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Physical Activity Through Adolescence: Trajectories and Predictions of Change

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Physical activity through adolescence: Trajectories and predictors of change

by

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ABSTRACT

Statement of the Problem: Physical activity levels generally decrease during adolescence and adulthood. A better understanding of patterns and determinants of physical activity through adolescence can inform physical activity interventions aimed at youth.

Methods of Investigation: Subjects were 1206 Montreal adolescents followed over 4.5 years. Physical activity was measured using a modified Weekly Activity Checklist. Trajectories were identified using the multilevel model for change. Demographic, psychological, and behavioural predictors were explored separately by sex.

Results: A cubic trajectory controlling for season emerged. Activity peaked at age 13.5, decreased, and increased again at age 16.5, but showed significant heterogeneity both within- and between-subjects. Males had higher physical activity levels than females at all ages. Depression, stress, sedentary behaviours, and alcohol use affected physical activity trajectories.

Conclusion: Physical activity levels follow a complex, curvilinear pattern during adolescence, and begin to decrease by age 14. Physical activity promotion interventions should focus toward this age group to promote increased physical activity participation.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Physical activity reduces the risk of several chronic diseases including coronary heart disease, hypertension, obesity, type II diabetes, osteoporosis, certain cancers (e.g., colon cancer), age-related functional limitations, and some depressions.[1-7] Although the association between physical activity and health has not been investigated among adolescents to the same extent as in adults, it has been reported that physical activity has at least modest positive effects on health outcomes in youth such as aerobic fitness,[8] blood lipids,[9] blood pressure,[10;11] body composition,[9] glucose metabolism, skeletal health,[6] and psychological health.[6;12-14] Positive effects of daily physical activity on student performance and academic achievement in terms of grade-point average, memory, decision-making and specific skills such as reading and mathematics have also been reported.[15-17] Active participation in sports and exercise that children enjoy may have beneficial emotional impact as well, such as reducing negative affect, increasing self-esteem, and elevating feelings of well-being.[11;12;12;18-20] In addition, several reports have linked later-life protective effects (e.g., reduced risk of breast cancer)[21;22] to physical activity in the adolescent years.

Despite these benefits, only 30% of Canadian females and 40% of Canadian males aged 13-17 years are active enough for optimal growth and development.[23] Physical activity guidelines for adolescents suggest that: 1) all adolescents should be physically active daily, or nearly every day; and 2) adolescents should engage in activities of at least 30 minutes duration, three or more times per week, at levels of moderate to vigorous intensity.[6] However, in 1999, only 57% of Canadian students engaged in at least 30 minutes of moderate or 20 minutes of vigorous activity for a minimum of four days per week.[24]

In addition, the literature is generally consistent that physical activity levels decline with age.[25-29] Longitudinal studies document age-related declines in the frequency of physical activity participation during the teen years ranging from 8.8% in males (4.7% in females) per year[26] to 43% (26%, respectively) over four years.[25] A ten-year study revealed a decline in total habitual physical activity of up to 83% from age 10 to age 19 years.[27]

Although many studies have described determinants of physical activity in youth,[30-35] few describe changing patterns of physical activity as a function of time during adolescence. Declines in physical activity may occur as a result of decreases in the number of activities in which adolescents participate, decreases in the time spent in each activity, or a combination of these.[25] There may also be psychological or behavioural factors that contribute to decreased participation, such as high stress or cigarette smoking.

It is generally believed that physical activity behaviours in youth are important determinants of physical activity levels in adulthood.[25;29;36] Therefore, increased understanding of factors that contribute to patterns of physical activity during adolescence might be able to inform the development of effective public health interventions for physical activity targeted to youth and adults. In addition, increased understanding of changes in physical activity participation in youth has the potential to identify critical time periods at which declines are greatest[37] so that interventions can be targeted to youth at critical or vulnerable ages or life stages.

1.2 Objectives

This thesis uses data from the McGill University Study on the Natural History of Nicotine Dependence in Teens (NDIT) to describe longitudinal patterns of physical activity levels during secondary school. The primary objectives are:

1) to describe trajectories of physical activity levels over time among adolescents aged 12-17 years; and
2) to determine if trajectories differ in males and females.

Secondary objectives are:

1) to identify factors that contribute to changes in physical activity levels over time; and
2) to determine if these factors differ in males and females.

1.3 Overview of thesis

Chapter one provides the background and importance of physical activity participation and objectives for conducting this research. Chapter two reviews the literature on the epidemiology of physical activity in adolescents, and includes a critical review of different approaches used to define and measure physical activity in youth. This is followed by a review of the published literature on age-specific longitudinal trends in physical activity in adolescents and determinants studied to date. Chapter three describes the methods used in the NDIT Study, as well as the methods used to address the objectives of this thesis, including analytical exploratory and explanatory techniques. Chapter four presents the results, including graphical representations of trajectories. Finally, Chapter five discusses the interpretation and implications of the findings, it describes study limitations, and it proposes directions for future research.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews the current literature on levels and determinants of physical activity in the adolescent population (aged 11-18 years). Specifically, the chapter will review current definitions of physical activity used in the literature, and methods for assessing physical activity will be described. Longitudinal studies examining changes in physical activity through the adolescent years will be reviewed, as well as the literature on predictors of physical activity in adolescents.

2.1 Definitions of physical activity

Physical activity is most often described as a behaviour encompassing "any bodily movement produced by the skeletal muscles that results in a substantial increase in energy expenditure over the amount expended at rest."[38, p.395] It can be categorized according to intensity, duration, pattern of intensity by duration, or frequency.[7;39] *Intensity* is often expressed in metabolic equivalents (METs; i.e., the rate of energy expenditure expressed in kilocalories per kilogram body weight). One MET is equivalent to the energy expended by a person while sitting at rest;[40] light activities (e.g., walking) are generally between 1.0 and 2.9 METs, moderate activities between 3.0 and 5.0 METs, vigorous activities between 5.1 and 6.9 METs, and very vigorous activities are generally 7.0 METs or greater. *Frequency* of physical activity is most often reported as the number of activities participated in per day or per week; *duration* is typically reported in minutes or the percentage of time spent being active.[41] The purpose of participation can also be used to categorize physical activity, for example, into either leisure-time physical activity or work-related physical activity. Habitual physical activity incorporates all types of physical activities that are participated in regularly.

Exercise is considered to be a subcategory of physical activity, referring to physical activity that is planned, structured, repetitive, and purposive for the improvement of physical fitness,[7;42] and often involves higher levels of exertion than physical activity.[39] Physical fitness is different from physical activity; it is considered generally as the ability to carry out daily tasks and includes characteristics such as cardiorespiratory endurance, skeletal muscular endurance, strength, and power, speed, flexibility, agility, balance, reaction time, and body composition.[7] Although physical activity and fitness are closely related in the sense that each fitness component aids in the ability to engage in physical activity, the terms should not be used interchangeably.

2.2 Measurement of physical activity in adolescents

There are many different ways to measure physical activity, and each has strengths and limitations. Methods of assessing physical activity in children and adolescents are similar to those used in adults, but the feasibility and validity of some methods may differ in the pediatric population.[39] Physical activity assessment based on self-report questionnaires, for example, must use items which are written in simple language so that children do not have difficulty reading or understanding the questions. In fact, pictures are sometimes used to help describe behaviours,[27] and reference cues may be provided to help estimate duration times for physical activity participation.[43]

Methods of physical activity measurement can be categorized into two groups: measures based on direct monitoring and measures based on self-report.

2.2.1 Direct monitoring

Methods of direct monitoring include direct observation, use of mechanical or electronic devices, and physiologic measurements. Each of these methods reduces the problem of recall bias (a difficulty with self-report measures), but are costly and often present significant burdens to participants and staff, and therefore are largely used in small-scale studies.

Direct (behavioural) observation involves watching a person and recording what they do, either in real time or on videotape. It is well suited to studies of children.[41] However, this approach is often difficult to use because the times and places available for observing children are limited.[44] As well, direct observation can be reactive, affecting the physical activity behaviours of the child, and cannot be used in large areas or to estimate physical activity during daily living (i.e., observations need to be confined to a defined space such as a school gymnasium or playground).[45]

Mechanical and electronic devices have been developed to measure physical activity by continuously monitoring heart rate, particularly to measure the duration and intensity of physical activity.[7] Heart rate monitors estimate daily energy expenditure (i.e., oxygen uptake), based on the assumption that the relationship between heart rate and oxygen intake is linear,[7] and thus provides an objective indicator of the physiological effect of physical activity. However, other factors can significantly influence heart rate, including psychological stress and changes in body temperature, introducing measurement error into the estimates.[41] Furthermore, heart rate monitors require calibration for each individual, they have to be worn for long periods of time (which may be inconvenient and cause discomfort), and they are unreliable for low intensity physical activities,[7] which are common in children,[44] and heart rate tends to remain elevated after the cessation of movement.[46] There are also risks of equipment failure, loss, or tampering, which could influence the data collected.[45]

Another direct measure of physical activity involves detecting motion. A simple example of this measure is a pedometer, which estimates the distance walked or run by counting steps. However, this method cannot accurately register energy expenditure during an activity which does not involve moving the lower limbs, such as throwing, carrying, or lifting.[41;47] A more sophisticated sensor is the Caltrac accelerometer: a motion sensor that measures vertical acceleration, but a major disadvantage is its inability to record activities in the horizontal plane accurately, such as cycling.[44] There are also physiological monitors of energy expenditure, but these methods are too complex and expensive for large scale studies. Some of the techniques are not appropriate for use with active subjects (e.g., with direct calorimetry, the participant has to remain in a metabolic chamber; indirect calorimetry requires that the participant wear a mask and carry equipment that analyzes expired air). A method based on doubly labeled water, which measures isotopes every few days or weeks in the urine of participants,[7] is suitable for use in active subjects since it is non-invasive, does not interfere with normal activity patterns, and can measure activity over one to two weeks. This method, however, is costly, has a high participant burden, and it is difficult to obtain stable isotopes.[41] Another limitation of these physiological methods is that they cannot distinguish between different types of activities in which the individual has participated. As well, participants are aware that they are being assessed, which may cause a change in typical behaviour.[45]

2.2.2 Self-report

Techniques used to gather information through self-report include: surveys/questionnaires, diaries, and logs. Surveys are the most practical method in large populations because they are convenient, relatively easy to administer, unobtrusive, and relatively inexpensive.[7;41;43;48] However, some participants may not remember specific details of past physical activity behaviours, resulting in recall bias. This is more likely to occur in retrospective surveys, especially when the time frame is many years. Children, in particular, have difficulties recalling past activity because levels of activity vary widely from day to day. In addition, children often lack the ability to estimate the duration of their activities.[41;44]

Diaries are prospectively completed records of physical activity engaged in during a pre-specified time period, generally limited to spans of one to three days.[7] They require sustained effort on the part of the participant, and they may produce changes in physical activity behaviours, resulting in self-report bias. Diaries are not feasible in studies involving young children.[44] Logs provide a record of participation in specific types of activities, rather than in all activities.[7] However, they have the same limitations as diaries, including that they can only be used for short periods of time and thus are not appropriate to measure long-term physical activity patterns.

In addition to the difficulties mentioned above, self-report methods have the potential for exaggerating the amount of activity participated in.[41] In a review of local and regional studies in the United States, those using self-report methods indicated much higher levels of physical activity than studies using other methods.[39] However, these studies varied considerably in their method of assessment and age of participants, and most were based on small sample sizes.[39]

Evidence suggests that children as young as ten years old can provide self-reports of at least modest reliability and validity.[43] Sallis et al.[43] developed several formats of physical activity self-report questionnaires for use with children and evaluated them in fourth grade students. Each questionnaire asked the subject to check off (for each day of the week) which activities on a list they participated in for at least 15 minutes continuously; 20 activities were provided in the list. One of the formats was the Yesterday Activity Checklist, which asked subjects to put an "X" beside any activity they had participated in the day before. Another format, the

Weekly Activity Sum, required subjects to write down the number of times they had participated in each activity in the preceding week. Finally, the Weekly Activity Checklist asked subjects to check which activities they had participated in on each individual day of the previous week. Validity of these three approaches was tested against the Caltrac accelerometer. The Weekly Activity Checklist had the highest reliability (R=.74) and validity (correlating significantly with the Caltrac scores at both assessment periods), compared with the Yesterday Activity Checklist (R=.60) and the Weekly Activity Sum (R=.51). They also noted that using a two-week recall performed more poorly compared to using a one-week recall, suggesting that shorter periods of recall place fewer cognitive demands on children.[43] In terms of reliability, a review of self-report methods[45] found higher test-retest reliability coefficients in older children and adolescents than in younger children.

To date, there is no accepted "gold standard" measure of physical activity, making it difficult to establish the validity of the simpler field measures.[39] For studies involving a large sample with interest in long-term activity patterns, it may be that the only feasible approach involves the use of questionnaires.[49] A standardized measurement approach would ensure comparability between studies and compatibility in the collection and analysis of large-scale surveillance data.[50] Ainsworth et al.[51] developed a coding scheme for physical activities in order to improve comparability across studies. Specifically, by knowing the purpose of the activity (i.e., occupation, sports), the specific type of activity, and the intensity (in METs), physical activities can be classified by rate of energy expenditure and can be estimated for all activities, specific activities, or activity types. This coding scheme is presented in the Compendium of Physical Activities,[51] but is based on adult data. Therefore, estimates for intensity level using this Compendium may be inappropriate for the pediatric population. Development of reliable and valid methods for the assessment of physical activity in children and adolescents is recognized as a priority for epidemiologic and interventions studies.[44]

2.3 Changes in physical activity in adolescents with age

Searches were conducted to locate all studies measuring physical activity in adolescents, using the following criteria: (i) the study had a longitudinal design with a follow-up period of at least one month; (ii) the study assessed physical activity or leisure habits, with no limits on the measurement technique (e.g., self-report, heart rate monitoring); and (iii) the study population included adolescents (preferably, but not restricted to, between age 12 and 17 years). Databases searched included Medline, PsycINFO, and SPORTDiscus using the OVID search engine (limited to English language articles and "human" subjects). The time period searched covered 1970 to 2005. Search terms included 'adolescen$ or youth$' (truncated to capture all relevant terms), 'physical activity or leisure', and 'longitudinal'. Reference lists from all key articles were also consulted.

Table 2.1 summarizes the 12 longitudinal studies identified in the search, that measured physical activity in early- to late-adolescence. (Text continues on page 20.)

Table 2.1. Summary of longitudinal studies measuring physical activity levels in adolescents.

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
Comparison of barriers self-efficacy and perceived behavioral control for explaining physical activity across 1 year among adolescent females. Motl et al.,[52] 2005.	• 1 year (baseline in spring semester of 1999, FU in spring semester of 2000) • FEMALES in 8th grade at baseline from 12 high schools (and associated middle schools) in South Carolina • n=1038 (856 baseline, 853 FU)	• 3-Day Physical Activity Recall (3DPAR) - included a list of 55 commonly performed activities; report intensity of participa-tion for every 30-minute time block (from 7am to midnight)	• Data were converted into the number of 30-min blocks per day for each of the previous 3 days in which the main activity was between 3 and 6 METs (MPA) and 6 or more METS (VPA)	• Structural equation modeling performed using full-information maximum likelihood	• The females reported participating in an average of approximately two 30-min blocks of moderate physical activity per day and an average of 1 30-min block of vigorous physical activity per day • Level of physical activity did not change significantly across baseline and FU	• Not generalizable to males • Only assess physical activity participation over 3 days • Large sample size
Longitudinal study of the number and choice of leisure time physical activities from mid to late adolescence. Aaron et al.,[25] 2002	• 4 years; FU annually in the spring • Students from grades 7-9 (aged 12-15 at baseline); Recruited from a single suburban school district near Pittsburgh, PA • n = 782 (410 male, 372 female)	• Modifiable Activity Questionnaire for Adolescents - subjects asked to indicate all activities participated in at least 10 times in past year; also recorded	• Derived an overall leisure time in hours per week; compared specific activities, as well as team sports vs individual sports, light-moderate activities vs vigorous,	• Repeated measures ANOVA to examine changes in number of activities • Linear regression for potential predictors • Sex differences examined using chi-	• Physical activity (hrs/wk) decreased 43% in males and 26% in females • Mean number of reported activities declined significantly by 56% from year 1 (7.05) to year 4 (3.08) • Males were significantly more active than females at each year • Males a consistent decline; females plateau and then slightly down	• Past year participation may be subject to recall bias • Requirement of participation at least 10 times per year may not capture some activities • No measure of intensity

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
		frequency and duration for each	year-round vs seasonal	squared analyses		
Ethnic differences in physical activity and inactivity patterns and overweight status. Gordon-Larsen et al.,[53] 2002	• 1 year; Wave 1 (collection from April to December 1995) and Wave 2 (April to August 1996) • Students in grades 7-12 (ages 11-19 years) at baseline from the National Longitudinal study of Adolescent Health • n=12,759 (6288 males, 6471 females)	• In-home survey – collected information on participa-tion in moderate to vigorous physical activity (MVPA) and low-intensity physical activity (LIPA)	• Units were bouts per week for MVPA and LIPA • MVPA defined as 5-8 METs; low-intensity activity (LIPA) defined as 2-3 METs	• Logistic regression models to investigate effects of initial and 1-year change in activity and inactivity status	• On average, adolescents decreased weekly moderate to vigorous physical activity, with a sample mean of -0.19 bouts per week • Greater decrements among males • On average, adolescents increased their low-intensity activity over the 1-yr period (0.13 bouts/wk)	• Sample was nationally represent-ative, school-based (in U.S.) • May be subject to seasonality differences (not controlled for) • Large sample size
Decline in physical activity in black females and white females during adolescence. Kimm et al.,[54] 2002	• 10 years; FU annually • FEMALES aged 9-10 years at baseline from the National Heart, Lung, and Blood Institute Growth and Health Study (recruited from school districts outside Berkeley, CA, and Cincinnati, OH; and also from a large health	• Habitual Activity Question-naire (HAQ) - asked about leisure-time activities that require energy expenditure above that required for activities of daily living	• Score computed by multiplying an estimate of the METs for each recorded activity by the weekly frequency and the fraction of the year during	• Generalized estimating equations to determine whether changes in activity scores from year 1 to year 5 differed from those from year 5 to year 8	• Median activity score for the whole group declined by 83% from year 1 to year 10 • During same period, the decrease in median HAQ scores for black females was 100% compared with 64% in white females • For both races, the mean annual decline in scores was greater at older ages (years 5-8: 4.1 MET-times per week for black females, 3.5 for white) than at younger ages (years 1-5: 3.5 for black, 2.7 for white); activity levels were lower for black females than	• Not generalizable to males • HAQ scores do not take into account the duration of activities performed • Past year assessment using the HAQ – potential recall bias

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
	maintenance organization in Washington, DC) • n=2379 females (1213 Black, 1166 white)	• Administer-ed in years 1, 3, 5, 7-10	which it was performed • Weekly tallies for all HAQ items were summed, and an overall average weekly score was calculated as MET-times per week		white females	• Long-term prospective design • Large sample size
Longitudinal changes in 11-13-year-olds' physical activity. Armstrong et al.,[55] 2000	• 3 years; FU annually • Students in grade 6 at baseline (mean age 11.1) recruited from 15 state schools in the city of Exeter (UK) • year 1: n=104 males, 98 females year 2: n=73 males, 70 females year 3: n=81 males, 79 females	• Continuous heart rate monitoring (minute-by-minute from 9am to 11pm over 3 schooldays)	• Chose heart rate cut-offs: brisk walking (moderate activity) generates heart rates of about 140 beats per minute (bpm) and jogging (vigorous activity) 160 bpm (determined from their previous work)	• Age, sex and maturity influences on longitudinal changes investigated using multilevel modeling	• 20-minute periods too infrequent, therefore only used 10-minute bouts • Males spent significantly more time than females with heart rates above both thresholds • for moderate physical activity, significant negative age effect (Beta=1.56), sex (females coefficient –1.72), no age*sex significant effect • for vigorous physical activity (age: -0.83, sex: -1.20)	• Only 3 day assessment period • Assessed each child during the same week, but from year-to-year was anytime throughout the school year (Sept-July) – but Britain apparently not subject to season influences
Changes in	• 6 years; annually	• Question-	• Each activity	• Mantel-	• At every age grp, males reported	• Frequency

