0.05, ** p<0.01

Table 3a. Of participants who were in the highest (fifth) age- and sex-specific quintile in 1981 for body mass index (n=35 M, 31 F) or physical activity (n=29 M, 26 F), percentage (n) who remained in the highest quintile or had moved into other quintiles in 2002-04

	BMI		PA	
Quintile	**Male**	**Female**	**Male**	**Female**
1	0% (0)	0% (0)	27.6% (8)	15.4% (4)
2	8.6% (3)	16.1% (5)	13.8% (4)	15.4% (4)
3	17.1% (6)	6.5% (2)	13.8% (4)	23.1% (6)
4	37.1% (13)	38.7% (12)	27.6% (8)	30.8% (8)
5	**37.1% (13)**	**38.7% (12)**	**17.2% (5)**	**15.4% (4)**

Table 3b. Of participants who were in the lowest (first) age- and sex-specific quintile in 1981 for body mass index (n=34 M, 30 F), or physical activity (n=26 M, 23 F), percentage (n) who remained in the lowest quintile or had moved into other quintiles in 2002-04

	BMI		PA	
Quintile	**Male**	**Female**	**Male**	**Female**
1	**38.2% (13)**	**46.7% (14)**	**15.4% (4)**	**21.7% (5)**
2	17.6% (6)	33.3% (10)	15.4% (4)	30.4% (7)
3	23.5% (8)	13.3% (4)	19.2% (5)	8.7% (2)
4	14.7% (5)	3.3% (1)	15.4% (4)	21.7% (5)
5	5.9% (2)	3.3% (1)	34.6% (9)	17.4% (4)

Table 4a. Proportion of healthy weight and overweight/obese youth in 1981 who became healthy weight and overweight/obese adults in 2002-04

1981 (Youth)		2002-04 (Adult)
Healthy Weight:	Male n=158	Healthy Weight: n=63 (39.9%) Overweight/Obese: n=93 (58.9%)
	Female n=144	Healthy Weight: n=89 (61.8%) Overweight/Obese: n=52 (36.1%)
Overweight/Obese:	Male n=15	Healthy Weight: n=0 (0%) Overweight/Obese: n=15 (100%)
	Female n=15	Healthy Weight: n=5 (33.3%) Overweight/Obese: n=10 (66.6%)

Note: 2 male and 3 female healthy weight youth became underweight (BMI<18.5kg/m^2) adults.

Table 4b. Proportion of healthy weight and overweight/obese adults in 2002-04 who had been healthy weight and overweight/obese youth in 1981

2002-04 (Adult)		1981 (Youth)
Healthy Weight:	Male n=63	Healthy Weight: n=63 (100%) Overweight/Obese: n=0 (0%)
	Female n=94	Healthy Weight: n=89 (94.7%) Overweight/Obese: n=5 (5.3%)
Overweight/Obese:	Male n=108	Healthy Weight: n=93 (86.1%) Overweight/Obese: n=15 (13.9%)
	Female n=62	Healthy Weight: n=52 (83.9%) Overweight/Obese: n=10 (16.1%)

CHAPTER 5

MANUSCRIPT 3

Are Youth BMI and Physical Activity Associated with Better or Worse than Expected Health-Related Quality of Life in Adulthood? The Physical Activity Longitudinal Study

This manuscript has been published in *Quality of Life Research* (2010, 19(3): 339-349), and is presented in a format consistent with journal requirements.

Abstract

Purpose. Body mass index (BMI) and physical activity (PA) affect health-related quality of life (HRQL); however, the long-term impact of youth BMI and PA on adult HRQL are unknown. We investigated the relationship of youth BMI and PA to adult HRQL 22 y later.

Methods. Subjects included 310 participants aged 7 to 18 y in the 1981 Canada Fitness Survey, followed up in 2002-04. The associations of youth BMI and leisure-time PA to adult HRQL were examined, comparing to age- and sex-adjusted Canadian SF-36 norms.

Results. Bivariate analyses revealed positive associations between youth overweight and mental aspects of adult HRQL, but little association with physical aspects. In logistic regression adjusting for adult BMI and other covariates, overweight youth were 7 times more likely than healthy weight youth to score at/above the norm on both Mental Health (MH) and Bodily Pain, and almost 18 times more likely on the Mental Component Score (MCS). Youth BMI was also positively associated with General Health (GH), Social Functioning, and Role Emotional. Removing adult BMI from the models led to attenuated associations with mental HRQL, and no association with GH. Longitudinal BMI status change was explored and findings supported the main regression results. Youth PA was not associated with adult HRQL.

Conclusions. Youth overweight conveyed a long-term positive impact on several aspects of adult HRQL, and this impact may be both direct, and indirect through BMI change and the effect on adult BMI. Youth PA had no long-term impact on adult HRQL.

Key Words: *Body Mass Index, Body Weight, Exercise, Adolescent Obesity, Longitudinal Studies, Mental Health, Quality of Life, SF-36.*

INTRODUCTION

Obesity is a major modifiable risk factor for numerous chronic diseases and conditions in adulthood [1], and physical activity (PA) is important in the prevention of several chronic conditions, often exhibiting a dose-response relationship with adult health outcomes [2,3]. However, currently 59% of Canadian adults are overweight or obese, while only 51% are sufficiently physically active during their leisure time to benefit their health [4]. Among Canadian youth aged 2 to 18 y, 26% are overweight or obese [4], and only 9% of youth aged 5 to 19 y accumulate 16,500 or more steps per day, as associated with current PA guidelines for children and youth [5].

The links between obesity, physical inactivity and health-related quality-of-life (HRQL) have been less studied, particularly in healthy general population samples, where this research has only recently begun to evolve. In adults, higher PA levels are positively related to physical and mental HRQL[6], and obesity is associated with significant impairments in HRQL, with greater impairments associated with greater degrees of obesity, and weight loss leading to improved HRQL [7]. A large US general population survey found that obese adults were significantly more likely than normal weight adults to have experienced >14 unhealthy days (physical or mental), or >14 days with activity limitations, over the past month [8], and adults meeting public health recommendations for PA were significantly less likely to report ≥14 unhealthy days compared to inactive adults [9], illustrating the public health impact in terms of adult productivity. More limited research also exists linking youth obesity to poorer youth HRQL, and youth PA to better youth HRQL, including effects on self-reported health, as well as physical, emotional, and social health and functioning [10-14]. However, not all research is consistent: in particular, some studies in adults have shown a positive association between adult obesity and mental HRQL [15-17].

No studies to date have explored the long-term effects of youth obesity and PA on HRQL in adulthood. Youth obesity and PA may affect physical growth and development into adulthood [18,19]. As well, youth overweight and obesity have been linked to poorer self-esteem [20] and bullying [21], while youth PA has been linked to better self-esteem, and reduced anxiety and depression [19,20]. These outcomes may affect social, psychological, and cognitive development into adulthood, creating the potential for long-term effects on both physical and mental HRQL, with ramifications at both the individual and population levels, especially as youth obesity and physical inactivity reach alarming levels in North America. In fact, when surveyed, over 90% of pediatricians believed that youth overweight could affect future HRQL [22]. The purpose of this study was to investigate the relationship of youth body mass index (BMI) and leisure time PA with adult physical and mental HRQL 22 y later in a Canadian population-based sample.

METHODS

Sample. The Physical Activity Longitudinal Study (PALS) represents the 22 y follow-up of a 20% sub-sample of participants aged 7-69 y from the nationally representative 1981 Canada Fitness Survey (CFS) (N=23,397) [23], who also participated in the 1988 Campbell's Survey of Well-Being (CSWB) (N=4345) [24]: these individuals, plus new family members, were eligible for

PALS, yielding 4904 eligible individuals aged 15 y and older in 2002-2004 [25]. Detailed information regarding the conceptual design and methods of PALS has previously been published [25]. The PALS sample included 2511 participants (51.2%) with questionnaire data, with a non-response rate of 29.8% (10% lost to follow-up, 18.8% refusals); 0.7% were unable to participate due to health reasons, and 18.9% were deceased. Baseline height and weight were measured for all participants during household visits in 1981, while PA was assessed by questionnaire for those aged 10 y and older. At the 2002-04 assessment, all data were self-reported via questionnaire. The PALS study was approved by the Ethics Review Board of the Faculty of Medicine of the Université de Montréal; participants were given an explanation of all protocols and provided informed consent indicating their awareness of the survey requirements in 1981, 1988, and 2002-04.

The PALS sub-sample used for this analysis included 310 male (N=153) and female (N=157) participants aged 7-18 y in 1981 who had BMI and/or PA data at baseline and HRQL data in 2002-2004 (aged 29-41 y). This represents 44.1% of the 817 participants aged 7-18 y in 1981 who participated in 1988. Of the 310 participants with HRQL data, 282 and 230 had baseline BMI and PA data respectively. Similar to adult findings [25], youth lost to follow-up were similar to participants according to a range of key characteristics, including age, 1981 and 1988 BMI category, 1981 and 1988 PA levels, 1981 and 1988 self-reported health status, 1988 smoking status, 1988 marital status, 1988 education status, and 1988 family income; the exceptions were that father's education was higher for participating males and mother's education was higher for participating females (data not shown).

Measures. BMI was calculated as measured weight (kg)/height (m^2). Youth overweight and obesity were categorized according to the International Obesity Task Force (IOTF) age- and gender-specific BMI cut-offs, associated with the predicted health-related BMI cut-offs of 25 and 30 kg/m^2 at age 18 y [26] which are the WHO-defined adult cut-offs for overweight and obesity [27].

Leisure time PA was assessed using an adaptation of the Minnesota Leisure Time Physical Activity Questionnaire [28], whereby participants referred to a list of 24 physical activities plus volunteered up to 3 activities from an additional list, indicating the frequency and average time spent on activities over the past year. The questionnaire has criterion validity (ρ) ranging from 0.30 to 0.45, and good 1-month retest reliability (0.91) [29]. Average daily PA was calculated as follows:

$$\text{PA } (\text{kcal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}) = \Sigma\ (N_i \times D_i \times \text{METs}_i / 365)$$

where N is the number of times the activity (i) was performed in the past 12 months, D is the average duration in hours, and METs [30] is the estimated energy cost ($\text{kcal}\cdot\text{kg}^{-1}\cdot\text{hr}^{-1}$). PA was categorized using a 3.0 KKD cut-off, or 180 MET-minutes, reflecting, on average, the equivalent of 60 minutes of moderate intensity activity daily [31].

Multidimensional HRQL was assessed using the Medical Outcomes Study Short Form 36 (SF-36) [32], comprised of 36 questions, assessing 8 physical and mental health domains: physical function (PF), role physical (RE), bodily pain

(BP), general health perceptions (GH), vitality (VT), social functioning (SF), role emotional (RE) and mental health (MH). Domain scores range from 0-100, with higher scores indicating better HRQL. Domains are also weighted and summed to calculate physical and mental component summary scores (PCS and MCS), standardized to a mean of 50, where scores above and below 50 represent better and worse than average function respectively [33]. A 5-point difference in domain scores and a 2-3 point difference in summary scores are considered clinically relevant [32,33].

Statistical Analysis. Examination of the outcome variables showed that the distributions of several domain scores were negatively skewed, with many participants achieving the maximum score of 100 on the 8 domains: only GH, VT, and MH appeared normally distributed, while PCS and MCS deviated only slightly from normal. Mean adult SF-36 scores were compared (independent samples t-tests, Holm method to adjust for multiple comparisons) to previously published Canadian age- and sex-standardized norms [34] for men and women aged 25-34 and 35-44 y to assess the representativeness of the sample to the current population. The t-test was used, despite some skewed data, as the normative data were only available in aggregate form and the t-test is considered sufficiently robust to incorporate sizeable deviations from normality while still producing a valid comparison.

The adult SF-36 scores were then dichotomized according to whether they fell below versus at or above the Canadian age- and sex-standardized norms. Chi-square tests (Pearson's or Fisher's Exact test as appropriate, Holm method to adjust for multiple comparisons) were used to determine whether significant differences existed between the percentage of participants scoring below versus at or above the norm, based on youth BMI or PA status.

Logistic regression was used to evaluate whether youth BMI or PA status predicted the likelihood of scoring at or above the Canadian norm for each of the SF-36 domains and composite scores. An initial analysis assessed the relation of Adult BMI to the SF-36 outcomes. Youth BMI and PA were then tested both as continuous and dichotomous predictors. Models were adjusted for age and sex, as well as adult BMI and PA (as continuous variables), whether or not the person was married, smoked, had a university education, and/or had a household income over $60,000, as well as number of comorbidities (0-7), based on differences in means of these variables between youth BMI or PA categories. Interactions of youth BMI and PA were tested but not retained, as there was no compelling evidence that these made any significant contributions to the models. Regression analysis stratified by Adult BMI was attempted; however, due to small cell sizes, especially when including multiple covariates, these models were largely unstable, producing erroneous results.

In an additional exploratory analysis, a 4-level variable was created to represent longitudinal change in BMI status from youth to adulthood (healthy weight - healthy weight, healthy weight - overweight/obese, overweight obese - healthy weight, overweight/obese - overweight/obese), and logistic regression used to assess the likelihood of scoring at or above the Canadian norm for each of the SF-36 domains and composite scores, controlling for age, sex, married, smoking, education, income, and comorbidities.

RESULTS

Descriptive characteristics of the 153 male and 157 female participants are reported in **Table 1**. At baseline, approximately 9% of participants were overweight (12 each male and female) or obese (1 female), while 53% and 43% of males and females respectively were physically active (PA ≥180 MET-minutes or 3.0KKD). Twenty-two years later, there was a substantially higher percentage of overweight males and females.

The means for the SF-36 scores in the PALS sample are presented in **Table** 2. The PALS sample was divided into those aged 29-34 and 35-41 for comparison of mean SF-36 scores with the normative data, which is grouped as 25-34 and 35-44 years. Men 29-34 y of age (n=58) scored significantly lower on GH, VT, RE, and MCS (all but RE remained significant after adjustment for multiple comparisons), while men 35-41 y of age (n=95) scored significantly lower VT but higher on RE (VT remained significant after adjustment), when compared to Canadian norms. Women 29-34 y of age (N=66) did not differ significantly in their mean scores from the normative values, while women 35-41 y of age (n=91) scored significantly lower on GH, VT, MH, and MCS (GH, VT, and MCS remained significant after adjustment), when compared to Canadian norms. These differences all exceeded 5 points on the domain scores and 2-3 points on the MCS, indicating potential clinical relevance.

Comparing the number of adults below versus at or above the Canadian SF-36 norms based on their youth weight status **(Table 3)**, overweight/obese male youth showed no statistically significant differences in their likelihood to be at or above the norm in adulthood on most SF-36 domains or summary scores, compared to their healthy weight counterparts. Falling just short of statistical significance, two differences are worth noting: 11 of 12 (92%) overweight/obese male youth scored below the norm on VT in adulthood (compared to 64% of healthy weight male youth), and 100% of overweight/obese male youth scored at or above the norm on RE (compared to 76% of healthy weight male youth). For females, a significantly higher percentage of overweight/obese youth were at or above the norm in adulthood for VT, RE, MH, and MCS, compared to their healthy weight youth counterparts. Notably, 100%, 85% and 92% of overweight/obese female youth scored at or above the norm on RE, MH, and MCS respectively (compared to 68%, 49% and 54% of healthy weight female youth); while these differences did not remain significant after adjustment for multiple comparisons, the relationship for MCS fell just short.

An initial adjusted regression analysis assessed the association of Adult BMI with HRQL in this sample, finding that being overweight/obese in adulthood was only significantly inversely related to the likelihood of scoring at/above the norm on GH (OR 0.4, $P<0.01$) compared to being healthy weight, while a positive relation to MCS fell just short of significance (OR 2.0, $p=0.06$) (data not shown). **Table 4** presents the logistic regression results for Youth BMI, with and without adjustment for Adult BMI. Prior to adjustment for Adult BMI, results showed that overweight/obese youth were over 4 times more likely to score at/above the Canadian norm on MH, and almost 9 times more likely on MCS **(Table 4a, Models A)**; on average, each unit increase in youth BMI led to about a 50% and 30% greater likelihood of scoring at/above the norm on RE and MCS respectively ($p<0.01$ for each), and about a 20% greater likelihood for MH ($P<0.05$) **(Table 4b,**

Models A). With the addition of Adult BMI to the models, overweight/obese youth were about 7 times more likely to score at/above the Canadian norm on both BP (OR 6.9, $p<0.05$) and MH (OR 7.2, $p<0.01$) in adulthood, and 18 times more likely to score at or above the norm on MCS (OR 17.9, $p<0.01$), compared to healthy weight youth; the model for GH approached significance **(Table 4a, Models B)**. Further, on average, each unit increase in youth BMI led to about a 50% and 40% greater likelihood of scoring at or above the norm on RE and MCS in adulthood respectively ($P<0.01$ for each), all other covariates being equal, as well as a 30% greater likelihood of scoring at or above the norm on GH, SF and MH ($p<0.05$ for each); models for BP and VT also approached significance **(Table 4b, Models B)**. In regression analyses stratified by Adult BMI groups (healthy weight vs. overweight/obese), inadequate cell sizes led to erroneous results for most outcomes and precluded the inclusion of covariates other than total comorbidities (most consistently significant in non-stratified models); however, in these more crude models, Youth BMI appeared to be a significant positive predictor of RE, MH, and MCS in both healthy weight and overweight/obese adults (data not shown).

A 4-level longitudinal BMI status change variable was created to describe relative increases or decreases in participant BMI between youth and adulthood **(Table 1)**. The 3rd category, representing a relative decline in BMI status from youth to adulthood, was dropped from analysis as only 4 participants (of whom 2 had all required data for multivariate analysis) fell into this category. Of the remaining categories, we found that healthy weight youth who became overweight/obese adults were less likely to score at/above the norm on GH (OR

0.33, P<0.01); however, those who were overweight/obese at both time points had greater odds of scoring at/above the norm on both MH (OR 6.2, p<0.05) and MCS (OR 22.4, p<0.01) (data not shown). It should be noted that this category also contained only 9 participants with all necessary data for multivariate analysis.

Youth PA was not significantly associated with any of the domain or summary SF-36 scores in adulthood in either bivariate or logistic regression analyses, and therefore the data are not shown.

DISCUSSION

This study investigated the long term effects of youth overweight and physical activity on future adult HRQL in the context of previously published Canadian normative data. To our knowledge, there is no other research to date examining the long term effects of youth overweight or PA on adult HRQL. Contrary to our hypothesis, our results showed significant positive associations between Youth BMI and subsequent adult HRQL outcomes (MCS and subscales SF, RE, MH, and possibly GH and BP) using the SF-36 instrument; however, no associations were found between Youth PA and adult mental or physical HRQL. Past research has shown that overweight and obese adolescents have significantly worse self-reported health, are more likely to report physical function limitations, and have decreased psychosocial functioning and self-esteem, compared to healthy weight adolescents [10,13]. Hence, it might be expected that these outcomes could carry negative implications into adulthood. However, some studies have shown relatively little effect of adolescent overweight on depression, self-esteem, and emotional and school functioning [13,14], and while adolescent obese girls may show greater dissatisfaction with their body weight and shape than their healthy weight counterparts, this may not lead to greater incidence of anxiety or depression [35].

The PALS sample was first compared to previously established Canadian norms [34], and several significant deviations were found, although in inconsistent directions. Some of these differences may be attributable to the differences in the age groups of the PALS sample (29-41 years) and normative data (25-44 years). However, additional analysis of the Canadian normative data indicated that HRQL remained relatively stable over a 5-y period, especially in younger age groups [36]. There is a tendency for the mental domain scores to increase with age and physical domains to decrease [36], which led us to expect somewhat higher and lower mental and physical scores respectively in 29-34 y PALS age group compared to the norms (age 25-34 y), and the reverse for the 35-41 y old PALS participants, but this was only somewhat observed.

We have presented regression results both with and without adjustment for Adult BMI. On one hand, the argument could be made that models should be adjusted for Adult BMI in order to explore an independent effect of Youth BMI [37], as there is a known association between Adult BMI and SF-36, in addition to strong tracking of BMI from youth to adulthood; of note however, in the current analysis, Adult BMI was only significantly inversely related to GH, while a positive association to MCS fell just short of significance. On the other hand, Adult BMI may not be a true confounder [37, 38], as it may also or instead have a moderating role in the pathway from Youth BMI to Adult SF-36. However, interaction terms involving BMI are ill-advised [37, 39]. Specifically, if there is no genuine relationship between Youth BMI and Adult HRQL, adjustment for Adult BMI could lead to an apparent association whose magnitude depends on the magnitude of the correlations between Youth and Adult BMI and between Adult BMI and HRQL [38]. If a genuine relation does exist between Youth BMI and Adult HRQL, this association could be exaggerated following adjustment for Adult BMI [38]. These phenomena illustrate the "reversal paradox", *a statistical effect whereby the* association between two variables can be reversed or enhanced when another variable is statistically controlled for [38, 39]. Given the strong tracking between Youth and Adult BMI in the PALS study [40], and that one evolves from the other, the change between time points or relative magnitude of one versus the other may be of importance; however, individual independent effects of Youth BMI or relative changes to it may be difficult to tease out. When adjusting for Adult BMI, the Youth BMI – Adult HRQL relationship could be interpreted in the context of Adult BMI: Youth BMI adjusted for Adult BMI, a measure of change in BMI between measurements, becomes the relevant factor, rather than Youth BMI itself [37]. Or it might be said that if all youth grew to the same adult BMI, higher BMI youth would, on average, have better HRQL in adulthood [38]; however, this goes against current knowledge that higher BMI youth develop into higher BMI adults.

In terms of the SF-36 physical domains and PCS, several studies of adult population samples have reported poorer scores with increasing levels of overweight and obesity [41, 42], or in overweight or obese compared to healthy-weight individuals [15, 16, 39, 44]. However, in this study, current Adult BMI significantly inversely predicted only GH, and Youth BMI appeared possibly related to only GH and BP, but in a positive direction. Notably, while tracking of BMI in the PALS sample is high, with over 80% of overweight youth having remained overweight or obese in adulthood, a large majority of overweight or obese adults had not been overweight youth [40]. Moreover, excess weight may have a greater negative effect on physical HRQL with increasing age [43]; not only were PALS participants only 29-41 y of age currently, but this may also indicate that youth weight status is less important to subsequent adult physical HRQL than current adult weight status.

The statistically significant positive association between Youth BMI and adult GH emerged only after adjusting for adult BMI (itself inversely associated with GH). This might indicate that the impact of Youth BMI on this later outcome is dependent on the relative change in BMI between time points, implicating this change in the causal pathway rather than initial Youth BMI [37]. In our analysis of longitudinal BMI status change, it appeared that relative “weight gain” over time led to decreased odds of scoring at/above the norm on GH, supporting this idea.

In terms of the SF-36 mental domains and MCS, previously reported associations with adult obesity have been weaker and less clear than those found for the physical domains and PCS [41, 42, 44]. In some cases, poorer emotional well-being among obese individuals was due to the presence of obesity-related comorbidities rather than to obesity itself [41]. This is supported by the present study, where number of comorbidities was a significant positive covariate in all models. Other studies have reported a positive association between adult obesity and the SF-36 mental domains: obesity in older men has been associated with higher scores on the SF-36 mental health scales, a result not explained by lifestyle or comorbidities [16], and obese women have scored higher on MH and MCS, and obese and overweight men higher on MH, compared to healthy weight persons [15]. Another study reported that overweight and obese women had better mental health, including lower anxiety, depression, and negative affect, while overweight and obese men had lower depression and negative affect, compared to healthy weight participants, once physical ill-health was controlled for – the authors concluded that "reducing obesity in the population was unlikely to have any direct effect on mental health or emotional well-being" [17].

In this study, significant positive associations of Youth BMI to the mental aspects of HRQL were present both prior to and following adjustment for Adult BMI, suggesting that a genuine relationship exists; however, these associations appeared to be amplified by the addition of Adult BMI to the models, indicative of the reversal paradox [38], and suggesting influences of both Youth and Adult BMI [37]. Unlike for GH, Adult BMI in this sample was not associated with the mental aspects of HRQL, save for MCS which approached significance in the same (rather than opposite) direction. Our analysis of longitudinal BMI status change also indicated that remaining overweight/obese from youth to adulthood led to increased odds of scoring at/above the norm on both MH and MCS in adulthood; very few participants "lost weight", indicating that a relative decline in BMI was not likely the driving force behind our results. Further, in the crude regression analyses stratified by Adult BMI groups, Youth BMI appeared to be a significant positive predictor of RE, MH, and MCS in both healthy weight and overweight/obese adults. While results of these latter two analyses should be interpreted with caution due to inadequate sample size in this study for valid assessments of this nature, they do further support the notion of a direct Youth BMI effect on adult mental HRQL. It is thus possible that Youth BMI has both an independent direct relationship to adult mental HRQL, as well as an indirect relationship through Adult BMI and the relative change in BMI that may occur between the two time points.