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
common activities of 3rd through 10th graders: The CHIC Study. Bradley et al.,[56] 2000	(to 9th-and 10th-grade; aged 14-17 years) • Students in grades 3 and 4 at baseline from the Cardiovascular Health in Children and Youth (CHIC) study recruited from elementary schools in North Carolina • n=656 (50.5% female)	naire - asked subjects to indicate the three activities they usually did most – anything from reading or participa-ting in a sport	was assigned a MET value of 2, 3, 5, or 8 • Categorized as sedentary if 2 of the 3 activities were METs of 2 or 3, considered active if 2 of the 3 were METs of 5 or 8	Haenszel chi-square tests assessed time effect on activity status for each subject • Generalized estimating equations model to test predictors of activity status for each gender	more vigorous activities in their top 3 activities than did females • Activities with METs of 2 or 3 (sedentary) were more frequently reported in the older subjects regardless of gender, but females reported more sedentary activities overall • Significant decrease in number of vigorous activities done with increasing age group for both genders	and duration not part of physical activity assessment • Long-term prospective design
Longitudinal changes in physical activity in a biracial cohort during adolescence. Kimm et al.,[27] 2000	• 10 years; FU annually until ages 18-19 years • FEMALES aged 9-10 years at baseline from the National Heart, Lung, and Blood Institute (NHLBI) Growth and Health Study (NGHS) recruited from schools outside Berkeley, CA, and Cincinnati, OH; and also from a large health maintenance organization in Washington, DC • n=2322 females	• Activity Diary (AD) - activities participated in for a select duration (1-15 min; 16-30 min; > 30 min) • Habitual Activity Question-naire (HAQ) – assessed type and frequency of participa-tion outside	• AD – calculated score based on MET for a summary MET value expressed as MET-minutes/ day. • HAQ – summary weekly activity score calculated for each activity category based on	• Wilcoxon matched pairs signed rank test to examine whether activity scores significantly changed over study period; Friedman chi-square test used to compare the change in median activity scores	• Median AD scores - consistent decrease in physical activity from year 1 to 10 (35%); sharp decrease in year 2, increase of 11% to year 3, steady decrease to year 8, increase in year 10 by 26% from year 8 – but all less than year 1 scores • Median HAQ scores - declined steadily from year 1 to 5, sharply from year 5 to 7 (by 70%) and to year 8, then increase to year 9 and plateau to year 10; over entire study period, decline of 83% in HAQ scores • Caltrac scores steady decrease from years 3-5; declined by 10% from years 3-4 and by 13% from years 4-5	• Not generalizable to males • Past year assessment using the HAQ – potential recall bias • Long-term prospective design • Large sample size

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
	(51% Black, 49% white)	of school during the past year • Caltrac Activity Monitor	MET times/week	between study years		
Decline of physical activity from youth to young adulthood in Finland. Telama et al.,[26] 2000	• 12 years; FU every 3 years • Subjects aged 9, 12, 15, and 18-years old at baseline (1980) from the Cardiovascular Risk in Young Finns study recruited from five university towns in Finland • n=depending on year and age, but smallest sample size was 121 for 18-year-old males in 1986	• Question-naire - asked about frequency and intensity of leisure-time PA participa-tion	• Sum Index of PA computed (based on frequency) • Dependent measure included subjects with a frequency of at least twice per week	• Describes trends over time – no hypotheses are tested • T-tests to compare gender differences at each age level	• Percentage decline in frequency per year was highest between ages 12 and 15 for both sexes (8.8% for males, 4.7% for females) • Decline steeper for males (57%) than females (28%) over entire study period • Frequency of participation in organized sport highest at age 12; declines steepest from 12-15 in males (3.7% per year) and from 15-18 in females (2.5% per year) • After age 18, females more frequently active than males	• No statistical hypothesis testing • Use of standard assessments at each measurement point • Long-term prospective design
Physical activity of young people: Amsterdam Longitudinal Growth and Health Study. Van Mechelen et al.,[28] 2000	• 15 years (1977-1991); FU annually to 1980 (age 16), then again in 1985 (age 21), then again in 1991 (age 27) • Subjects 13 years old at baseline from the Amsterdam Growth and Health Study recruited from one	• Semi-structured interview covered areas of habitual physical activity during the 3 months prior to the interview	• Average total weekly physical activity (THPA) time calculated (in minutes/ week), then subdivided into 3 levels of intensity (moderate,	• MANOVA for repeated measure-ment (sex, time, sex*time entered)	• Decrease in females during age 13-16 was 3%, followed by a 5% increase from age 16-21 • Decrease in males, 20% during age 13-16, 5% increase from age 16-21 • No significant differences between males and females in THPA; males and females showed similar patterns over time • Over 15 years, females decreased 8% (9.1 hrs/wk to 8.4) but time	• Potentially subject to seasonality issues because not clear which time of year physical activity was measured • Fairly small sample size

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
	Secondary school in Amsterdam, Netherlands • n=181 (83 male, 98 female)	(restricted to physical activities that were equal to or exceeded 4 METs)	4-7 METs; vigorous, 7-10 METs; very vigorous, >10 METs)		effect was not significant; males decreased 31% (10.6 to 7.3) and time effect was significant	
Determinants of exercise among children. II. A longitudinal analysis. DiLorenzo et al.,[29] 1998	• 3 years • 5th and 6th grade students at baseline from a Midwestern community (in Missouri) • n=54 females, n=57 males	• Structured in-home interview in May/June 1991 and 1994 - assessed child's activities during the previous 3 days, including duration and intensity	• Amount of time participated was multiplied by that activity's MET value; values were summed to provide a total MET expenditure for each day	• Repeated measures ANOVA to examine changes in the number of activities	• Over the 3 years, activity levels decreased by 17.8% for males and 11.0% for females in mean vigorous minutes of PA	• Generalizability limited to educated, middle-class Caucasian families • Small sample size • Analyses included those that participated in both Phases
Continuity and change in sporting and leisure time physical activities during adolescence. Dovey et al.,[57] 1998	• 3 years; baseline at age 15 (collected during 1997-1998) and FU at age 18 (1990-1991) • Participants were part of the Dunedin Multidisciplinary Health and Development Study (DMHDS) in New	• Face to face interview consisted of the Minnesota Leisure Time Physical Activity Question-naire -	• Frequency of activities • Time spent in physical activity based on hours/week	• Non-parametric Wilcoxon matched pairs sign rank test to compare activity time and numbers of activities in	• Mean time per week spent in physical activity at age 15 was significantly higher than at age 18 (9.7 hrs/wk vs 6.1 hrs/wk) • At both ages, males spent significantly more time in physical activity than females: at age 15 males spent 11.7 hrs/wk in PA compared with 7.5 hrs/wk for females; at age 18, males spent 7.8 hrs/wk, compared to 4.3 hrs/wk	• Cohort somewhat biased socioecon-omically towards the advantaged and ethnically towards those of

Study Title / Reference	Follow-up (FU) period / Subjects / Setting / Sample Size	Data Source	Measure of PA	Statistical methods	Major findings	Limitations / Strengths
	Zealand (recruited at birth from a hospital in Dunedin between April 1 1972 and March 31 1973); this study assesses subjects from age 15-18 • n=775 (400 males, 375 females)	participants asked to recall, for each month of the previous year, the type, frequency, and duration of sports and similar physical activities in which they had participated		which individuals participated at each age • Repeated measures ANOVA to study differences between ages and sexes	for females • No significant sex*time interaction suggesting that time reductions were of similar magnitude for both sexes • Median number of activities at age 15 was 7 and at age 18 was 3 – no significant difference between males and females	European descent • Self report based on recall for activities each month in past year; potential recall bias
Patterns of physical activity among German adolescents: The Berlin-Bremen Study. Fuchs et al.,[58] 1988	• 2 years; 5 waves of data at 6-month intervals • Students in grade 7 or 8 at baseline from 22 schools in Berlin (large city) and Bremen (suburban town) as part of the Berlin-Bremen Study of Health Behavior in Childhood and Adolescence in West Germany • n=932	• Self-administ-ered question-naire – assessed the type, frequency, and duration of 11 activities	• Measures included time spent per week (hrs/wk on a yearly average), frequency of activity episodes per week, and average duration per episode	• Not specifically stated – seems to consist of basic descriptive analyses (and chi-square for comparison) • Analyses consisted only of fall surveys (3 cycles)	• Median level of time for total activity was 10.1 hrs/wk at baseline, decreased by 10% after 2 years (9.1 hrs/wk) • Time for moderate activity dropped 9% (6.5 to 5.9 hrs/wk) • Time for vigorous dropped 13% (2.4 to 2.1); only 5-6% • Males higher median levels of time for total activity at all 3 waves	• Classrooms randomly selected; consecutive sample • Low response rate (52% completed all 3 cycles); 36% did not do baseline survey • Subjects reported at all 3 fall waves

The studies in Table 2.1 differed in subject demographics, sample size and levels of external generalizability. Two of the studies present results from the same longitudinal data source: the National Heart, Lung, and Blood Institute (NHLBI) Growth and Health Study (NGHS).[27;54] However, the studies differ in their main objectives and in the outcome measure assessed and therefore both are included. The generalizability of these two studies and one additional study[52] are limited to females only.

2.3.1 Physical activity assessment

The methods of physical activity assessment differed between studies, contributing to variation in the results. Most used self-report measures, one used self-report in addition to a direct monitoring measure (the Caltrac accelerometer),[27] and one used continuous heart rate monitoring.[55] Of the studies that used self-report measures (one used a semi-structured interview[28]), no two studies administered the same questionnaire (other than the two studies that used the same longitudinal data set). Therefore, the physical activities measured do not necessarily reflect the same behaviours. For example, the Minnesota Leisure Time Physical Activity Questionnaire used in the study by Dovey et al.,[57] asked participants about sports and similar physical activities in which subjects had participated during school and outside of school, including competitive sports and leisure time activities. Other questionnaires asked the participant to report only those activities in which they had participated a minimum number of times (e.g., the Modifiable Activity Questionnaire used by Aaron et al.[25] required the participant to report an activity only if they had participated in it at least ten times in the past year). Several studies examined only moderate to vigorous physical activities.[28;29;52;53;55] These differences in measurement limit the ability to compare results across studies.

2.3.2 Measures of physical activity and change over time

In addition to differing methods of measurement across studies, the physical activity (outcome) score that was followed over time differed across studies. For this reason, we will briefly describe the outcome measure used in each study when describing the results. Several studies presented here had baseline and follow-up data outside of the 12—17-year-old age range; where possible, the results describe only the change in physical activity behaviours throughout these adolescent years.

Two of the 12 studies used the frequency of activities (per year) as the outcome measure, to determine how the number of activities changed over time.[25;26] Aaron et al.[25] conducted a 4-year population-based longitudinal study to describe the pattern of change in the number and choice of leisure time physical activities from mid to late adolescence. Subjects were 782 adolescents aged 12 to 15 years at baseline recruited from a single suburban school district near Pittsburgh. Subjects provided information about their involvement in a pre-determined list of common recreational and leisure time activities, as well as the frequency and duration for each activity during the past year, using the Modifiable Activity Questionnaire for Adolescents. Each activity, however, had to have been performed at least ten times over the past year, which may not capture spontaneous physical activities or those performed in physical education classes. Moreover, a recall period of one year introduces a potential for recall bias. The mean number of activities reported each year for the entire sample decreased from 7.05 activities per week in year one to 3.08 activities per week in year four, a significant decrease of 56%. Overall, 85% of subjects reported a decrease in the number of activities they participated in, and only 5% increased the number of activities over the four years. The decrease related primarily to a decrease in the number of activities, rather than a decrease in the time spent in specific activities.

Telama and Yang[26] found similar results in Finnish youth. The data were collected in a nationwide longitudinal study of subjects aged 9, 12, 15, and 18 years at the beginning of the study in 1980. The subjects completed questionnaires every three years up to 1992. The questionnaire included questions on the frequency and intensity of leisure time physical activity, participation in sports club training, participation in sports competitions, and the respondent's habitual ways of spending their leisure time. The outcome measured was frequency of participation based on a summed index of the physical activities reported in the questionnaire. The results were reported for those participants who reported a frequency of doing at least two activities per week. A consistent decline was found in subjects after age 12, with the greatest percentage decline in frequency per year between the ages of 12 and 15 years (8.8% for males, 4.7% for females). The three-year percentage decline between these ages was 26.4% for males, and 14.0% for females. From age 15 to 18 years, males decreased their (three-year) percentage frequency by 15.9% and females by 7.6%; the percentage decline in frequency per year through these ages was 5.3% in males and 2.5% in females. The decline in physical activity was steeper among males than among females, and by the age of 18, female subjects engaged in more physical activities than males. The frequency of participation in organized sports also declined significantly (at its steepest, by 3.7% per year between the ages of 12 and 15 years in males, and by 2.5% per year between 15 and 18 years in females).

Dovey et al.[57] reported the frequency of participation in terms of duration (hours per week). They found that adolescents from New Zealand also showed a significant decline in physical activity from age 15 to 18. This study measured time spent in physical activity (in hours per week) based on the frequency and duration of participation reported. Overall, the mean time per week spent participating in physical activity decreased from 9.7 hours per week at age 15, to 6.1 hours per week at age 18. Sex-specific analyses revealed that males decreased the time spent on physical activity from 11.7 hours per week at age 15 to 7.8 hours per week at age 18; in females, this decrease was from 7.5 hours per week to 4.3 hours per week. A significant difference was found between the sexes (males' activity was consistently higher than females'; $p < 0.001$), but the sex by time interaction was not significant ($p = 0.257$), suggesting that reductions over time were of similar magnitude in both sexes. Further analyses showed that the median number of activities reported decreased over the three years, from seven to three activities for both genders, from seven activities to three for males, and from six activities to three for females.

Aaron et al.[25] reported a decrease in the mean number of activities from seven to three in a similar age group (age 12 to 15 at baseline), but over a four-year period. They produced an overall leisure time physical activity estimate (in hours per week) by summing the individual (physical activity) response items, weighted for duration and frequency. Similar to results reported by Dovey et al.,[57] the total number of hours of physical activity per week for the entire sample declined by 26% throughout the four-year period. Sex-specific analyses revealed a 43% decrease in males, and a 26% decrease in females in terms of total hours of physical activity per week. However, at each year, males were consistently more active than females.

A decline was also seen in West German adolescents aged 11 years at baseline and who were followed for two years. Fuchs et al.[58] collected data in questionnaires, including the type, frequency, and duration of activities (chosen from a predetermined list of 11 specific activities). In addition to a total time for activity measure, they grouped the activities into moderate and vigorous intensity to determine the change in time spent in these activities. Overall, the median time for total activity decreased by 10% over two years, from 10.1 hours per week at baseline, to 9.1 hours per week two years later. This decline is slightly smaller than that reported by Aaron et al.[25] and Dovey et al.,[57] but the subjects were younger and the follow-up period was shorter (two years vs three years[57] and four years[25]). This study[58] was consistent with Dovey et al.[57] in that males had higher median activity levels than females. Results presented by intensity revealed that the time spent in moderate activity declined by 9% (from 6.5 to 5.9 hours per week), and the time spent in vigorous activity declined by 13% (from 2.4 to 2.1 hours per week).

Several other studies examined moderate and/or vigorous activities specifically; most present the results in terms of the number of sessions/episodes in which subjects participated. A longitudinal study of adolescents aged 11 to 19 years, conducted by Gordon-Larsen et al.,[53] showed that the frequency of weekly moderate or vigorous physical activity decreased by about 0.2 sessions per week, on average, over a one-year period, with greater declines seen in males (0.25 vs 0.17 bouts per week in females). The baseline number of sessions per week was 4.2 for males and 3.3 for females. Motl et al.[52] examined in South Carolina how the average number of 30-minute blocks of moderate physical activity and vigorous physical activity participated in per day changed in a sample of females from grade 8 to grade 9. Females participated, on average, in two 30-minute blocks of moderate physical activity and only one 30-minute block of vigorous physical activity per day in grade 8. These scores did not change significantly over one-year of follow-up. The subjects were, however, only asked to report their physical activity from the three days (Tuesday, Monday, Sunday) prior to the assessment (which was always done on a Wednesday), which may not be a sufficient amount of time to capture usual physical activity. The results from this study are not generalizable to males.

Armstrong et al.[55] used continuous heart rate monitoring to measure moderate and vigorous activity behaviours in males and females aged 11 at baseline, with follow-up annually to age 13 years. The monitoring period for this study was three days. They chose a heart rate cut-off of 140 beats per minute (bpm) to represent moderate activity and 160 bpm for vigorous activity (based on previous assessments of subjects in the same age group, in which brisk walking [a moderate activity] generated heart rates of about 140 bpm, and jogging [a vigorous activity] generated heart rates of about 160 bpm). The objective was to determine the number of 20-minute periods in the three-day monitoring period that subjects had sustained continuous heart rates above each threshold, in order to compare with recommended guidelines. However, at age 13, 82.7% of males and 86.1% of females did not demonstrate even one 20-minute period of vigorous physical activity during the three-day monitoring period; only 2.5% of males and no females participated in the equivalent of one daily 20-minute period of moderate physical activity. Ten-minute periods were more likely but still infrequent. The percentage of subjects who sustained periods when their heart rates were above 139 and 159 bpm during the three-day monitoring period decreased over the two-year follow-up. For the percent of time with heart rates above 139 bpm, each increasing year of age contributed to a 1.6% decrease in time spent above the threshold, and this was 1.7% lower for females. Similar results were seen for the percent of time spent with heart rates above the cut-off for vigorous activity; each increasing year of age contributed to a decrease of 0.8% of time spent, and was 1.2% lower for females. Neither activity threshold revealed a significant age*sex interaction effect, suggesting that reductions over time were similar in males and females. Consistent with Motl et al.[52] (in females only), periods of 20 to 30 minutes of moderate to vigorous physical activity are infrequent in this age group. It is possible that a measure of duration (in minutes or hours per week) of moderate to vigorous physical activity, rather than bouts, is needed to capture a more reliable estimate of this type of participation.

DiLorenzo et al.[29] conducted a longitudinal study on 5th and 6th grade students from Missouri, with follow-up three years later (in grade nine). The primary measure of interest was time (in minutes) spent participating in vigorous physical activity, calculated from the average three-day MET expenditure (see description in Table 2.1). They noted a decrease in participation of 17.8% in males and 11.0% in females over the three-year study period (the average MET expenditure per three days for males was 4.5 at baseline vs 3.7 at follow-up; for females, the average MET expenditure per three days was 3.3 at baseline vs 2.9 at follow-up). Only the physical activity participated in during the three days prior to the interview were assessed, and the sample size was quite small, consisting of predominantly Caucasian, middle-class families (therefore generalizability may be limited).

Bradley et al.[56] examined changes in specific activities of elementary, middle, and high school students longitudinally over six years of follow-up. The primary outcome measure was a self-report of the three activities respondents did most often. This was used to estimate their typical activity patterns, with activities being classified by intensity level. In each grade, males reported more vigorous activities than females. Overall, there was a decrease in the number of vigorous activities reported as subjects graduated to higher grades.

Three studies examined change in habitual physical activity (HPA). Van Mechelen et al.[28] assessed HPA annually from age 13 to 16 years in Dutch male and female subjects, with another follow-up assessment at age 21. Data were collected from subjects in a secondary school in Amsterdam as part of the Amsterdam Longitudinal Growth and Health Study, which began in 1977. The physical activity measure included participation in organized sport activities, non-organized sport activities and other leisure time activities, transportation to school, work, etc., and work-related activities. However, to be included in the HPA measure, an activity had to equal or exceed an intensity of four METs (activities of moderate intensity). Sex-specific analyses revealed that from age 13 to 16 years, males decreased their total HPA by 20%, but then increased their HPA by 5% between ages 16 and 21. There was a lesser change observed in females: their HPA decreased by only 3% between ages 13 and 16, but increased their HPA by a similar 5% between ages 16 and 21. The time trends for both males and females, however, were not significant. Males were significantly more active than females, and the decline was greater in males than females (such that by age 16, females were 3.5% more active than males). For both sexes at each measurement point, at least 50% of the time was spent doing activities other than organized or non-organized sports (except for males at ages 13 and 14). In fact, at age 21, participation in organized and non-organized sport activities contributed relatively little to the total amount of physical activity for both sexes. This is likely due to the fact that most participants would have left high school between the interviews at age 16 and age 21, and consequently there are fewer options for team sports.

Kimm et al.[27] examined patterns of physical activity throughout adolescence in females only using data from the National Heart, Lung, and Blood Institute's Growth and Health Study, and also noted increases in participation during late adolescence. Baseline data collection began in 1985, when subjects were aged nine and ten who were recruited from schools in California and Ohio, as well as from a large health maintenance organization in Washington, DC. Follow-up was conducted annually until ages 18-19 years. Two self-report instruments were used: a three-day Activity Diary (AD) to capture detailed, short-term activity, completed for two consecutive weekdays and one weekend day, and a Habitual Activity Patterns Questionnaire (HAQ) to assess habitual activity during the past year. The HAQ assessed the type and frequency of participation in physical activity but was limited to activities done outside of school. A Caltrac Activity Monitor was also used in years three to five. Over the entire study period, there was a significant decline of 35% in the activity diary scores (expressed in MET-minutes/day; see Table 2.1), suggesting that the level of females' daily activity declined by 35% from ages 9-10 to ages 18-19 years. HAQ scores showed a greater decline: 83% from ages 9-10 to 18-19. However, a more detailed analysis over time (by study year) revealed an increase in participation from ages 16-17 to ages 18-19 years (according to both the AD and the HAQ), although the level of physical activity did not achieve the same level as at baseline (aged 9-10 years).

Using the same data and follow-up period, Kimm et al.[54] examined the HAQ scores separately for black and white females. There was a consistent decline in median HAQ scores over the entire study period: by 100% in black females and by 64% in white females. More specifically, by year eight, 56% of black females and 31% of white females had HAQ scores of zero. The median HAQ scores, however, increased among white females after year eight (aged 17-18 years). The mean annual declines in HAQ scores were greater at the older ages for both races: from years five to eight, from 4.1 MET-times per week for black females and 3.5 for white females, whereas annually from years one to five, the decline was 3.5 MET-times per week for black females and 2.7 for white females, annually.

Summary

Despite substantial variation between studies in the characteristics of the sample, in the methods, and in the type of physical activity measured, the results of the longitudinal studies reviewed here indicate that physical activity generally declines through adolescence. Studies have reported reductions specific to organized and non-organized sports, moderate and/or vigorous activities, and in habitual physical activity. All studies consistently reported that males participated in more activities than females, and although the participation in physical activity decreased for both sexes as they got older, five studies found that males decreased their activity level at a faster rate than females.[25;26;28;29;53] Three studies reported increases in physical activity as subjects grew older,[27;28;54] namely in the late-adolescent years (at approximately age 16 years), but the increases followed years of steady decreases and thus, did not reach the same level of participation as at baseline.

All longitudinal studies reviewed had subject follow-up intervals of either one-year[25;27;28;53;55] or three-years.[26;29;57] One study assessed the subjects at six-month intervals,[58] but only reported the baseline and annual follow-up measures. Assessment of physical activity behaviours using shorter follow-up time intervals (i.e., every two months) could provide a more accurate description of how physical activity levels change through adolescence. It might identify ages where physical activity increased (i.e., upon entry to high school when opportunities to play sports increases[59]), or ages where the decline was greatest.

Furthermore, identifying predictors of physical activity assessed over short time intervals may help to explain patterns of physical activity throughout adolescence; specifically, which factors predict increasing activity, and which factors predict decreasing activity. This kind of data will help inform interventions targeted at this age group in order to prevent or minimize reductions in physical activity.

2.4 Predictors of physical activity in adolescents

Identification of the determinants of physical activity provides the groundwork needed to develop more effective physical activity promotion interventions, particularly if these determinants can be targeted for change.[60] To date, information on the determinants of physical activity relies largely on cross-sectional studies, which can only provide information on factors associated with physical activity (referred to as correlates). Inferences regarding causality cannot be made based on cross-sectional data.[61] Although longitudinal studies are necessary to examine predictors of physical activity behaviour, few have been conducted to date in adolescents.

2.4.1 Theoretical models

Studies of determinants of physical activity are typically based on theories of behaviour, such as the Theory of Reasoned Action[33;34] and the Social Cognitive Theory.[29;33-35;62] Ecological frameworks have also been used to examine interactions between the individual and multiple levels of the environment (e.g., social, organizational, community, and legislative/policy influences).[63] Potential influences have been classified into five categories, based on previous reviews on determinants of physical activity:[60;64;65]

1. demographic and/or biological factors ;
2. psychological/cognitive/emotional factors ;
3. behavioural attributes/skills;
4. social/cultural factors;
5. indicators of the physical environment.

Table 2.2 summarizes the most commonly studied predictors/correlates of physical activity in adolescents in both cross-sectional and longitudinal (published) studies. Numerous other predictors/correlates have been examined but were not incorporated into the table because there was relatively limited evidence about their potential value as predictors (i.e., they were infrequently studied), or because they were captured under the subheadings presented in Table 2.2. Appendix A presents a thorough review of the studies reviewed (including a description of the study population, analytical techniques, each predictor/correlate examined, and the main findings).

2.4.2 Demographic/biological factors

As shown in Table 2.2, the most commonly studied demographic and biological factors examined include sex, age, and race. In all studies comparing sex,[33;37;63;66-68] males were consistently more active than females.

Table 2.2. Summary of the results of studies on the predictors/correlates of adolescent physical activity (PA).€

	Demographic/biological factors					Psychological/cognitive/ emotional factors							Behavioural attributes/ skills					Social/ cultural factors		Physical environ- ment	
Reference	Sex	Age	Race	SES [a]	BMI	Self-efficacy	Benefits of PA [b]	Barriers of PA [c]	Stress	Depression	Body image [d]	Academic grades	Smoking	Alcohol	Healthy diet	Sedentary activity [e]	Previous activity	Support from family/friends	Parent's PA level	Season	Availability of PA resources
Longitudinal Studies:																					
Motl et al.,[52] 2005																	*F				
McMurray et al.,[37] 2003	*																				
Neumark-Sztainer et al.,[35] 2003						*F		*F										*F			
Aarnio et al.,[69] 2002	S			*M									*M *F		*M *F						
Kimm et al.,[54] 2002				*F	*F								*F				*F				
Schmitz et al.,[70] 2002	S		*M	*M *F																	
Bradley et al.,[56] 2000	S		*M *F																		
DiLorenzo et al.,[29] 1998	S					*F		*F													
Dovey et al.,[57] 1998	C																				
Crocker et al.,[66] 1997	*	*																		*	
Raitakari et al.,[71] 1994	S														* *M *F						
Norris et al.,[14] 1992									*												

Reference	Demographic/biological factors					Psychological/cognitive/ emotional factors							Behavioural attributes/ skills					Social/ cultural factors		Physical environ-ment	
	Sex	Age	Race	SES [a]	BMI	Self-efficacy	Benefits of PA [b]	Barriers of PA [c]	Stress	Depression	Body image [d]	Academic grades	Smoking	Alcohol	Healthy diet	Sedentary activity [e]	Previous activity	Support from family/friends	Parent's PA level	Season	Availability of PA resources
Reynolds et al.,[34] 1990	S				*F	*M *F			*F								*M *F				
Cross-sectional studies:																					
Allison et al.,[72] 2005‡	C									*											
Fein et al.,[63] 2004	*																	*			*
Kirkcaldy et al.,[73] 2002‡										*			*								
Strauss et al.,[33] 2001	*	* C				*		* ?								*					
Gordon-Larsen et al.,[74] 2000	C	C	C	* C *M																C	
Gordon-Larsen et al.,[75] 1999	C	C	C	C																C	
Sallis et al.,[31] 1999	S			*M	*F		*M *F	*M *F										*M*F			
Bungum et al.,[32] 1997		*F				*F	*F									*F					
Pate et al.,[76] 1996	C	C	C								*	*	*	*							
Heath et al.,[67] 1994	*	*F																			
Page et al.,[77] 1994											*										
Zakarian et al.,[62] 1994	S	*M *F	*M			*M *F	*M *F	*M *F			*M *F	*M				*M		*M*F			*M*F
Aaron et al.,[78] 1993	*	*F	*M *F																		
Gottlieb et al.,[68] 1985	*		*	*																	

Notes. Shaded areas represent variables tested. Abbreviations: S—stratified by sex; C—results adjusted for sex; ?—contradictory direction of association

€ For more detailed results, see Appendix A. NOTES CONTINUE ON NEXT PAGE.

* Statistically significant in males and females combined;

*M statistically significant in males only;

*F statistically significant in females only ($\alpha < 0.05$)

[a] SES also includes measures of household income; participation in free/reduced meal program at school; number of parents in household; parental level of education; parental employment/occupation

[b] Benefits of physical activity also includes measures of physical activity attitude; enjoyment of physical activity

[c] Barriers include general barriers; physical activity barriers; social barriers; environmental barriers; perceived barriers; mother/father's barriers; cost; time constraints

[d] Body image also includes satisfaction with body weight; weight perception; perceived attractiveness; physical appearance

[e] Sedentary activity includes measures of TV-watching; computer/video game-playing

‡ Depression measure also includes anxiety

Studies that did not examine the predictive effect of sex either stratified the analysis by sex,[29;31;34;56;62;69-71] adjusted for sex,[57;72;74-76] or the sample consisted of females only.[32;35;52;54] On balance, physical activity decreases as teenagers get older. Cross-sectional studies found significant differences between ages such that younger subjects participated in more activity than older subjects.[32;33;62;67;78] This is consistent with the longitudinal studies reviewed in the previous section—that physical activity decreases with age. However, age was not a significant predictor in four[35;37;56;70] of the five[35;37;56;66;70] longitudinal studies presented in Table 2.2.

Race was an inconsistent predictor, particularly when comparing race by sex. Some studies found that Caucasian subjects participated in more physical activity than African-American or Asian subjects.[68;70;78] This was most consistent among males than among females; Bradley et al.[56] found African-American females participated in more physical activity than Caucasian females.

Socioeconomic status (SES) has been examined in this literature. Several measures such as parental educational attainment,[31;54;70;74] number of parents in the household,[31;54;70] and parents' employment[68;70] were used as proxy measures for SES. Higher SES is typically assumed to be predictive of higher physical activity levels; six[31;54;68-70;74] of nine[31;32;54;68-70;74;75;79] studies found this association.

Body mass index (BMI) is a biological factor used to measure overweight and obesity and is hypothesized to be negatively associated with physical activity levels. Three studies found that a higher BMI is predictive of lower activity, but for females only;[31;34;54] the other three studies found BMI was not predictive/correlated with physical activity.[32;35;77]

2.4.3 Psychological/cognitive/emotional

Self-efficacy and other Social Learning variables (e.g., barriers/benefits of physical activity) were the most commonly studied predictors of physical activity in this category. Self-efficacy is a measure of self-confidence to be physically active; generally, higher self-efficacy is hypothesized to be predictive of higher physical activity. Six[29;32-35;62] of the eight[29;32-35;52;62;63] studies which examined self-efficacy reported this relationship. Self-worth was a significant predictor of change in moderate physical activity and vigorous physical activity,[35] although self acceptance was not.[35]

Perceived benefits of physical activity were found to be positively associated with physical activity in all cross-sectional studies,[31;32;62] but were not significant predictors in the two longitudinal studies which examined this factor.[29;35] Barriers to physical activity, such as social barriers, cost, and time constraints, are hypothesized to be negatively associated with physical activity. Four studies[29;31;35;62] provided evidence to support this hypothesis although one study contradicted this assumption: perceived barriers were found to be positively associated with physical activity in subjects aged 10-16 years.[33] Two studies[32;52] found no significant association between perceived barriers and physical activity.

Stress and depression are hypothesized to be negatively associated with physical activity. Two longitudinal studies in this review investigated the effects of stress.[14;34] Reynolds et al.[34] found stress to be inversely related to physical activity levels among females, but not among males. In an intervention study, Norris et al.[14] reported that subjects who participated in a ten-week high-intensity training program had significantly lower perceived stress than subjects in either the moderate-intensity or flexibility training groups or the control group. Depression was investigated in five studies,[14;37;70;72;73] but only two (cross-sectional) studies found it was a significant predictor of physical activity (inversely).[72;73] Both studies, however, included a measure of anxiety as part of the depression measure. It should also be noted that in one of these studies,[72] the anxiety/depression measure was only found to be significant in bivariate analysis; it was no longer significant when the model controlled for sex, age, and SES.

Five studies examined the relationship between body image (or similar constructs) and physical activity. The one longitudinal study[35] (which included only females) did not find a significant relationship; three of the four cross-sectional studies[31;62;76;77] found that body image was positively correlated with physical activity.[62;76;77]

Academic grades are also hypothesized to be positively associated with physical activity, such that activity levels should be higher with higher academic achievement. Of the five studies that studied academic grades,[31;32;62;69;76] only two found a significant, positive relationship, one while controlling for sex[76] and the other in males only.[62]

2.4.4 Behavioural attributes/skills

Behavioural attributes and skills include such behaviours as smoking and alcohol use, diet, sedentary activities (TV-watching, video game-playing), and previous/baseline physical activity participation. Seven studies examined the predictive ability of smoking and four found that smokers participated in less activity;[54;69;73;76] the other three studies found that smokers' participation in physical activity did not differ from that of non-smokers.[32;62;71] Of the four studies that examined alcohol consumption, three studies found no association between alcohol use and physical activity.[62;69;73] However, one study found that those who drank more, participated in more physical activity.[76]

Eating a healthy diet was associated with higher physical activity in two of three studies:[69;71;76] those who ate more fruits and vegetables[76] and those who ate breakfast regularly[69] had higher physical activity levels.

Only one longitudinal study examined the predictive ability of sedentary behaviours on physical activity, and no significant relationship was found.[35] All three cross-sectional studies, however, found a significant, negative association, such that higher participation in sedentary behaviours was associated with less physical activity participation.[32;33;62]

Baseline/previous activity level was only considered in longitudinal studies; three of the four[34;52;54;71] found that it was a significant, positive predictor of follow-up activity levels,[34;52;54] although two of these studies included female subjects only.[52;54]

2.4.5 Social/cultural factors

Social and cultural factors relate mainly to perceived support for physical activity shown from friends, family, teachers and coaches. Four of five studies that investigated social support found that social support was predictive of higher levels of participation in physical activity,[31;35;62;63] although one study found no association.[29] Support and modeling from a coach was also a significant predictor, but support and modeling from teachers was not (see Appendix A).[62] Physical activity levels of the mother or father were not predictive of, or correlated with, physical activity in adolescents.[29;31;68]

2.4.6 Physical environment

Factors associated with the physical environment include season, availability of resources, and characteristics of the neighbourhood. The extent of, and impact of, seasonality differences depend on the country of research; Canada has a highly variable climate with considerably colder winters. Therefore, it is hypothesized that participation in physical activity would be lower in the winter months. Only two studies measured season as a predictor/correlate of physical activity,[66;74] although one adjusted for season in the analysis.[75] Of the two studies, one conducted nationally in the United States found no association between season and physical activity,[74] and the other (conducted in Saskatchewan) found that activities were higher in the spring than in the fall or winter.[66]

Three studies investigated access to recreational/environmental facilities, hypothesizing that lower access would be associated with lower levels of participation in physical activity.[29;62;63] Two studies supported this hypothesis: resources available in the home, neighbourhood, and school[63] and access to recreational facilities[62] were significant predictors of higher physical activity.

Summary

This review of predictors/correlates of physical activity behaviours in adolescents shows there has been limited research conducted in this area within the adolescent population. While demographic/biological factors were examined most frequently, many predictors included in other categories were only examined in one study, and therefore due to a lack of evidence, were not presented in Table 2.2; see Appendix A. This limits the strength of the evidence and suggests a need for further research. The evidence for predictors examined in multiple studies is generally inconclusive; some show evidence of an association with physical activity, others show no association. This also suggests a need for further research. Sex was the most consistent predictor of physical activity in adolescents, such that males participate in more physical activity than females.

2.5 Contributions of this thesis to the literature

The studies summarized in this chapter contribute to our understanding of physical activity behaviour in adolescents, but the studies reviewed have marked limitations, particularly in describing physical activity over time. The longitudinal studies reviewed in Table 2.1 (on page 13) describe patterns of physical activity based on time intervals between assessments that were lengthy, possibly obscuring short-term patterns of change. Furthermore, individuals are likely to have their own distinct pattern of physical activity over time, and few studies considered (or even adjusted for) within-person (intra-individual) change, which may have biased the results. Studies examining predictors or correlates of physical activity were limited, supporting the necessity for further research. Most of these studies were based on simple pre-/post- designs, which provide a baseline estimate and one follow-up measure, ignoring for the most part, that variables change over time. Elucidating the nature of the relation between potential predictor variables and physical activity over time requires that both physical activity and the predictor variables be measured frequently over an adequate follow-up period. Trajectories using sophisticated developmental models are critical to identifying inter-individual change in participation in physical activity with age. These kinds of analyses will help identify critical time periods when adolescents should be targeted for activity promotion interventions. The availability of potential predictor data over time will enhance the ability to determine which factors predict the shape of these trajectories, which in turn can inform the development of more effective interventions.

This thesis will use the multilevel model for change to investigate trajectories of physical activity participation in adolescents. Data were collected approximately every two months from age 12 to age 17 (inclusive). This thesis will also investigate factors that may explain both within-person and between-persons differences in physical activity levels over time. The results of this thesis will further our understanding of adolescent physical activity behaviours and predictors of change, which can be used to improve existing efforts and interventions aimed at youth of this age group.

CHAPTER THREE: METHODS

This chapter is divided into two parts. Since this thesis is a secondary analysis of data collected in the McGill University Study on the Natural History of Nicotine Dependence in Teens (NDIT),[80;81] the first section (3.1) describes the methods used in the NDIT Study, including the study design, method of sample selection, data collection methods, and the survey instrument. The second section (3.2) describes the methods used in this thesis. More specifically, the study sample is described based on inclusion and exclusion criteria and missing data; the study variables are defined; and all analytical techniques, including preliminary, exploratory, and explanatory strategies are described.

3.1 NDIT Study Methods

3.1.1 Study Design

The NDIT Study is a prospective cohort study (1999-2005) designed to investigate the natural course of early cigarette use and the development of nicotine dependence in novice smokers. The cohort included 1293 students initially aged 12-13 years. Participants were recruited from all grade seven classes in a convenience sample of ten secondary schools in Montreal, including seven English and three French schools. Data were collected with self-report questionnaires every two to three months during the ten-month school year. Ethics approval for the study was obtained from the McGill University Faculty of Medicine Institutional Review Board.

Although the primary purpose of the NDIT Study was to describe the development of nicotine dependence symptoms in relation to tobacco exposure, data were also collected on a variety of other behaviours, indicators of health status and possible health determinants. These included (among others): level of physical activity, anthropometric characteristics, blood pressure, and psychosocial characteristics including symptoms of stress and depression. Blood samples were collected for investigation of a possible genetic predisposition to tobacco use and nicotine dependence.

The present thesis uses data from the NDIT Study to describe patterns in physical activity participation over time among adolescents during their secondary school years, and to identify factors associated with changes in physical activity levels over time.

3.1.2 Sample

Description of schools

Secondary schools were selected based on consultation with school boards and school principals to identify a mix of French and English schools, urban, suburban, and rural schools, and schools located in high and low socioeconomic neighbourhoods, all with a relatively low turnover of students. Thirteen schools were approached and agreed to participate. However, two schools were excluded due to a very low return rate of signed parental consent forms, and one school was excluded because the school administrators could not guarantee cooperation over the entire study.

Recruitment of subjects

All students in all Secondary I (grade 7) classes at participating schools were invited to participate in the NDIT Study. Potential subjects were given an information letter to bring home to their parents. Signed informed consent was obtained from all subjects and from a parent/guardian.

3.1.3 Response

Over half of eligible students (56.2%) participated in the baseline data collection. This relatively low response rate was due, in part, to a labour dispute in Quebec that resulted in teachers in several schools refusing to collect consent forms. The need for blood sampling for genetic analysis also likely impacted adversely on the response rate.

3.1.4 Data collection methods

Baseline data were collected in the fall 1999. Subjects completed a 45-minute questionnaire administered either in the classroom or in the school cafeteria to groups of classes. Questionnaire administration was repeated at approximately two to three month intervals during the ten-month school year. Most data collection took place during the months of October, January, March, and May. Alternative data collection dates were scheduled for students who were not available on the originally scheduled date.

The NDIT questionnaire was administered in French or English according to the language used in each school. Trained technicians measured height, weight, waist circumference and triceps and subscapular skinfold thickness according to a standardized protocol[82] at baseline and then again at the end of year three (spring 2002).

3.1.5 Survey Instrument

The NDIT questionnaire collected data on behaviours (including cigarette smoking, use of alcohol, and participation in physical activity, among others), psychosocial variables (including symptoms of stress and depression, among others), and sociodemographic characteristics. The items relevant to this thesis are described in detail in Section 3.2.5. The specific questionnaire items for all variables included in this thesis are presented in Appendix B.

3.2 Methods specific to thesis

This section describes the methods specific to the thesis analyses, including data preparation, variable definitions and analysis. The NDIT team provided the study data files containing all requested variables (a total of 103 variables per wave of data collection) for 1293 subjects (623 male and 670 female). Prior to the start of the analysis, ethics approval was obtained from the Ottawa Hospital Research Ethics Board.

3.2.1 Data processing

There were 18 survey cycles (data collection waves) available for analysis in this thesis (4.5 years of data). Each wave of data was entered into a separate SAS file. NDIT staff provided a copy of each file which contained the relevant variables for the thesis analyses. The individual files were combined into a master file with the variables renamed to indicate the data collection wave in which they had been collected. This file was then restructured to create a person-period structure in which each subject had multiple records, one for each wave of collection.[83]

Each subject in the study had his/her own unique identification (ID) number to facilitate tracking and merging of data on single subjects.

3.2.2 Inclusion/exclusion criteria

The analysis was restricted to data collected when subjects were between age 12 and 17 years inclusive. There were only 22 measurement points for 11-year-olds and eight points for 18-year-olds. Subjects were required to have physical activity (outcome) measures for at least four time points to be eligible for inclusion in this analysis. Only 6.7% of subjects were excluded for this reason.

The final data set included 1206 subjects (579 males, 627 females) with results for up to 18 waves of data when subjects were aged between 12-17 years (for a total of 17,172 data points).

3.2.3 Missing data

A serious problem in longitudinal studies is failure to obtain data from all subjects at each wave of data collection, due to drop-out (attrition) or missing one or more intermediate visits.[84;85] In this study, subjects might not have participated in one or more survey cycle for several reasons including absence from school on the day of data collection; moved permanently (reason unknown or reason known); transferred to another school; or refused to continue to participate in the study. Missingness patterns will not be addressed in this thesis.