This study found no significant associations between youth physical activity levels, and adult HRQL 22 y later. More active children report better HRQL than sedentary children [12]; however, a previous study found that weekly PA hours at age 15-16 y were only weakly associated with mental health just 3 y later in boys, and no association for girls [11]. In adults, studies have reported significant positive associations between current PA and most SF-36 domains in healthy general populations for both genders and across all age groups [45-48], indicating the importance of regular PA for HRQL as well as for objective health measures and disease prevention [48]. It is possible that only *current* PA levels impact HRQL: A randomized controlled trial previously showed that while participation in a PA program lead to improvements in both physical and mental HRQL, these improvements were maintained only if exercise participation continued [49]. Current adult PA was a significant positive covariate for several SF-36 outcomes in the PALS sample. Further, a previous analysis of this cohort showed that PA did not track from youth to adulthood [40]. Hence, while youth PA may confer immediate health benefits, this study advances the notion that PA must be current not only to maintain overall health benefits [50] but also to maintain quality of life.

The main strengths of this study are the 22-y length of follow-up from childhood into adulthood in a representative Canadian population sample, the use of Canadian population norms to enhance the meaning and interpretation of absolute scores by comparing with typical values, and the availability of measured baseline BMI data. Further, the SF-36 instrument is one of the most widely used and accepted measures of functional health and well-being in healthy or sick persons aged 14 y and up, for the purpose of documenting and comparing disease burden and treatment benefits.

There are several limitations to be noted. The current sample size is not large and suffered from fairly high attrition, which is not uncommon in longitudinal studies spanning several decades, however the smaller sample did result in wide 95% CI's particularly when using BMI as a dichotomous predictor. Moreover, while the youth in this study were representative of the 1981 CFS cohort and therefore the Canadian population at baseline, accurately reflecting the lower prevalence of youth overweight/obesity in 1981, the low absolute number of overweight/obese youth (only 1 obese child) in the sample may have hindered the examination of relationships. As currently greater than 1 in 4 youth are overweight or obese [4], it will be of interest to see how this increasingly prevalent youth characteristic impacts the HRQL of individuals over the long term. BMI as a measure of obesity is inherently limited in its lack of information regarding body composition, and lack of sensitivity to youth maturational age; however, it remains the most widely investigated and easily used indictor of weight-related health risk on a population level, and our use of IOTF cut-offs for youth BMI categorization diminishes the effects of biological age in this study. Inherent difficulties also exist in validly and accurately measuring PA via self-report, thus possibly influencing the results – although the validity of self-reported PA in children <10 y of age is deemed very poor, it is considered somewhat better in those ≥10 y [51], as were the PALS participants. Self-reported BMI (as in the PALS follow-up) tends to be underestimated in both men and women, although the degree and patterns of variability in under-reporting differ between the sexes, with increasing age and BMI, and between studies, and individual variability in reporting exists as well [52, 53].

In conclusion, this first attempt to investigate the possible long term effects of youth overweight and physical activity on future adult quality of life has shown that youth overweight may impact adult HRQL, both directly, and indirectly through its effect on adult BMI; however, youth PA appears to have no long term effects on adult HRQL. While there appears to be an independent positive effect of youth BMI on the mental aspects of adult HRQL, the latter may also be related to the magnitude of relative weight gain between youth and adulthood. As these results were derived from a small cohort, the study needs to be replicated on a larger cohort before clear conclusions may be drawn. Nonetheless, with the increasing prevalence of youth obesity, it is encouraging that, at least at moderate levels of overweight, these youth may not be at increased risk of poorer HRQL in adulthood if prevention, control, and treatment efforts are successful. As well, degree of obesity in children may be relevant in predicting potential negative effects on HRQL [54,55]. As the prevalence of youth overweight and obesity in the PALS sample was low, it is possible that greater and more negative consequences might result from higher levels of obesity, both immediately in youth and potentially carrying forward to affect HRQL in adulthood. In addition, overweight in youth has known immediate health consequences [18], and tracks at a very high level into adulthood [40], then leading to substantially increased risk of a large number of other biomedical conditions [1], and as such is not an issue that can be ignored. In terms of HRQL, more research is needed with larger sample sizes to verify our results, exploring the effects of the greater degrees of youth obesity present in the current day population, as well as possible mechanisms, including the role of BMI status changes over time, in order to assess additional long term effects on both physical and mental health in the future adult population.

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Table 1. Baseline (1981) and Follow-up (2002-4) Characteristics of PALS Sample who returned for 22-year Follow-up; Values are means (SD) or percentages of total sample.

Baseline 1981	**Males (N=153)**	**Females (N=157)**
Age 7-18 years	13.0 (3.4)	12.6 (3.5)
BMI: Healthy Weight	91.4%	90.8%
Overweight/Obese[a]	8.6%	9.2%
PA (kcal/kg/day)	4.7 (5.3)	4.1 (4.7)
PA ≥ 1.5 kcal/kg/day	78.8%	64.3%
PA ≥ 3.0 kcal/kg/day	53.4%	42.9%
Follow-up 2002-2004		
Age 29-41 years	35.6 (3.4)	35.2 (3.6)
BMI (kg/m^2)	26.1 (3.5)	25.3 (5.0)
Underweight (<18.5)	1.3%	1.4%
Healthy Weight (18.5-24.9)	38.8%	59.9%
Overweight (25.0-29.9)	48.7%	24.5%
Obese (≥ 30.0)	11.2%	14.4%
PA (kcal/kg/day)	4.3 (5.2)	3.2 (4.2)
PA ≥ 1.5 kcal/kg/day	64.5%	60.8%
PA ≥ 3.0 kcal/kg/day	42.8%	32.0%
Current Smoker	20.5%	23.2%
Self-Reported Health: Very Good/Excellent	50.0%	45.9%
Married	71.1%	80.8%
Employed	82.9%	52.2%
Education: ≥ 1 University Degree	41.7%	44.5%
Total Household Income: < 20 K	6.1%	5.3%
20-60 K	31.3%	29.0%
60-100 K	39.1%	40.5%
>100 K	23.5%	25.2%
Comorbidities: ≥1	49.0%	63.1%
Longitudinal BMI change (Youth – Adult):		
Healthy Weight – Healthy Weight	41.2%	59.1%
Healthy Weight – Overweight/Obese	50.7%	32.6%
Overweight/Obese – Healthy Weight	0.0%	3.0%
Overweight/Obese – Overweight/Obese	8.1%	5.3%

[a] There is only 1 obese child (F); 12 each overweight M and F.
Minor discrepancies in proportions are due to occasional missing data.

Table 2. Means for SF-36 Scores at Follow-Up (2002-2004)**,** and Comparison of PALS Adult SF-36 Scores (Means) to Canadian Age- and Sex-Standardized Norms

Male	**PALS All Ages N=153 Mean (SD)**	**PALS Age 29-34 N=58 Mean (SD)**	**Normative Age 25-34 N=200 Mean**	**PALS Age 35-41 N=95 Mean (SD)**	**Normative Age 35-44 N=212 Mean**
PF	93.8 (14.6)	94.4 (11.7)	94.0	93.3 (16.1)	91.7
RP	88.3 (27.6)	89.7 (27.3)	90.6	87.5 (27.9)	85.8
BP	78.4 (21.6)	77.8 (24.0)	79.1	78.7 (20.1)	77.3
GH	74.6 (16.2)	72.4 (14.4)*	80.1	76.0 (17.2)	79.6
VT	60.8 (16.9)	59.9 (15.7)**	68.7	61.3 (17.6)***	69.4
SF	89.1 (15.3)	87.3 (18.1)	88.9	90.1 (13.3)	87.5
RE	86.3 (28.6)	78.2 (37.2)	88.3	91.4 (20.2)	84.3
MH	74.3 (14.1)	72.5 (13.2)	77.7	75.4 (14.5)	78.0
PCS	54.2 (8.0)	55.2 (8.2)	53.5	53.7 (7.8)	52.6
MCS	48.8 (9.6)	46.3 (11.4)***	51.7	50.4 (8.0)	51.7

Female	**PALS All ages N=157 Mean (SD)**	**PALS Age 29-34 N=66 Mean (SD)**	**Normative Age 25-34 N=199 Mean**	**PALS Age 35-41 N=91 Mean (SD)**	**Normative Age 35-44 N=212 Mean**
PF	90.8 (16.3)	92.4 (15.6)	90.9	89.7 (16.8)	90.1
RP	83.8 (32.9)	84.2 (32.5)	83.7	83.5 (33.4)	81.0
BP	76.7 (20.8)	80.4 (17.0)	75.0	74.0 (22.9)	75.1
GH	72.6 (19.0)	77.2 (16.4)	77.9	69.3 (19.8)***	78.1
VT	57.4 (17.7)	59.5 (16.2)	61.2	55.9 (18.6)**	62.9
SF	84.1 (21.5)	83.1 (21.5)	83.7	84.8 (21.6)	83.5
RE	80.9 (33.0)	85.4 (29.3)	77.6	77.7 (31.2)	82.1
MH	73.0 (15.0)	73.9 (13.5)	74.1	72.2 (16.0)	76.6
PCS	53.3 (9.1)	54.2 (9.4)	52.4	52.6 (8.9)	51.5
MCS	47.0 (11.9)	47.9 (11.0)	48.6	46.3 (12.6)*	50.2

SD Standard Deviation; PF physical functioning; RP role physical; BP bodily pain; GH general health; VT vitality; SF social functioning; RE role emotional; MH mental health; PCS physical component summary; MCS mental component summary.

Independent-samples t-test, PALS vs. normative data: * $p<0.05$, ** $p < 0.01$, *** $p < 0.001$ after adjustment for multiple comparisons by Holm method.

Table 3. Percentage of healthy weight youth and overweight/obese youth who were below vs. at or above the Canadian Age- and Sex-Standardized Norms on SF-36 scores in adulthood

	Healthy Weight Youth		Overweight/Obese Youth		Unadjusted p-value[a]
Male	**Below Norm N (%)**	**At/Above Norm N (%)**	**Below Norm N (%)**	**At/Above Norm N (%)**	
PF	26 (20.8)	99 (79.2)	3 (25.0)	9 (75.0)	0.717
RP	23 (18.4)	102 (81.6)	2 (16.7)	10 (83.3)	1.000
BP	44 (34.9)	82 (65.1)	6 (50.0)	6 (50.0)	0.352
GH	89 (70.6)	37 (29.4)	9 (75.0)	3 (25.0)	1.000
VT	81 (64.3)	45 (35.7)	11 (91.7)	1 (8.3)	0.061
SF	40 (31.8)	86 (68.3)	5 (41.7)	7 (58.3)	0.527
RE	30 (24.2)	94 (75.8)	0 (0)	12 (100.0)	0.068
MH	69 (54.8)	57 (45.2)	5 (41.7)	7 (58.3)	0.385
PCS	35 (28.0)	90 (72.0)	5 (41.7)	7 (58.3)	0.332
MCS	69 (54.8)	57 (45.2)	5 (41.7)	7 (58.3)	0.385
Female					
PF	39 (30.2)	90 (69.8)	5 (38.5)	8 (61.5)	0.541
RP	31 (24.0)	98 (76.0)	3 (23.1)	10 (76.9)	1.000
BP	51 (39.5)	78 (60.5)	4 (30.8)	9 (69.2)	0.536
GH	72 (56.3)	56 (43.8)	7 (53.9)	6 (46.2)	0.868
VT	71 (55.0)	58 (45.0)	3 (23.1)	10 (76.9)	0.040
SF	45 (34.9)	84 (65.1)	4 (30.8)	9 (69.2)	1.000
RE	41 (31.8)	88 (68.2)	0 (0)	13 (100)	0.020
MH	66 (51.2)	63 (48.8)	2 (15.4)	11 (84.6)	0.014
PCS	33 (25.6)	96 (74.4)	3 (23.1)	10 (76.9)	1.000
MCS	59 (45.7)	70 (54.3)	1 (7.7)	12 (92.3)	0.008

PF physical functioning; RP role physical; BP bodily pain; GH general health; VT vitality; SF social functioning; RE role emotional; MH mental health; PCS physical component summary; MCS mental component summary.

Pearson Chi-square; Fisher's Exact test for expected cell counts less than 5.
[a] Differences are not statistically significant after adjustment for multiple comparisons by Holm method.

Table 4. Odds ratios (95% confidence intervals) for scoring at or above the norm on adult SF-36 outcomes by youth BMI (dichotomous and continuous)

SF-36 Outcome	(A) OR (95% CI)	p	(B) OR (95% CI)	p	Significant Covariates
a) Youth BMI Overweight/Obese vs. Healthy Weight (OR = 1.00)					
PF	1.6 (0.4, 7.4)	0.530	2.6 (0.4, 16.5)	0.299	d*, e**, h*, i*
RP	3.4 (0.6, 20.1)	0.171	3.3 (0.5, 22.7)	0.225	e**, i***
BP	4.1 (0.9, 18.2)	0.067	6.9 (1.1, 42.3)	0.036	i***
GH	2.0 (0.6, 7.0)	0.291	4.6 (0.9, 23.1)	0.065	c***, i**
VT	3.3 (0.8, 13.1)	0.092	3.5 (0.8, 15.7)	0.109	d*, i**
SF	1.6 (0.4, 6.6)	0.494	2.5 (0.5, 13.1)	0.272	e**, i**
RE	All overweight youth scored 100 (i.e. ≥ Norm)				i***
MH	4.6 (1.1, 18.8)	0.034	7.2 (1.3, 39.5)	0.023	b*
PCS	3.5 (0.6, 19.0)	0.148	4.4 (0.7, 27.8)	0.116	i***
MCS	8.7 (1.7, 46.2)	0.011	17.9 (1.9, 165.0)	0.011	i***
b) Youth BMI Continuous					
PF	1.0 (0.9, 1.2)	0.906	1.1 (0.9, 1.3)	0.389	d**, h*, i*
RP	1.1 (0.9, 1.3)	0.430	1.1 (0.9, 1.4)	0.264	e*, i***
BP	1.1 (1.0, 1.3)	0.099	1.2 (1.0, 1.4)	0.065	b*, i***
GH	1.1 (0.9, 1.2)	0.563	1.3 (1.0, 1.5)	0.031	c**, d*, i***
VT	1.1 (1.0, 1.3)	0.118	1.2 (1.0, 1.4)	0.063	b*, d*, i**
SF	1.2 (1.0, 1.4)	0.078	1.3 (1.0, 1.5)	0.023	e**, i***
RE	1.5 (1.2, 1.8)	0.001	1.5 (1.2, 1.9)	0.002	b***, i***
MH	1.2 (1.0, 1.4)	0.020	1.3 (1.1, 1.5)	0.014	b***
PCS	1.0 (0.9, 1.2)	0.955	1.1 (0.9, 1.3)	0.567	i***
MCS	1.3 (1.1, 1.6)	0.001	1.4 (1.1, 1.6)	0.002	b**, i**

PF physical functioning; RP role physical; BP bodily pain; GH general health; VT vitality; SF social functioning; RE role emotional; MH mental health; PCS physical component summary; MCS mental component summary.

"A" models adjusted for sex (a), age (b), adult PA (d), household income (e), education (f), married (g), current smoker (h), # comorbidities (i); "B" models adjusted for adult BMI (c) in addition to previous factors. Significant covariates indicated for "B" models. * p<0.05, ** p<0.01, *** p<0.001.

CHAPTER 6

MANUSCRIPT 4

Sex Differences in the Association of Youth Body Mass Index to Adult Health-Related Quality of Life: The Physical Activity Longitudinal Study

This manuscript has been accepted by the *Canadian Journal of Public Health*, (August 2010, in press) and is presented in a format consistent with journal requirements.

ABSTRACT

Objective. The long term consequences of youth overweight on adult health-related quality of life (HRQL) have not been documented. This study examines sex differences in the association between youth body mass index (BMI) and adult HRQL. **Methods.** Subjects included 139 male and 142 female participants aged 7-18 in the 1981 Canada Fitness Survey, followed up in 2002-04. The associations of youth BMI to adult HRQL (SF-36) were examined with bivariate correlations, differences in means and multivariate linear regression analyses. **Results.** Bivariate analyses revealed positive associations between youth overweight and mental aspects of adult HRQL in females, and weak negative associations with physical aspects, but no significant associations in males. All overweight male and female youth scored the maximum (100) on Role Emotional (RE). In females, compared to healthy weight youth, overweight youth scored 16.0, 13.4, 13.1, and 10.9 points higher on general health (GH), vitality (VT), mental health (MH), and the mental component score (MCS) in adulthood, respectively; a 1 unit increase in youth BMI led to 1.7, 1.6, and 1.4 point increases in adult VT, MH and MCS scores, respectively. Associations were attenuated with the removal of adult BMI from the models, but remained strong for MH and MCS. **Conclusions.** Overweight in youth did not have a significant negative impact on HRQL two decades later; rather, a positive association was found with mental aspects of adult HRQL in females.

Keywords: *Body Mass Index, Body Weight, Adolescent Obesity, Longitudinal Studies, Mental Health, Quality of Life.*

Abbreviations HRQL Health-related quality of life; BMI body mass index; CFS Canada Fitness Survey; PALS Physical Activity Longitudinal Study; OR Odds ratio; CI Confidence interval; SD Standard Deviation; PF Physical functioning; RP Role physical; BP Bodily pain; GH General health; VT Vitality; SF Social functioning; RE Role emotional; MH Mental health; PCS Physical component summary; MCS Mental component summary.

INTRODUCTION

Obesity leads to increased risk of numerous chronic diseases and conditions, including early mortality (1); however, almost 60% of Canadian adults and over 1 in 4 young people aged 2-18 years are overweight/obese (2).

Health-related quality of life (HRQL) refers to perceived physical and mental health over time (3). Research examining the links between obesity and HRQL in healthy general population samples has only recently begun to evolve. In adults, obesity is often associated with significant impairments in HRQL, with greater impairments associated with greater degrees of obesity, and weight loss leading to improved HRQL (4). Yet, some studies have shown a positive association between mental HRQL and weight status (5-7). More limited research exists linking youth obesity to poorer youth HRQL, including effects on self-reported health, self-esteem, and physical and social health and functioning (8-10).

The long-term effects of youth obesity on adult HRQL are unclear; however, over 90% of pediatricians believe that youth overweight could affect future HRQL (11). In a previous investigation of Canadian youth followed up 2 decades later, we reported that overweight youth had *greater* odds of scoring at or above the norm on several aspects of HRQL in adulthood, particularly the mental aspects, compared to healthy weight youth (12). To our knowledge, the study, using dichotomized HRQL outcomes based on Canadian normative values, was the first to explore the potential long-term effects of youth body mass index (BMI) on HRQL in adulthood. The current objectives are to explore the relationship between youth BMI and adult physical and mental HRQL using continuous HRQL outcomes, examining differences by sex.

METHODS

Sample. Data were from the Physical Activity Longitudinal Study (PALS) (13), the 22-year follow-up of a 20% sub-sample of participants ages ≥7 from the nationally representative 1981 Canada Fitness Survey (CFS; N=23,397) (14). Detailed information regarding the conceptual design, methods and ethics approval of PALS has previously been published (13). The final sample included 2511 participants (51.2% of eligible individuals); the sub-sample for this analysis included 281 males (N=139) and females (N=142) ages 7-18 in 1981, who had BMI data at baseline and HRQL data in 2002-2004 (ages 29-41). This represents 34.4% of the 817 participants aged 7-18 at baseline.

Measures. Baseline height and weight were measured in 1981. At follow-up (2002-04), all data were self-reported via questionnaire. BMI was calculated as weight (kg)/height (m^2). Youth overweight and obesity were categorized according to the International Obesity Task Force (IOTF) age- and gender-specific cut-offs (15), associated with the predicted WHO-defined adult BMI cut-offs of 25 (overweight) and 30 (obese) kg/m^2 at age 18 (16).

Multidimensional HRQL was assessed using the self-administered Medical Outcomes Study Short Form 36 (SF-36), comprised of 36 questions, assessing 8 physical and mental health domains: physical function (PF), role physical (RP), bodily pain (BP), general health perceptions (GH), vitality (VT), social functioning (SF), role emotional (RE) and mental health (MH) (17). Scores range from 0-100, with higher scores representing better health and less pain. Domains are also weighted and summed to calculate physical and mental component summaries (PCS and MCS), standardized to a mean of 50, with scores above and below 50 representing better and worse than average function respectively (18). A 5-point difference (domain scores) and 2-3 point difference (summary scores) are considered clinically relevant (17, 18).

Statistical Analysis. The distributions of 5 of 8 SF-36 outcomes were negatively skewed, with many participants achieving the maximum score of 100 on the 8 domains: GH, VT, and MH appeared normally distributed, and PCS and MCS deviated only slightly from normal. Spearman correlations between youth BMI (ages 7-18) and adult SF-36 scores were calculated. To account for the effect of age on youth BMI, the latter was regressed on age, and the residuals used in analysis to represent age-adjusted youth BMI. Differences in mean adult SF-36 scores by youth weight status were then assessed by independent samples t-tests and Mann Whitney U tests adjusted for multiple comparisons (Holm method). Linear regression analysis was performed for GH, VT, MH, PCS, and MCS. Initially, the association between adult BMI and the SF-36 outcomes was assessed; youth BMI was then tested both as a continuous and dichotomous predictor. Models were adjusted for age, adult BMI and physical activity, marital and smoking status, education level (university degree), household income (</≥ $60,000), and number of comorbidities (0-7). All analyses were performed separately for males and females.

RESULTS

Descriptive characteristics of the study participants are reported in **Table 1**. At baseline, approximately 9% of participants were overweight (12 each male and female) or obese (1 female); 22 years later, approximately 58% of males and 37% of females were classified as overweight/obese. Over 80% of overweight youth remained overweight/obese as adults, while about 36% of healthy weight youth became overweight/obese.

In *females*, youth BMI was significantly negatively correlated with PCS, and significantly positively correlated with RE, MH, and MCS **(Table 2).** No significant correlations existed for *males*.

Figure 1 (a & b) illustrates the mean SF-36 scores by sex for healthy weight vs. overweight/obese youth. Both *male* and *female* overweight youth scored higher on RE (all scored the maximum of 100), and overweight *females* scored higher on MH and MCS, compared to their healthy weight counterparts; however, these differences did not remain statistically significant following adjustment for multiple comparisons.

An initial adjusted regression analysis assessed the association of *adult* BMI with the 5 normally distributed SF-36 scores. Overweight/obese males scored significantly lower on PCS ($p<0.01$) and overweight/obese females scored significantly lower on GH ($p<0.05$) compared to their healthy weight adult counterparts (data not shown).

Tables 3 and **4** show the linear regression results, by sex, for *youth* BMI and adult SF-36 scores, with and without adjustment for *adult* BMI. No significant predictions were observed in the *male* participants **(Table 3).** Prior to adjustment for adult BMI, overweight/obese *female youth* scored 10 points higher on both VT and MH and 9.1 points higher on MCS in adulthood, compared healthy weight female youth **(Table 4a, Models A)**, and a 1 unit increase in youth BMI led to 1.3 and 1.1 point increases in adult MH and MCS, respectively **(Table 4b, Models A)**. After adjustment for adult BMI, on average, overweight/obese *female youth* scored 16, 13.4, and 13.1 points higher on GH, VT, and MH in adulthood respectively, and 10.9 points higher on MCS, compared to healthy weight female youth **(Table 4a, Models B)**; a 1 unit increase in youth BMI led to 1.7, 1.6 and 1.4 point increases in adult VT, MH and MCS, respectively **(Table 4b, Models B)**.

DISCUSSION

To our knowledge, the PALS study is the first to examine the long term effects of youth overweight on adult HRQL. Building on earlier findings (12), we found significant positive associations between youth BMI and subsequent adult HRQL 22 years later in females, but no association in males. Past research has shown that youth overweight/obesity can affect physical growth and development into adulthood (19), and is linked to worse self-reported health (9), increased likelihood of physical limitations (8-9), decreased psychosocial functioning and self-esteem (8,20), and increased incidence of bullying (21). However, we found no long term negative implications on adult HRQL, at least at moderate levels of youth overweight.

In a previous analysis comparing the PALS sample against Canadian SF-36 normative values, overweight youth were more likely than healthy weight youth to score at/above the norm on both MH and MCS, with positive associations also found for GH, SF, and RE; however, results for GH in particular implicated adult BMI in a moderating role, with the relative increase in BMI from youth to adulthood likely the key factor involved, rather than youth BMI itself exerting an independent effect (12).

In the present sex-stratified analysis, a higher youth BMI predicted higher absolute scores on RE, VT, MH, and MCS in adulthood, but only in *females*. Regression results are presented both with and without adjustment for adult BMI, for reasons discussed at length previously (12). Briefly, as this variable may not be a true confounder (22-23), but may instead (or also) be a moderator in the pathway from youth BMI to adult HRQL, the *reversal paradox* may be invoked whereby the association between two variables can be reversed or enhanced when another variable is statistically controlled (23-24). Indeed, the relationship of youth BMI with GH in females became significant only upon inclusion of adult BMI in the regression model. This inclusion also somewhat strengthened the positive relationship of youth BMI to VT, MH and MCS. As adult BMI was also found to be a significant negative predictor of GH, it is likely that the relationships may be partly (VT, MH and MCS) or completely (GH) due to the relative change in BMI from youth to adulthood, rather than to a purely independent effect of youth BMI on adult HRQL (12).

In adults, several studies have reported that overweight and obesity were related to poorer physically oriented SF-36 outcomes (5-6,25-28). In this analysis, current adult BMI was a significant negative predictor of GH (females) and PCS (males) only. While tracking of BMI in the PALS sample is high, with over 80% of overweight youth becoming overweight/obese adults, the majority of overweight/obese adults were not overweight in their youth (29). Thus, current adult weight status may be more important to physical HRQL than past youth weight status.