In order to ensure sufficient sample size over time in the study, the NDIT team accepted new students after the baseline collection cycle. "Late joiners" included those attending participating schools who agreed to participate in the study after the baseline cycle, as well as new students who wanted to participate.

3.2.4 Time scale

The primary goal of this thesis was to describe changes in physical activity as young persons mature through adolescence. The longitudinal nature of the data collection, with multiple observations per subject, allowed a description of the physical activity trajectory for every subject. The objective of the modeling process was to describe the shape of these trajectories, as well as identify factors that explain differences in trajectories between subjects.

The analysis models activity changes in relation to age. We considered using calendar time rather than age, which would have identified grade-specific changes more easily than using age. However, age is the primary marker of the physiological changes which occur during the adolescent years, as well as a key marker of changes in the social environment.

Age was derived based on the subject's date of birth and the date of questionnaire completion, thus producing a continuous measure of age. As recommended in the literature,[83] age was centered in the regression analyses at the approximate mean age of subjects (14.5 years) over follow-up. This reduces collinearity between age and higher-order polynomials of age (i.e., age^2, age^3).

3.2.5 Study variables

Dependent variable

The NDIT questionnaire included a seven-day physical activity recall, which was used to develop the outcome measure investigated in this thesis. The seven-day activity recall provided a measure of the frequency of physical activity during the week preceding the questionnaire. Specifically, students were asked to check, for each day, which activities (from a list of 29 activities; Table 3.1) they had participated in for at least five minutes. This instrument was adapted from Sallis's Weekly Activity Checklist,[43] which has been validated in fourth grade students, and is presently used in the SPARK Project.[86] The SPARK version asked respondents to complete a daily check list for a range of activities in which they participated for at least 15 minutes.

Table 3.1. List of activities included in the seven-day recall of participation in physical activity, in the NDIT questionnaire.

- Bicycling to school, bicycling to do errands, going for a bicycle ride
- Swimming/diving
- Basketball
- Baseball/softball
- Football
- Soccer
- Volleyball
- Racket Sports (badminton, tennis)
- Ice hockey/ball hockey
- Jump rope
- Downhill skiing, snowboarding
- Cross-country skiing
- Ice skating
- Rollerblading, skateboarding
- Gymnastics (bars, beams, tumbling, trampoline)
- Exercise / physical conditioning (push-ups, sit-ups, jumping jacks, weight-lifting, exercise machines)
- Ball-playing (dodge ball, kickball, wall-ball, catch)
- Track and field
- Games (chase, tag, hopscotch)
- Jazz/classical ballet
- Dancing (aerobic, folk, at a party)
- Outdoor play (climbing trees, hide and seek)
- Karate/ Judo/ Tai Chi/ Kung Fu
- Boxing, wrestling
- Outdoor chores (mowing, raking, gardening)
- Indoor chores (mopping, vacuuming, sweeping)
- Mixed walking / running / jogging
- Walking
- Running/Jogging
- Other(s) → Name them

The original instrument correlated with an objective activity measure (Caltrac accelerometer) at r=0.34 ($p < .01$), with a three-day test-retest reliability coefficient of 0.74.[43] The NDIT Study modified the checklist by reducing the time of participation to five minutes in order to include all activities in which subjects had participated, even if only for a very short period of time. The list of activities was also adapted to better reflect the physical activities commonly engaged in by adolescents in Montreal. Students were provided with the option to add any activity not listed in the checklist. No information was available about the length of time the student spent on each activity.

The number of activities reported in the seven-day activity recall was summed for each student to provide a continuous score indicating the number of physical activities participated in during the previous week. This score was used as the main outcome measure investigated in this thesis. Scores ranged from 0 to 154 (median=15.0; mean=19.7; standard deviation=15.6).

Candidate predictor variables

The NDIT questionnaire also collected data on a range of factors hypothesized to be associated with physical activity behaviours. These factors were either time-invariant (fixed; not changing over time) or time-varying (changing over time). Consistent with previous reviews on determinants of physical activity,[60;64;65] the candidate predictor items were classified into four categories: 1) demographic/biological factors, 2) psychological/emotional factors, 3) behavioural attributes, and 4) indicators of the physical environment.

The 11 candidate predictor variables examined in the analysis are summarized in Table 3.2.

Table 3.2. List of candidate predictor variables examined in the analysis.

Category	Variable	Level of measurement	Range / Groups
Demographic/ biological	Sex	Dichotomous	Male* vs Female
	Subject country of birth	Dichotomous	Born in Canada* vs Born outside Canada
	Parent's country of birth	Dichotomous	Both parents born in Canada* vs One or both parent(s) born outside Canada
	Baseline BMI	Continuous	13.3 – 39.8
Psychological/ emotional	Depression score	Continuous	1.0 - 4.0 (higher score means more depressed)
	Stress score	Continuous	1.0 - 4.0 (higher score means more stressed)
Behavioural attributes	TV-watching (hours per day)	Continuous	0 – 18
	Computer/internet/video game-playing (hours per day)	Continuous	0 – 18
	Alcohol use	Dichotomous	Does not drink at least once per month* vs Drinks at least once per month
	Cigarette smoking	Dichotomous	Does not smoke everyday* vs Smokes everyday
Physical environment	Season	Categorical	Spring* vs Fall or Winter

Note. * denotes reference group.

Demographic/biological items

Candidate predictor variables in the demographic/biological category included sex, country of birth of student, and country of birth of the biologic father and mother. Each of these factors was a time-invariant (dichotomous) candidate predictor. The information regarding these variables was collected at replicate interviews; the replicate information was checked for consistency throughout the study.

Baseline body mass index (BMI) was also included in this category. BMI was calculated based on physical measures of height and weight (taken by trained technicians at baseline). Height was converted to meters and weight to kilograms. BMI was then calculated according to the standard formula: weight(kg)/height(m)^2. Although BMI was collected at two waves, only baseline values were examined because there were fewer than the four data points per subject needed for the trajectory analysis. Therefore, baseline BMI was a continuous, time-invariant candidate predictor variable.

Psychological/emotional items

Psychological/emotional factors included symptoms of depression and stress. Depression symptoms were measured using a validated scale[87-90] which comprised six items. Subjects were asked to report how often in the past three months they had experienced each of the following: too tired to do things; trouble going to sleep or staying asleep; feeling unhappy, sad or depressed; feeling hopeless about the future; feeling nervous or tense; worrying too much about things. Responses ranged from *never* to *often* on a 4-point scale. Depression symptoms were measured as the mean value of the summary score based on these six items. Subjects who did not complete at least 60% of the items (i.e., 4 of 6 items) were assigned a missing value for their depression score at that wave. The available items were summed and the sum was then divided by the number of valid responses to obtain a depression score between 1 and 4. Higher scores represented more depression symptoms. This variable was a continuous, time-varying candidate predictor, measured at each data collection wave.

Stress was measured using a 13-item scale.[91] Subjects reported how much they had been worried or stressed (*not at all, a little bit, quite a bit,* or *a whole lot*) during the past three months by any of the following factors: parents separating or divorcing, loneliness, breaking up with a boy or girlfriend, relationship with father, relationship with mother, relationship with sibling, relationship with friends, a health problem, weight, sex, a new family, financial problems in family, or school work. Symptoms of stress were measured as the mean value of the summary score based on these 13 items. Subjects who did not complete at least 60% of the items (i.e., 8 of 13 items) were assigned a missing value for the stress score at that wave. The available items were summed and the score was divided by the number of valid responses to obtain a stress score between 1 and 4. Higher scores represented more symptoms of stress. This variable was a continuous, time-varying candidate predictor, measured at each data collection wave.

Behavioural attributes

Data on behaviours other than participation in physical activity included sedentary activities (time spent watching television (TV); time spent using the computer or internet, or playing video games), use of alcohol, and cigarette smoking. Each behavioural attribute was asked at each data collection wave.

Subjects were asked to report how many hours, on average, they watched television per day. They provided separate estimates for weekdays and weekends. The average amount of time spent watching TV (daily) was computed from the weekday and weekend estimates using the calculation: (average hours during the week * 5) + (average hours on weekend * 2) / 7 days per week. TV-watching was a continuous, time-varying candidate predictor.

Subjects were also asked to report how many hours per day, on average, they played on the computer, used the internet, or played video games. Estimates were provided separately for weekdays and weekends; therefore the average time spent (daily) on these activities was computed from the weekday and weekend estimates using the calculation: (average hours during the week * 5) + (average hours on weekend * 2) / 7 days per week.
Computer/internet/video game-playing was a continuous, time-varying candidate predictor.

It was decided *a priori* that any reported value over 18 (hours per day) for the measures of TV-watching and computer/internet/video game-playing would be discarded as a reporting error (and therefore set to missing), since it is effectively impossible to watch TV or play video/computer games more than 18 hours per day.

Alcohol use during the previous three months was measured on a 6-point scale with responses ranging from *never* to *everyday*. For this analysis, a respondent was categorized as using alcohol if he/she reported drinking alcohol at least once per month during the three months preceding the interview. Alcohol use was a dichotomous, time-varying candidate predictor.

Cigarette smoking was measured on a 6-point scale ranging from "I *have never smoked a cigarette*" to *"I smoke cigarettes every day"*. A respondent was considered to be a smoker if he/she reported smoking cigarettes every day. Cigarette smoking was a dichotomous, time-varying candidate predictor.

Physical environment items

The only candidate predictor related to the physical environment was season (fall, winter, spring). The effect of Canada's highly variable climate on physical activity participation was explored by defining a variable to reflect the season in which each questionnaire was completed. These were grouped into seasons according to calendar dates: Spring (March 20 to June 21), Summer (June 22 to September 21); Fall (September 22 to December 20) and Winter (December 21 to March 19). Since the only questionnaires completed during the summer were collected within two days of the start of fall (nine subjects on September 20, 2000; five subjects on September 21, 2000), these observations were allocated to the fall season and the summer season was excluded from the analyses. Season was a categorical variable, with spring as the reference category and dummy variables for fall and winter. Season was a time-varying candidate predictor, measured at each data collection wave.

3.2.6 Analysis

Selection of analytical technique

Longitudinal data involves the collection of data on the same subject from at least two distinct time points. The focus is on the within-person change or trajectory. Predictors or determinants of the outcome will often influence the trajectory of change (e.g., the slope of a linear trajectory) rather than altering a mean value. In addition, within-subject observations display auto-correlation which can lead to violation of the standard assumption of independence between data points, which is required for traditional analyses such as analysis of variance (ANOVA) and ordinary least squares (OLS) regression. Therefore standard analytical approaches cannot be applied[92] and statistical techniques that account for repeated observations of the same individual are required.[84] A range of techniques were considered for this thesis.

In addition to the issues outlined above, specific features of the study design must be considered. The simplest design involves collecting information from every subject at each data collection wave (a balanced design) where the waves are spaced at equal time intervals (time-structured). The outcome variables can be either continuous or categorical.

For a balanced, time-structured design, multivariate analysis of variance (MANOVA) or ANOVA for repeated measurements can be used. However, both require that each subject in the sample have complete data; if one subject is missing data for one time point, all other data for that subject are deleted from the analysis. These methods are inappropriate when there are unequal time intervals between measurements (time-unstructured). Since the NDIT data involved an unbalanced, time-unstructured design, MANOVA and mixed model ANOVA were ruled out as possible analytic techniques.

Time series and survival analysis are two alternative techniques for analyzing longitudinal data. Time series analysis can identify patterns/trends over time and can be used to predict future events or occurrences. However, it is based on the assumption that succeeding values in the data file represent consecutive measurements taken at equally spaced intervals (i.e., time-structured). Survival analysis is used to describe whether and/or when events such as death occur. The outcome measure in this thesis is not an "event" and therefore survival analysis was not appropriate.

OLS methods can be applied to estimate within-subject trajectories. A separate regression analysis is performed for each subject, leading to a set of regression coefficients, and the distribution of these coefficients can be examined to identify trajectory patterns. While OLS provides unbiased estimates of the subject-specific coefficients, statistical testing is invalid due to auto-correlation. However, OLS regression methods are suitable for an initial examination of unbalanced, time-unstructured designs.

The Random Coefficient model is an extension of the OLS approach which treats the regression coefficients of the OLS regression models as random variables rather than as fixed values, unique to each subject. This approach forms the basis for the Multilevel Model for Change, the analytic approach which is adopted in this thesis. This technique does not require the data set to be balanced, nor does it require it to be time-structured; it is also designed for continuous outcomes, the values of which change over time.[83] In addition, it can quantify variation around the mean at two levels,[55] summarizing the degree to which within- and between-person values differ from the population average values.[93] Consequently, the Multilevel Model for Change was selected as the most appropriate analytic strategy.

Multilevel Model for Change

The multilevel model for change incorporates two independent but linked regression models which are designated as the level-1 and level-2 models. The level-1 submodel describes how each person in the sample changes over time (within-person), and the level-2 model describes how these changes vary across all persons in the sample (between-person).[83] Specifically, once an individual growth trajectory has been specified at level-1, a level-2 model can be postulated to describe how level-1 individual growth parameters are associated with between-subject (level-2) factors, such as sex or country of birth.

The level-1 submodel for individual change

At level-1, the goal is to describe the shape of each subject's individual growth trajectory (i.e., the way his/her physical activity levels change over time). The level-1 component, also referred to as the individual growth model, represents the change we expect each subject to experience during the study period. If the individual growth model changes linearly over time, the level-1 submodel can be described as:

$$Y_{ij} = \pi_{0i} + \pi_{1i}\,(AGE_{ij} - 14.5) + \varepsilon_{ij} \qquad (1)$$

where the subscripts i and j identify individuals and occasions (data collection waves), respectively. The individual growth parameter for intercept (π_{0i}) describes individual i's physical activity level at age 14.5 years; the individual growth parameter for slope (π_{1i}) characterizes the shape of the ith subject's true trajectory of change over time. We can compare inter-individual (between-person) differences in change (at level-2) by studying the inter-individual variation in these growth parameters (since each subject's trajectory differs only in the magnitude of these parameters).

The level-1 submodel also accounts for the effect of random error, ε_{ij}, associated with the measurement of individual i on occasion j, accounting for the differences between true and observed trajectories. Each level-1 residual (ε_{ij}) thus represents the part of subject i's level of physical activity at time j not predicted by his or her age. It is possible to reduce the magnitude of the level-1 residuals by introducing time-varying predictors, other than age, into the level-1 submodel.

There are, however, assumptions about the distribution of the level-1 residuals that must be taken into account. In traditional OLS regression, the residuals are assumed to be normally and independently distributed with mean 0, with a common but unknown variance, σ_{ε}^{2}. This assumption, however, does not usually hold up in longitudinal data.[83] Since the same person is measured on more than one occasion over time, any unexplained person-specific (time-invariant) effect on the residuals will create a correlation across occasions, referred to as auto-correlation.[83;92] In addition the outcome may have a different precision and reliability for individuals at different times, being higher or lower on some occasions over others, having an inconsistent effect for each individual subject. Consequently, the error variance may differ over time, and thus, the level-1 residuals will be heteroscedastic over within-person occasions. This introduces a bias in the estimated variance components, which does not have critical implications for this thesis.

The level-2 submodel for systematic inter-individual differences in change

The level-2 model assumes that the regression coefficients in the level-1 submodel are random variables. It develops a second regression model which uses the level-1 regression coefficients as the dependent variable and time-invariant predictors as the independent variables. The goal is to identify heterogeneity in change across individuals, and to determine the relationship between time-invariant predictors and the shape of each person's individual growth trajectory, assessing inter-individual (between-person) differences in change.[83] Modeling the individual growth parameters from the (linear) level-1 submodel, and testing if they differ by sex (a time-invariant predictor), we can write the level-2 submodels as:

$$\pi_{0i} = \gamma_{00} + \gamma_{01}\mathrm{SEX}_i + \xi_{0i} \tag{2}$$

$$\pi_{1i} = \gamma_{10} + \gamma_{11}\mathrm{SEX}_i + \xi_{1i} \tag{3}$$

In general, the two components consider the intercept (π_{0i}) and the slope (π_{1i}) of an individual's growth trajectory as level-2 outcomes that may be associated with the predictor, sex, allowing each component to have its own residual - ξ_{0i} and ξ_{1i}, which are assumed to follow a bivariate normal distribution with mean 0, and unknown variances, σ_0^2 and σ_1^2, and unknown covariance, σ_{01}. These assumptions can be expressed as: $\begin{bmatrix}\xi_{0i}\\ \xi_{1i}\end{bmatrix} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}\begin{bmatrix}\sigma_0^2 & \sigma_{01}\\ \sigma_{10} & \sigma_1^2\end{bmatrix}\right)$. The two level-2 submodels have seven population parameters: four regression parameters (the γ's), two residual variances (σ_0^2 and σ_1^2), and a parameter representing the covariance between the residuals (σ_{01}). The regression parameters — γ_{00}, γ_{01}, γ_{10} and γ_{11} –are known collectively as the fixed effects: γ_{00} and γ_{10} are level-2 intercepts, γ_{01} and γ_{11} are level-2 slopes. The fixed effects capture inter-individual differences in change trajectories according to values of the level-2 predictors, in this case, sex. The three residual parameters (ξ_{0i} and ξ_{1i}) and the covariance between them (which are labeled σ_0^2, σ_1^2, and σ_{01}, respectively), represent the portion of the level-2 outcomes that remain unexplained by the level-2 predictors. Specifically, the variance σ_0^2 represents the population residual variance in true physical activity level at age 14.5 years, and σ_1^2 represents the population residual variance in true annual rate of change. Finally, the covariance σ_{01} represents the relationship between the unexplained variance components, permitting the level-2 residuals to be correlated, and thus summarizing the association between individual status at age 14.5 years and individual rates of change.

We must also make assumptions about the level-2 residuals. In this example (of a linear change trajectory), the residuals are assumed to follow a bivariate distribution: the two level-2 residuals ξ_{0i} and ξ_{1i} are bivariate normal with mean 0 and unknown variances, σ_0^2 and σ_1^2, and unknown covariance, σ_{01}.

Composite specification

The level-1 and level-2 models can be combined algebraically into one composite model. This specification is required by some statistical software programs, including SAS, and represents a more parsimonious way to codify hypotheses.[83] This composite model reflects the conceptual framework behind the multilevel model: focus first on individual change, and next on inter-individual differences in change.

By substituting the level-2 models into the level-1 submodel, the composite specification becomes:

$$Y_{ij} = \gamma_{00} + \gamma_{10}\,(\mathrm{AGE}_{ij} - 14.5) + \gamma_{01}\,\mathrm{SEX}_i + \gamma_{11}\,\mathrm{SEX}_i\,(\mathrm{AGE}_{ij} - 14.5)$$

$$+ \xi_{0i} + \xi_{1i}(\text{AGE}_{ij} - 14.5) + \varepsilon_{ij} \tag{4}$$

This substitution results in a cross-level interaction (associated with γ_{11}) between the time-invariant predictor and (temporal) age. This examines the possibility that the effect of age on physical activity trajectories differs by sex.

Interpretation of the parameters can be described using the composite model in equation (4). In this case, we have modeled a linear change trajectory of physical activity over time (i.e., with age centered at 14.5 years) that assesses inter-individual differences based on the time-invariant predictor, sex. In particular, the fixed effects (the γ's) describe the average change trajectories for individuals distinguished by sex; γ_{00} and γ_{10} are the intercept and slope for the average change trajectory of males (the reference group for sex), ($\gamma_{00} + \gamma_{01}$) and ($\gamma_{10} + \gamma_{11}$) are the intercept and slope for the average change trajectory of females.

The random effects (associated with the corresponding fixed effect) quantify the variation around these (fixed effect) estimates. If the level-1 variance component is significant, we conclude that, for an individual, physical activity levels vary over time; also, that there is within-person variation that can still potentially be explained by modifying the trajectory shape through inclusion of higher-order polynomials of time (age) or by adding other time-varying predictors to the model. If the level-2 variance components are significant, we conclude that individuals vary from one another in their level of physical activity (for intercept) and their rate of change (for age) to an extent greater than would have been expected by chance. We can also say that there is variation at that level that can still potentially be explained by adding other predictors to the model. One benefit of the composite model is that the (time-invariant) residuals in the composite model (ξ_{0i}, ξ_{1i}) adjust for both auto-correlation and heteroscedasticity within-persons.

Computer software for analysis

All analyses were conducted using SAS version 8 (SAS Institute, Inc., Cary, NC). Multilevel modeling was carried out using SAS PROC MIXED. An unstructured covariance structure was chosen to estimate the variance-covariance matrix, in order to estimate a separate variance/covariance component for each of the elements in the model.[94] This structure was chosen because it is the most suitable for data with unequally spaced intervals.[95] Full Unrestricted Maximum Likelihood Estimation methods (MLE) were used to estimate the growth trajectories (model parameters).

3.2.7 Data analysis

Preliminary analysis was conducted to detect data quality issues, problems with variable definitions, etc. Exploratory analysis was conducted to identify the general shape of physical activity behaviours over time, in preparation for building the multilevel model. Finally, explanatory analyses (the focal analytic techniques for this thesis), were used to identify quantitative trajectories and the impact of candidate predictor variables.

Preliminary analysis

Data clean-up

Preliminary analysis involved a thorough examination of the data to identify outliers, errors, and missing values. Descriptive statistics were produced at each time point to identify unusual or implausible values (e.g., subjects who reported playing more than 18 hours of video games per day); these were detected based on frequency distributions (for categorical variables), and by examining mean, range, and variance (for continuous variables). If we identified a value which was a data entry error, corrections were made to the data file. Values which were implausible but which were verified as correct by the NDIT office were re-coded as missing. No subject had the physical activity score re-coded since even the highest level (154 activities per week) was considered possible if the subject was very physically active. All time-invariant candidate predictors were assessed for consistency of the results obtained at multiple data collection times; it was decided *a priori* that for those subjects with inconsistent responses, their fixed variables would be based on their baseline survey. The only exceptions were when responses were the same at each time point except at baseline: the consistent response was used as the value for the fixed variable. Only two subjects required corrections due to data entry errors, 72 subjects required corrections due to inconsistent (time-invariant) responses, and 54 subjects required re-coding due to implausible values.

Exploratory analysis

Exploratory analyses served to identify important features of the data and to prepare for model building.[83] Before defining a level-1 growth model, it was necessary to conduct a number of exploratory descriptive analyses to detect general trends (or shapes) in subjects' physical activity behaviours over time. This involved an investigation of empirical growth plots (i.e., subject-specific graphs to reveal the trajectory of physical activities levels over time). Two approaches were used to produce these plots: spline curving methods and OLS regression modeling.

Initially, empirical growth plots were produced: the physical activity responses for each subject were plotted on a graph (one graph for each subject). Spline methods, which do not impose a specific functional form, were used to smooth the curve in each empirical plot.[83] Subsequently, OLS regression, which imposed a linear trajectory model, was conducted within each subject. Each OLS model produced estimates for the model parameters as well as estimates of the residual variance statistic (a measure of the goodness of fit of the model). These were examined using scatterplots to detect extreme values.

For all other (continuous) time-varying predictors (i.e., depression, stress, TV-watching and computer/internet/video game-playing), Loess smoothing methods were used to detect overall temporal trends for these factors.

Distributions of the variables at baseline were examined for significant differences between males and females; chi-square tests were conducted for all categorical variables and Wilcoxon rank-sum tests for all continuous variables (a non-parametric test was required because the continuous variables were not normally distributed).

Explanatory analysis

The explanatory analysis involved examination of a sequence of models. Initially, we explored methods to model the trajectories using two level-1 predictors: age and season. Then, we examined the impact of time-invariant predictors (sex, country of birth, baseline BMI) through a level-2 model. Finally, we examined the impact of time-varying predictors by including them in the level-1 submodel. Analyses were first conducted on the entire sample, but it was decided *a priori* that if physical activity trajectories differed by sex, the analyses would be stratified by sex to model the independent predictors.

The primary time predictor in the level-1 submodel was age. In order to model a curvilinear trajectory, age was included with quadratic (age^2) and cubic (age^3) terms in addition to the linear term. Season was also introduced and controlled for as a level-1 time-varying predictor. As noted earlier, age was centered (by subtracting 14.5) in the models to reduce collinearity with the non-linear terms.

Goodness of fit statistics, including deviance, AIC (Akaike's Information Criterion)[96], and BIC (Bayesian Information Criterion)[97], were used to assess the best fit models for change in physical activity over time. The deviance is based on a likelihood ratio test, and is defined as: –2 times the difference between the residual log likelihoods of two models nested within each other. This statistic can be compared to the chi-square distribution with degrees of freedom equal to the difference in the number of parameters for the two models. Comparison of the deviance for two models requires that models be nested within each other (i.e., the comparison model has constrained parameters that are a subset of those in the model being compared) and both are fit to the identical set of data. If the deviance decreases significantly, the model with the smaller deviance is a better fit than the model with the larger deviance. The AIC and BIC can be compared for any models, regardless if they are nested, but similar to the deviance, they must also be fit to the identical set of data. Both the AIC and BIC apply a penalty to the deviance based on the number of parameters calculated; BIC also penalizes the deviance based on the sample size. Raftery[98] declares a difference in BIC of 0-2 to be "weak", 2-6 to be "positive", 6-10 to be "strong", and over 10 to be "very strong". Improvements to the model should be evident in all three statistics. However, if there were any discrepancies between the measures as to whether a model is better, the final decision was made based on the BIC statistic; in such a case, the effect of the predictor is most likely to be marginal. In addition to these measures of goodness of fit, we also produced pseudo-R^2 statistics, similar to traditional adjusted-R^2 statistics, by comparing the residual variance of the model to a reference model.

All models produced fixed effects (which describe the overall trajectory of the sample) and random effects (the deviations from the overall trajectory).

Hypothesis tests (in the form of a Wald *z*-statistic: the ratio of the estimated variance component to its asymptotic standard error[83]) were conducted to examine the two-sided null hypothesis that, controlling for all other predictors in the model, the population value of the parameter is 0. Tests on the fixed effects help identify which predictors to retain, and thus, which have an effect on physical activity trajectories.

The fixed effects provide the Beta values for the average trajectory for the subjects. The random effects are variance components which can be used to determine the variability of Beta value between individuals. A high variance component suggests that there could be factors not included in the model which might explain the variability in Betas.

All age effects and the intercept were included as random effects, allowing the associated regression parameters to vary across subjects. Significance of the variances of these random effects indicates sufficient variation in the individual trajectories and that there are non-random differences which can still potentially be explained by predictor variables. In particular, significance of the level-1 residual implies the existence of additional outcome variation at level-1. Significance of the level-2 residuals imply the existence of variation in the corresponding level-1 regression parameter: true physical activity status at 14.5 years (variance associated with the intercept), true rate of change (variance associated with age), and in the case of a significant cubic model, in the true quadratic (variance associated with age^2) and cubic variation (variance associated with age^3). Significance of the residual covariance between each level-2 residual summarizes the strength of association between the parameters; for example, the covariance between the true intercept and the true rate of change. It must be noted that the covariances produced by the multilevel model for change do not contribute to the objectives of this thesis, and therefore were not reported or assessed for significance.

Those variables with both a p-value < 0.05 and which improved the goodness of fit of the model (based on measures of deviance, AIC, and BIC) were considered to have an effect on and explain physical activity levels over time. The addition of time-invariant predictors to the composite model automatically produces cross-level interactions between each level-1 predictor and the time-invariant predictor added, and thus was assessed to determine whether age, age^2, age^3, or season effects varied with the predictor. No interactions were generated between time-varying predictors and the variables in the level-1 model. However, if there were *a priori* reasons to believe that a specific time-varying predictor had a different effect on physical activity at different ages, these interactions were derived. This was only the case for depression and stress effects.

Level-1 models

At level-1, physical activity was expressed as a function of age. The overall physical activity trend across subjects was modeled using a nested series of candidate models of increasing complexity. Four primary models were considered: the unconditional means model (which contained no predictors), the unconditional growth model (a linear age effect) and models with quadratic and cubic growth terms. The non-linear terms were included since previous studies have indicated a non-linear association between physical activity throughout adolescence.[27;28] We also considered higher order models, but the complexity and potential for model over-specification were significant issues and, taking into account there has been no prior evidence or theoretical basis to suggest such a complex trend, we decided to limit the models to the cubic term. We allowed the intercept and each time effect to vary across persons (random effects).

The **unconditional means** model includes only a random effects intercept term. It quantifies the total outcome variation across people without regard to time or other predictors and produces a comparison of within- and between-subject variability.[83] This model also provides the benchmark of within-person variance that was used to judge successive models.[99]

The **unconditional growth** model introduces age to the unconditional means model to produce a linear trajectory in activity. The addition of higher powers of age permits the level-1 model to incorporate non-linear trends. With the additional terms, the interpretation of the model becomes more complex, but as we describe in the next chapter (Results), these terms were required for describing the physical activity trajectories of this sample. To consider the most complex model, we express the level-1 model for a cubic change trajectory as:

$$Y_{ij} = \pi_{0i} + \pi_{1i}(\text{AGE}_{ij} - 14.5) + \pi_{2i}(\text{AGE}_{ij} - 14.5)^2 + \pi_{3i}(\text{AGE}_{ij} - 14.5)^3 + \varepsilon_{ij}. \quad (5)$$

There are four parameters of a cubic change trajectory: the intercept (π_{0i}), which defines the average physical activity at age 14.5 years, and three higher order polynomials of time: linear time (age, π_{1i}) which defines the slope of the physical activity curve at age 14.5 years, quadratic time (age^2, π_{2i}) which represents the curvature of the slope at age 14.5 years, and finally, cubic time (age^3, π_{3i}) which represents the rate of change of the curvature of the slope at age 14.5 years.

Season

Season was included in the level-1 submodel primarily to adjust for potential confounding. Season was not, however, included as a random effect because it was assumed that the effects of season did not vary across subjects.[34]

Predictor analyses

All models which included predictors were based on the optimal model selected from level-1 (the base model). Hence, the analysis implemented a series of models consisting of the base model and models including various terms to represent the predictor(s) under study. Specifically, potential predictors were added one-by-one to their appropriate component of the multilevel model, and examined for their relationship with physical activity at age 14.5 years, linear age effects, quadratic age effects, and cubic age effects.

The predictor analyses began with the inclusion of sex (at level-2) to determine if physical activity trajectories were different for males and females. As mentioned above, if the fixed effect for sex was significant (an indication that the sex-specific physical activity trajectories are, in fact, different), all predictor analyses were to be conducted separately for males and females. Time-invariant predictors were introduced (at level-2) first, followed by the addition of time-varying predictors (at level-1). In order to ensure statistical comparability of nested models within each predictor analysis, it was necessary to exclude any observations with missing values for any of the variables potentially included in the model. For example, when modeling depression, data points with missing values for age, season and depression were excluded from all models. Essentially this means that various predictor models are based on different sample sizes.

Significance of the fixed and/or random effects, as well as the goodness of fit statistics of the model were assessed to determine which predictors influenced the age-specific trajectories of physical activity in this sample. No attempt was made to examine the joint predictive ability of the predictor variables (in a multivariate model), as this is a preliminary study of physical activity trajectories and predictors in this data set. (This limitation will be addressed in the Discussion; see Chapter 5.)

CHAPTER FOUR: RESULTS

4.1 Subject characteristics

The study sample included 1293 subjects at baseline (defined as a subject's first measurement wave). From this initial sample, 1206 subjects (579 males [48.0%] and 627 females) responded to at least four follow-up questionnaires over 4.5 years, yielding a total of 17,172 measurement points.

Characterization of the sample is challenging since many of the variables are time-varying and were measured at multiple time points. We will initially present a summary description of each variable at the baseline visit. This will be followed by a description of the age-related trends for the variables which were measured on more than one occasion.

4.1.1 Distribution of study variables at baseline

Demographic characteristics of the sample are presented in Table 4.1. The majority of subjects (97.4%) were aged 12 or 13 years on entry into the study and most had been born in Canada. The few subjects who were older than age 13 years at baseline had not been present at the time of data collection in grade 7 but joined the study in later grades. The distribution of age (p =0.31) and country of birth (p =0.95) was similar in males and females.

Table 4.2 shows sex-specific descriptive statistics for the primary outcome (number of physical activities per week) at baseline, and the potential predictor variables.

Table 4.1. Demographic characteristics of subjects (n=1206) at baseline by sex among adolescents aged 12-17 years.

Characteristic	All participants (n=1206) n (%)	Males (n=579) n (%)	Females (n=627) n (%)
Age			
12	910 (75.5)	428 (73.9)	482 (76.9)
13	263 (21.8)	137 (23.7)	126 (20.1)
14	24 (2.0)	9 (1.6)	15 (2.4)
15	8 (0.7)	5 (0.9)	3 (0.5)
16	1 (0.1)	0 (0.0)	1 (0.2)
Country of birth (n=1206)			
Canada	1117 (92.6)	536 (92.6)	581 (92.7)
Other	89 (7.4)	43 (7.4)	46 (7.3)
Parents' country of birth (n=1142)			
Both in Canada	700 (61.3)	349 (62.5)	351 (60.1)
One or both in Other	442 (38.7)	209 (37.5)	233 (39.9)

Note. No significant differences were found between males and females at $p < 0.05$.

Table 4.2. Descriptive characteristics of subjects' level of physical activity and potential predictor variables at baseline, by sex among adolescents aged 12-17 years.[€]

Characteristic	Number of subjects[a]	All participants	Males (n= 579)	Females (n= 627)
Outcome Measure				
Number of physical activities (per week); median	1206	15.0	16.0*	14.0
Potential Predictor Variables				
Baseline BMI; median	1117	19.1	19.1	18.9
TV- watching (hours per day); median	1174	2.5	2.6*	2.3
Computer/internet/video game- playing (hours per day); median	1182	0.9	1.3*	0.5
Depression score (range 1-4); median	1189	2.0	1.8*	2.2
Stress score (range 1-4); median	1184	1.3	1.2*	1.4
Alcohol use (at least once per month); n (%)	1206	152 (12.6%)	83 (14.3%)	69 (11.0%)
Cigarette smoking (daily); n (%)	1196	33 (2.8%)	10 (1.7%)*	23 (3.7%)

Note. € Medians reported for continuous variables due to skewed distribution.
[a] Missing values excluded. * Significant difference between males and females at $p<0.05$.

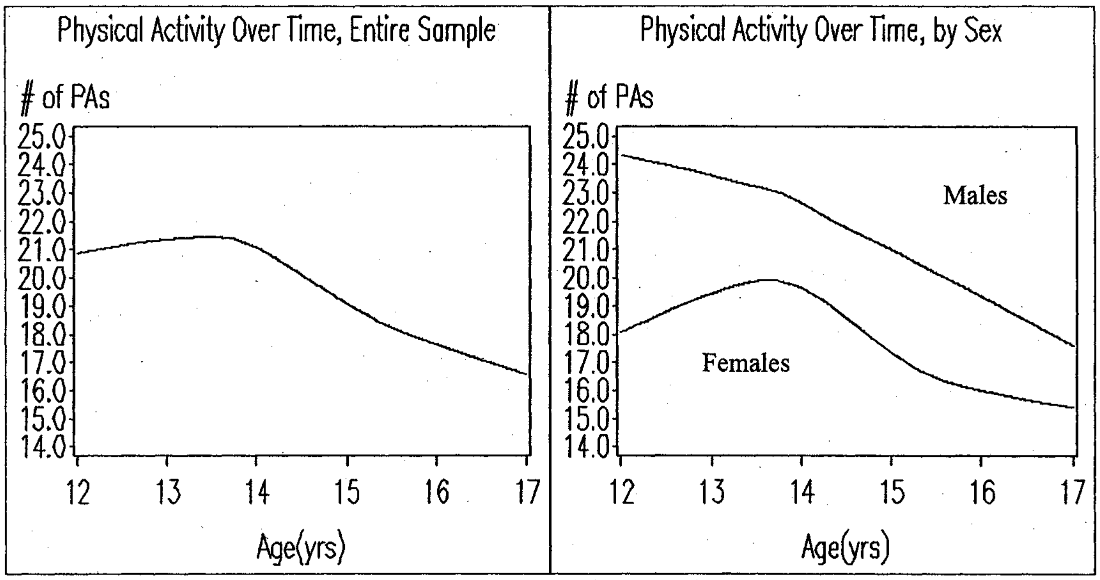
Participants reported a median of 15 activities per week at baseline, although males reported significantly more activities per week (16.0) than females (14.0, $p < 0.001$). Baseline BMI was similar in males and females (p=0.40). Males reported spending significantly more time watching television (p=0.002) and playing computer/internet/video games (p<0.001) than females. Females had significantly higher depression (p<0.001) and stress (p<0.001) scores than males. There were no differences between males and females in the use of alcohol (p=0.08), however significantly more females smoked cigarettes every day (p=0.04).

4.1.2 Age-related changes in study variables

Outcome measure

Figure 4.1 shows age-related trends in physical activity participation, both overall and by sex. This preliminary trend curve treats the data points as if they were independent observations and ignores the fact that each subject contributed multiple observations and displays a unique age-specific trend. These curves are presented to give an initial overview of the trends with age. The curves were smoothed using Loess. Overall, activity levels remained unchanged to age 14 and generally decreased to age 17. In males, there was a steady decline in activity level from age 12 to age 17. Activity levels increased in females up to age 14 and declined to age 17.

Figure 4.1. Temporal trends in number of physical activities per week over 4.5 years, by sex among adolescents aged 12-17 years.



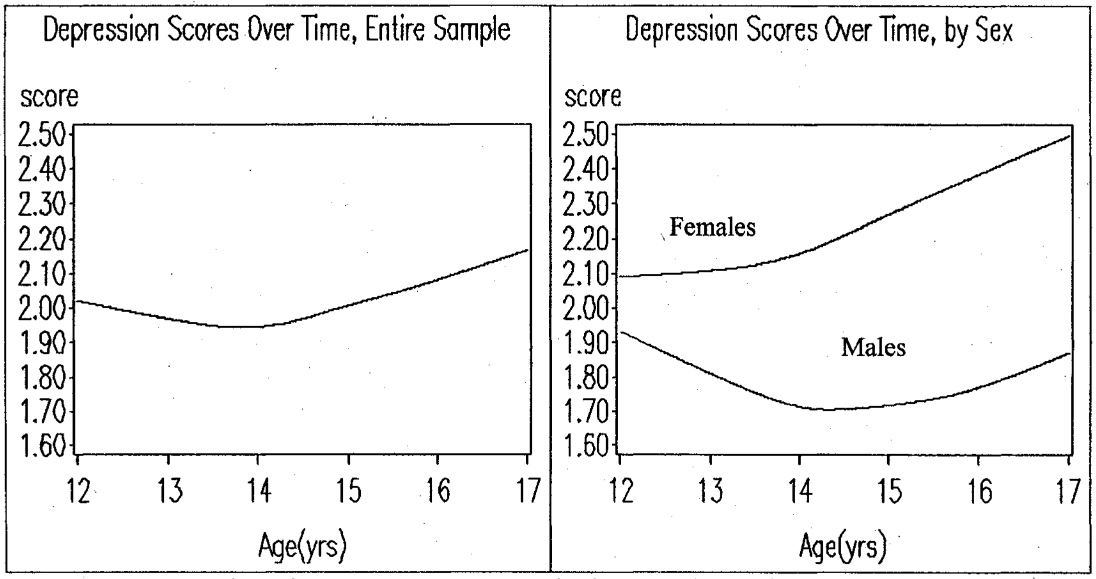
Note. Interpret graph with caution: Loess smoothed curves (smoothing parameter = 0.6) ignores within-subject linkages.

Potential predictors

Figure 4.2 shows temporal changes in depression scores. Overall, depression scores were constant over time until age 14, and then increased to age 17. Females showed steady increases in depression symptoms with increasing age while males showed an initial decline in depression scores, followed by an increase. It is not known if small changes (0.1-0.3) in depression scores have clinical significance. Females in this sample reported higher levels of depression symptoms than males at all ages; again, the clinical significance is unknown.

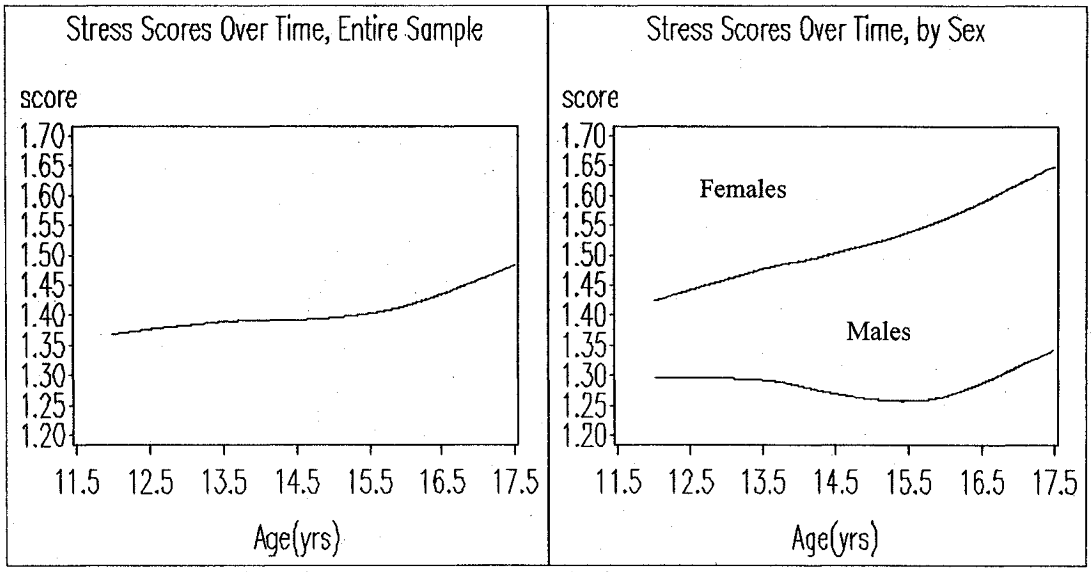
Stress scores were constant over time (Figure 4.3). Females had higher stress scores than males at all ages, and their scores tended to increase with age.