Previously reported associations of adult obesity with the mentally oriented SF-36 outcomes have been weaker and less clear than those found for the physical domains and PCS (6,25-26,28), including some studies which found a positive association between adult obesity and the SF-36 mental domains (5-7,27); as such, our findings of a positive association of youth BMI to the adult RE, MH, and MCS may not be completely unusual.

While potential sex differences have been identified in previous studies, these have been inconsistent. One study showed that obese men ages 16-34 were more likely to rate both their physical and mental HRQL lower than healthy weight men, compared to women who did not report worse mental HRQL (28). Another found that after controlling for physical ill-health, overweight and obesity were associated with better mental health in women, but not in men (7). Another reported that while both obese men and women showed worse physical functioning than healthy weight persons, obesity was associated with better mental HRQL in males only (5).

As very few overweight youth became healthy weight adults **(Table 1)**, relative “weight loss” over time is unlikely to be driving the positive association of youth overweight with adult mental HRQL in females. In a previous analysis of longitudinal BMI status change, PALS participants who were overweight/obese both as youth and adults had significantly greater odds of scoring at/above the norm on both MH and MCS, while relative “weight gain” over time led to decreased odds of scoring at/above the norm on GH (12). As well, in a logistic regression stratified by adult BMI categories, youth BMI appeared to be a significant positive predictor of scoring at/above the norm on RE, MH, and MCS in both healthy weight and overweight/obese adults (12). The present analysis confirms a positive association of youth BMI to adult mental HRQL in terms of absolute scores in females, which seems at least partly independent of adult BMI or the change in weight between the two time points.

The main strengths of this research are the 22-year length of follow-up from childhood into adulthood in a representative Canadian population sample, the use of measured BMI data at baseline, and the use of the valid and widely-accepted SF-36 instrument.

Study limitations include the small sample size and high attrition, a common problem in longitudinal studies spanning several decades. BMI as a measure of overweight is inherently limited in its lack of information regarding body composition, and lack of sensitivity to youth maturational age; however, it remains the most widely investigated and easily used indicator of weight-related health risk on a population level. Moreover, the effect of age and maturation were diminished by our use of IOTF cut-offs for youth BMI categorization, age-adjusting youth BMI to examine correlations, and adjusting for age in regressions, all within a sex-stratified analysis. Finally, while the prevalence of youth overweight in the PALS sample is representative of Canada in 1981, the low absolute number of overweight/obese youth (only 1 obese child) may have impacted results. As our results are based on a primarily healthy weight sample, caution should be used when extrapolating findings to overweight/obese groups due to the small sample in these groups. The prevalence of youth overweight/obesity has nearly tripled since that time (2), which may yet lead to negative consequences on HRQL over the long term.

In conclusion, these results suggest that moderate levels of youth overweight may not lead to increased risk of poorer HRQL in adulthood, and may be associated with better mentally-oriented HRQL in females. However, as youth overweight has known immediate health consequences (19), and tracks strongly into adulthood (29), where it is associated with substantially increased risk of a host of other biomedical conditions (1), it is not an issue that can be ignored. It is also possible that greater and more negative HRQL consequences might result from the higher degrees of youth obesity present in today's population. More research is needed on larger cohorts with a higher prevalence and degree of youth obesity to further assess the long term impact on physical and mental health, including further exploration of sex differences, possible critical age ranges, and the role of BMI status changes over time.

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Table 1. Sample characteristics at baseline (1981) and 22-year follow-up (2002-04) – The Physical Activity Longitudinal Study. Values are means (SD) or percentages of total sample.

Characteristic	Males (N=139)	Females (N=142)
Baseline 1981: Age 7-18 years	12.7 (3.4)	12.2 (3.5)
BMI: Healthy Weight	91.4%	90.8%
Overweight/Obese[a]	8.6%	9.2%
PA (kcal/kg/day)	4.9 (5.5)	4.4 (4.9)
PA ≥ 1.5 kcal/kg/day	80.8%	67.0%
PA ≥ 3.0 kcal/kg/day	57.7%	46.4%
Follow-up 2002-2004: Age 29-41 years	35.4 (3.4)	34.9 (3.6)
BMI (kg/m^2)	26.0 (3.4)	25.3 (5.2)
Underweight (<18.5)	1.4%	1.5%
Healthy Weight (18.5-24.9)	40.6%	61.2%
Overweight (25.0-29.9)	47.1%	22.4%
Obese (≥ 30.0)	10.9%	14.9%
PA (kcal/kg/day)	4.2 (5.0)	3.0 (3.6)
PA ≥ 1.5 kcal/kg/day	63.7%	60.2%
PA ≥ 3.0 kcal/kg/day	42.0%	31.2%
Current Smoker	19.0%	21.3%
Self-Reported Health: Very Good/Excellent	48.5%	45.1%
Married	71.7%	82.3%
Education: ≥ 1 University Degree	43.1%	43.6%
Total Household Income: ≥ 60 K	63.8%	68.5%
Comorbidities: ≥1	46.8%	62.0%
Longitudinal BMI change (1981 – 2002-2004):		
Healthy Weight – Healthy Weight	41.2%	59.1%
Healthy Weight – Overweight/Obese	50.7%	32.6%
Overweight/Obese – Healthy Weight	0.0%	3.0%
Overweight/Obese – Overweight/Obese	8.1%	5.3%

[a] There is only 1 obese child (F); 12 each overweight M and F.

Table 2. Spearman Correlations between Youth BMI [a] (1981) and Adult SF-36 Scores (2002-04) – The Physical Activity Longitudinal Study.

	Male (n=139)		**Female (n=142)**	
SF-36	**r**	**p-value**	**r**	**p-value**
PF	-0.02	0.784	-0.03	0.777
RP	0.06	0.507	-0.08	0.355
BP	0.09	0.320	-0.09	0.301
GH	-0.02	0.815	-0.08	0.339
VT	-0.07	0.409	0.14	0.090
SF	0.00	0.976	0.14	0.095
RE	0.10	0.231	0.19*	0.031
MH	0.09	0.319	0.22**	0.008
PCS	-0.04	0.647	-0.21*	0.013
MCS	0.02	0.781	0.26**	0.002

[a] Age-adjusted residuals from regression of BMI on Age.
PF physical functioning; RP role physical; BP bodily pain; GH general health; VT vitality; SF social functioning; RE role emotional; MH mental health; PCS physical component summary; MCS mental component summary; * $p<0.05$, ** $p<0.01$.

Table 3. Adjusted Linear Regression of Adult SF-36 Outcomes (2002-04) on Youth BMI (1981) – The Physical Activity Longitudinal Study – Males

SF-36 Outcome	(A) β (95% CI)	p-value	(B) β (95% CI)	p-value
a) Youth BMI (Overweight/Obese vs. Healthy Weight)				
GH	2.7 (-9.0, 14.3)	0.650	5.4 (-6.3, 17.1)	0.362
VT	-3.4 (-16.4, 9.5)	0.602	-1.8 (-15.0, 11.5)	0.791
MH	6.7 (-4.6, 17.9)	0.242	6.8 (-4.8, 18.4)	0.245
PCS	-1.5 (-7.0, 4.0)	0.599	0.3 (-5.2, 5.7)	0.924
MCS	5.0 (-2.8, 12.7)	0.206	4.7 (-3.3, 12.6)	0.246
b) Youth BMI (Continuous)				
GH	-0.1 (-1.5, 1.5)	0.987	0.5 (-1.1, 2.1)	0.517
VT	-0.8 (-2.5, 0.8)	0.319	-0.6 (-2.3, 1.2)	0.518
MH	0.4 (-1.0, 1.9)	0.577	0.4 (-1.1, 2.0)	0.591
PCS	-0.1 (-0.8, 0.6)	0.743	0.2 (-0.5, 1.0)	0.525
MCS	0.4 (-0.6, 1.4)	0.466	0.3 (-0.8, 1.4)	0.571

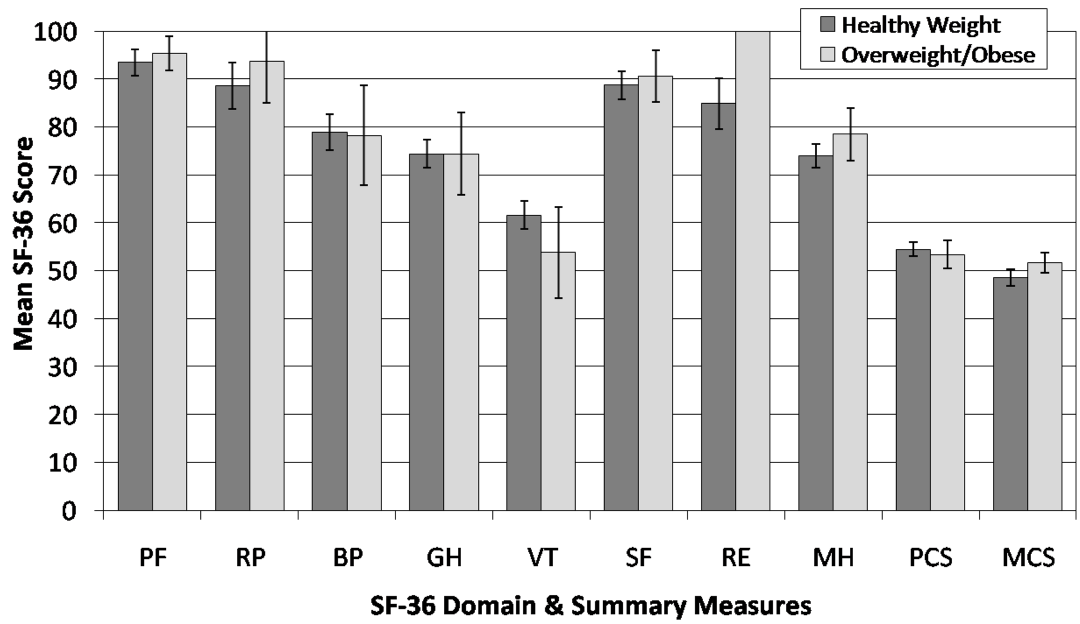
GH general health; VT vitality; MH mental health; PCS physical component summary; MCS mental component summary.
"A" models adjusted for sex, age, adult physical activity, household income, education, married, current smoker, # comorbidities; "B" models adjusted for adult BMI, in addition to previous factors.

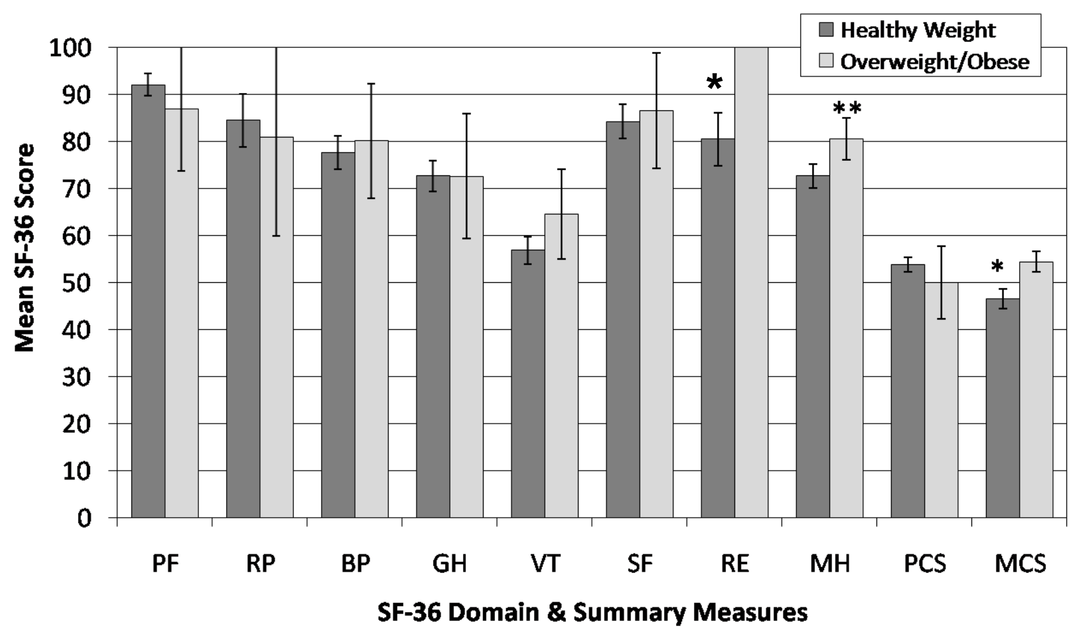
Table 4. Adjusted Linear Regression of Adult SF-36 Outcomes (2002-04) on Youth BMI (1981) – The Physical Activity Longitudinal Study – Females

SF-36 Outcome	(A) β (95% CI)	p-value	(B) β (95% CI)	p-value
a) Youth BMI (Overweight/Obese vs. Healthy Weight)				
GH	9.4 (-1.8, 20.5)	0.098	16.0 (3.7, 28.4)	0.011
VT	10.0 (0.4, 19.5)	0.041	13.4 (2.8, 24.1)	0.014
MH	10.2 (1.2, 19.2)	0.026	13.1 (2.9, 23.2)	0.013
PCS	1.6 (-3.6, 6.7)	0.547	2.4 (-3.5, 8.3)	0.429
MCS	9.1 (2.2, 16.0)	0.010	10.9 (3.0, 18.8)	0.007
b) Youth BMI (Continuous)				
GH	0.1 (-1.3, 1.4)	0.929	1.2 (-0.5, 2.8)	0.162
VT	0.8 (-0.4, 2.0)	0.173	1.7 (0.3, 3.1)	0.017
MH	1.3 (0.2, 2.3)	0.023	1.6 (0.3, 2.9)	0.018
PCS	-0.3 (-0.9, 0.3)	0.290	-0.3 (-1.1, 0.4)	0.396
MCS	1.1 (0.3, 1.9)	0.010	1.4 (0.4, 2.4)	0.008

GH general health; VT vitality; MH mental health; PCS physical component summary; MCS mental component summary.
“A” models adjusted for sex, age, adult physical activity, household income, education, married, current smoker, # comorbidities; “B” models adjusted for adult BMI, in addition to previous factors.

Figure 1. Mean (95% CI) adult SF-36 scores (2002-04) by youth weight status (1981) – The Physical Activity Longitudinal Study: (a) Males; (b) Females.





* p <0.05, ** p<0.01

CHAPTER 7

MANUSCRIPT 5

Physical Activity Trumps Body Mass Index: Health-Related Quality of Life Among Canadian Adults and Older Adults

This manuscript will be submitted to *International Journal of Obesity*, and is presented in a format consistent with journal requirements.

ABSTRACT

Background. Physical activity (PA) positively impacts health-related quality of life (HRQL), while obesity is associated with significant HRQL impairments. Active-obese persons often have similar or lower risk of cardiovascular outcomes and mortality than inactive-healthy weight persons; however, the combined PA-weight status effects on HRQL are less clear.

Objectives. The aim was to investigate the combined association of PA and body mass index (BMI) on HRQL indicators in Canadian adults and older adults.

Methods. Cross-sectional data included110,986 male and female participants ages 18 y and older from the 2005 Canadian Community Health Survey, representing an estimated 22,563,527 Canadians. HRQL indicators included: Self-Rated Health (SRH), Participation and Activity Limitation due to illness/injury (PAL), and Total Disability Days (physical + mental) over the past 14 days (TDD). The prevalence of adverse HRQL was estimated by BMI, PA, and combined BMI-PA categories. Logistic regression was used to assess the odds of adverse HRQL by BMI, PA, and BMI-PA, controlling for potential confounders. Analyses were stratified by sex and age (18-44, 45-64, ≥65 y).

Results. In both men and women of all ages, **i**nactive individuals had a greater likelihood of Fair or Poor SRH, and Sometimes/Often PAL, at all BMI levels; conversely, being underweight, overweight or obese had little effect on SRH and PAL, if individuals were active. Associations were weaker for TDD, where the greatest impact was in older adults from inactivity combined with underweight. Overweight was of less consequence in males and in older adults, while underweight was of greater consequence in males and in older adults.

Conclusions. When examining BMI and PA in combination as predictors of HRQL, PA emerges as the key determinant, regardless of weight status. This reinforces the importance of PA to health outcomes over and above the benefits related to weight loss or maintenance.

Keywords: quality of life, body mass index, physical activity, cross-sectional studies, health status, activity limitation, disability days, adults, older adults.

Abbreviations: HRQL Health-related quality of life; PA physical activity; BMI body mass index; PAL Participation and Activity Limitation; TDD Total Disability Days (physical + mental); OR Odds Ratio; CI Confidence Interval; SD Standard Deviation; UW Underweight; HW Healthy Weight; OW Overweight; OB Obese; IA Inactive; MA Moderately Active; A Active.

INTRODUCTION

Obesity and physical inactivity are major modifiable risk factors for numerous chronic diseases and conditions in adulthood, including premature mortality.[1-4] Greater levels of physical activity (PA) are also positively related to physical and mental health-related quality of life (HRQL),[5] and obesity is associated with significant impairments in HRQL, with greater impairments associated with greater degrees of obesity, and weight loss leading to improved HRQL.[6] Despite the health benefits of PA and healthy body weight, only 51% of adult Canadians are sufficiently physically active during their leisure time to benefit their health,[7] while 61% are overweight or obese.[8]

HRQL has been defined by the U.S. Centers for Disease Control (CDC) as "an individual's or group's perceived physical and mental health over time".[9] Further, the CDC has identified 4 valid and reliable core population surveillance measures: Self-Rated Health (SRH), number of recent Physically Unhealthy Days, number of recent Mentally Unhealthy Days, and number of recent Activity Limitation Days due to physical or mental health.[9]

In terms of cardiovascular disease (CVD) risk factors, and all-cause and CVD mortality, while not eliminating the risk associated with excess body weight or abdominal fat, several studies have shown that PA or fitness is beneficial at all body mass index (BMI) or waist circumference levels: mortality and health risk in lean but inactive/unfit persons has often approached or sometimes eclipsed that of obese but active/fit persons.[10-15] It is of interest to know whether a similar pattern occurs for indicators of HRQL; however, research to this end is lacking.

In large representative studies of the U.S. adult population, both underweight and increasing levels of overweight/obesity have been consistently shown to have a negative impact on SRH,[16-18] as well as physically or mentally unhealthy days and activity limitation days.[16, 18, 19] Associations of overweight and moderate obesity have varied by sex and age, presenting less of a risk of fair/poor SRH, unhealthy days and activity limitation days for men than for women, especially for ages ≥ 45 y. While the likelihood of fair or poor SRH, unhealthy days and activity limitation days associated with underweight may increase with age, the negative impacts associated with obesity decline.[16, 17]

Similar to findings for obesity, the proportions of U.S. adults reporting fair or poor SRH, or ≥14 unhealthy days in the past month, were significantly lower among those meeting PA recommendations compared to inactive adults, across age groups.[20] Elsewhere, the prevalence/odds of poor SRH decreased as PA levels increased, similarly across all age/sex groups,[21] and sufficiently or highly active individuals were more likely to have good SRH than those who were insufficiently active.[22]

In a recently published study, overweight and obese U.S. men and women of all ages who attained recommended PA levels had lower relative odds of fair or poor SRH and ≥ 14 unhealthy days than their inactive counterparts.[23] Another recent study of U.S. adults showed that regular PA was associated with better HRQL regardless of BMI; similar to the literature for mortality and CVD risk, the prevalence of fair or poor SRH, ≥ 14 unhealthy days, or ≥ 14 activity limitation days was comparable in obese active persons and healthy weight inactive persons.[24]

Of further interest, it is known that overweight and moderate obesity may be of less significance to morbidity and mortality in older adults,[25-27] that PA and HRQL indicators have different meanings at different stages of life,[28] that increasing age may have both positive and negative impact on various HRQL indicators in overweight and obese persons,[29] and that older survey respondents give disproportionately positive health assessments.[30] Compared to men, women may suffer a greater burden of disease attributable to overweight and obesity, largely due to lower HRQL across all ages,[31] and women's self-assessments of health are formed based on a broader range of health and non-health factors.[32]

Hence, while physical inactivity and obesity separately lead to adverse HRQL, and recent U.S. research suggests that PA is the more important determinant, these relationships need to be better understood across various populations and population sub-groups. The objectives of this study were to 1) explore the combined association of PA and BMI to HRQL in Canadian adults and older adults, extending previous research on U.S. adults; 2) determine differences in the association of BMI/PA to HRQL between sexes and across age groups; 3) also determine the impact on HRQL of underweight (as well as overweight and obese) in combination with PA level; and 4) validate results based on self-reported BMI using a sub-sample with measured BMI.

METHODS

Data/Sample.

This study used data from the Canadian Community Health Survey (CCHS), Cycle 3.1. In depth methodology has been published.[33] Briefly, the CCHS is a cross-sectional survey conducted by Statistics Canada to collect information related to health determinants, health status and health system utilization for the Canadian population across 133 health regions plus the territories.[34] Using computer-assisted interviews (in person and telephone), the CCHS targets persons 12 years of age and older living in private dwellings in the ten provinces and three territories, covering approximately 98% of the Canadian population. Persons living on Indian Reserves or Crown lands, institutional residents, full-time members of the Canadian Armed Forces and residents of certain remote regions are excluded. CCHS Cycle 3.1 data collection took place January – December, 2005, with a combined response rate of 78.9% at the Canadian population level: of 168,464 households selected to participate, responses were obtained from 143,076 (84.9% household-level response rate), and of the 143,076 individuals (one per household) selected to participate, a total of 132,947 valid interviews were conducted (92.9% individual-level response rate). The present analysis included all respondents ≥ 18 y of age, excluding pregnant women, who had complete data for all study variables (N=110,986), representing an estimated 22,563,527 Canadians (50% female). Data from "Sub-Sample 2" (N=4735; no territories), a sub-sample of Cycle 3.1 respondents from whom measured height and weight data were collected in addition to self-reported data, were used to validate results obtained with the self-reported BMI data from the main datafile. The analysis included 3974 participants ≥ 18 y of age, excluding pregnant women, who had both self-reported and measured height and weight data, as well as covariate data.

Measures.

Independent Variables:

Physical Activity (PA) was assessed using an adaptation of the Minnesota Leisure Time Physical Activity Questionnaire.[35] Respondents were asked about their participation in 21 specified physical activities, and could volunteer up to 3 additional activities, indicating participation frequency over the past 3 months and average session duration. Average daily energy expended during leisure time physical activities over the past 3 months was calculated, weighting each activity by its MET value, the result expressed in kilocalories expended per kilogram of body weight per day (KKD). A *Physical Activity Index* categorized participants as Active (A: ≥ 3.0 KKD), Moderately Active (MA: 1.5-2.9 KKD), or Inactive (IA: < 1.5 KKD), whereby 3.0 KKD, reflects, on average, the equivalent of 60 minutes of moderate intensity activity daily [36] as recommended by public health guidelines in Canada [37] and the US.[38]

Body mass index (BMI) was calculated as weight (kg) / height (m^2). Height and weight were self-reported in the Cycle 3.1 main-file, and directly measured in “Sub-sample 2”. Participants were classified based on Canadian [39] and WHO guidelines [40] as Underweight (UW: < 18.5 kg/m^2), Healthy Weight (HW: 18.5 – 24.9 kg/m^2), Overweight (OW: 25 – 29.9 kg/m^2), or Obese (OB: ≥ 30 kg/m^2).

Participants were stratified by sex (male/female), and into 3 age groups: 18-44, 45-64, and ≥ 65 years.

Outcomes:

Self-rated health (SRH) – Participants were asked “Would you say your health in general is excellent, very good, good, fair, or poor?” A dichotomous SRH variable was defined to estimate the probability that participants would rate their health as “fair” or “poor” (FP-SRH), in contrast to “excellent”, “very good”, or “good”. This measure of health status has been used widely in the literature, and has been shown to be a significant independent predictor of morbidity, mortality and health care utilization.[41]

Participation and Activity Limitation (PAL) – Respondents were classified according to the frequency with which they experienced activity limitations due to a condition(s) or by a long-term physical and/or mental health problem(s). Participants were asked 5 questions as follows: “Do you have any difficulty hearing, seeing, communicating, walking, climbing stairs, bending, learning or doing any similar activities?”; “Does a long-term physical condition or mental condition or health problem, reduce the amount or the kind of activity you can do… at home?”; “... at school?; “... at work?”; and “... in other activities, for example, transportation or leisure?” A dichotomous PAL variable was defined to estimate the probability that participants experienced any of the above limitations “sometimes” or “often” (SO-PAL), in contrast to “never”.

Total Disability Days in the past 14 days (TDD) – Respondents were classified according to the number of days in the past 2 weeks they had stayed in bed or cut down in activities due to illness or injury – including both physical health and injury, and emotional or mental health or participant use of alcohol or drugs. Participants were asked “During that period [past 14 days], did you stay in bed at all because of illness or injury, including any nights spent as a patient in a hospital?" and then "How many days did you stay in bed for all or most of the day?" They were then asked "Not counting days spent in bed during those 14 days, were there any days that you cut down on things you normally do because of illness or injury?" and then "How many days did you cut down on things for all or most of the day?". A dichotomous TDD variable was defined to estimate the probability that participants experienced ≥1 disability day (≥1 TDD), in contrast to 0 disability days, in the past 14 days. As too few respondents reported any disability days due to emotional or mental health, the composite variable was used including both physical and mental disability days; however, physical ill health accounted for close to 99% of disability days reported.