Figure 4.2. Temporal trends in depression scores over 4.5 years, by sex among adolescents aged 12-17 years.



Note. Interpret graph with caution: Loess smoothed curves (smoothing parameter = 0.6) ignores within-subject linkages.

Figure 4.3. Temporal trends in stress scores over 4.5 years, by sex among adolescents aged 12-17 years.



Note. Interpret graph with caution: Loess smoothed curves (smoothing parameter = 0.6) ignores within-subject linkages.

Among males, stress scores tended to decrease until age 15.5, and then began to increase to age 17. It is not known if these differences in stress scores have clinical significance.

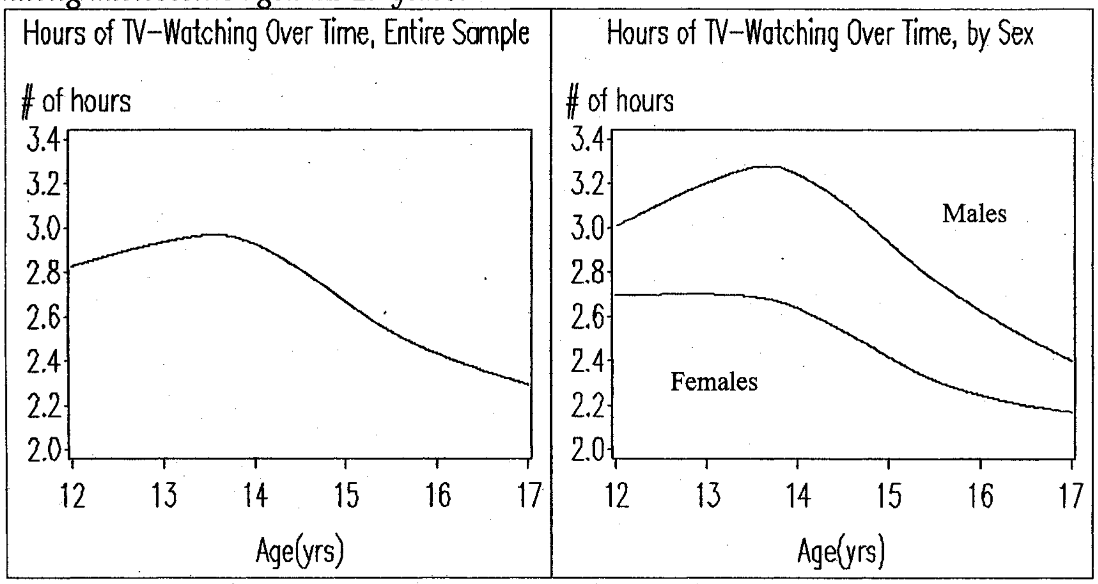
Figure 4.4 shows age-related changes in the number of hours per week spent watching television. Overall, hours of TV-watching increased to age 14, and then declined steadily to age 17. Males at all ages reported more hours of TV than females at all ages; males increased the hours of TV-watching to age 14 and then decreased to age 17, whereas for females hours of TV-watching was stable to age 14 and then decreased to age 17.

Figure 4.5 displays temporal trends in hours spent on the computer/internet or playing video-games. Computer/internet/video game-playing followed an inverted U-shape pattern, with number of hours increasing until age 14.5, and then decreasing to age 17. Males spent more time on the computer/internet or playing video games than females at all ages, but their use declined at a faster rate than females.

4.2 Exploratory analyses of temporal trends in physical activity participation

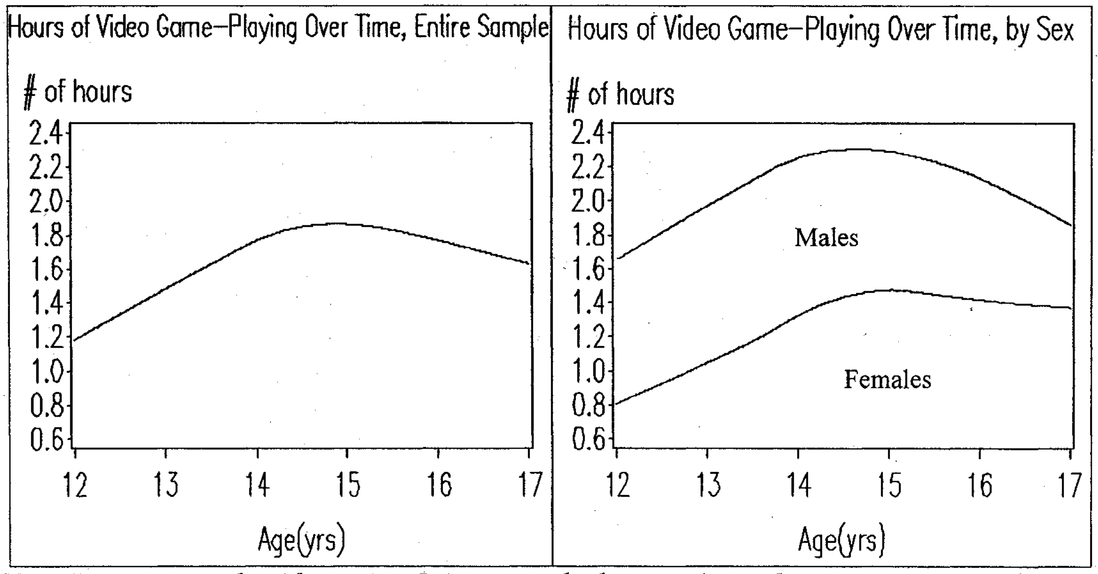
Empirical growth plots (scatterplots of physical activity level and age at each measurement wave) produced for each of the 1206 subjects were examined to characterize the subject-specific shape of the age-trajectory (linear vs non-linear), the degree of variability in activity levels, and the presence of outliers.

Figure 4.4. Temporal trends in hours per day spent watching TV over 4.5 years, by sex among adolescents aged 12-17 years.



Note. Interpret graph with caution: Loess smoothed curves (smoothing parameter = 0.6) ignores within-subject linkages.

Figure 4.5. Temporal trends in hours per day spent playing video games over 4.5 years, by sex among adolescents aged 12-17 years.



Note. Interpret graph with caution: Loess smoothed curves (smoothing parameter = 0.6) ignores within-subject linkages.

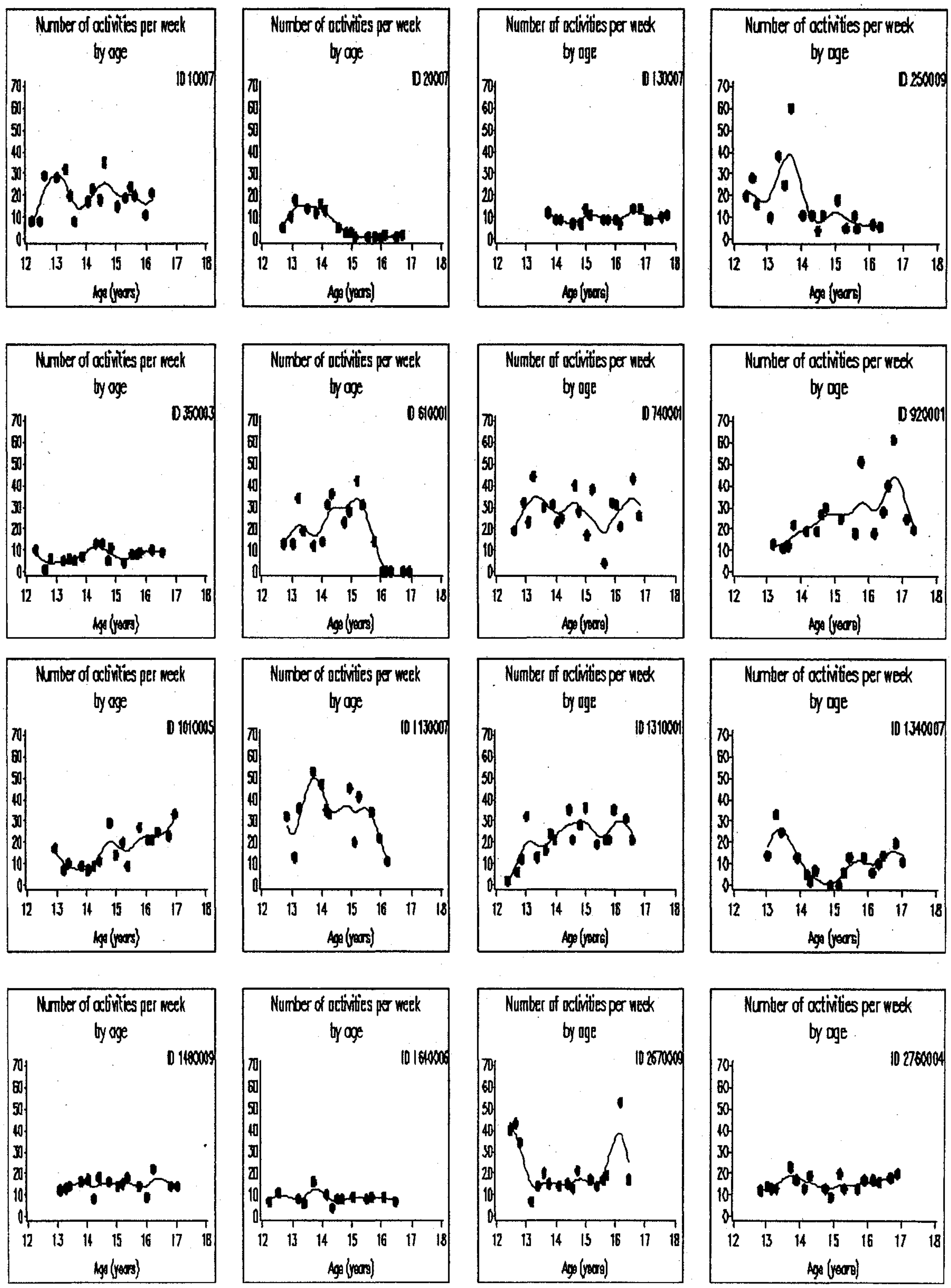
Spline smoothing methods were used to further identify the overall trajectory shape. A number of observations can be made from examination of the plots for all 1206 subjects:

1. Most plots displayed substantial variation in physical activity participation over time. In many cases, the pattern appeared random, with peaks and valleys showing a fluctuating pattern. This may reflect, at least in part, seasonal effects or measurement error.
2. Physical activity levels were generally below 40 activities per week. However, subjects with large variation in physical activities across measurement occasions tended to have more occasions when the activity levels were over 40.
3. A substantial range of trajectory patterns was observed. Some subjects displayed a relatively constant level of physical activity over time. Others showed evidence for increasing, decreasing or non-linear patterns of change.

Figure 4.6 displays representative spline-smoothed growth trajectories for a sample of subjects selected to reflect the range of patterns observed in the sample.

Ordinary Least Squares (OLS) regression was used to fit a preliminary model to explore the range of trajectories. A separate linear OLS model was fit to each of the 1206 subjects, providing estimates of the intercept, slope, and residual variance for each subject. Since this analysis ignores the correlation

Figure 4.6. Smoothed empirical growth plots for a selected, representative sample of subjects.



between observations of the same subject, formal statistical analysis is not useful. However, the distributions of these parameters provide descriptive information to inform more formal modeling. For example, if there is a wide distribution of residual variances, we can assume that a linear model may not be appropriate to explain the physical activity trajectories in this sample.

Figure 4.7 displays histograms of the observed variation in the fitted OLS trajectories for (a) the intercept, (b) the slope, and (c) the residual variance. It is apparent from Figure 4.7 that there is considerable variation in both the fitted intercepts and fitted slopes, reflecting the heterogeneity in trajectories for each subject. The distribution of the residual variances (the majority are well above zero) confirms that linear OLS regression is a poor summary of the trajectories of this sample.

Summary of exploratory analyses

Examination of the collection of empirical growth plots reveals that the overall trend appears to be a gradual decline in number of physical activities. However, there is substantial variation in trajectories of physical activity levels in this sample. In particular, it appears unlikely that a linear change trajectory is suitable to model these trajectories and that a quadratic or a cubic change trajectory will need to be explored.

Figure 4.7a. Distribution of the fitted intercept in OLS regression.

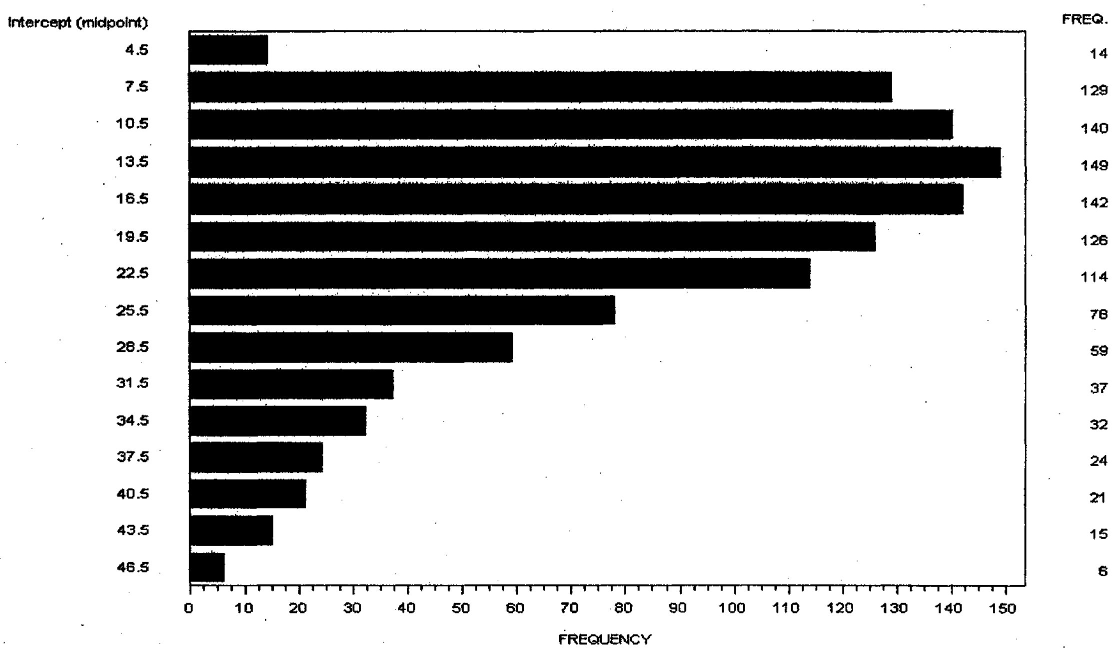


Figure 4.7b. Distribution of the fitted rate of change in OLS regression.

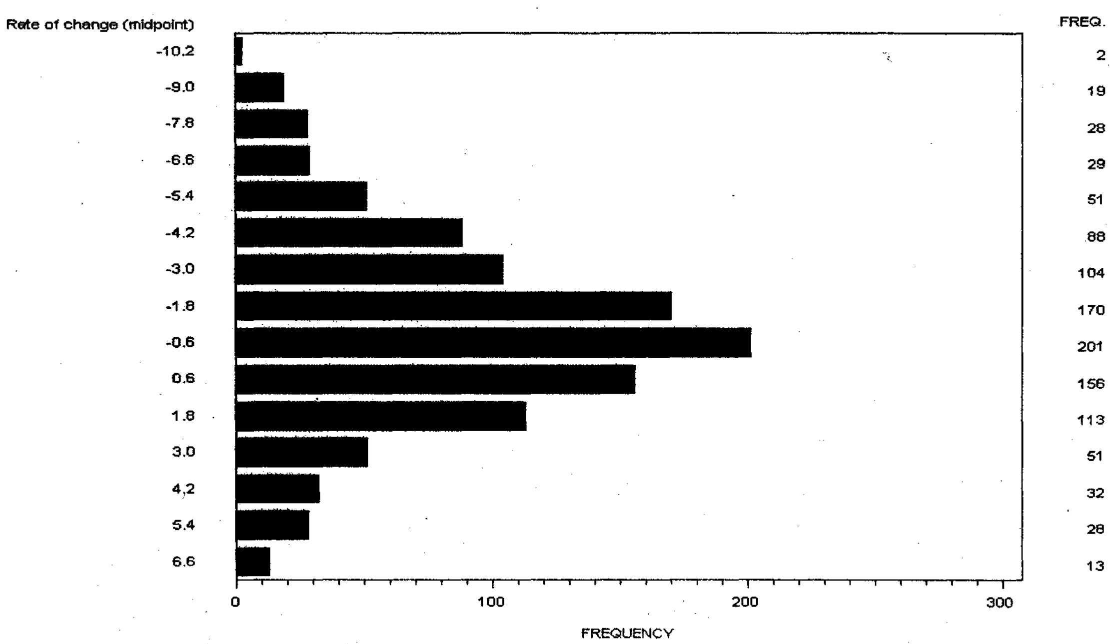
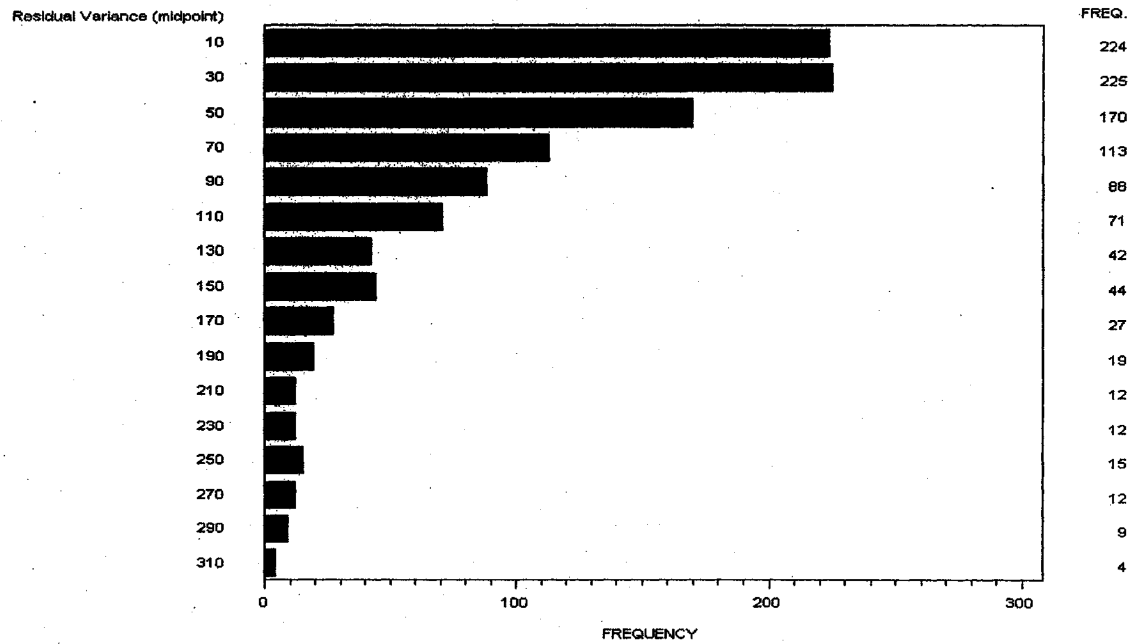


Figure 4.7c. Distribution of the fitted residual variance in OLS regression.



4.3 Explanatory analyses of temporal trends in physical activity participation

Explanatory analyses were conducted to determine the overall physical activity trajectories of this sample. Subsequent analyses identified predictors of change (or shape) in these overall trajectories and in particular, their ability to explain variation in the trajectories of this sample.

4.3.1 Modeling the physical activity trajectory using age and season—the level-1 individual growth model

As discussed in the Methods (Chapter 3), the overall physical activity trend across subjects was modeled using a nested series of candidate models. For all models, the time effect was modeled by age, with age being centered at its approximate mean (14.5 years). The results of the four nested models are presented in Table 4.3.

The unconditional means model, which contains no predictors (only the intercept term) and produces trajectories which are parallel to the x-axis, provides a benchmark for comparison of the remaining models.[99] It partitions the total variability of the physical activity values into within- and between-subjects. Subsequent models will reduce the within-subject variability.[83] The within-subject variance represents 42% of the variance in physical activity levels. The remaining 58% of the total variance in mean physical activity lies between-subjects. Both the within- and between-subject random effects are statistically significant ($p < .001$), showing that adolescents differ from one another in physical activity (between-persons) and that the average adolescents' physical activity varies over time (within-person), respectively.

The unconditional growth model represents a linear change trajectory, assuming that physical activity for all subjects follows a linear trend. The unconditional growth model is preferable to the unconditional means model as shown by the goodness of fit statistics (Table 4.3). Comparing the level-1 residual variance with that of the unconditional means model yielded a pseudo-R^2 of 17%, indicating that 17% of the within-subject variation in physical activity is explained by a linear trajectory.