Covariates:

Race/ethnicity (white, visible minority), marital status (married/common law, single/divorced/widowed), smoking status (current smoker, non-smoker), education (< post-sec grad, post-secondary graduate), household income (< $30,000, $30,000-$59,999, ≥ $60,000, 'Missing'), number of comorbidities (continuous 0-8+), and residence (urban/rural) were included as covariates in multivariate analysis. For income, a large number of non-responders necessitated retaining an additional 'missing' category; respondents with answers of ''not stated'' or ''refused'' for any other study variable were excluded from the analyses.

Statistical analysis.

Participants were categorized based on combined PA and BMI levels, as follows:

Inactive – Underweight	Moderately Active – Underweight	Active – Underweight
Inactive – Healthy Weight	Moderately Active – Healthy Weight	Active – Healthy Weight
Inactive – Overweight	Moderately Active – Overweight	Active – Overweight
Inactive – Obese	Moderately Active – Obese	Active – Obese

Weighted prevalences were calculated to estimate the number of Canadians falling into each BMI, PA and BMI-PA category for each of the 3 outcomes. Three-dimensional (x-y-z) figures were constructed to illustrate the combined impact of PA and BMI status on SRH, PAL, and TDD.

Multivariate logistic regression was used to predict the odds of FP-SRH, SO-PAL, or ≥1 TDD, based on BMI, PA, and BMI-PA status, controlling for demographic covariates. Healthy weight and active were the referent groups for BMI and PA respectively.

All analyses were stratified by sex and 3 age groups (18-44, 45-64, ≥ 65 y), to explore how the associations of BMI and PA to SRH, PAL, and TDD varied by sex and across the adult lifespan.

Appropriate weights (provided) were applied to the data to calculate summary statistics for the Canadian population; boostrapping techniques were used to calculate 95% confidence intervals for all estimates, using bootstrap weights provided by Statistics Canada.

Prevalence estimates for SRH, by sex and age, were calculated for the sub-sample participants for whom both measured and self-reported height and weight were available. Sample size limitations precluded the inclusion of the underweight group, or use of multivariate analysis. The general bias resulting from the use of self-reported versus directly measured BMI in the CCHS 3.1 has previously been quantified.[42]

RESULTS

Demographic and health characteristics of the population are presented in **Table 1**. Average BMI was just into the overweight range, with 50% of the population overweight or obese (58% of males, 42% of females). About 50% were classified as completely Inactive, while only 1 in 4 were Active. Overall, 11% of the population reported FP-SRH, 30% reported SO-PAL, and 17% (with a greater proportion of females than males) reported ≥1 TDD in the past 14 days – translating to over 2.5, 6.7 and 3.8 million Canadians respectively with adverse HRQL by these indicators.

Due to small numbers of *underweight* participants per sex and age groups, especially when further subdivided into PA categories, results for prevalences and odds of adverse HRQL outcomes should be interpreted with caution when indicated by wide 95% confidence intervals.

Self-rated health

The prevalence of FP-SRH increased with age within all BMI, PA and BMI-PA categories, for both sexes (**Table 2**). In males, being OW did not result in a greater prevalence of FP-SRH compared to HW, while UW and OB led to similar increased prevalences for those 18-64 y; however, UW appeared to be of greater consequence in males ≥ 65 y. For females, OW and OB were associated with progressively higher prevalences of FP-SRH at all ages, compared to HW females. Similar to males, UW was of greater consequence in females ≥ 65 y, the prevalence of FP-SRH similar in UW and OB older females. Increasing prevalence of FP-SRH was also seen with decreasing PA level, in both sexes, across all age groups. The consequences of inactivity increased with age: one third of inactive older adults reported FP-SRH.

The combined effects of BMI and PA on prevalence of FP-SRH are illustrated in **Figure 1a**. Across all age-sex groups, HW-A persons had the lowest prevalence of FP-SRH. Within each weight category, the prevalence of FP-SRH was significantly greater among inactive compared active persons. At all ages and for both sexes, OB-A was associated with similar or lower prevalence of FP-SRH compared to HW-IA. The highest prevalence of FP-SRH was in UW-IA and OB-IA, the former especially notable in older males. Within all PA categories, OW did not have significant impact on prevalence of FP-SRH for either sex, whereas OB was associated with increased prevalence.

In logistic regression analysis (**Table 3**), the odds of FP-SRH did not increase significantly with age in either sex. In males, OB was associated with increased odds of FP-SRH, compared to HW, but the strength of this effect was significantly lower in older compared to younger adult males; OW did not significantly increase the odds of FP-SRH in males. In females, OB was associated with increased odds of FP-SRH at all ages, while OW was associated with increased odds of FP-SRH in younger females only. UW was also associated with increased odds of FP-SRH in both sexes. Both inactive males and females had significantly greater odds of FP-SRH, compared to their active counterparts; being classified as moderately active also led to increased odds for younger males, as well as younger and middle age females. ORs were only mildly attenuated with the inclusion of both BMI and PA in the same model thus controlling for the other **(models (b) in Table 3)**, vs. each in their own model **(models (a) in Table 3)**, demonstrating the independent effects of BMI and PA on SRH.

For the combined BMI-PA categories, with HW-A as the referent group, a similar pattern emerged as seen with the prevalence estimates: OB-A individuals of both sexes had, on average, similar or lower odds of FP-SRH compared to HW-IA individuals. In older adult males and in middle aged and older females, OB did not lead to greater odds of FP-SRH if those persons were active (in younger males and females, OB led to increased odds of FP-SRH across all activity levels). In males, OW was not associated with increased odds of FP-SRH, unless inactive; in females, OW led to increased odds of FP-SRH if inactive or only moderately active, but not if active. Both males and females who were UW-IA had greater odds of FP-SRH, while UW older adult females had greater odds of FP-SRH regardless of PA level. For both sexes, inactivity was associated with increased odds of FP-SRH, across all ages regardless of weight status.

Participation and Activity Limitation

For both sexes, prevalence of SO-PAL increased with age within all BMI and PA groups (**Table 2**). In males, OB was related to increased prevalence at all ages, but OW only for those ≥ 65 y. In females, both OW and OB were related to increased prevalence at all ages. Inactivity was associated with higher prevalence of SO-PAL for all sex-age groups, but most dramatically in older adults.

The combined effects of BMI and PA on prevalence of SO-PAL are illustrated in **Figure 1b**. In males, OB-A had similar prevalence of SO-PAL as HW-IA; in females, OB-A had higher prevalence of SO-PAL in those < 65 y, but similar prevalence at older ages. OW-A was not associated with increased prevalence of SO-PAL in either sex, compared to HW-A. Inactive persons had a significantly higher prevalence of SO-PAL compared to their active counterparts across most age/weight categories.

In logistic regression analysis (**Table 3**), the odds of SO-PAL were not affected by weight status in younger males, but increased slightly with OB at ≥ 45 y. OW and OB were associated with greater odds of SO-PAL in females < 65 y, but only OB in older females. UW also increased the odds of SO-PAL in older females. Inactive persons had greater odds of SO-PAL, especially in older adulthood, compared to their active counterparts. ORs were not greatly attenuated by inclusion of both BMI and PA in the same model **(models (b) in Table 3)**, illustrating the independent effects of BMI and PA. For the combined BMI-PA groups, in both sexes, OW and OB were of little consequence if active (increased odds of SO- PAL for OB adults 45-64 y only). Inactivity was associated with increased odds of SO-PAL in HW males and females, especially in older adulthood, and UW was an issue for inactive adults ≥ 65 y.

Total Disability Days

Prevalence of ≥1 TDD was not affected by age in males; however, older females reported a lower prevalence of ≥1 TDD compared to their younger counterparts (**Table 2**). In males, prevalence of ≥1 TDD was not greatly affected by BMI, although UW is a potential issue especially in older males; Prevalence of ≥1 TDD was more affected by weight in females, showing an increase in all age groups with OB. In both sexes, inactivity was associated with higher prevalence of ≥1 TDD in adults ≥ 65 y. Females generally showed a higher prevalence of ≥1 TDD than their same-age male counterparts within most BMI and PA categories.

The combined BMI-PA effects on prevalence of ≥1 TDD are illustrated in **Figure 1c**. In males, overlapping 95% CIs indicate no effect of any BMI-PA group compared to HW-A for ages 18-44 y, while inactivity was associated with a higher prevalence of ≥1 TDD across all weight categories in older males. In females 18-44 y, OB was associated with a greater prevalence of ≥1 TDD compared to HW, regardless of PA level. However, in older females, OB women had a higher prevalence of ≥1 TDD only if inactive; OW and UW older women also had a higher prevalence of ≥1 TDD if inactive. OB-A had similar prevalence of ≥1 TDD in middle and older age, while OB was associated with a higher prevalence in females < 45 y.

In logistic regression analysis (**Table 3**), weight status did not affect the odds of ≥1 TDD in males 18-44 y, or in females of any age; UW was associated with increased odds for males ≥ 45 y compared to their HW counterparts. There was also no effect of PA on the odds of ≥1 TDD for males 18-44y or 45-64 y, or for females 18-44 y; Inactivity was associated with increased odds in older males and females. Including both BMI and PA together in the regression model did not attenuate ORs **(models (b) in Table 3)**. Similarly, results from the combined BMI-PA groups show little effect of BMI-PA category in adulthood, but inactivity is an issue for both sexes across all weight categories in older age, especially for UW persons.

Sub-Sample 2: Measured BMI and Self-Rated Health

Sub-Sample participants were similar to those of the CCHS 3.1 main datafile on BMI (mean, and category proportions), prevalence of FP-SRH, and most demographic characteristics, with the exception that sub-sample participants were more physically active (higher mean PA level, and higher proportion “active”/lower proportion “inactive”), and a slightly larger proportion chose not to report their income (data not shown). Approximately 39% of participants were HW, 35% OW, and 24% OB using measured BMI, compared to 48%, 34%, and 16% respectively using self-reported BMI (data not shown).

Examining the prevalence of FP-SRH by BMI category, overall and across all sex and age groups, the prevalence of FP-SRH was slightly higher in the HW group and slightly lower in both the OW and OB groups when participants were categorized by objectively measured BMI versus self-reported BMI; however, overlapping 95% CI's in all cases indicated that none of the differences were statistically significant (data not shown).

DISCUSSION

This study examined the associations of leisure-time PA and BMI with indicators of HRQL in Canadian adults and older adults, by sex and age. The results show that individually, BMI and PA are each strong independent predictors of adverse HRQL; however, when taken in combination, PA emerges as the key determinant. Using healthy weight active persons as the reference, an individual's weight status makes little difference if that individual is active. Inactive persons have a greater likelihood of Fair or Poor Self-Rated Health (FP-SRH), and Sometimes/Often Participation and Activity Limitation (SO-PAL), regardless of their weight status. Conversely, being underweight, overweight or even obese appears to be of little consequence for SRH and PAL, as long as the individual is active. Results and patterns were especially striking and consistent for SRH, an indicator associated with changes in functional ability,[43] and a consistent and powerful independent predictor of morbidity and mortality.[41] Associations were not as strong for Total Disability Days (TDD), where the greatest impact was of inactivity in older age, especially in underweight individuals. In general, overweight was of less consequence to HRQL in males, and in older adults, while underweight was of greater consequence in males, especially those over the age of 65. Sex and age differences were less apparent in terms of the benefits of physical activity to HRQL.

Few previous studies have examined the combined association of BMI and PA on HRQL. A recent U.S. study found that participation in regular PA was associated with better HRQL regardless of weight status, and the prevalence of FP-SRH, ≥ 14 unhealthy days, or ≥ 14 days with activity limitations was similar in

OB-A persons and HW-IA persons.[24] Similarly, in a study of OW and OB U.S. adults, those who met recommended PA levels had better SRH and lower odds of ≥14 unhealthy days than inactive adults across all age strata; in fact, OB-A individuals had better SRH and unhealthy days vs. HW-IA (OW similar to HW for all PA categories), highlighting the importance of regular PA on HRQL in OW and OB persons despite their excess weight.[23] Supporting the U.S. findings, our results from a Canadian population sample also suggest that when PA and BMI are examined together, PA emerges as the key determinant of HRQL in adults and older adults. Our results further indicate that variations in these associations exist based on sex and age, particularly in terms of weight status with respect to the OW and UW groups.

Previous studies have examined separately the association of either PA, or BMI, with HRQL. A systematic review concluded that that physical function and well-being were related to higher levels of PA in older adults, but that results of randomized intervention studies did not always support this relationship.[28] In a large U.S. population sample, the proportion of adults reporting ≥ 14 unhealthy days and the likelihood of FP-SRH were significantly lower among adults attaining recommended levels of PA vs. insufficiently active or inactive adults for all age and sex groups.[20] A study of PA and SRH in Korean adults found a lower prevalence and odds of poor SRH with increasing PA level across all age and sex groups, and in both healthy and physically impaired or chronically ill individuals.[21] Our current findings lend further support to the benefits of PA to HRQL for men and women of all ages.

In terms of BMI, in U.S. adults, UW, OW and OB persons had increased odds of FP-SRH, while UW and OB persons fared worse in terms of unhealthy days and activity limitation days; patterns were similar for both sexes across age groups, although there was a greater impact of UW and little effect of OW in males.[16] In another study, the proportion of U.S. adults reporting FP-SRH increased with increasing BMI for OW, OB, and severely-OB compared to non-OW individuals, while OB and severely-OB (but not OW) individuals had greater odds of experiencing >14d unhealthy days, or >14 activity limitation days.[19] In a study of the association between OB and SRH in individuals free of chronic conditions, the proportion reporting excellent health decreased with increasing BMI, but there were no greater odds of reduced SRH for OW persons.[18] Another study examining the association of BMI with SRH and functional status in U.S. adults reported that UW and severe-OB showed consistent association with increased disability and poorer health status; however, associations for OW and moderate-OB varied significantly by age and sex, suggesting that a single "ideal body weight category" may not apply to all ages or all health outcomes in both men and women.[17] Our current findings support past research into the relationship of BMI and HRQL in adults, further highlighting potential age- and sex-based differences, especially with respect to the consequences of OW and UW.

Finally, in terms of biomedical outcomes, in a mortality follow-up of over 25,000 men in the Aerobics Center Longitudinal Study, low cardio-respiratory fitness was a strong independent predictor of CVD and all-cause mortality in all BMI groups, whereas men who were overweight or obese, but fit, did not have greater risk of mortality compared to their healthy weight fit counterparts.[10] The health benefits of "leanness" were limited to fit men, and fitness reduced the hazards otherwise associated with obesity; however, unfit-lean men had double the risk of all-cause and CVD mortality of fit-lean men, and also higher risk of mortality than fit-obese men, while the latter had no greater risk of mortality than fit-lean men.[11] In studies of women, being fit/active reduced, but did not completely eliminate the increased risks associated with obesity, while being of healthy weight did not eliminate the increased risk associated with being unfit/inactive.[12, 13] A recent systematic review concluded that the risk for all-cause and CVD mortality was lower in high-BMI fit individuals, compared with normal-BMI unfit individuals, but that the evidence was inconclusive for PA and BMI. Moreover, a high BMI, even if physically active, was still associated with other health issues, including type 2 diabetes and CVD risk factors, compared with normal BMI inactive individuals.[15] Our findings provide further evidence that patterns similar to those found in biomedical research may also apply to HRQL, such that active-obese individuals experience similar or better HRQL than inactive-healthy weight individuals. Our results showing less impact of OW on HRQL in adults over the age of 65 also echo the literature showing that overweight and moderate obesity may be of less significance to morbidity and mortality in older compared to younger adults.[25-27]

STRENGTHS and LIMITATIONS

This study is the first to use nationally representative data from the Canadian population to examine the relationship of BMI and PA to HRQL, adding to recently published U.S. reports. In addition, the large sample size has allowed analysis by age and sex, and inclusion of the underweight group which had previously been sparsely studied. Finally, the opportunity to perform a basic analysis on a sub-sample of participants with measured BMI data, showing similar results, validates results obtained with self-reported BMI from the main CCHS sample.

This study also has several limitations. First, the cross-sectional data precludes the inference of causal relationships, and reverse causation may be present. While PA can improve HRQL, it is also possible that individuals with impaired HRQL are less likely to participate in PA, and that improved HRQL is the cause of higher PA rather than the consequence. Healthier individuals may be more likely to be active, and conversely, factors leading to poor general health, unhealthy days, or activity limitations may also preclude PA participation. Likewise, while obesity may lead to impaired HRQL, other factors leading to weight gain may also contribute to impaired HRQL. Underweight may also be the result of underlying illness, the latter leading to impaired HRQL while also inhibiting PA participation, leading to underestimation of the effects of obesity.[44] This may be especially true for older adults, as over 80% of Canadians 65+ report at least 1 chronic condition;[45] however, the impact of chronic conditions on HRQL may be partially attributed to a relative lack of PA in those older adults.[46] The current study controlled for total number of comorbidities (chronic conditions and otherwise) in regression analysis, in hopes of reducing this bias; however, longitudinal studies are needed to provide additional insight.

A second limitation is the reliance on self-reported BMI and PA, potentially leading to underestimation of BMI and overestimation of PA. While we were able to validate the essence of our results to some extent by way of basic analysis of a sub-sample of participants with measured BMI data, this analysis also showed that the potential for over/under-estimation of outcomes does exist. Under-reporting of weight (and under-estimation of BMI) increases with increasing weight and age, and women under-report more than men,[47, 48] potentially explaining some of our results. If obese individuals were misclassified as merely overweight, the obese category thus comprising a falsely elevated proportion of extremely obese individuals, the negative impacts of overweight and obesity on HRQL may be overestimated. [49] Some respondents may have also misreported their PA levels to reflect the socially desirable nature of PA participation,[50] leading to overestimation of PA prevalence. On the other hand, as only leisure-time PA was measured, while over-reporting may have occurred, this also misses other daily activity possibly performed, potentially leading to a conservative PA estimate.

Finally, BMI as a measure of weight status does not necessarily reflect body composition in terms of fat versus fat-free mass, or fat distribution. This may be particularly important for younger males with a BMI in the overweight range, which may reflect increased muscle rather than fat mass. This may partly explain the apparent lack of effect of overweight on HRQL in males.

CONCLUSIONS

Similar to results seen with biomedical outcomes, our results support the promotion of PA for reasons beyond merely the goal of weight loss or maintenance. While both BMI and PA are strong independent predictors of adverse HRQL individually, PA emerges as the key determinant when taken in combination. This reinforces the importance of maintaining an active lifestyle for prevention and treatment of obesity-related outcomes, independent of weight loss. Future research should include objectively measured BMI, body composition/fat distribution, PA and fitness, and a larger sample of underweight individuals across age groups. Longitudinal studies in particular would provide additional insight into the role that weight status and PA play in the maintenance of good physical health and health-related quality of life.

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Conflict of Interest

The authors declare no conflict of interest.

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Table 1. Demographic and health characteristics of Canadian adults and older adults – Canadian Community Health Survey Cycle 3.1 (2005). Values are means (SD) or weighted percentages.

Characteristic		Total sample (N=110,986)		Men 49.9% (N=51,198)		Women 50.1% (N=59,788)	
		N[a]	%	N	%	N	%
Age (y)	(mean)		45.49 (16.98)		44.71 (16.50)		46.28 (17.42)
	18-44	48,753	50.5	23919	52.1	24834	48.8
	45-64	37,237	34.5	17258	34.6	19979	34.4
	≥ 65	24,996	15.0	10021	13.3	14975	16.8
Race/Ethnicity	White	99196	83.9	45525	83.6	53671	84.2
	Visible Minority	11790	16.1	5673	16.4	6117	15.8
Education	< Post-Sec grad.	51334	41.9	23219	41.3	28115	42.5
	Post-Sec grad.	59652	58.1	27979	58.7	31673	57.5
Household Income	< 30,000	27942	16.3	10512	13.6	17430	19.0
	30,000-59,999	31685	26.2	15140	25.9	16545	26.5
	≥ 60,000	38813	45.5	20739	50.4	18074	40.6
	'Missing'	12546	12.0	4807	10.1	7739	13.9
Smoker	Non-Smoker	83062	76.4	37125	74.2	45937	78.5
	Current Smoker	27924	23.6	14073	25.8	13851	21.5
Marital Status	Married/CL	61490	64.8	29924	67.4	31578	62.3
	Not married	49467	35.2	21274	32.6	28210	37.7
Residence	Urban	82760	82.1	37645	81.6	45115	82.5
	Rural	28226	17.9	13553	18.4	14673	17.5
Comorbidities	0	28472	29.4	15982	34.0	12490	24.9
	≥ 1	82514	70.6	35216	66.0	47298	75.1
BMI (kg/m^2)	(mean)		25.74 (4.87)		26.41 (4.38)		25.07 (5.22)
	Underweight (UW)	2737	2.7	492	1.0	2245	4.4
	Healthy Weight (HW)	49806	47.2	20002	40.7	29804	53.8
	Overweight (OW)	38439	34.1	21184	41.3	17255	27.0
	Obese (OB)	20004	15.9	9520	17.0	10484	14.8
PA (kcal/day)	(mean)		2.09 (2.21)		2.24 (2.38)		1.94 (2.02)
	Inactive (IA)	55950	49.4	24852	47.6	31098	51.3
	Moderately Active (MA)	28268	25.6	12673	25.1	15595	26.2
	Active (A)	26768	24.9	13673	27.3	13095	22.5
BMI-PA	UW-IA	1498	1.5	272	0.6	1226	2.4
	UW-MA	625	0.6	103	0.2	522	1.0
	UW-A	614	0.6	117	0.2	497	1.0
	HW-IA	22916	21.5	9128	18.3	13788	24.8
	HW-MA	13147	12.5	4978	10.2	8169	14.8
	HW-A	13743	13.2	5896	12.2	7847	14.3
	OW-IA	19323	16.8	9976	19.1	9347	14.6
	OW-MA	9961	8.9	5404	10.7	4557	7.1
	OW-A	9155	8.4	5803	11.5	3351	5.3
	OB-IA	12213	9.6	5476	9.6	6737	9.6
	OB-MA	4535	3.7	2188	4.0	2347	3.3
	OB-A	3256	2.7	1856	3.4	1400	2.0
SRH	Excellent/Very Good/Good	95376	88.8	44236	89.4	51140	88.3
	Fair/Poor	15610	11.2	6962	10.6	8648	11.7
PAL	Never	72537	69.8	34329	71.0	38208	68.6
	Sometimes/Often	38449	30.2	16869	29.0	21580	31.4
TDD	0	91968	83.1	43872	85.8	48096	80.4
	≥ 1	19018	16.9	7326	14.2	11692	19.6

a All N's are unweighted sample size (all % are weighted). BMI Body Mass Index; PA Physical Activity; SRH Self-Rated Health; PAL Participation Activity Limitation; TDD Total Disability Days

Table 2. Estimated prevalence (weighted %) of adverse health-related quality of life outcomes among Canadian adults and older adults, by sex and age – Canadian Community Health Survey Cycle 3.1 (2005).