Table 4.3. Parameter estimates and standard errors for individual growth-curve models (level-1) of physical activity among adolescents aged 12-17 years.

	Model				
Parameter and Fit statistic	Unconditional means model	Unconditional growth model	Quadratic (Age & Age^2)	Cubic (Age & Age^2 & Age^3)	Season (Level-1 base model)
Fixed Effects:					
Intercept (Status at 14.5 years)	19.78 (0.36[a])***	19.78 (0.35)***	20.34 (0.39)***	20.48 (0.39)***	21.76 (0.40)***
Age		-1.29 (0.11)***	-1.18 (0.12)***	-2.02 (0.19)***	-2.01 (0.19)***
Age^2			-0.39 (0.07)***	-0.58 (0.08)***	-0.58 (0.08)***
Age^3				0.31 (0.04)***	0.32 (0.04)***
Fall					-0.93 (0.17)***
Winter					-3.06 (0.17)***
Variance Components (Random Effects):					
Level-1					
Within-person	103.95 (1.17[b])***	86.42 (1.00)***	81.28 (0.98)***	77.59 (0.95)***	75.56 (0.93)***
Level-2					
Intercept variance	144.42 (6.26)***	141.11 (6.14)***	167.47 (7.51)***	170.61 (7.63)***	170.72 (7.62)***
Linear term variance		10.12 (0.62)***	11.48 (0.71) ***	24.78 (1.77)***	25.20 (1.78)***
Quadratic term variance			2.07 (0.21)***	3.76 (0.32)***	3.84 (0.32)***
Cubic term variance				0.64 (0.09)***	0.68 (0.09)***
Overall R^2 †		0.169	0.218	0.254	0.273
Change in R^2 ‡			0.059	0.045	0.026
Deviance	131630.6	129992.1	129594.6	129258.2	128910.4
AIC	131636.6	130004.1	129614.6	129288.2	128944.4
BIC	131651.9	130034.7	129665.6	129364.6	129031.1

Note. *** $p<0.001$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to previous model

The addition of a quadratic term to the model revealed a significant fixed effect, demonstrating that the trajectory of physical activity has a curvilinear component over time (or with age). Addition of the quadratic term significantly improved the fit of the model over the linear model (Table 4.3; page 90). Furthermore, the random effect for age^2 was significant, indicating that subjects displayed heterogeneity in the curvature (quadratic) effects of age on physical activity participation. The quadratic model accounted for 22% of the within-person variation over time and improved the pseudo-R^2 by 5% over the linear model.

The inclusion of a cubic term to the trajectory also revealed a significant fixed effect, suggesting that the trajectory of physical activity follows a cubic pattern with age. All goodness of fit statistics improved substantially (Table 4.3; page 90). In addition, the random effect for age^3 was significant, suggesting that subjects displayed heterogeneity in the cubic effects (the rate of change of the curvature) of age on physical activity participation. The overall cubic trajectory model accounted for 25% of the within-person variance in physical activity levels over time and improved the pseudo-R^2 by 3% over the quadratic model.

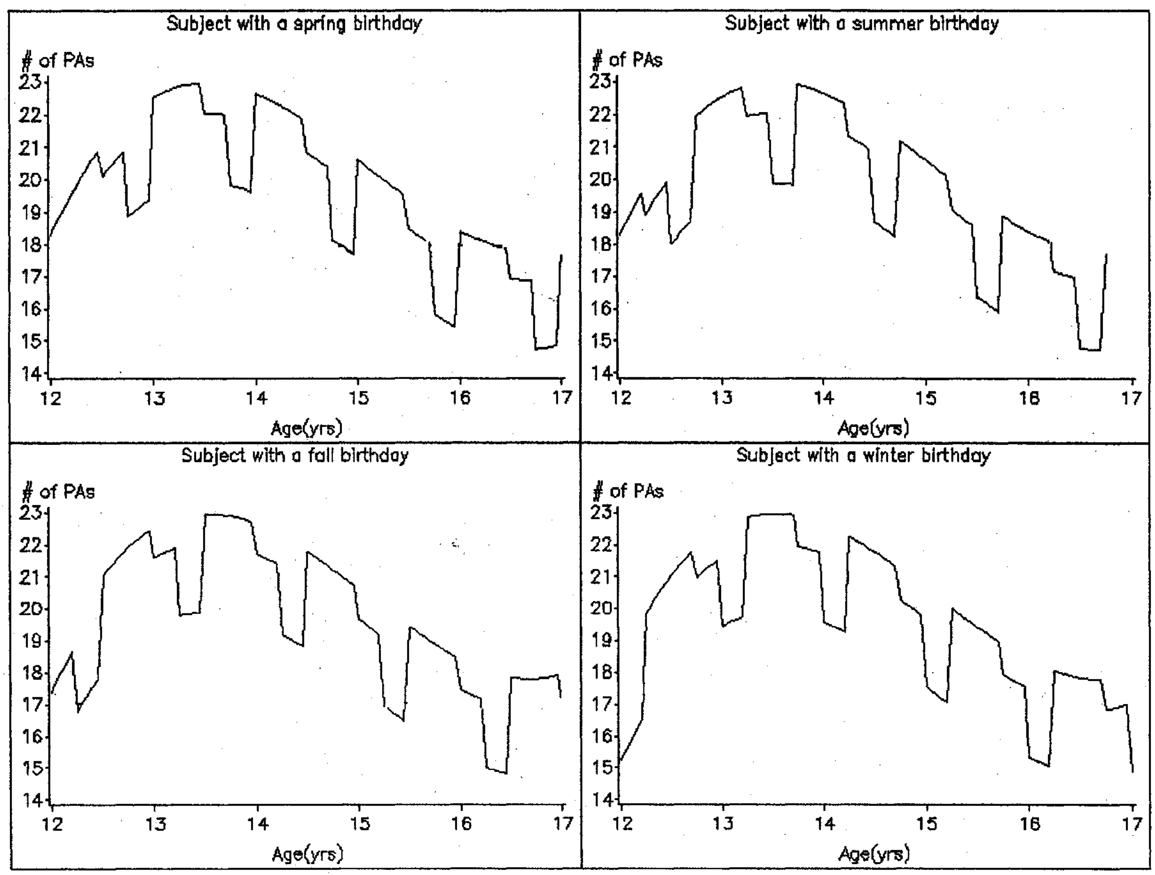
Controlling for seasonality

The cubic model provided the best fit to the temporal trends in physical activity. However, this model ignores the possibility that physical activity varies by season (e.g., lower in the winter, higher in the spring). We introduced seasonality for two reasons: first, because there was a fluctuating temporal physical activity pattern evident in the exploratory graphs (suggesting season may be a factor, since there are four measurement points per year); and second, because physical activity levels have been shown to vary by season in other studies.[38] Since there were no measurements in the summer, we were only able to consider three seasons: fall, winter and spring. Spring was chosen as the reference season because it had the largest number of data points. Two dummy variables were created for fall and winter. These seasonal (fixed) effects were then added to the cubic model (Table 4.3; page 90).

The addition of seasonality into the level-1 submodel improved the fit considerably. The within-person variance was reduced by an additional 3% in comparison to the cubic model without season. The level-1 model containing linear, quadratic, and cubic age effects, as well as seasonality, explained 27% of the within-subject variance of physical activity over time. We therefore considered this "base model" as the most appropriate in explaining individual differences in subjects' physical activity levels over time, and base all subsequent models as comparisons to this one.

The trajectories of the level-1 submodel are shown in Figure 4.8. The interpretation of the curve is complex. The effect of season in the model will produce a step-like discontinuity in the curve with three "steps" for each one-year period (i.e., one for spring, one for fall, and one for winter). Seasonality is particularly difficult to graph when using age as the temporal factor because the

Figure 4.8. Trajectories of the level-1 growth model (displaying the effects of season).



"steps" will depend on the age of the subject at certain measurement occasions (i.e., a subject who has a birthday in the fall, will be the same age six months later in the spring). Consequently, we present four representative graphs, one for each season a subject might be born. In future presentations of representative trajectories, the seasonal effect will not be displayed since it can tend to obscure the overall effects being considered. Instead, we will display hypothetical curves that would be observed if subjects remained in the spring (reference) season throughout the year.

As can be seen in Figure 4.8 and from the results in Table 4.3 (on page 90), the average number of activities at age 14.5 for the previous week (in the spring) was 21.8. These activities decrease by 0.9 activities in the fall (represented by the shorter "step"-down) and by more than 3 in the winter (the greater "step"-down). The overall trend is that activity levels peak at about age 13.5 years, decrease, and then increase slightly at about age 16.5.

4.3.2 Addressing Model Assumptions

The multilevel model for change invokes a number of assumptions regarding the data, particularly related to the residuals. First, since the level-1 errors are unobserved, the distribution of the level-1 residuals are assumed to be normally distributed with mean 0 and unknown variance, σ_ε^2. The level-2 residuals are assumed to be multivariate normal (because there are four random effects in the base model: intercept, age, age^2, and age^3) with mean 0 and unknown variances and covariances. These assumptions can also be stated as:

$$\varepsilon_{ij} \sim N(0,\ \sigma_\varepsilon^2) \text{ and } \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01} & \sigma_{02} & \sigma_{03} \\ \sigma_{10} & \sigma_1^2 & \sigma_{12} & \sigma_{13} \\ \sigma_{20} & \sigma_{21} & \sigma_2^2 & \sigma_{23} \\ \sigma_{30} & \sigma_{31} & \sigma_{32} & \sigma_3^2 \end{bmatrix} \right).$$

Maximum likelihood estimation also assumes that the level-2 residuals are independent of the level-1 residual and that all residuals are independent of the model's predictors.

Two important properties of the composite multilevel model are that the occasion-specific residuals can be both auto-correlated and heteroscedastic within-person. Auto-correlation is expected given there are up to 18 measurement waves. To assess the assumption of homoscedasticity, scatterplots of the level-1 residual against time (age), the fall season, and the winter season were assessed (see Figures 4.9 – 4.11). Despite slight variability with age and season, there is no strong heteroscedasticity evident in the graphs.

Normality plots were also developed to assess the assumption of normally distributed residuals, by plotting the raw residuals at level-1, and the four raw residuals at level-2 against their normal scores (Figures 4.12 – 4.16). None of the plots form a straight line, which would be the case if the distribution was normal. Given that the base model is a curvilinear trajectory, departing from the linearity assumptions most often required in regression analysis, these figures confirm the departure from normality.

Figure 4.9. Test of heteroscedasticity in the base model, age.

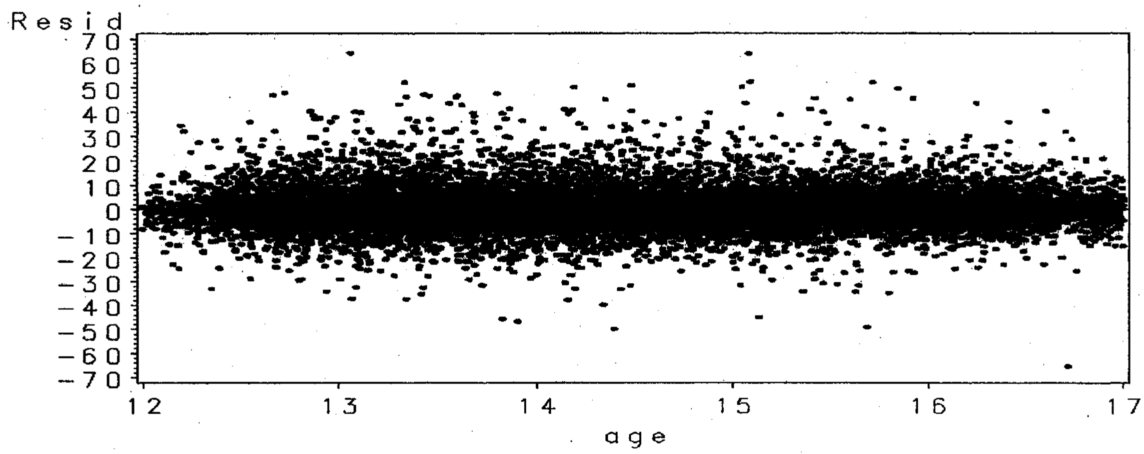


Figure 4.10. Test of heteroscedasticity in the base model, fall season.

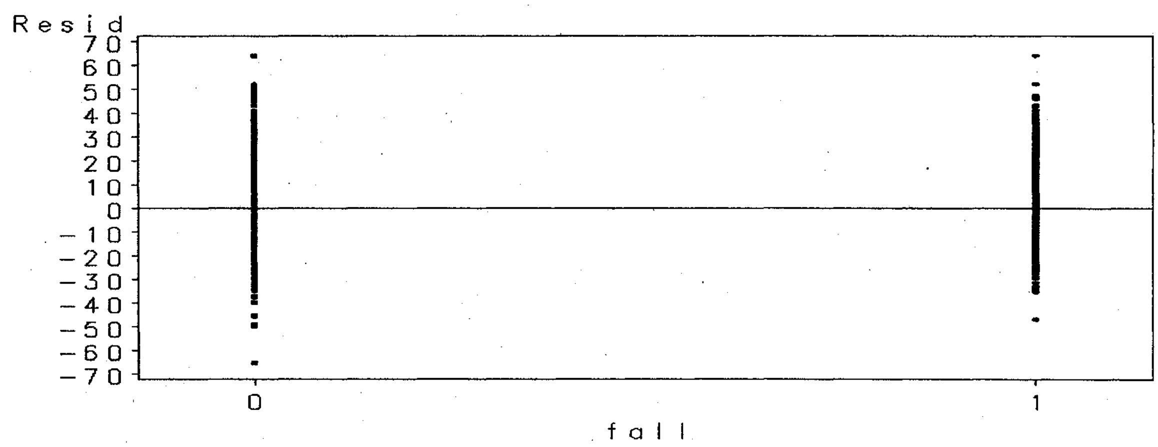


Figure 4.11. Test of heteroscedasticity in the base model, winter season.

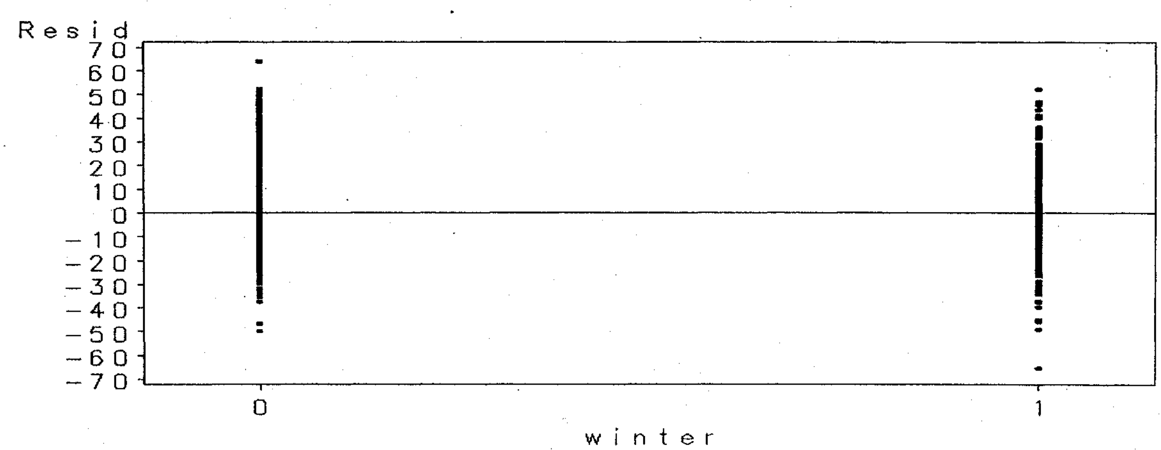


Figure 4.12. Test of normality in the base model, residual.

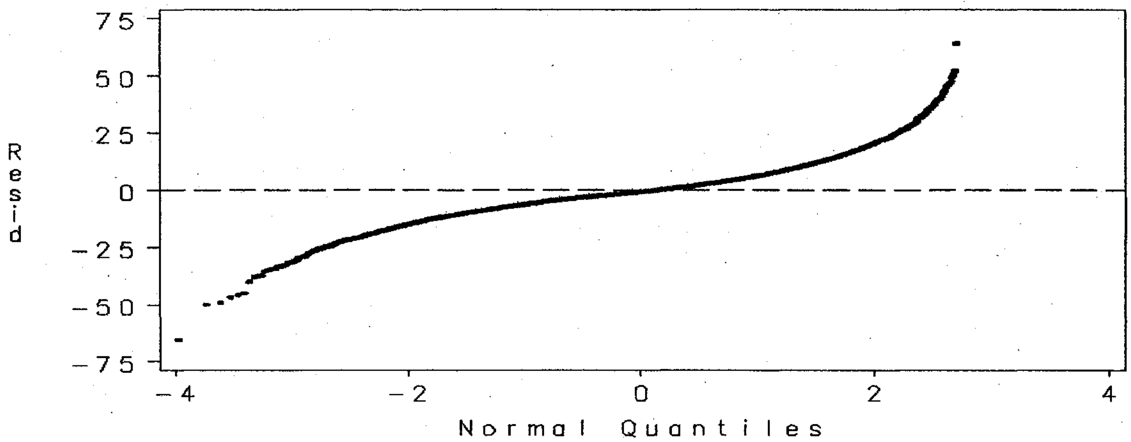


Figure 4.13. Test of normality in the base model, intercept.

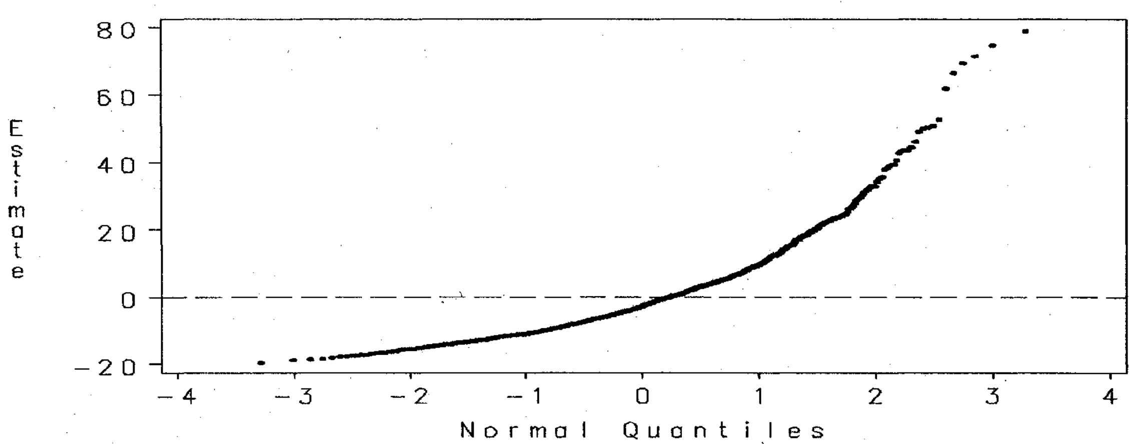


Figure 4.14. Test of normality in the base model, age.

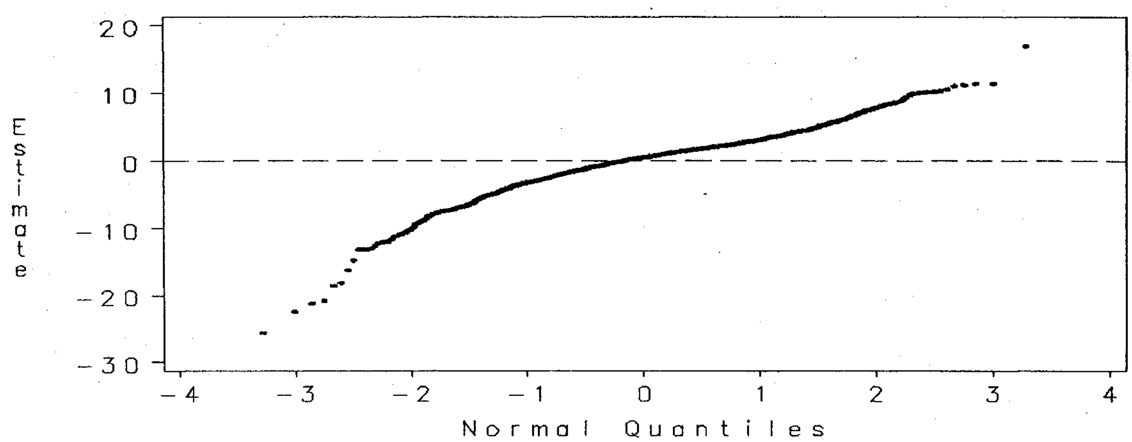


Figure 4.15. Test of normality in the base model, age².