	Males			Females		
Outcome	**18-44 % (95% CI)**	**45-64 % (95% CI)**	**≥ 65 % (95% CI)**	**18-44 % (95% CI)**	**45-64 % (95% CI)**	**≥ 65 % (95% CI)**
Fair/Poor Self-Reported Health						
by BMI						
Underweight	12.4 (7.0, 17.8)	21.4 (10.6, 32.2)	43.4 (29.6, 57.3)	8.9 (6.3, 11.4)	18.0 (10.8, 25.2)	35.0 (29.5, 40.6)
Healthy Weight	**4.5 (4.0, 5.0)**	**10.3 (9.2, 11.4)**	**21.0 (19.2, 22.8)**	**4.4 (3.9, 4.9)**	**9.5 (8.5, 10.4)**	**19.1 (17.7, 20.5)**
Overweight	4.9 (4.2, 5.5)	10.9 (9.8, 12.0)	22.5 (20.9, 24.1)	6.8 (5.9, 7.7)	13.1 (11.9, 14.3)	23.0 (21.3, 24.6)
Obese	11.2 (9.6, 12.7)	21.3 (19.4, 23.3)	34.2 (31.0, 37.4)	12.9 (11.4, 14.4)	24.3 (22.3, 26.2)	37.4 (34.5, 40.4)
by PA						
Inactive	7.8 (7.1, 8.5)	16.9 (15.7, 18.0)	33.6 (31.8, 35.4)	8.8 (8.0, 9.6)	18.1 (16.9, 19.2)	29.9 (28.5, 31.2)
Mod. Active	4.6 (4.0, 5.3)	9.9 (8.6, 11.3)	16.8 (14.8, 18.8)	4.4 (3.8, 5.0)	10.5 (9.2, 11.7)	15.8 (14.1, 17.6)
Active	**3.6 (2.9, 4.2)**	**7.7 (6.6, 8.8)**	**12.6 (10.7, 14.5)**	**3.2 (2.7, 3.8)**	**6.5 (5.4, 7.5)**	**12.0 (9.9, 14.0)**
by BMI-PA						
UW-IA	14.8 (6.8, 22.7)	21.5 (8.3, 34.8)	61.7 (43.7, 79.7)	11.4 (7.3, 15.4)	23.3 (15.1, 31.5)	38.4 (31.4, 45.5)
UW-MA	13.2 (2.6, 23.7)	---[a]	24.9 (0, 50.1)	4.0 (1.4, 6.6)	20.5 (0, 43.0)	30.4 (18.4, 42.5)
UW-A	6.8 (0, 15.3)	19.8 (0, 41.5)	14.9 (0, 35.1)	7.4 (3.1, 11.7)	7.3 (1.0, 13.7)	24.3 (10.6, 38.1)
HW-IA	5.9 (5.1, 6.7)	14.1 (12.1, 16.0)	32.9 (29.8, 36.0)	6.5 (5.5, 7.4)	13.9 (12.2, 15.6)	25.1 (23.1, 27.0)
HW-MA	4.1 (3.1, 5.1)	8.0 (6.2, 9.8)	12.6 (9.9, 15.4)	3.3 (2.6, 4.0)	6.7 (5.2, 8.2)	12.8 (10.3, 15.2)
HW-A	**2.9 (2.1, 3.6)**	**5.8 (4.4, 7.1)**	**10.5 (7.6, 13.4)**	**2.3 (1.8, 2.9)**	**4.7 (3.6, 5.9)**	**9.6 (7.1, 12.0)**
OW-IA	7.1 (6.0, 8.1)	14.1 (12.2, 16.0)	29.9 (27.3, 32.5)	9.3 (7.8, 10.8)	16.3 (14.4, 18.2)	27.8 (25.5, 30.0)
OW-MA	3.1 (2.2, 3.9)	7.8 (6.1, 9.4)	18.3 (14.9, 21.6)	5.3 (3.9, 6.7)	11.2 (9.0, 13.4)	16.3 (13.3, 19.3)
OW-A	3.3 (2.2, 4.3)	7.7 (6.0, 9.4)	13.0 (10.3, 15.7)	3.2 (2.0, 4.4)	7.1 (4.8, 9.4)	12.3 (8.8, 15.7)
OB-IA	13.3 (11.1, 15.4)	25.4 (22.7, 28.1)	41.3 (36.9, 45.8)	15.8 (13.5, 18.0)	27.6 (25.0, 23.7)	42.2 (38.9, 45.6)
OB-MA	10.4 (7.5, 13.2)	17.5 (13.3, 21.6)	25.1 (18.7, 31.5)	9.3 (7.0, 11.6)	19.9 (16.1, 23.7)	23.6 (17.7, 29.6)
OB-A	7.3 (4.7, 9.9)	12.5 (8.9, 16.2)	19.4 (13.6, 25.1)	8.5 (5.8, 11.2)	14.1 (9.9, 18.3)	22.6 (13.0, 32.3)

Table 2. (cont'd)

Sometimes/Often Participation and Activity Limitation

by BMI						
Underweight	25.9 (18.8, 33.0)	33.0 (21.0, 44.9)	52.3 (36.6, 68.0)	20.3 (17.3, 23.4)	35.0 (27.2, 42.8)	59.9 (53.5, 66.4)
Healthy Weight	**19.0 (17.9, 20.0)**	**29.2 (27.3, 31.0)**	**45.1 (42.7, 47.5)**	**18.7 (17.8, 19.6)**	**28.9 (27.4, 30.4)**	**45.9 (44.1, 47.7)**
Overweight	20.0 (18.8, 21.2)	32.2 (30.6, 33.8)	51.1 (49.1, 53.0)	24.1 (22.5, 25.7)	36.0 (34.2, 37.8)	51.4 (49.4, 53.4)
Obese	25.7 (23.7, 27.7)	43.6 (41.0, 46.2)	60.6 (57.3, 64.0)	31.5 (29.2, 33.7)	51.5 (49.1, 54.0)	70.2 (67.6, 73.8)
by PA						
Inactive	22.7 (21.6, 23.8)	36.7 (35.1, 38.3)	58.3 (56.3, 60.3)	23.4 (22.3, 24.6)	39.7 (38.1, 41.2)	59.8 (58.3, 61.2)
Mod. Active	19.9 (18.4, 21.3)	32.2 (30.0, 34.4)	46.6 (43.7, 49.5)	20.3 (18.9, 21.7)	33.0 (31.0, 34.9)	42.5 (40.1, 44.9)
Active	**17.6 (16.4, 18.8)**	**28.3 (26.2, 30.4)**	**38.3 (35.7, 40.8)**	**19.0 (17.7, 20.3)**	**28.5 (26.6, 30.5)**	**35.8 (32.8, 38.7)**
by BMI-PA						
UW-IA	27.1 (16.8, 37.4)	42.5 (24.5, 60.5)	67.6 (48.8, 86.4)	21.5 (16.9, 26.0)	35.8 (25.5, 46.2)	67.2 (59.3, 75.0)
UW-MA	25.8 (10.8, 40.9)	---[a]	47.7 (17.0, 78.3)	19.8 (13.7, 26.0)	42.2 (19.3, 65.1)	50.6 (37.0, 64.2)
UW-A	23.3 (11.0, 35.6)	35.0 (7.0, 63.0)	18.7 (0, 41.5)	18.0 (12.6, 23.4)	27.1 (16.4, 37.9)	36.9 (21.4, 52.4)
HW-IA	20.6 (19.0, 22.2)	33.2 (30.4, 36.0)	54.5 (50.6, 58.4)	19.9 (18.5, 21.3)	34.0 (31.5, 36.4)	53.8 (51.4, 56.3)
HW-MA	19.1 (17.1, 21.2)	27.2 (23.5, 30.9)	40.7 (36.3, 45.2)	17.8 (16.1, 19.6)	25.5 (22.5, 28.4)	38.1 (34.9, 41.4)
HW-A	**16.6 (14.8, 18.5)**	**23.9 (20.5, 27.3)**	**34.7 (30.7, 38.7)**	**17.8 (16.2, 19.3)**	**23.6 (21.1, 26.1)**	**32.5 (28.9, 36.1)**
OW-IA	22.6 (20.8, 24.5)	34.4 (31.9, 36.9)	57.9 (55.1, 60.7)	26.6 (24.1, 29.1)	37.5 (34.9, 40.1)	57.3 (54.9, 59.7)
OW-MA	18.8 (16.5, 21.0)	31.2 (28.1, 34.4)	49.5 (45.3, 53.7)	22.5 (19.6, 25.5)	36.6 (33.3, 39.9)	43.5 (39.3, 47.8)
OW-A	17.3 (15.5, 19.2)	28.7 (25.6, 31.8)	39.9 (36.0, 43.7)	20.4 (17.4, 23.4)	31.1 (25.5, 46.2)	37.4 (32.3, 42.6)
OB-IA	27.8 (25.1, 30.5)	45.3 (42.1, 48.5)	65.5 (61.3, 70.0)	33.2 (30.2, 36.1)	53.2 (50.0, 56.3)	75.5 (72.6, 78.4)
OB-MA	25.0 (20.7, 29.3)	42.7 (37.0, 48.4)	56.0 (48.4, 63.6)	30.4 (26.0, 34.8)	48.2 (43.5, 53.0)	55.9 (49.3, 62.5)
OB-A	21.8 (18.3, 25.3)	38.8 (32.5, 45.1)	48.5 (40.9, 56.0)	27.3 (22.2, 32.4)	48.8 (42.0, 55.6)	51.9 (40.9, 62.8)

Table 2. (cont'd)

≥ 1 Total Disability Days (Physical + Mental)

by BMI						
Underweight	13.9 (7.8, 20.0)	26.3 (14.4, 38.3)	19.2 (9.7, 28.7)	17.8 (15.2, 20.4)	24.4 (16.4, 32.4)	17.9 (13.3, 22.5)
Healthy Weight	**14.8 (13.8, 15.8)**	**12.7 (11.3, 14.0)**	**9.0 (7.8, 10.2)**	**18.7 (17.8, 19.5)**	**18.7 (17.3, 20.0)**	**13.1 (11.9, 14.4)**
Overweight	15.2 (14.1, 16.2)	13.6 (12.3, 14.8)	12.0 (10.6, 13.4)	22.1 (20.5, 23.7)	20.3 (18.8, 21.9)	16.0 (14.5, 17.5)
Obese	16.7 (15.0, 18.3)	16.4 (14.5, 18.2)	12.3 (10.1, 14.5)	26.6 (24.6, 28.7)	26.4 (24.1, 28.6)	19.6 (17.2, 22.0)
by PA						
Inactive	14.8 (13.9, 15.8)	15.4 (14.2, 16.6)	13.7 (12.5, 15.0)	20.2 (19.1, 21.2)	22.7 (21.3, 24.1)	17.4 (16.2, 18.6)
Mod. Active	14.9 (13.7, 16.1)	12.4 (10.9, 13.9)	9.0 (7.4, 10.7)	20.8 (19.4, 22.3)	19.8 (17.9, 21.8)	13.4 (11.7, 15.0)
Active	**16.0 (14.7, 17.2)**	**12.3 (10.7, 13.8)**	**7.5 (5.9, 9.1)**	**19.9 (18.5, 21.2)**	**17.2 (15.4, 19.1)**	**9.7 (7.9, 11.5)**
by BMI-PA						
UW-IA	17.5 (8.1, 26.9)	24.7 (9.7, 39.8)	28.1 (13.8, 42.5)	16.0 (12.6, 19.3)	19.7 (11.4, 27.9)	19.5 (13.5, 25.4)
UW-MA	3.5 (0, 7.3)	---[a]	---[a]	19.9 (13.8, 26.0)	38.3 (14.7, 61.9)	19.9 (9.2, 30.6)
UW-A	14.5 (4.8, 24.3)	39.4 (9.1, 69.7)	---[a]	20.2 (14.5, 25.9)	19.4 (9.6, 29.3)	6.5 (7.6, 12.2)
HW-IA	14.0 (12.6, 15.5)	14.3 (12.3, 16.4)	12.1 (10.2, 14.0)	18.2 (16.9, 19.4)	21.5 (19.3, 23.7)	15.2 (12.4, 17.0)
HW-MA	14.9 (12.9, 16.9)	10.1 (7.8, 12.4)	6.2 (4.4, 7.9)	19.7 (17.9, 21.6)	16.8 (14.3, 19.4)	11.4 (9.3, 13.4)
HW-A	**15.8 (14.0, 17.5)**	**12.0 (9.4, 14.6)**	**7.1 (4.7, 9.4)**	**18.4 (16.8, 20.0)**	**15.6 (13.1, 18.0)**	**9.3 (6.9, 11.6)**
OW-IA	15.2 (13.7, 16.8)	15.2 (13.1, 17.2)	14.0 (11.9, 16.1)	22.5 (20.3, 24.7)	21.0 (18.8, 23.3)	17.6 (15.6, 19.7)
OW-MA	13.9 (12.0, 15.8)	12.2 (10.1, 14.2)	11.1 (8.3, 13.9)	22.0 (19.0, 24.9)	21.2 (18.1, 24.2)	15.6 (12.3, 19.0)
OW-A	16.2 (14.1, 18.2)	11.7 (9.5, 14.0)	9.0 (6.6, 11.4)	21.4 (18.3, 24.6)	17.3 (14.1, 20.6)	8.7 (5.8, 11.5)
OB-IA	15.9 (13.8, 18.0)	17.0 (14.8, 19.3)	15.2 (12.3, 18.2)	26.4 (23.6, 29.2)	27.3 (24.4, 30.2)	21.2 (18.2, 24.1)
OB-MA	18.8 (14.7, 22.8)	16.2 (11.5, 20.9)	10.9 (5.1, 16.6)	25.8 (21.6, 30.0)	24.2 (20.0, 28.4)	13.7 (8.8, 18.6)
OB-A	16.4 (13.0, 19.8)	14.3 (9.6, 18.9)	2.9 (7.5, 5.0)	28.6 (23.6, 33.6)	25.2 (19.5, 31.0)	18.2 (10.9, 25.6)

[a] Empty cells denote unweighted N did not meet minimum required by Statistics Canada for data release.

Table 3. Adjusted Odds of adverse health-related quality of life outcomes among Canadian adults and older adults, by sex and age – Canadian Community Health Survey Cycle 3.1 (2005).

	Males			Females		
Outcome	**18-44 OR (95% CI)**	**45-64 OR (95% CI)**	**≥ 65 OR (95% CI)**	**18-44 OR (95% CI)**	**45-64 OR (95% CI)**	**≥ 65 OR (95% CI)**
Fair/Poor Self-Reported Health						
by BMI (a)						
Underweight	2.09 (1.18, 3.68)	1.89 (0.84, 4.21)	2.34 (1.31, 4.19)	1.83 (1.27, 2.63)	1.77 (1.00, 3.14)	2.27 (1.67, 3.08)
Healthy Weight	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	1.15 (0.94, 1.40)	1.11 (0.92, 1.34)	0.94 (0.80, 1.79)	1.32 (1.08, 1.61)	1.16 (0.98, 1.39)	1.07 (0.93, 1.23)
Obese	2.44 (1.97, 3.01)	1.89 (1.54, 2.29)	1.48 (1.22, 1.79)	2.03 (1.64, 2.50)	1.80 (1.51, 2.16)	1.67 (1.41, 1.98)
by PA (a)						
Inactive	2.15 (1.70, 2.72)	2.11 (1.72, 2.59)	2.76 (2.23, 3.41)	2.84 (2.28, 3.53)	2.65 (2.14, 3.27)	2.51 (2.04, 3.08)
Mod. Active	1.45 (1.11, 1.89)	1.21 (0.94, 1.56)	1.23 (0.96, 1.60)	1.47 (1.13, 1.90)	1.62 (1.27, 2.05)	1.29 (1.02, 1.64)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI (b)						
Underweight	2.03 (1.16, 3.55)	1.75 (0.77, 3.97)	2.31 (1.31, 4.07)	1.71 (1.20, 2.45)	1.84 (1.03, 3.29)	2.18 (1.59, 2.99)
Healthy Weight	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	1.15 (0.94, 1.40)	1.10 (0.91, 1.31)	0.92 (0.78, 1.08)	1.26 (1.03, 1.53)	1.11 (0.93, 1.33)	1.04 (0.90, 1.19)
Obese	2.33 (1.88, 2.89)	1.78 (1.46, 2.17)	1.32 (1.08, 1.60)	1.82 (1.47, 2.26)	1.62 (1.35, 1.95)	1.52 (1.28, 1.81)
by PA (b)						
Inactive	2.06 (1.63, 2.60)	2.00 (1.63, 2.46)	2.70 (2.18, 3.35)	2.69 (2.15, 3.35)	2.53 (2.03, 3.14)	2.40 (1.95, 2.95)
Mod. Active	1.42 (1.09, 1.85)	1.17 (0.91, 1.51)	1.24 (0.96, 1.60)	1.45 (1.12, 1.88)	1.59 (1.25, 2.03)	1.27 (1.00, 1.61)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI-PA						
UW-IA	4.65 (2.07, 10.42)	3.17 (1.35, 7.47)	10.43 (4.21, 25.81)	5.02 (3.15, 8.02)	4.85 (2.80, 8.40)	4.76 (2.96, 7.67)
UW-MA	3.4 (1.59, 9.77)	4.60 (0.29, 71.9)	2.60 (0.61, 11.07)	1.40 (0.57, 3.41)	3.80 (0.52, 27.75)	3.95 (2.18, 7.17)
UW-A	1.25 (0.24, 6.40)	1.82 (0.13, 26.19)	1.29 (0.27, 6.11)	2.56 (1.10, 5.97)	1.14 (0.45, 2.87)	3.06 (1.20, 7.80)
HW-IA	2.08 (1.48, 2.93)	2.28 (1.59, 3.27)	3.66 (2.58, 5.21)	2.90 (2.14, 3.94)	2.70 (1.97, 3.71)	2.51 (1.85, 3.42)
HW-MA	1.64 (1.11, 2.41)	1.30 (0.87, 1.94)	1.22 (0.79, 1.88)	1.47 (1.02, 2.10)	1.44 (1.00, 2.08)	1.27 (0.89, 1.83)
HW-A	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
OW-IA	2.60 (1.85, 3.67)	2.39 (1.69, 3.38)	2.73 (1.94, 3.85)	3.58 (2.58, 4.97)	2.68 (1.98, 3.61)	2.53 (1.86, 3.44)
OW-MA	1.35 (0.88, 2.07)	1.31 (0.88, 1.95)	1.45 (0.95, 2.20)	2.21 (1.48, 3.31)	2.00 (1.39, 2.88)	1.47 (1.01, 2.15)
OW-A	1.26 (0.80, 1.96)	1.41 (0.94, 2.12)	1.36 (0.89, 2.06)	1.02 (0.64, 1.64)	1.29 (0.79, 2.12)	1.02 (0.66, 1.58)
OB-IA	4.79 (3.36, 5.86)	3.94 (2.75, 5.65)	4.02 (2.80, 5.75)	4.76 (3.38, 6.71)	4.21 (3.05, 5.81)	3.87 (2.82, 5.29)
OB-MA	3.70 (2.33, 5.87)	2.50 (1.53, 4.08)	2.56 (1.59, 4.13)	3.12 (2.08, 4.67)	2.62 (1.74, 3.94)	1.67 (1.07, 2.61)
OB-A	2.56 (1.53, 4.28)	1.70 (1.05, 2.76)	1.44 (0.86, 2.40)	2.45 (1.53, 3.93)	1.53 (0.96, 2.46)	1.78 (0.89, 3.55)

Table 3. (cont'd)

Sometimes/Often Participation and Activity Limitation						
by BMI (a)						
Underweight	1.24 (0.87, 1.78)	1.03 (0.54, 1.96)	1.18 (0.66, 2.13)	1.04 (0.84, 1.27)	1.17 (0.83, 1.66)	1.80 (1.31, 2.48)
Healthy Weight	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	1.02 (0.91, 1.14)	1.12 (0.98, 1.27)	1.12 (0.98, 1.29)	1.16 (1.02, 1.30)	1.16 (1.02, 1.31)	1.06 (0.94, 1.20)
Obese	1.14 (0.99, 1.32)	1.43 (1.22, 1.68)	1.39 (1.14, 1.68)	1.26 (1.10, 1.44)	1.64 (1.42, 1.90)	1.87 (1.60, 2.18)
by PA (a)						
Inactive	1.26 (1.13, 1.42)	1.34 (1.16, 1.54)	1.91 (1.63, 2.23)	1.28 (1.13, 1.44)	1.45 (1.26, 1.67)	2.31 (1.99, 2.68)
Mod. Active	1.16 (1.02, 1.33)	1.12 (0.95, 1.30)	1.29 (1.09, 1.53)	1.07 (0.94, 1.22)	1.15 (0.99, 1.34)	1.26 (1.06, 1.50)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI (b)						
Underweight	1.22 (0.85, 1.74)	1.00 (0.53, 1.90)	1.16 (0.66, 2.05)	1.01 (0.83, 1.25)	1.19 (0.84, 1.68)	1.72 (1.24, 2.39)
Healthy **Weight**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	1.02 (0.92, 1.14)	1.11 (0.98, 1.26)	1.11 (0.96, 1.28)	1.14 (1.01, 1.29)	1.14 (1.00, 1.29)	1.02 (0.91, 1.15)
Obese	1.12 (0.97, 1.30)	1.39 (1.19, 1.63)	1.29 (1.06, 1.57)	1.22 (1.07, 1.40)	1.56 (1.35, 1.80)	1.70 (1.45, 1.99)
by PA (b)						
Inactive	1.25 (1.12, 1.41)	1.30 (1.13, 1.49)	1.87 (1.60, 2.19)	1.26 (1.11, 1.42)	1.37 (1.19, 1.58)	2.21 (1.90, 2.57)
Mod. Active	1.16 (1.02, 1.33)	1.10 (0.94, 1.27)	1.28 (1.60, 2.19)	1.06 (0.93, 1.21)	1.12 (0.95, 1.32)	1.24 (1.04, 1.49)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI-PA						
UW-IA	1.50 (0.89, 2.54)	2.23 (1.01, 4.91)	3.10 (1.40, 6.85)	1.27 (0.94, 1.71)	1.69 (1.11, 2.58)	3.89 (2.46, 6.15)
UW-MA	1.53 (0.71, 3.30)	0.08 (0.01, 0.49)	1.96 (0.50, 7.73)	1.06 (0.69, 1.63)	1.84 (0.65, 5.24)	2.07 (1.14, 3.75)
UW-A	1.14 (0.59, 2.21)	1.18 (0.36, 3.93)	0.41 (0.11, 1.59)	0.77 (0.51, 1.14)	0.96 (0.52, 1.77)	1.23 (0.60, 2.55)
HW-IA	1.22 (1.02, 1.46)	1.46 (1.13, 1.88)	2.00 (1.55, 2.58)	1.15 (0.99, 1.35)	1.55 (1.27, 1.89)	2.10 (1.72, 2.56)
HW-MA	1.18 (0.97, 1.43)	1.11 (0.82, 1.50)	1.26 (0.95, 1.68)	0.95 (0.81, 1.13)	1.07 (0.85, 1.36)	1.21 (0.96, 1.51)
HW-A	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
OW-IA	1.30 (1.09, 1.56)	1.49 (1.16, 1.91)	2.08 (1.66, 2.61)	1.40 (1.15, 1.69)	1.48 (1.21, 1.82)	2.12 (1.73, 2.59)
OW-MA	1.16 (0.93, 1.45)	1.31 (0.99, 1.74)	1.46 (1.13, 1.89)	1.15 (0.92, 1.44)	1.55 (1.24, 1.94)	1.32 (1.03, 1.68)
OW-A	0.99 (0.81, 1.22)	1.22 (0.93, 1.61)	1.19 (0.91, 1.55)	0.94 (0.74, 1.20)	1.26 (0.96, 1.65)	0.98 (0.73, 1.32)
OB-IA	1.40 (1.12, 1.75)	1.86 (1.41, 2.46)	2.37 (1.79, 3.14)	1.39 (1.14, 1.70)	2.26 (1.80, 2.83)	3.96 (3.15, 4.99)
OB-MA	1.25 (0.92, 1.68)	1.71 (1.22, 2.40)	1.89 (1.29, 2.77)	1.38 (1.06, 1.78)	1.67 (1.27, 2.23)	1.58 (1.11, 2.26)
OB-A	1.16 (0.89, 1.50)	1.52 (1.04, 2.23)	1.31 (0.87, 1.97)	1.04 (0.77, 1.41)	1.84 (1.27, 2.65)	1.47 (0.88, 2.47)

Table 3. (cont'd)

≥ 1 Total Disability Days (Physical + Mental)						
by BMI (a)						
Underweight	0.80 (0.47, 1.37)	2.29 (1.09, 4.83)	2.14 (1.14, 4.02)	0.90 (0.74, 1.10)	1.30 (0.81, 2.06)	1.45 (1.02, 2.06)
Healthy Weight	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	1.00 (0.88, 1.12)	1.06 (0.90, 1.24)	1.27 (1.03, 1.56)	1.11 (0.99, 1.25)	0.96 (0.83, 1.10)	1.14 (0.96, 1.35)
Obese	0.96 (0.82, 1.12)	1.04 (0.84, 1.28)	1.13 (0.86, 1.47)	1.16 (1.01, 1.33)	1.00 (0.85, 1.18)	1.16 (0.96, 1.42)
by PA (a)						
Inactive	0.88 (0.78, 0.99)	1.17 (0.98, 1.41)	1.72 (1.33, 2.21)	1.01 (0.90, 1.14)	1.23 (1.04, 1.46)	1.71 (1.37, 2.15)
Mod. Active	0.92 (0.80, 1.05)	0.94 (0.76, 1.16)	1.13 (0.83, 1.53)	1.06 (0.94, 1.21)	1.11 (0.91, 1.36)	1.33 (1.03, 1.72)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI (b)						
Underweight	0.81 (0.48, 1.38)	2.26 (1.07, 4.76)	2.04 (1.08, 3.84)	0.90 (0.74, 1.10)	1.31 (0.82, 2.09)	1.41 (0.99, 2.00)
Healthy Weight	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Overweight	0.99 (0.88, 1.12)	1.05 (0.89, 1.24)	1.26 (1.02, 1.55)	1.11 (0.99, 1.25)	0.94 (0.82, 1.09)	1.12 (0.94, 1.33)
Obese	0.97 (0.83, 1.13)	1.02 (0.83, 1.26)	1.05 (0.80, 1.37)	1.16 (1.01, 1.33)	0.97 (0.82, 1.15)	1.10 (0.90, 1.34)
by PA (b)						
Inactive	0.88 (0.78, 0.99)	1.17 (0.97, 1.40)	1.72 (1.33, 2.21)	1.00 (0.89, 1.12)	1.24 (1.05, 1.48)	1.69 (1.35, 2.12)
Mod. Active	0.92 (0.80, 1.05)	0.93 (0.75, 1.16)	1.13 (0.83, 1.53)	1.06 (0.93, 1.20)	1.11 (0.92, 1.36)	1.32 (1.03, 1.71)
Active	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
by BMI-PA						
UW-IA	0.99 (0.47, 2.10)	2.17 (0.96, 4.91)	3.98 (1.75, 9.01)	0.86 (0.65, 1.14)	1.23 (0.69, 2.21)	2.17 (1.29, 3.62)
UW-MA	0.17 (0.05, 0.58)	1.89 (0.13, 27.83)	2.31 (0.32, 16.69)	1.06 (0.72, 1.57)	2.84 (0.88, 9.21)	2.45 (1.22, 4.92)
UW-A	0.76 (0.36, 1.61)	3.93 (0.94, 16.45)	0.34 (0.08, 1.55)	0.95 (0.62, 1.46)	1.08 (0.57, 2.05)	0.73 (0.24, 2.23)
HW-IA	0.86 (0.71, 1.03)	1.12 (0.83, 1.51)	1.66 (1.13, 2.45)	1.01 (0.87, 1.18)	1.35 (1.06, 1.73)	1.60 (1.16, 2.21)
HW-MA	0.94 (0.77, 1.14)	0.76 (0.96, 4.91)	0.85 (0.54, 1.33)	1.08 (0.91, 1.28)	1.07 (0.81, 1.44)	1.19 (0.83, 1.70)
HW-A	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
OW-IA	0.89 (0.74, 1.08)	1.18 (0.89, 1.55)	1.85 (1.23, 2.77)	1.17 (0.98, 1.39)	1.13 (0.89, 1.44)	1.76 (1.27, 2.44)
OW-MA	0.86 (0.68, 1.07)	0.92 (0.67. 1.26)	1.40 (0.86, 2.26)	1.15 (0.93, 1.43)	1.22 (0.93, 1.61)	1.58 (1.07, 2.34)
OW-A	1.00 (0.82, 1.22)	0.93 (0.66, 1.31)	1.30 (0.82, 2.04)	1.08 (0.87, 1.35)	1.00 (0.69, 2.21)	0.83 (0.50, 1.37)
OB-IA	0.81 (0.66, 1.00)	1.04 (0.77, 1.42)	1.76 (1.15, 2.70)	1.13 (0.93, 1.38)	1.27 (0.99, 1.64)	1.78 (1.24, 2.54)
OB-MA	1.01 (0.73, 1.38)	1.05 (0.77, 1.42)	1.34 (0.67, 2.70)	1.21 (0.93, 1.57)	0.98 (0.70, 1.35)	1.04 (0.62, 1.73)
OB-A	0.92 (0.68, 1.24)	0.94 (0.57, 1.54)	0.31 (0.12, 0.81)	1.36 (1.02, 1.81)	1.14 (0.78, 1.64)	1.73 (0.99, 3.04)

Healthy Weight and Active are referent groups. All models adjusted for race/ethnicity, education, household income, smoking, marital status, residence, comorbidities. (a) BMI or PA each in model without the other; (b) BMI and PA in model together

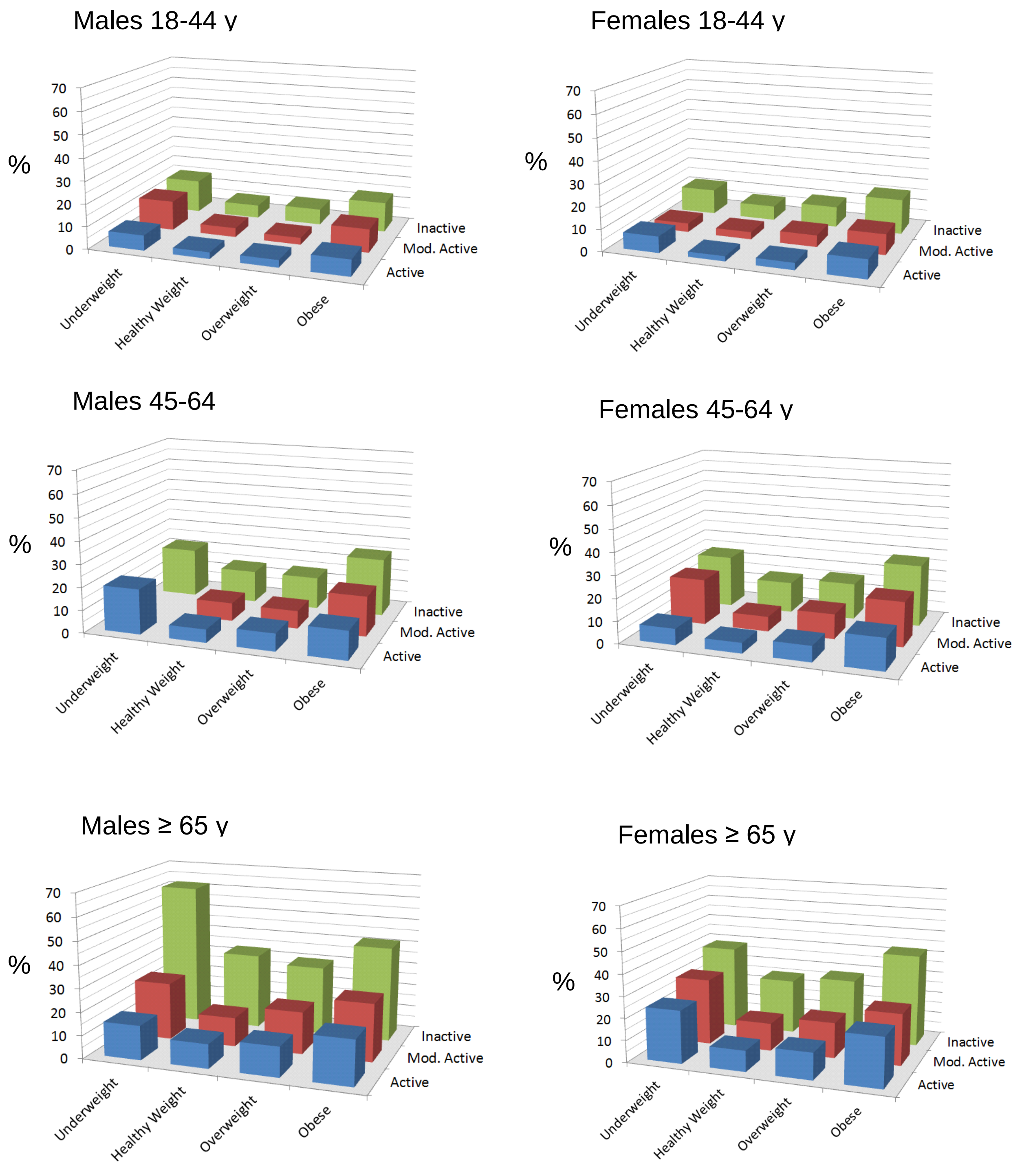

Figure 1 (a). Prevalence (%) of Fair or Poor Self-Rated Health (FP-SRH) in Canadian adults and older adults, by age and sex – Canadian Community Health Survey Cycle 3.1 (2005).

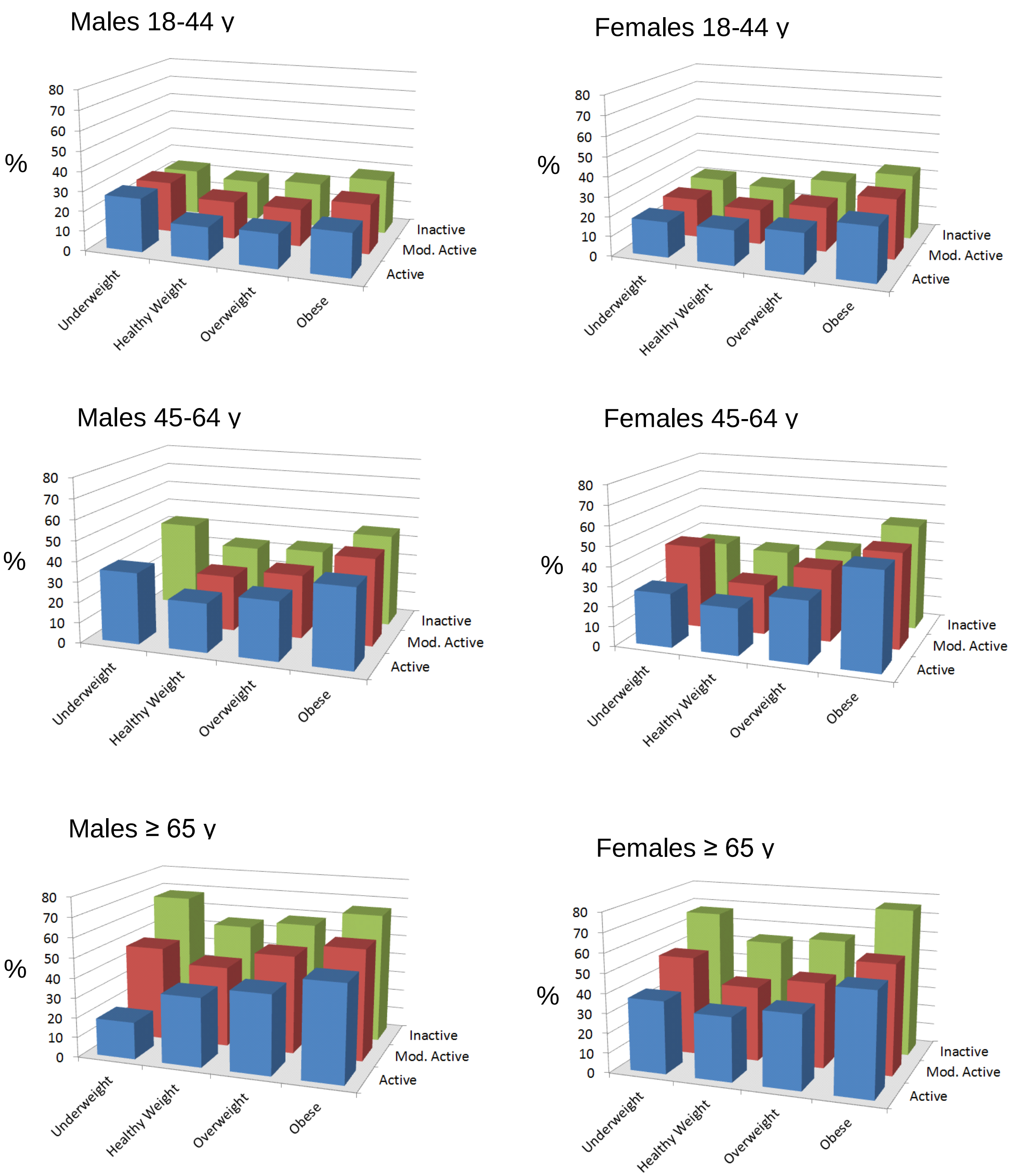

Figure 1 (b). Prevalence (%) of Sometimes or Often Participation & Activity Limitation (SO-PAL) in Canadian adults and older adults, by age and sex – Canadian Community Health Survey Cycle 3.1 (2005).

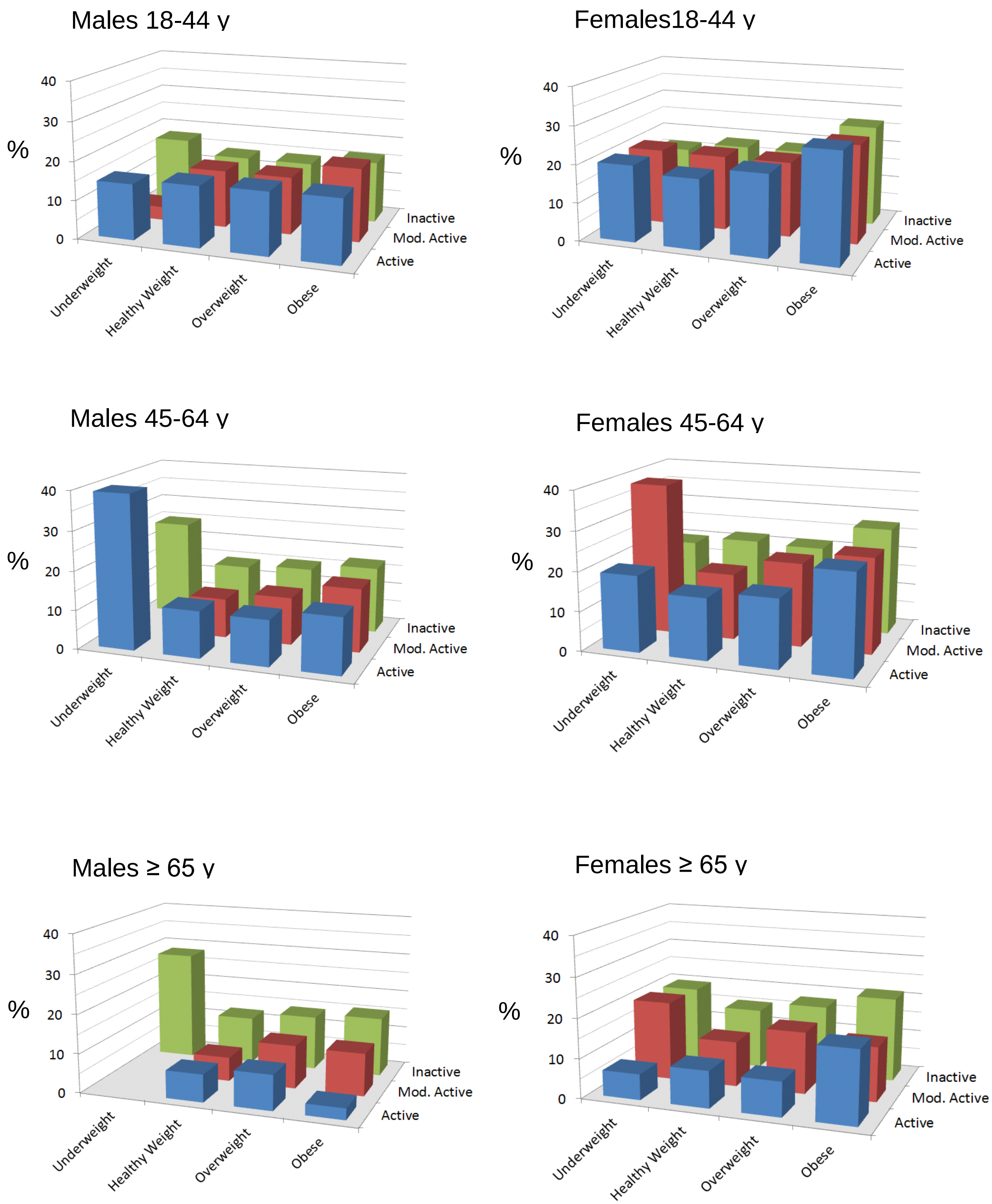

Figure 1 (c). Prevalence (%) of ≥ 1 Total (physical + mental) Disability Days (≥ 1 TDD) in the past 14 days in Canadian adults and older adults, by age and sex – Canadian Community Health Survey Cycle 3.1 (2005).

CHAPTER 8

GENERAL DISCUSSION

8.1 Preamble

An attractive generalization in the public health literature is that *"A lifestyle of regular physical activity during childhood and adolescence which continues into and throughout adulthood will have a beneficial effect on the health and well-being of the individual and the population."* [Robert M. Malina, University of Texas at Austin and Tarleton State University, Personal Communication, Feb 2007] Although the hypothesis that childhood physical activity has long-term beneficial effects on health outcomes is an attractive one, strong evidence to support this theory is lacking. Higher levels of physical activity during childhood and adolescence are positively linked to immediate health outcomes.[1] Data also exist on the tracking of chronic disease risk factors from childhood and adolescence into adulthood,[2, 3] including the tracking of physical activity [4, 5] and obesity.[6, 7] However, there is a lack of research to date investigating the longitudinal relationship of childhood and adolescent physical activity to adult health outcomes, especially spanning the entire time frame from early childhood into later adulthood. On the other hand, relationships between physical activity and health outcomes in adulthood are well-documented and indisputable.[8, 9]

Physical activity, obesity, and health outcomes evidently form a dynamic inter-related web affecting health outcomes across the lifespan, as hypothetically depicted in **Figure 1**. First, physical activity early in life may affect other risk factors early in life, including obesity, essentially working to "derail" the tracking of adverse risk profiles. Second, physical activity may have an independent effect on adulthood risk factor levels, irrespective of current adulthood physical activity levels. Third, if physical activity patterns can track from childhood into adulthood, the implications are clear: the benefits of adulthood physical activity and the consequences of inactivity, as related to various chronic diseases and conditions both directly and indirectly through other risk factors, are well established [8]. Finally, childhood and/or adolescent physical activity may have an effect on retarding the general pathological processes (e.g. atherosclerosis) leading to adult disease.

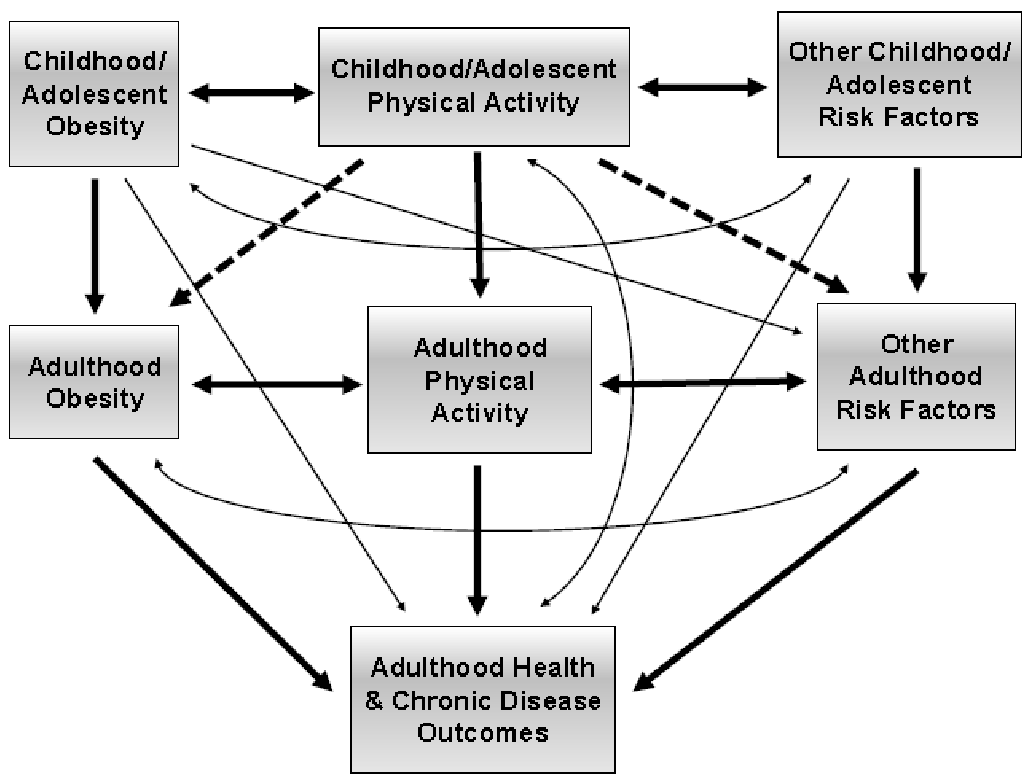

Figure 1. Hypothetical model of relationships and pathways between childhood and adolescent physical activity and obesity, and adulthood health outcomes.

The mechanisms suggested by this model all support increased attention to the promotion of physical activity in childhood and adolescence. However, studies have generally shown only low tracking of physical activity over time spans longer than five years.[4, 5] While methodological issues may mask true tracking strength to some degree, it is clear that merely targeting physical activity in childhood and adolescence will not entirely combat the high prevalence of physical inactivity and obesity currently seen in the adult population. On the other hand, physically active children and adolescents may at least stand a fighting chance of developing into active adults. Hence, while promoting physical activity in childhood and adolescence may not guarantee the acquisition of a lifetime physical activity habit, allowing children to be inactive may well guarantee the formation of a lifetime sedentary habit. Clearly, physical activity promotion should take a life-span approach, targeting all ages to ensure successful public health efforts.

Similar to physical activity, the health risks associated with childhood and adolescent obesity are both immediate [10, 11] and based on the extent to which this trait is carried into adulthood.[10-12] Youth overweight and obesity track strongly into adulthood,[6, 7] at which time the treatment of established obesity has proven largely ineffective: in adulthood substantial weight-loss is difficult to achieve and maintain.[13, 14] Hence, it is crucial that more attention be paid to childhood and adolescent obesity, with prevention of adulthood obesity as the preferred public health goal. A prevention strategy may elicit better response in children, and risk factors identified early in life may be more amenable to change. Physical activity, both throughout childhood and adolescence and carried on through adulthood, is one aspect of this strategy.

However, while overweight and obese youth have a very high probability of becoming overweight or obese adults, only a small proportion of overweight and obese adults were in fact overweight or obese in their youth;[6, 7] as the adult population prevalence of overweight and obesity is twice that in youth,[15, 16] much of the population is gaining weight following a normal-weight youth. Targeting childhood and adolescent obesity in isolation will therefore not solve the current problem. Rather, for the greatest population benefit, as with physical activity, a multi-factorial approach is needed to target obesity throughout the lifespan. Targeting only high risk individuals (inactive/obese children) may have the greatest benefit for those individuals, but lead to unsatisfactory results at the population level.

8.2 Summary of Key Findings

This thesis sought to explore various facets of the burden of obesity and physical inactivity in Canadians, focusing especially on health-related quality of life. Through a series of five manuscripts, both the long-term impacts of youth overweight and physical inactivity on adult outcomes, and the immediate impacts of weight status and physical activity within adulthood and older adulthood, were evaluated.

The **first study** (Chapter 3) set the stage by assessing the current "state of the nation" in terms of physical activity research in Canada, including an illustration of trends over time, and identification of greater- and lesser-represented research areas. Based on over 5000 Canadian physical activity articles identified for 1990-2005, as hypothesized, it was found that Canadian physical activity research underwent a fairly steady increase in volume during the 15 year period, mirroring global trends, but still comprised a small proportion of global physical activity research, holding steady over that time-frame at approximately 5% (similar to or greater than Canada's research contribution on other key cardiovascular risk factors). The most productive province was Ontario, producing almost 50% of this research. Over 90% of Canadian physical activity research involves human subjects, and over 90% of those studies involve adults. Also confirming an initial hypothesis, most recently (2001-2005) the majority of Canadian physical activity research was determined to be biomedical and clinical in nature at almost 40% each, representing a gradual shift over time since 1990-1995 when the research was 62% biomedical and 20% clinical. By contrast, a relative lack of physical activity research exists in the population health realm (14%), and there is a dearth of research involving health services (2%).

The **second study** (Chapter 4) investigated the longitudinal tracking of obesity and physical activity over 22 years from youth (ages 7-18) to adulthood (ages 29-40). Using the follow-up data (PALS) from the 1981 Canada Fitness Survey, results showed moderate to strong tracking of BMI in females, and moderate tracking in males. Approximately 40% of participants in the highest and lowest BMI quintiles in their youth remained in those extreme quintiles as adults, and the odds of becoming an overweight adult were over six-fold greater for overweight compared to healthy weight youth. Notably, while over 80% of overweight youth remained overweight as adults, over 80% of overweight adults (including 70% of obese adults) had not been overweight in their youth – only 50% of healthy weight youth remained healthy weight as adults. However, almost all healthy weight adults had been healthy weight youth. In contrast to this strong evidence found for BMI tracking, physical activity tracking over the same time frame was non-apparent, although appearing at moderate levels when looking at a time span from later adolescence/early-adulthood onward (20-25 to 35-41).

The **third study** (Chapter 5) investigated the long term impact of youth overweight and physical activity on adult physical and mental health-related quality of life, also using the 22-year follow-up data from the 1981 Canada Fitness Survey. Contrary to the initial hypothesis, results showed *positive* associations between youth overweight and mental aspects of adult HRQL, both in terms of percentage of overweight versus healthy weight youth scoring at or above Canadian age- and sex-standardized norms in adulthood, and likelihood of scoring at or above the norm based on youth weight status. This long term impact was deemed likely to be both direct, and indirect through BMI change (magnitude of relative weight gain between youth and adulthood) and the effect of youth BMI on adult BMI. Little association was found between youth BMI and physical aspects of adult HRQL. As well, no long-term associations were found between youth physical activity and adult HRQL.

Building on results from the third study, again using the same data, the **fourth study** (Chapter 6) further explored the relationship of youth overweight to adult physical and mental health-related quality of life, including the investigation of sex differences. Results confirmed those of the third study, again showing a positive association between youth overweight and mental aspects of adult HRQL (overweight youth scoring higher than healthy weight youth, and higher youth BMI predicting higher adult HRQL scores), and no negative impacts; however, this association appeared to be present only in females, while no associations (in either direction) were apparent in males.

Finally, the **fifth study** (Chapter 7) investigated the combined association of physical activity and weight status on indicators of health-related quality of life in adults and older adults, including analysis by sex and age. Using data from the 2005 CCHS (Cycle 3.1), the results showed that weight status and physical activity are both strong independent predictors of HRQL; however, when taken in combination, physical activity emerges as the key determinant. Confirming the initial hypothesis, physical activity was found to be beneficial regardless of weight status, to the extent that active-obese individuals showed similar or better HRQL than inactive-healthy weight individuals. Inactive individuals had a greater likelihood of Fair/Poor Self Rated Health or Sometimes/Often Participation and Activity Limitation, regardless of their weight status; conversely, being underweight, overweight or even obese was of little consequence to these indicators as long as individuals were active. For Total Disability Days, the strongest association was for inactivity in older age, especially for underweight individuals. In general, overweight presented less of a risk for males and for older adults, while underweight presented more of a risk in these individuals, thus the second hypothesis was also confirmed.

8.3 Public Health Implications

Taken together, the research results presented in this thesis help in our understanding of how obesity and physical inactivity impact the lives of Canadians. Given the alarming prevalence of overweight/obesity and physical inactivity across both youth and adult segments of the Canadian population [15-18] and the association with health outcomes, chronic disease and conditions, and premature mortality,[8, 12] the results have wide ranging public health implications.

Initially, results of the **first study** assessing the current state of physical activity research in Canada can be used by researchers to better target their research programs to areas of need, allowing researchers, governments and funding agencies to better align themselves on priorities and future opportunities. Currently less physical activity research is being conducted in population health and health services than in the biomedical and clinical areas; however, these areas play a crucial role in the development and evaluation of public health policy and programs targeted at reducing the burden of physical inactivity and obesity in Canada and globally.

As well, currently Canada's contribution (5%) to global physical activity research is similar to its contribution to global research involving smoking, obesity, hypertension, cholesterol and diabetes (3-5% Canadian contribution).

Among these major chronic disease risk factors, physical inactivity has 1.5 times the population prevalence of high cholesterol, more than double the prevalence of smoking and obesity, more than triple the prevalence of hypertension, and 10 times the prevalence of diabetes,[18, 19] and is thus arguably the greatest target for modification. Further, physical inactivity, smoking, hypertension and high cholesterol carry similar relative risks for all-cause mortality,[20] suggesting that, at least for some diseases, the population attributable risk for physical inactivity is higher. Thus, a strong rationale exists for greater investment in physical activity research in Canada.

Finally, results show that currently the large majority of Canadian physical activity research is based on adults, pointing to a need for more research based on children and adolescents, given the current high levels of inactivity, overweight/obesity, and the known and yet-unknown immediate and long term health impacts for this segment of the population.

Prior to the **second study**, there had been a dearth of long term tracking studies examining weight status and physical activity, with follow-up from childhood and adolescence all the way into adulthood. Given the alarming prevalence of childhood obesity and physical inactivity in Canada, tracking of these risk factors from youth into adulthood would create a poor outlook for the future health of the population. While the current study sample contained relatively few overweight or obese participants at baseline (representative in proportion to the Canadian population in 1981), youth overweight or obesity presented a virtual guarantee of adulthood overweight or obesity, especially for males. However, being of healthy weight in childhood offered no guarantee of future healthy weight status; rather, the large majority of overweight or obese adults have gained the excess weight as adults. Whereas almost all healthy weight adults were healthy weight as youth, only about 50% of healthy weight youth maintained their healthy weight in adulthood – females appear more likely to maintain a healthy weight into adulthood, while males seem more likely to gain and become overweight or obese adults. This evidence for significant long-term stability of overweight and obesity, coupled with the knowledge that greater than one in four Canadian children are currently overweight or obese,[15] forecasts serious consequences for the obesity epidemic. Given the health risks associated with adulthood obesity, and the increasing prevalence of youth obesity in Canada, the notion that 80% or more of these overweight children will develop into overweight or obese adults presents a serious public health concern.

In the case of physical activity, while no tracking from youth to adulthood was found, the direction of this "instability" is important to consider: active youth might not remain active – but inactive youth might also not remain inactive. Physical activity levels may be highly variable in both directions across the lifespan, and indeed data exist to support this.[21] Hence, low tracking of physical activity can be taken to indicate that intervention opportunities exist if behaviours are not firmly entrenched; however, at the other end of the spectrum, programs must also ensure that those who are active remain active.

Finally, while the youth included in this research were representative of the Canadian population at baseline, as adults a greater proportion were active above 1.5 kcal/kg/day compared to the current adult general population,[18] and prevalence of youth overweight/obesity was lower in 1981 than presently (10%

vs. 26%).[15] This secular trend of increasing overweight/obesity among youth, in addition to likely under-reporting of BMI/weight-gain in adults, may mean the results of this research underestimate the current reality: if over 80% of currently overweight or obese youth are destined to become overweight or obese adults, the health status of the adult population (and ensuing burden on the health care system) several decades from now appears grim. As the treatment of established obesity is difficult, public health strategies should focus on prevention goals, with more attention paid to youth obesity, physical activity comprising one aspect of these strategies. However, while youth overweight/obesity persists into adulthood, the current prevalence of adult overweight/obesity is twice that of youth: much of the population is becoming overweight even following a healthy-weight youth. The best prevention strategies will therefore be multi-factorial and population-based, targeting obesity and physical inactivity throughout the lifespan, rather than focusing solely on overweight and inactive youth, in order to combat the overall health risks.

The **third and fourth studies** within this thesis represent the first known studies to date to explore the potential long-term effects of youth obesity and physical activity on health-related quality of life in adulthood. While exercising caution in drawing definitive conclusions from these results due to study limitations, it does appear that neither youth inactivity nor overweight (at moderate levels) will lead to negative consequences in terms of poorer HRQL in adulthood if prevention, control, and treatment efforts are successful. This notion conflicts with current paediatric beliefs that youth overweight can affect future HRQL,[22] implying that physicians should maintain a focus on present and future biomedical outcomes when counselling and treating moderately overweight children and adolescents.

There is no doubt that youth overweight has known immediate health consequences,[10, 11] and tracks strongly into adulthood,[6, 7] where it is associated with substantially increased risk of a host of other biomedical conditions;[12] hence, the issue must certainly remain at the forefront of public health priorities and strategies. The implication here may indeed simply be that of "one less thing to worry about", while staying attuned to the possibility that greater and more negative HRQL consequences might yet result from the higher degrees of youth obesity present in today's population, both immediately in youth and carrying forward to affect HRQL in adulthood.

The results of these studies indicate that, while youth obesity has immediate health consequences and youth physical activity immediate health benefits, current adult weight status and physical activity levels may be more important to adult HRQL than past youth weight status and physical activity. Indeed, studies on adults have generally shown that higher physical activity levels are positively associated with both physical and mental HRQL,[23] while obesity is associated with impairments in HRQL,[24] with a notable public health impact in terms of adult productivity.[25, 26] On the other hand, even adult studies have occasionally found positive associations of obesity with mental HRQL, the authors in one case similarly concluding that "reducing obesity in the population was unlikely to have any direct effect on mental health or emotional well-being".[27] Likewise, reducing the prevalence of overweight in the youth population may not have any direct effect on future adult HRQL.

The **fifth study** within this thesis was completed in order to extend to the Canadian population recently published US research examining the combined effects of physical activity and weight status on indicators of HRQL, with additional novel contributions including analysis by sex and age, and inclusion of older adults and the underweight group. Similar to previous research examining cardiovascular and mortality outcomes,[28, 29] results of this study confirm that physical activity is also a key determinant of HRQL in adults and older adults, regardless of weight status. This reinforces the importance of physical activity to health outcomes over and above the biomedical benefits related to weight loss or maintenance. From a clinical perspective, the implications are for continued encouragement of adoption and maintenance of active lifestyles: a) for prevention and treatment of obesity-related outcomes, independent of weight loss; and b) for overall health benefits regardless of patient weight status and/or related concerns (i.e. in fact, equally towards patients in all BMI groups).

Similarly, public health programs and services should more clearly disseminate the message that inactivity can lead to similar adverse health consequences, including both biomedical and quality of life outcomes, regardless of weight status (i.e. “leanness” alone is not a ticket to good health) – and conversely, that those with weight concerns can greatly (and in some cases, perhaps completely) offset their health risks by becoming and/or remaining active, even should weight loss not occur. At both the individual and population levels, an emphasis on increased physical activity should supersede the promotion of achieving or maintaining a healthy body weight (and in fact, be independent from it), the latter which, based on increases in obesity prevalence over the past three decades,[16, 30] has apparently thus far not succeeded.

Results of this study also confirmed those of previous research [31, 32] in that a single “ideal body weight category” may not apply to all ages, to both sexes, or to all health outcomes. In terms of HRQL, overweight (as defined by BMI standards) seems to have little negative effect in males or in older adults, while underweight has greater negative impact in males, and especially in older males. Further, underweight combined with inactivity is an important concern in older age, especially where disability days are concerned. These differences illustrate the need to more specifically target health promotion programs and services to specific population groups, rather than disseminating knowledge and information as a “one size fits all” message, which may be confusing or even misleading.

In summary, the research presented in this thesis has the potential to have far-reaching public health implications in the face of today’s youth and adult epidemics of overweight/obesity and physical inactivity.

8.4 Strengths & Limitations

The research contained within this thesis has several strengths, as well as some important limitations. Overall, the findings are based on representative samples of the Canadian population. The longitudinal nature of the PALS data, the large sample size of the CCHS data, the use of sex-based analysis, the exploration of a wide array of HRQL indicators, and the overall “lifespan approach" taken, all constitute strengths of the research. Limitations include the cross-sectional nature of the CCHS data, the small sample size of the PALS data, and the use of self-reported physical activity and weight status. As the research is based on purely Canadian data, from largely Caucasian populations, caution should be exercised in generalizing to other countries, cultures and races/ethnicities.

Specific limitations of the **first study** included the fact that Medline was the only database searched, and although this represents the most important database cataloguing physical activity research, inevitably some relevant published academic research would have been missed, in particular studies of sociological and behavioural aspects of physical activity. As well, Canadian population health research conducted by the Federal Government, Provincial/Territorial Health Ministries, and national research agencies is often published as reports, rather than in peer-reviewed journals; however, across several thousand papers, the difference created by this unpublished research is arguably small. The use of an online database also limited the ability to document research trends from earlier decades as the database evolved, due to journals not yet indexed, and abstracts missing identifying information. The categorization of physical activity research into predefined CIHR "pillars" was limiting by nature due to frequent overlap among areas, which was dealt with by forcing each abstract into the "best fit" category. However, much of the physical activity research retrieved and discussed in the study might actually be more appropriately funded by other more relevant agencies.

The main strength of the **second, third and fourth studies**, all conducted using the same PALS dataset representing the follow-up from the 1981 Canada Fitness Survey, was the 22-year length of follow-up from childhood into adulthood in a representative Canadian population sample. As well, measured BMI data were available at baseline, and the data span a time-frame in the midst of the obesity epidemic, while several previous longitudinal studies commenced prior to it. Both the **second and third studies** used the SF-36 instrument, one of the most widely used and accepted measures of functional health and well-being in healthy or sick persons aged 14 years and up, for the purpose of documenting and comparing disease burden and treatment benefits. As well, **the second study** used previously estimated Canadian population norms to enhance the meaning and interpretation of absolute scores by comparing with typical values.

Limitations of these studies included small overall sample size suffering from fairly high attrition, as is common in longitudinal studies spanning several decades, as well as low absolute numbers of overweight children within the sample, the use of self-reported BMI and physical activity data, and the inherent limitations of using BMI as a measure of weight status.

The youth included in the PALS dataset used for these studies were representative of the overall 1981 cohort and therefore the Canadian population at baseline; however, youth overweight/obesity prevalence was lower in 1981 than in the present-day Canadian population (10% vs. 26%).[15] This secular trend of increasing overweight and obesity among youth, in addition to the likely under-reporting of BMI/weight-gain in adults, may lead to underestimation of tracking in terms of the current reality. As well, the low absolute number of overweight/obese youth (only 1 obese child) in the sample may have hindered the examination of relationships; in fact, results are based on a primarily healthy weight sample, such that caution should be used when extrapolating findings to overweight/obese groups due to the small sample sizes of these groups. The greater prevalence and degree of obesity present in today's youth population may yet lead to long-term negative impacts on HRQL.

Self-reported BMI (as in the PALS follow-up) tends to be underestimated in both men and women, although the degree and patterns of variability in under-reporting differ between the sexes, with increasing age and BMI, and between studies, and individual variability in reporting exists as well.[33, 34] Inherent difficulties also exist in validly and accurately measuring physical activity behaviour via self-report, especially in children, although the validity is considered somewhat better in those ≥ 10 years, as were the PALS participants.[35] However, adult physical activity assessment methods may be inappropriate for describing more sporadic and spontaneous childhood physical activity,[36] which may be more influenced by physiologic, environmental, and psychological and sociodemographic factors [37] and vary by gender, maturational status, and socioeconomic status, as well as daily, seasonal, and "life transition" variations.[36, 38]

BMI as a measure of overweight is inherently limited in its lack of information regarding body composition, and lack of sensitivity to youth maturational age; however, it remains the most widely investigated and easily used indicator of weight-related health risk on a population level. As well, the effect of biological age and maturation were diminished by using the IOTF cut-offs for youth BMI categorization, age-adjusting the youth BMI variable to examine correlations with adult outcomes, adjusting for age in regressions, and using sex-stratified analyses.

The **fifth study**, using data from the CCHS Cycle 3.1, was the first to use nationally representative data from the Canadian population to examine the relationship of BMI and physical activity to HRQL, adding to recently published US-based literature. The large sample size allowed analysis by age and sex, and inclusion of the underweight group which had previously been seldom studied. The opportunity to perform a basic analysis on a sub-sample of participants with measured BMI data, showing similar results, validated results obtained with self-reported BMI from the main CCHS sample.

Limitations included the cross-sectional nature of the data, precluding the inference of causal relationships, and permitting the possibility of reverse causation (e.g. between physical activity and HRQL). Temporal sequence amongst a variety of variables cannot be established: while healthier individuals may be more likely to be active, factors leading to poor general health, unhealthy days, or activity limitations may also preclude physical activity participation. Likewise, while obesity may lead to impaired HRQL, other factors leading to weight gain may also contribute to impaired HRQL. Underweight may also be the result of underlying illness, the latter leading to impaired HRQL while also inhibiting physical activity participation.

This study also relied on self-reported BMI and physical activity, potentially leading to underestimation of BMI and overestimation of physical activity. If obese individuals were misclassified as merely overweight, the obese category thus comprising a falsely elevated proportion of extremely obese individuals, the negative impacts of overweight and obesity may be overestimated.[39] And again, BMI as a measure of weight status does not necessarily reflect body composition in terms of fat versus fat-free mass, or fat distribution, an issue perhaps particularly important for younger males with a BMI in the overweight range. Respondents may also misreport physical activity levels to reflect the socially desirable nature of participation,[40] leading to overestimation of physical activity prevalence.

8.5 Future Directions

It is anticipated that the research contained within this thesis will set the stage for future research, both building on the current findings as well as exploring new questions which have now been generated.

The greater tracking of BMI with an increasing baseline level of BMI [7] suggests that a cohort assembled today, given the current prevalence of youth overweight/obesity in Canada,[15] might exhibit even stronger BMI tracking if followed for several decades. More longitudinal studies spanning childhood to adulthood are needed, including larger sample sizes and ideally followed for longer time-spans. These cohorts should include larger absolute numbers of overweight and obese youth, reflecting both the greater prevalence and degrees of youth overweight/obesity in the current day population, in order to continue to assess the evolving long term impacts on mental and physical health. Future research should also ideally include objective measures of weight status and physical activity and/or fitness levels. Indeed, recently-published results from the U.S. National Longitudinal Study of Adolescent Health, involving over 8500 participants with measured height and weight followed for 12 years from adolescence (1996; 13% obesity prevalence) into adulthood, showed that 90% of obese adolescents (≥ 95th percentile) remained obese in adulthood; however, there was also a dramatic increase in obesity prevalence into adulthood, doubling from adolescence to early 20s, and doubling again from early 20s to late 20s/early 30s.[41] It will be important to continue to follow this larger and more modern cohort, and to also investigate more moderate levels of overweight.

Additional questions when assessing the impacts of youth overweight/obesity and physical inactivity involve the role of weight status changes over time, possible mechanisms for long term impacts on health, disease and quality of life, the identification of possible critical age ranges in childhood and adolescence setting the stage for these long term health impacts, and further exploration of sex differences relative to the tracking and long term health consequences in adulthood. For studies of adults and older adults, assessments of body composition are warranted in order to tease out the effects of lean body mass versus adiposity, particularly when exploring health outcomes in individuals categorized in the overweight range.

Longitudinal studies exploring the combined impact of weight status and physical activity on quality of life, functional ability and activity limitations throughout adulthood and older adulthood are also necessary. These would include investigations of end-of-life HRQL based on weight status and physical activity, in terms of health outcomes in the final years prior to death in the elderly. Retrospective mortality studies would also offer quality information to this end, using longitudinal data retrospectively to examine indicators of HRQL at various intervals prior to death, testing the hypothesis that healthy body weight and physical activity add “life to years” even in the absence of adding “years to life”.[42]

Finally, as the populations studied in the current research were primarily Caucasian, it would be of interest to explore potential racial, ethnic and cultural differences in terms of weight status and physical inactivity, their potential to track from youth to adulthood, and their impact on HRQL throughout the lifespan. Past research has established the presence of racial/ethnic differences in the prevalence of obesity in both Canadian youth [43] and adults,[44] and differences in HRQL are also known to exist among racial/ethnic groups.[45]

In summary, out of both the results and limitations of the research comprising this thesis arise opportunities for continued future research, including numerous new potential research questions and directions.

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CHAPTER 9

SUMMARY & CONCLUSIONS

9.1 Summary

The overall objective of this thesis was to explore the impact of obesity and physical inactivity in Canadians across the lifespan, using both longitudinal and cross-sectional data, with a particular focus on health-related quality of life outcomes. The questions asked are important in the development of public health policy, and in the identification of appropriate targets for public health programs concerned with the lifelong health of the population.

The results demonstrate that while Canadian increases in physical activity research productivity have kept up with global trends, this research remains largely clinical and biomedical in nature, with more research needed in population health and health services. While overweight and obese youth present with a virtual guarantee of carrying this trait into adulthood, a majority of overweight and obese adults have gained their weight following a healthy weight youth. Moderate levels of youth overweight do not appear to pose long term risk in terms of adult health-related quality of life; however, this is not to say that higher levels of obesity would not have more negative consequences, nor that youth overweight can be ignored, as overall immediate and future health risks are high. Physical activity levels generally appear to be more variable across the lifespan, with poor prediction of adult lifestyle from youth habits, and also little consequence of youth activity levels to future adult health-related quality of life.

Finally, throughout adulthood and older adulthood, maintaining a physically active lifestyle leads to better health-related quality of life, regardless of weight status; in fact, as with biomedical outcomes, often active-overweight or even active-obese individuals are better off than their inactive-healthy weight counterparts, highlighting the importance of looking "beyond the scale" for physical activity benefits.

As chronic diseases are the leading cause of death and disability in Canada and worldwide,[1] an enormous burden of disease ensues. However, much of this burden is avoidable through reduction of several known major risk factors – including physical inactivity and obesity. These health risks are widely distributed in the population, with individuals differing in the extent of their risk rather than whether they are at risk.[2] While convenient to dichotomize risk factors into "exposed" and "unexposed" for analysis, in reality risk factors are present in the population across an entire continuum: those individuals in "high risk" categories in fact represent only a small portion of that continuum, while risk usually increases across the entire continuum. Hence, focusing on high risk individuals (the minority) only addresses a tiny part of the problem, and has limited effect on the large proportion of disease occurring in the large proportion of the population who are at moderate risk, especially if there is a tendency for individuals to progress along the continuum. Population approaches seek to shift the entire distribution of a risk factor to the left, by changing population behavioural and social norms. Small changes in risk levels in the population can lead to major reductions in disease burden. However, preventive measures that benefit populations tend to offer little to individuals, creating a "prevention paradox". The WHO [2] contends that these approaches should be complementary in striving to reduce the global burden of risk factors and associated chronic diseases.

In 2005, the Integrated Pan-Canadian Healthy Living Strategy [3] set the goal of a 20% increase in the proportion of Canadians who are physically active by the year 2015, based on the recommendation of 30 minutes per day of moderate to vigorous activity. Based on the 2003 CCHS data available at the time of the Strategy, 50.4% of Canadians reported at least 30 minutes of daily physical activity, hence a 20% increase would mean that 60.5% of people would be participating in regular physical activity by 2015. Using a relative risk estimate for CHD of 1.5,[4] this would lead to a reduction in population attributable risk for CHD from 19.9% to 16.5%, in addition to the reduced burden of many other physical inactivity associated conditions.

In May 2010, the *Toronto Charter for Physical Activity: A Global Call for Action* was launched at the 3rd International Congress for Physical Activity and Health in Toronto, Canada, giving Canada a memorable role at the forefront of global physical activity promotion. This document is intended as an advocacy tool, "a call to all countries to seek greater political [and social] commitment, resources and community action to [prioritize and] support health enhancing physical activity for all".[5] It is hoped that this document will be effectively utilized within Canada's own borders, to help advocate for greater commitment at all levels towards reaching this country's physical activity goals, thus reducing the associated disease burdens on the population.

9.2 Conclusions

In conclusion, the findings from this thesis help to further highlight the health burdens of the physical inactivity and obesity epidemics in Canada, and the urgency of reducing these burdens. It is evident that continued efforts should be made to increase Canadian physical activity research productivity, especially in the population health realm. In terms of public health policy and practice, the prevention of obesity and physical inactivity in adulthood, leading to increased health of the population, cannot be based solely on the identification and treatment of overweight and inactive children and adolescents. While tracking of youth overweight is high, population based prevention approaches will be more effective than approaches targeted only at high risk youth, due to the poor and incomplete prediction of adulthood obesity and physical inactivity from youth measures, and because adult health risks are high for those who become overweight and/or inactive after adolescence. While youth overweight and inactivity may not have negative long-term consequences on future adult HRQL, this does not diminish the importance of combating these epidemics, in light of the vast known immediate and long-term biomedical health and disease risks. Finally, physical activity promotion must emphasize benefits to all weight categories, over and above weight loss or maintenance results, emphasizing not only biomedical outcomes, but also health-related quality of life. It is hoped that this research can help lead to more efficient resource allocation, and aid in the development and implementation of more effective programs and interventions, leading to improved health across the population and significant reductions in the burden of disease and associated long-term health care costs in Canada.

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APPENDIX A

PHYSICAL ACTIVITY QUESTIONNAIRE

Canada Fitness Survey (CFS: 1981)

Campbell Survey of Well-Being in Canada (CSWB: 1988)

Physical Activity Longitudinal Survey (PALS: 2002-2004)

4. ACTIVITIES IN THE LAST YEAR

Please refer to the reference card for a list of activities. Answer the following for the physical activities you have done in the last 12 months.

(Do not include activities you have already listed.)

Activity	J	F	M	A	M	J	J	A	S	O	N	D	Number of occasions in last 12 months	15 or less	16–30	31–60	61 or more
Walking for exercise																	
Jogging (using short strides)																	
Running (using long strides)																	
Bicycling																	
Home exercise (push-ups, sit-ups)																	
Exercise classes																	
Weight training																	
Yoga																	
Golf (walking and carrying clubs)																	
Racquetball																	
Squash																	
Tennis																	
Baseball																	
Softball																	
Ice hockey																	
Curling																	
Swimming in a pool																	
Cross country skiing																	
Alpine/Downhill skiing																	
Ice skating																	
Names of activities:																	

Physical Activity Questionnaire: Campbell Survey of Well-Being in Canada (1988)

PHYSICAL ACTIVITY IN YOUR SPARE TIME

9. The following activities refer to physical activities that are not related to work.
Have you done any of the following physical activities in the past 12 months?

Please indicate whether you have done each activity listed below. Then for those activities which you have done, please complete the number of times done each month, and the average time spent on each occasion (not counting travel time, changing etc.).

	No	Yes	Number of times each month												Average time per occasion	
	No	Yes	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	hrs	min
walking for exercise	1[1]	2 →														
bicycling	1[2]	2 →														
jogging or running	1[3]	2 →														
home exercises	1[4]	2 →														
exercise class, aerobics	1[5]	2 →														

	No	Yes	J	F	M	A	M	J	J	A	S	O	N	D	hrs	min
ice skating	1[6]	2 →														
cross-country skiing	1[7]	2 →														
downhill skiing	1[8]	2 →														
ice hockey	1[9]	2 →														
swimming	1[10]	2 →														

	No	Yes	J	F	M	A	M	J	J	A	S	O	N	D	hrs	min
gardening, yard work	1[11]	2 →														
golf	1[12]	2 →														
tennis	1[13]	2 →														
weight training	1[14]	2 →														
baseball, softball	1[15]	2 →														

	No	Yes	J	F	M	A	M	J	J	A	S	O	N	D	hrs	min
popular or social dance	1[16]	2 →														
ballet, modern or jazz dance	1[17]	2 →														
square or folk dance	1[18]	2 →														
bowling	1[19]	2 →														

Please refer to the Physical Activity Reference Card and list any other activities that you have done in the past 12 months.

		J	F	M	A	M	J	J	A	S	O	N	D	hrs	min
____________	20														
____________	21														
____________	22														
____________	23														
____________	24														

Physical activity

10. Thinking back over the *past twelve months*, have you done any of the following physical activities in your spare time?

(*circle all that apply and complete the questions*)	number of times in the past 12 months	average time per occasion hours	minutes
1 Walking for exercise →			
2 Gardening or yard work			
3 Home exercise with equipment Specify:			
4 Home exercise, calisthenics			
5 Swimming			
6 Bicycling			
7 Social dancing			
8 Exercise classes or aerobics			
9 Bowling			
10 Golf			
11 Yoga or tai chi			
12 Cross country skiing			
13 Alpine or downhill skiing, snowboarding			
14 Running or jogging			
15 Weight training			
16 Skating			
17 In-line skating, rollerblading			
18 Tennis			
19 Badminton			
20 Baseball or softball			
21 Football			
22 Basketball			
23 Ice hockey			
24 Ballet or modern dance			

In the *past twelve months*, have you done any other physical activity not mentioned on this list?

activity	number of times	hours	minutes

11. a) In the past 12 months, did you walk or bicycle all or part of the way to or from work or school or to do errands for at least ten minutes at a time?

	number of times	average time per occasion hours	minutes	Was this time included in question 8 above? no	yes
1 walked				1	2
2 bicycled				1	2

APPENDIX B

SAMPLE:

Canada Fitness Survey (CFS: 1981)

⇓

Campbell Survey of Well-Being in Canada (CSWB: 1988)

⇓

Physical Activity Longitudinal Study (PALS: 2002-04)

The 1981 Canada Fitness Survey (CFS) was conducted to increase understanding of the health risks associated with physical inactivity, notably the relationships of physical activity, musculoskeletal fitness, body mass, and adiposity to all-cause mortality. The CFS sample was comprised of 23, 397 participants aged 7 and older from a geographically-based, randomly selected multi-stage cluster sample, representative of the non-institutionalized population.

Seven years later, the aim of the 1988 Campbell Survey of Well-Being in Canada (CSWB) was to describe long-term participation in physical activity, in an approximate 20% place- and participant-based subsample of CFS participants: Participants were selected from a representative sample of Census Metropolitan Areas and Rural Areas, including 61 of the original 80 geographic areas.

In 2002-2004, PALS sought to gather information on the socio-environmental determinants of lifetime involvement in physical activity, examining the evolution of physical activity involvement in persons across socio-economic, age, and gender groups over a 22 year period, identifying socio-environmental determinants of different trajectories, and examining associations with health outcomes. The addition of new family members to the CSWB sample yielded 4904 eligible individuals aged 15 years and older in 2002-2004. **Figure** 1 illustrates the derivation of the PALS sample which included 2511 participants (51.2%) with questionnaire data, with a non-response rate of 29.8% (10% lost to follow-up, 19.8% refusals). Further, 0.7% were unable to participate due to health reasons, and 18.3% were deceased. Of the 2511 participants, 1440 had data from all three time points.

The manuscripts contained within this thesis using the PALS data (studies 2, 3 and 4) are based on those individuals (of the 2511) who were original CFS participants, aged 7-18 years in 1981 (n=817), and who had data available on the key variables of interest at both baseline (1981) and 22-year follow-up (2002-04). This resulted in overall sample sizes of 374, 310 and 281 participants for studies 2, 3 and 4, respectively. Some variations in sample sizes existed for between various analyses, depending availability of required data for those analyses.

Source:

Craig CL, Gauvin L, Cragg S, Katzmarzyk PT, Stephens T, Russell SJ, Bentz L, Potvin, L. Towards a social epidemiological perspective on physical activity and health: the aims, design, and methods of the Physical Activity Longitudinal Study (PALS). J Phys Act Health 2005;2:272-284.

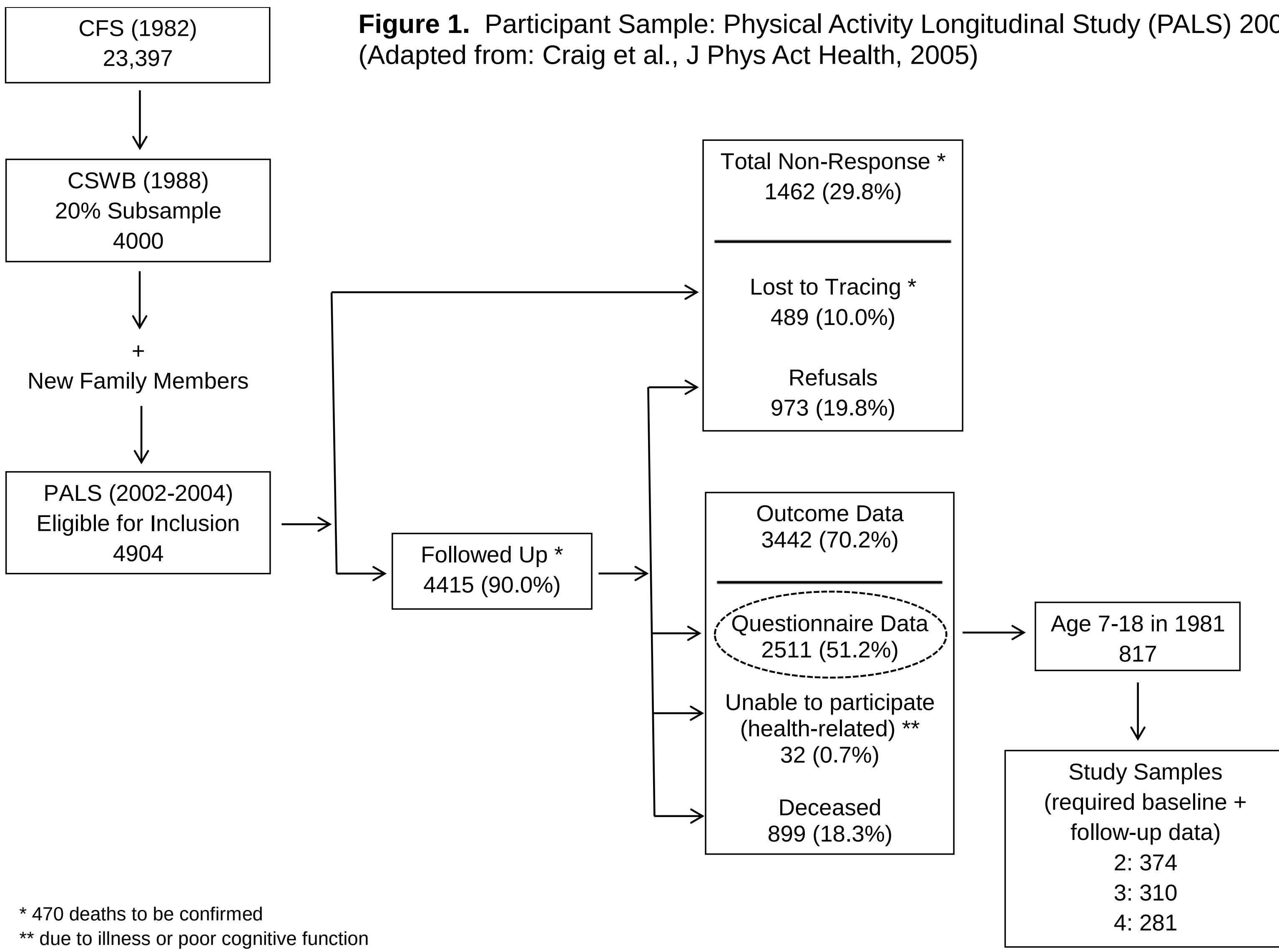

Figure 1. Participant Sample: Physical Activity Longitudinal Study (PALS) 2002-2004.
(Adapted from: Craig et al., J Phys Act Health, 2005)

* 470 deaths to be confirmed
** due to illness or poor cognitive function

APPENDIX C

REPRESENTATIVENESS OF PALS DATA

Results of a previously published in depth examination of the PALS data indicated that there was no selection bias on key individual- (PA, other lifestyle, health) and area-level (income, housing) variables; however, fewer respondents than non-respondents smoked or were underweight at baseline. While some demographic groups were over- or under-represented in the group eligible for inclusion, this was not the case ultimately among participants.

In comparing baseline (1981) characteristics **(Table 1)**, the PALS cohort had fewer individuals with low education and low family income, compared to CFS participants not involved in PALS, as well as slightly differing age-sex group distribution; however, these differences were unapparent within the PALS cohort in comparing participants with those who refused or were not found. Baseline lifestyle behaviours (PA, smoking, alcohol consumption), BMI, general health status ratings and aerobic fitness did not differ between the groups, with the exceptions that fewer PALS participants vs. non-participants were smokers or had low BMI (< 18.5).

Source:

Craig CL, Gauvin L, Cragg S, Katzmarzyk PT, Stephens T, Russell SJ, Bentz L, Potvin, L. Towards a social epidemiological perspective on physical activity and health: the aims, design, and methods of the Physical Activity Longitudinal Study (PALS). J Phys Act Health 2005;2:272-284.

Table 1 Baseline Demographic, Lifestyle, and Health Profiles of the Physical Activity Longitudinal Study Cohort and Canada Fitness Survey Participants Age 10 and Older in 1981

	CFS participants[a]		PALS cohort[b]		
Persons 10 y and older in 1981	Non-PALS n = 19,004	PALS cohort n = 4107	Eligible n = 4107	Participants n = 2392	Refused/ not found n = 1715
Men (%)					
10-24	32.6	33.1	37.6	35.6	40.4
25-34	20.5	20.8	20.9	20.4	21.5
35-44	14.1	16.4	16.4	16.5	16.2
45-54	12.0	13.4	11.0	11.2	10.6
55-64	10.0	10.3	8.3	9.5	6.6
≥ 65	10.9	6.1*	5.9	6.7	4.7
Women (%)					
10-24	31.2	28.9	36.2	34.4	38.9
25-34	19.5	21.9	22.1	23.0	20.9
35-44	13.1	17.5*	15.7	16.2	13.8
45-54	11.8	11.7	10.8	11.4	10.0
55-64	10.8	10.2	8.2	6.9	9.9
≥ 65	13.6	9.8*	7.5	8.3	6.5
Education (%)					
< secondary	43.9	35.8*	36.6	36.2	37.3
secondary	20.4	21.3	21.1	20.3	22.3
some post-secondary/ college	24.2	27.3	27.6	27.7	27.4
university	11.5	15.7	14.7	15.9	13.1
Family income (%)					
< 10,000	19.5	12.1*	14.0	13.3	15.2
10,000-14,999	14.1	12.5	12.5	13.2	11.3
15,000-24,999	27.3	28.3	28.0	27.1	29.3
25,000-29,999	12.2	15.6	15.1	15.9	14.0
30,000-35,000	9.8	11.1	11.5	11.5	11.4
> 35,000	17.1	20.5	18.9	19.0	18.8

Table 1 ***(continued)***

Persons 10 y and older in 1981	CFS participants[a] Non-PALS n = 19,004	CFS participants[a] PALS cohort n = 4107	PALS cohort[b] Eligible n = 4107	PALS cohort[b] Participants n = 2392	PALS cohort[b] Refused/ not found n = 1715
Leisure-time physical activity level (MET-min/wk)					
median daily	462	462	462	462	462
interquartile range	1134	1134	1092	1092	1218
1260+ MET-min/wk (%)	24.6	24.4	24.6	23.7	25.8
Cigarette smoking (%)					
current cigarette smokers	36.8	34.7	35.0	33.1	37.6**
Alcohol consumption (%)					
4+ times/wk	12.3	14.3	12.6	13.3	11.6
Body-mass index (kg/m²)					
< 18.5	8.5	8.8	10.5	8.5	13.1**
18.5-24.9	58.0	59.5	60.7	61.3	59.8
25.0-29.9	26.1	25.2	23.3	25.1	20.7
≥ 30.0	7.5	6.5	5.6	5.2	6.1
Aerobic fitness level					
Recommended category (%)	44.5	44.9	46.3	45.7	47.3
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)					
median	37.0	36.0	36.0	36.0	37.0
interquartile range	11.0	11.0	11.0	11.0	11.0
mean	37.2	36.7	37.3	37.1	37.6
standard error	0.1	0.2	0.2	0.3	0.4
General health (%)					
very good	21.3	22.7	21.6	22.2	20.9
good	41.4	43.9	44.1	45.1	42.7
average or below	37.3	33.5	34.3	32.8	36.4

Note. [a]weighted, 1981 Canada Fitness Survey weights on participants age 10 y and older in 1981 (19,004 of 23,397); [b]self-weighted subsample of 1981 participants (4107 age 10 y and older in 1981 of 4904 age 15 y and older in 2002); *Student's t-test with Bonferroni adjustment significant at $P > 0.05$ compared to non-PALS respondents to the Canada Fitness Survey. **Student's t-test with Bonferroni adjustment significant at $P > 0.05$ compared to PALS participants.

(From: Craig et al., J Phys Act Health, 2005)

For the three studies contained within this thesis using the PALS data, the samples included only those participants who were aged 7-18 at baseline. Thus the baseline differences that were previously reported to exist (e.g. proportions in older age groups, having greater than a secondary education, smoking status, underweight) are less likely to be directly relevant. In fact, when comparing PALS participants aged 7-18 at baseline, with those of the same age lost to follow-up, the only differences that emerged over a series of 1981 and 1988 (age 14-25) variables were that father's education was higher for participating males, and mother's education was higher for participating females **(Table 2)**.

Table 2. 1981 and 1988 demographic, lifestyle, and health characteristics of PALS cohort aged 7-18 at baseline (1981): Comparison of participants and non-returning.

	Male		**Female**	
	Return	**Non-Return**	**Return**	**Non-Return**
Age (mean)	13.0	12.6	13.0	12.5
PA 1981 (mean)	5.3	5.0	4.1	3.8
PA 1988 (mean)	5.3	5.7	3.5	3.3
BMI 1981 (%)				
Healthy Weight	90.8	88.9	89.2	88.0
Overweight/Obese	9.2	11.1	10.8	12.0
PA 1981 (%)				
0-1.49 KKD	20.8	21.9	37.1	44.3
1.50-2.99 KKD	26.2	18.1	18.9	17.9
≥ 3.0 KKD	53.0	60.0	43.9	37.9
General Health 1981 (%)				
Very Good	30.9	27.4	21.6	27.7
Good	42.1	43.5	40.3	37.2
Average or Below	27.0	29.2	36.1	33.6

Table 2. (*continued*)

Cigarette Smoking 1988 (%)				
Current smoker	19.9	28.9	22.2	31.4
Marital Status 1988 (%)				
Single/Never Married	91.9	88.1	84.4	82.8
Education 1988 (%)				
Elementary or less	0.6	2.6	1.8	2.9
Some secondary	31.5	38.3	35.3	38.5
Secondary diploma	22.2	22.5	22.2	26.8
Some post-secondary	20.4	15.9	16.8	14.1
Comm.Coll./CEGEP dip.	14.2	14.5	13.2	11.2
≥ 1 University degree	9.9	5.7	10.8	5.4
General Health 1988 (%)				
Excellent	25.3	24.9	17.5	15.0
Very Good	42.9	43.3	36.9	35.2
Good	26.0	26.9	40.6	42.0
Fair or Poor	5.8	5.0	5.0	7.7
Father's Educ. 1988 (%)				
Elementary or less	14.0	15.3	12.7	9.6
Some secondary	19.1	29.7 *	31.5	34.5
Secondary diploma	21.0	12.6 *	17.0	18.8
Some post-secondary	6.4	10.8	7.3	6.6
Comm.Coll./CEGEP dip.	13.4	8.1	12.1	7.6
≥ 1 University degree	26.1	23.4	19.4	22.8
Mother's Educ. 1988 (%)				
Elementary or less	8.9	12.2	6.7	9.6
Some secondary	15.9	23.9	20.9	31.8 *
Secondary diploma	27.4	24.8	25.2	25.8
Some post-secondary	7.6	10.8	12.3	4.5 *
Comm.Coll./CEGEP dip.	25.5	14.4	20.2	13.6 *
≥ 1 University degree	14.6	14.0	14.7	14.6
Family Income 1988 (%)				
< $20,000	7.4	5.7	10.1	9.3
$20,001-40,000	4.4	4.5	3.6	7.0
$40,001-60,000	4.4	6.8	4.3	7.0
$60,001-80,000	8.8	8.5	10.1	7.6
$80,001-100,000	16.9	14.8	18.8	14.5
$100,001-250,000	27.2	29.0	26.1	32.6
> $250,000	30.1	30.7	26.8	22.1

Independent samples t-test or Chi-square (Fisher's Exact Test for expected cell counts <5). * $p < 0.05$

APPENDIX D

POST-HOC POWER ANALYSIS

(Study 4)

The *power* of a statistical test refers to the probability that the test will lead to rejection of the null hypothesis, in favour of the alternative, when the null hypothesis is indeed false.[1] Power is a function of the significance criterion (α), the sample size, and the population effect size.[1] Traditionally when no other basis is available for setting a desired power value, the value of 0.80 is used, such that the probability of Type II error (β) is at most 0.20.[1] It is accepted that a null hypothesis is not proven merely by failure of a study to show statistical significance. However, while the common notion is that it is bad science to conclude a difference exists when one does not, in matters of public health it can be worse to erroneously conclude no difference exists when one does.[2]

Post-hoc power analysis often uses the obtained sample size and effect size to determine the *observed* power of the statistical tests performed. Whereas the utility of *a priori* power analysis in experimental design is universally accepted, the utility of the post-hoc observed power is questioned.[2-4] While common for reviewers/editors to request post-hoc power analysis for negative results to determine whether there was adequate power to detect the observed effect, this exercise is fundamentally flawed.[2-4]

It is stated that "power calculations tell us how well we might be able to characterize nature in the future given a particular state and statistical study design, but they cannot use information in the data to tell us about the likely states of nature."[2] In depth discussion is available from several authors.[2-4] Most importantly, using observed results to determine power assumes (likely incorrectly) that the effect size in the sample is equal to the effect size in the population, and observed power is then directly related to the observed significance of the test (p-value) in a 1-to-1 fashion – thus adding nothing to the interpretation of the results.[2] Given non-significant results, any calculated power based on observed results will *always* be low - nothing is gained by conducting a post-hoc power analysis to rule out inadequate power as a cause for non-significant results, since inadequate power is guaranteed by the non-significant result.[3, 4] All relevant information is known from the p-value, showing the probability the observed difference could occur by chance alone, in repeated studies, if there truly were no difference.[3, 4]

Rather than power analysis, the rational use of confidence intervals for interpretation of negative results once data analysis has occurred is advocated.[2-5] Confidence intervals describe the values (outside) which are unlikely to be true, and the values (inside) which are not refuted by the current data. If "the central focus of good data analysis should be to find which parameter values are supported by the data and which are not", then this is exactly the information revealed by confidence intervals.[2]

One instance where post-hoc power calculations may be useful is when based on plausible population effect sizes of independent interest, specified on a priori grounds.[4] A power analysis can be conducted based on achieved sample size, determining power to detect weak, moderate, and strong correlations. Similarly, using a desired power of 0.80, the sample sizes that *would have been* required to find significant effects of varying strengths can be determined. Again, p-values and confidence intervals provide as much or more information: if a 95% confidence interval around an observed correlation has an upper limit of 0.30, it makes little sense to assess the power to detect a correlation of 0.40, since the confidence interval makes it clear that such an effect in the population is unlikely.[4] Albeit, power analysis can provide an alternate way of displaying this relevant information – high power for detecting such an unlikely effect, but no significant result achieved, corresponds with the unlikelihood demonstrated by the confidence intervals.[4]

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Study 4: Sex Differences in SF-36 Outcomes based on Youth BMI

Confidence Intervals calculated for Spearman Correlations between Youth BMI [a] (1981) and Adult SF-36 Scores (2002-04) – PALS.

	Male (n=139)			**Female (n=142)**		
SF-36	**r**	**p-value**	**95% CI**	**r**	**p-value**	**95% CI**
PF	-0.02	0.784	-0.18, 0.15	-0.03	0.777	-0.19, 0.14
RP	0.06	0.507	-0.11, 0.22	-0.08	0.355	-0.24, 0.09
BP	0.09	0.320	-0.08, 0.25	-0.09	0.301	-0.25, 0.08
GH	-0.02	0.815	-0.18, 0.15	-0.08	0.339	-0.24, 0.09
VT	-0.07	0.409	-0.23, 0.10	0.14	0.090	-0.03, 0.30
SF	0.00	0.976	-0.17, 0.17	0.14	0.095	-0.03, 0.30
RE	0.10	0.231	-0.07, 0.26	0.19*	0.031	0.03, 0.34
MH	0.09	0.319	-0.08, 0.25	0.22**	0.008	0.06, 0.37
PCS	-0.04	0.647	-0.21, 0.13	-0.21*	0.013	-0.36, -0.05
MCS	0.02	0.781	-0.15, 0.19	0.26**	0.002	0.10, 0.41

[a] Age-adjusted residuals from regression of BMI on Age.
PF physical functioning; RP role physical; BP bodily pain; GH general health; VT vitality; SF social functioning; RE role emotional; MH mental health; PCS physical component summary; MCS mental component summary; * $p<0.05$, ** $p<0.01$.

Post-hoc power analysis, with parameters specified on a priori grounds:

For the sample sizes achieved in Study 4 (n=139-142), and assuming significance set at $\alpha=0.05$, the statistical power ($1-\beta$) to detect effect sizes of 0.15, 0.30, and 0.60 (weak, moderate, and strong correlations) is calculated at 0.42, 0.95, and 1.00, respectively.

Assuming a desired statistical power ($1-\beta$) of 0.80, and significance set at $\alpha=0.05$, the sample sizes (n) that *would have been* required to detect effect sizes of 0.15, 0.30, and 0.60 (weak, moderate, and strong correlations) would have been 346, 84, and 19, respectively.

It is important to note that based on 95% confidence intervals, the likelihood of an effect size of 0.60 in the population is highly remote, while the likelihood of an effect size of 0.30 in the population is unlikely except for some outcomes in females.

Study 4: Sex Differences in SF-36 Outcomes based on Youth BMI

Observed Power for Adjusted Linear Regression of Adult SF-36 Outcomes (2002-04) on Youth BMI (1981) – PALS: Males

SF-36 Outcome	(A) Full Model	Youth BMI	(B) Full Model	Youth BMI
a) Youth BMI (Overweight/Obese vs. Healthy Weight)				
GH	1.00	0.07	1.00	0.15
VT	0.79	0.08	0.80	0.06
MH	0.65	0.22	0.61	0.21
PCS	0.92	0.08	0.98	0.51
MCS	0.72	0.24	0.93	0.21
b) Youth BMI (Continuous)				
GH	1.00	0.05	1.00	0.10
VT	0.98	0.17	0.97	0.10
MH	1.00	0.09	0.99	0.08
PCS	0.92	0.06	1.00	0.10
MCS	0.97	0.11	0.64	0.09

GH general health; VT vitality; MH mental health; PCS physical component summary; MCS mental component summary.
"A" models adjusted for sex, age, adult physical activity, household income, education, married, current smoker, # comorbidities; "B" models adjusted for adult BMI, in addition to previous factors.

Observed Power for Adjusted Linear Regression of Adult SF-36 Outcomes (2002-04) on Youth BMI (1981) – PALS: Females

SF-36 Outcome	(A) Full Model	Youth BMI	(B) Full Model	Youth BMI
a) Youth BMI (Overweight/Obese vs. Healthy Weight)				
GH	0.99	0.38	1.00	0.73
VT	0.99	0.54	1.00	0.70
MH	0.79	0.61	0.83	0.71
PCS	0.94	0.92	0.92	0.13
MCS	0.92	0.74	1.00	0.77
b) Youth BMI (Continuous)				
GH	0.97	0.05	1.00	0.29
VT	0.85	0.28	0.95	0.67
MH	1.00	0.63	1.00	0.67
PCS	0.95	0.18	1.00	0.14
MCS	0.95	0.73	0.90	0.77

GH general health; VT vitality; MH mental health; PCS physical component summary; MCS mental component summary.
"A" models adjusted for sex, age, adult physical activity, household income, education, married, current smoker, # comorbidities; "B" models adjusted for adult BMI, in addition to previous factors.

APPPENDIX E

COMORBIDITIES LISTINGS

Listed below are the specific comorbidities included in the composite (count) "*Comorbidities*" variables created with the PALS (studies 2, 3, 4) and CCHS (study 5) data, respectively. These diseases and conditions may have the potential to impact physical activity and/or weight status, as well as health-related quality of life.

PALS	CCHS
Asthma	Asthma
Diabetes	Diabetes
Cancer	Cancer
Fibromyalgia	Fibromyalgia
Arthritis or Rheumatism	Arthritis or Rheumatism
Back Problems (excl. fibromyalgia/arthritis)	Back Problems (excl. fibromyalgia/arthritis)
Epilepsy	Epilepsy
Heart Disease	Heart Disease
Angina	Stroke
Congestive Heart Failure	High Blood Pressure
Stroke	Migraine Headaches
High Blood Pressure	Chronic Bronchitis
Migraine Headaches	Emphysema
Chronic Bronchitis	Chronic Obstructive Pulmonary Disease
Emphysema or COPD	Stomach or Intestinal Ulcers
Stomach or Intestinal Ulcers	Urinary Incontinence
Urinary Incontinence	Bowel Disorder/Crohn's Disease or Colitis
Bowel Disorder/Crohn's Disease or Colitis	Thyroid Condition
Thyroid Condition	Chronic Fatigue Syndrome
Chronic Fatigue Syndrome	Multiple Chemical Sensitivities
Multiple Chemical Sensitivities	Cataracts
Food Allergies	Glaucoma
Other Allergies	Mood Disorder
	Anxiety Disorder
	Other long-term physical/mental health cond.