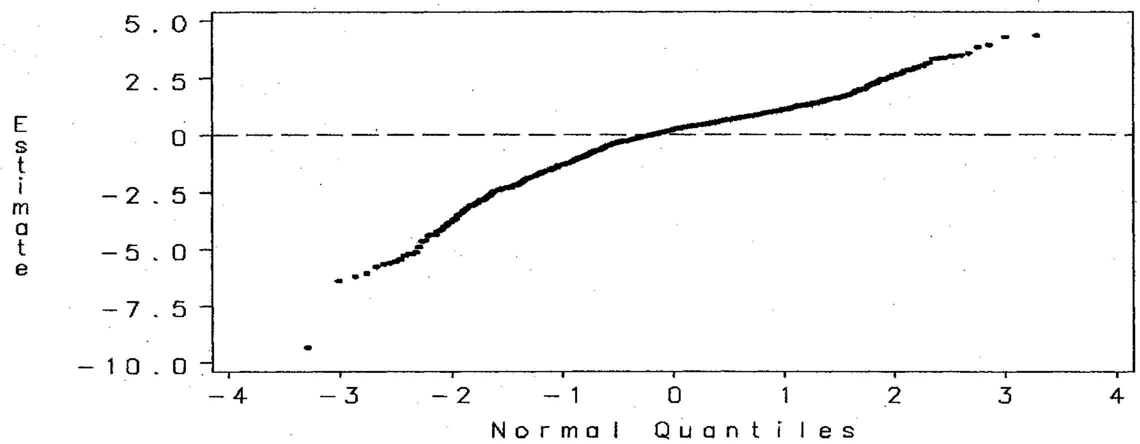
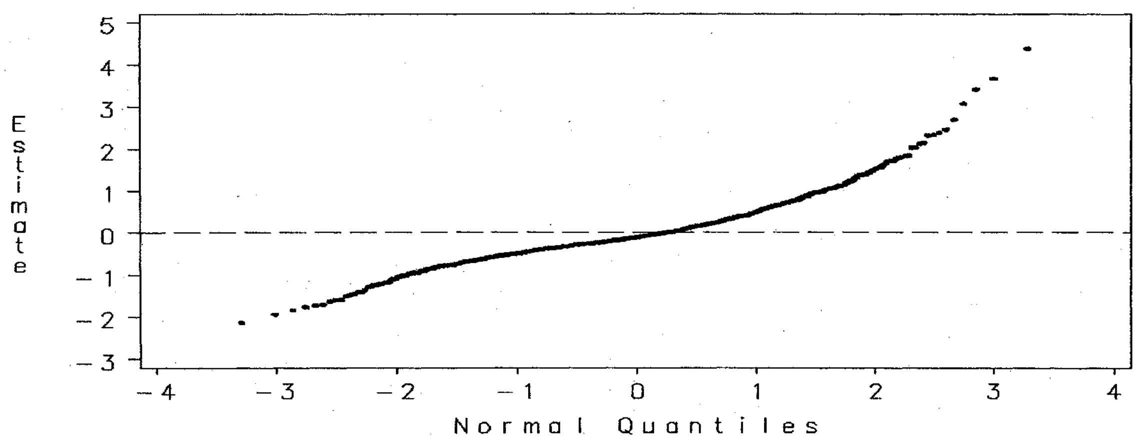


Figure 4.16. Test of normality in the base model, age³.



4.3.3 Approaches to improve the level-1 growth model

Several approaches were explored to further improve the level-1 submodel. First, the physical activity outcome was transformed to test if variability was reduced and compliance improved with the linearity/normality assumptions. Examination of the raw data for physical activity showed that, while the number of physical activities per week ranged from 0 to 154, about 99%

of measurements were below 78. Furthermore, the residuals from the base model were skewed. Three transformations of physical activity were explored: square root, cube root and log(PA+1) (refer to Appendix C for tabular displays of the results). These reduced the long tail of physical activity values. However, none of these transformations improved the fit of the model; the R^2 values for the transformed models were similar to those of the untransformed base model (0.27; Table 4.4). They also did not improve compliance with the linearity/normality assumptions. Therefore, it was decided to retain the untransformed physical activity outcome variables since this simplified interpretation of the results.

A second approach addressed the potential that extreme levels of physical activity might influence the models. High values of physical activity might reflect reporting errors or a lifestyle involving high activity levels (e.g., a competitive athlete). The analyses were repeated after excluding subjects with more than 84 activities per week (84 activities per week is a high participation level, requiring participation in at least 12 activities per day and a total time commitment of at minimum, 60 minutes per day). All level-1 submodels were re-run in the reduced data set. The results were essentially identical to the previous analyses which included these subjects (Appendix C). In the absence of any statistical evidence to support excluding the extreme values, it was decided to retain the extreme values of physical activity in the data file.

Table 4.4. Overall R^2 values for transformed models of physical activity.

	Model				
	Untransformed (level-1 base model)	Transformed: square root PA	Transformed: cube root PA	Transformed: log(PA+1)	Removal of extreme values (PAs < 85)
R^2	0.27	0.27	0.23	0.24	0.26

4.3.4 Explaining variability in trajectories

This section presents the results of our examination of several potential predictor variables on the physical activity trajectories in this sample. It was decided *a priori* that if differences between trajectories were found by sex, all predictor analyses would be conducted separately for males and females. The first section discusses the findings of time-invariant predictors introduced to the base model at level-2 (to explain between-person variability in trajectories), and second, the effects of time-varying predictors introduced at level-1 (to explain within-person variability in trajectories).

Time-invariant characteristics at level-2 to examine between-person differences in physical activity trajectories

It was hypothesized that trajectories will vary depending on certain characteristics of individuals (typically time-invariant). For example, we hypothesize, based on theoretical and empirical evidence, that physical activity trajectories will differ according to sex. To examine between-person differences in physical activity trajectories, time-invariant predictors were introduced into the level-2 model. Each time-invariant predictor was modeled as a linear predictor for each of the Beta values for age, age^2, age^3, and season. The composite model yields interaction effects between the level-2 predictor and each of the time variables, as well as with season.

Assessing differences in physical activity trajectories by sex

Sex was introduced to the base model at level-2 to examine whether the distribution of the intercept or the pattern of change differed between males and females. If this is the case, and the fixed effects for sex are significant, further predictor analyses will be conducted separately for males and females.

The results of adding sex to the base model are presented in Table 4.5. The fixed effect for sex was significant, suggesting that the average level of physical activity in males and females were different. The significant interactions with both age^3 ($p < .01$) and winter season ($p < .001$) indicate that there were differences in the age-trajectories by sex. In particular, there was less of a decrease in physical activity during the winter in females than in males; as well, females' activity began to increase at age 16.5, whereas males' physical activity just decreased at a slower rate. The goodness of fit statistics were much lower than the base model, but the interactions between sex and age, age^2, and the fall season were not significant, suggesting that linear age effects, quadratic age effects, and activity participation in the fall are the same for males and females. Consequently, these fixed effects were dropped from the model. Exclusion of

Table 4.5. Parameter estimates and standard errors for physical activity models including sex.§

Parameter and Fit statistic	Model: Level 1 Base Model	Model: Model with Sex	Model: Final Sex Model
Fixed Effects:			
Intercept (Status at 14.5 years)	21.76 (0.40[a])***	23.55 (0.58)***	23.74 (0.53)***
Sex		-3.46 (0.80)***	-3.82 (0.67)***
Age	-2.01 (0.19)***	-1.96 (0.27)***	-2.10 (0.19)***
Age^2	-0.58 (0.08)***	-0.57 (0.11)***	-0.57 (0.08)***
Age^3	0.32 (0.04)***	0.24 (0.06)***	0.26 (0.05)***
Fall	-0.93 (0.17)***	-0.62 (0.24)*	-0.93 (0.17)***
Winter	-3.06 (0.17)***	-3.49 (0.24)***	-3.64 (0.22)***
Sex*age		-0.27 (0.38)	
Sex*age^2		-0.01 (0.16)	
Sex*age^3		0.12 (0.04)**	0.12 (0.04)**
Sex*fall		-0.59 (0.34)	
Sex*winter		0.84 (0.33)*	1.13 (0.29)***
Variance Components (Random Effects):			
Level 1			
Within-person	75.56 (0.93[b])***	75.49 (0.93)***	75.50 (0.93)***
Level 2			
Intercept variance	170.72 (7.62)***	167.99 (7.51)***	167.99 (7.51)***
Linear term variance	25.20 (1.78)***	25.17 (1.77)***	25.19 (1.77)***
Quadratic term variance	3.84 (0.32)***	3.83 (0.32)***	3.83 (0.32)***
Cubic term variance	0.68 (0.09)***	0.67 (0.09)***	0.67 (0.09)***
Overall R^2 †	0.273	0.274	0.274
Change in R^2 ‡		0.154	0.154
Deviance	128910.4	128860.2	128863.8
AIC	128944.4	128906.2	128903.8
BIC	129031.1	129023.4	129005.7

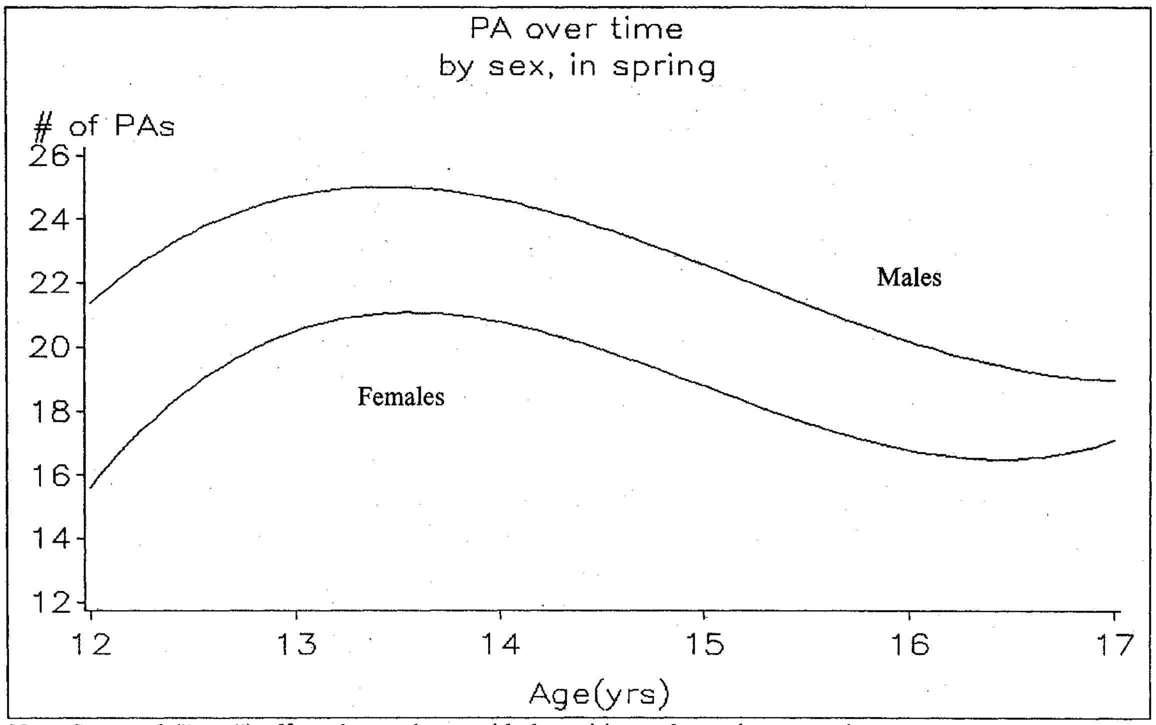
Note. § Model based on n=579 (8226 observations) males, n=627 (8888 observations) females; *** $p<0.001$; ** $p<0.01$; * $p<0.05$; † compared to unconditional means model; ‡ compared to the base model's level-2 intercept variance; [a] standard error of the fixed effect
[b] standard error of the variance component

these terms resulted in the same overall R^2 as when these interactions were included. Furthermore, despite the slightly higher deviance than the model including these terms, the AIC and BIC in particular, are lower. Overall, this model accounts for 27.4% of the within-person variation in physical activity trajectories; sex explained almost 2% of the between-person variance. The trajectories shown in Figure 4.17 display the physical activity patterns in spring, by sex.

Predictor trajectory analyses – stratified by sex

The significant fixed effect of sex was evidence that males and females have different physical activity trajectories. Therefore, further predictor analyses were conducted sex-specifically.

Figure 4.17. Trajectories of physical activity by sex.



Note. Seasonal ("step") effects ignored to avoid obscurities and ease interpretation.

Subject country of birth

Subjects' country of birth was introduced at level-2 to examine whether trajectories differ for subjects born in Canada or born outside of Canada. The results of adding this characteristic to both the males' and females' base model are presented in Table 4.6. Despite a significant fixed effect and change in deviance for males, the BIC measure was higher than the base model; the goodness of fit statistics for the female models were much larger than their base model. Therefore, there was no evidence to suggest that subject country of birth influenced age-specific trajectories of physical activity in either males or females.

Country of parent's birth

Country of parent's birth was introduced at level-2 to examine whether trajectories differ for subjects who have both parents born in Canada with subjects who have at least one parent born outside of Canada (Table 4.7, page 106). For both males and females, the addition of parental country of birth to their respective base models increased the goodness of fit of the models, and neither revealed a significant fixed effect. Therefore, there was no evidence that country of parent's birth influenced the age-specific trajectories of physical activity in either males or females.

Table 4.6. Parameter estimates and standard errors for physical activity models including subject country of birth, by sex among adolescents aged 12-17 years.§

	Males' model			Females' model		
Parameter and Fit statistic	Unconditional means model	Level-1 base model	Model with Subject COB	Unconditional means model	Level-1 base model	Model with Subject COB
Fixed effects:						
Intercept (Status at 14.5 years)	21.46 (0.57[a])***	23.56 (0.65)***	24.02 (0.68)***	18.23 (0.43[a])***	20.10 (0.48)***	20.19 (0.50)***
Subject COB			-6.29 (2.51)*			-1.20 (1.86)
Age		-1.97 (0.31)***	-2.14 (0.32)***		-2.26 (0.21)***	-2.28 (0.23)***
Age^2		-0.57 (0.13)***	-0.67 (0.13)***		-0.58 (0.09)***	-0.56 (0.10)***
Age^3		0.24 (0.07)***	0.29 (0.07)***		0.41 (0.05)***	0.42 (0.05)***
Fall		-0.61 (0.27)*	-0.70 (0.28)*		-1.22 (0.20)***	-1.20 (0.21)***
Winter		-3.49 (0.27)***	-3.73 (0.28)***		-2.66 (0.20)***	-2.28 (0.23)***
Subject COB*age			2.54 (1.23)*			0.01 (0.88)
Subject COB*age^2			1.35 (0.51)**			-0.23 (0.39)
Subject COB*age^3			-0.68 (0.26)**			-0.004 (0.20)
Subject COB*fall			1.28 (1.09)			-0.34 (0.83)
Subject COB*winter			3.78 (1.11)***			0.61 (0.83)
Random effects (variance components):						
Level-1 variance						
Within-person	134.24 (2.17[b])***	95.88 (1.69)***	95.65 (1.68)***	75.91 (1.18[b])***	56.79 (0.97)***	56.65 (0.98)***
Level-2 variances						
Intercept	178.29 (11.21)***	214.38 (13.93)***	213.10 (13.84)***	108.06 (6.48)***	125.23 (7.68)***	125.09 (7.68)***
Linear term		33.11 (3.23)***	32.86 (3.22)***		17.40 (1.78)***	17.89 (1.92)***
Quadratic term		4.94 (0.60)***	4.90 (0.59)***		2.86 (0.33)***	2.85 (0.34)***
Cubic term		0.80 (0.16)***	0.78 (0.16)***		0.55 (0.10)***	0.60 (0.12)***
Overall R^2 †		0.286	0.287		0.252	0.254
Change in R^2 ‡			0.002			0.002
Deviance	65348.1	63927.7	63905.9	65582.4	64262.7	64259.0
AIC	65354.1	63961.7	63951.9	65588.4	64296.7	64305.0
BIC	65367.2	64035.8	64052.2	65601.7	64372.2	64407.1

Note. § Models based on n=579 (8226 observations) males, n=627 (8888 observations) females; *** $p<0.001$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base mode

Table 4.7. Parameter estimates and standard errors for physical activity models including parent's country of birth, by sex among adolescents aged 12-17 years.[§]

	Males' model			Females' model		
Parameter and Fit statistic	Unconditional means model	Level-1 base model	Model with Parental COB	Unconditional means model	Level-1 base model	Model with Parental COB
Fixed effects:						
Intercept (Status at 14.5 years)	21.62 (0.59)***	23.74 (0.67)***	23.39 (0.84)***	18.06 (0.44[a])***	19.90 (0.49)***	19.19 (0.64)***
Parental COB			0.95 (1.38)			1.77 (1.01)
Age		-1.94 (0.32)***	-2.12 (0.39)***		-2.33 (0.23)***	-2.28 (0.29)***
Age^2		-0.57 (0.13)***	-0.80 (0.17)***		-0.58 (0.10)***	-0.61 (0.12)***
Age^3		0.23 (0.07)***	0.32 (0.09)***		0.43 (0.05)***	0.42 (0.07)***
Fall		-0.57 (0.28)*	-0.58 (0.35)		-1.16 (0.20)***	-0.89 (0.26)***
Winter		-3.55 (0.27)***	-3.73 (0.34)***		-2.57 (0.20)***	-2.20 (0.26)***
Parental COB*age			0.50 (0.65)			-0.15 (0.47)
Parental COB*age^2			0.60 (0.27)*			0.08 (0.20)
Parental COB*age^3			-0.23 (0.14)			0.02 (0.11)
Parental COB*fall			0.03 (0.58)			-0.69 (0.42)
Parental COB*winter			0.48 (0.57)			-0.96 (0.42)*
Random effects (variance components):						
Level 1 variance						
Within-person	135.12 (2.22)***	96.46 (1.72)***	96.46 (1.72)***	74.10 (1.19[b])***	54.28 (1.01)***	54.17 (0.98)***
Level 2 variances						
Intercept	181.02 (11.58)***	218.15 (14.39)***	217.55 (14.34)***	106.11 (6.58)***	125.37 (7.93)***	124.96 (7.90)***
Linear term		33.11 (3.28)***	32.99 (3.26)***		18.10 (2.10)***	18.30 (1.98)***
Quadratic term		5.07 (0.62)***	5.00 (0.62)***		3.02 (0.36)***	3.02 (0.36)***
Cubic term		0.82 (0.16)***	0.81 (0.16)***		0.63 (0.14)***	0.65 (0.13)***
Overall R^2 †		0.286	0.286		0.267	0.269
Change in R^2 ‡			0.000			0.002
Deviance	63570.0	62185.0	62174.3	61180.5	59844.6	59835.8
AIC	63576.0	62219.0	62220.3	61186.5	59878.6	59881.8
BIC	63589.0	62292.5	62319.7	61199.6	59952.9	59982.3

Note. [§] Models based on n=558 (7996 observations) males, n=584 (8319 observations) females; *** $p<0.001$; * $p<0.05$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

Baseline body mass index (BMI)

Baseline BMI (a continuous measure) was introduced at level-2 to examine whether trajectories of subjects with lower BMIs differ from subjects with higher BMIs. The results of adding this measure to both the males' and females' base models are presented in Table 4.8. Neither model produced a significant fixed effect for baseline BMI, nor did the goodness of fit statistics improve. Therefore, there was no evidence that BMI at baseline influenced the age-specific trajectories of physical activity in either males or females.

Predictive utility of time-varying predictors within sex-specific sub-groups

The impact of each potential time-varying predictor on physical activity was explored independently in several models, as described in the Methods (page 75). We also assessed whether the effect of the predictor was constant for all subjects, by including the potential predictor as a random effect in the base model. And finally, when there was an *a-priori* reason suggesting that the potential predictor could be expected to affect the pattern of change in physical activity with age, interactions between the potential predictor and each age effect were modeled.

Table 4.8. Parameter estimates and standard errors for physical activity models including baseline BMI, by sex among adolescents aged 12-17 years.[§]

	Males' model			Females' model		
Parameter and Fit statistic	Unconditional means model	Level-1 base model	Model with Baseline BMI	Unconditional means model	Level-1 base model	Model with Baseline BMI
Fixed effects:						
Intercept (Status at 14.5 years)	21.57 (0.60[a])***	23.70 (0.68)***	26.44 (3.79)***	18.17 (0.43)***	20.01 (0.48)***	16.16 (2.48)***
Baseline BMI			-0.14 (0.19)			0.19 (0.12)
Age		-1.86 (0.32)***	-0.21 (1.78)		-2.21 (0.22)***	-1.96 (1.08)
Age^2		-0.59 (0.13)***	-0.22 (0.73)		-0.55 (0.09)***	-0.04 (0.48)
Age^3		0.22 (0.07)**	-0.10 (0.38)		0.40 (0.05)***	0.23 (0.23)
Fall		-0.55 (0.28)	-2.97 (1.59)		-1.28 (0.21)***	0.39 (1.05)
Winter		-3.54 (0.28)***	-5.15 (1.56)***		-2.63 (0.21)***	-1.45 (1.06)
Baseline BMI*age			-0.02 (0.04)			-0.01 (0.05)
Baseline BMI*age^2			0.02 (0.02)			-0.03 (0.02)
Baseline BMI*age^3			0.02 (0.02)			0.009 (0.01)
Baseline BMI*fall			0.12 (0.08)			-0.08 (0.05)
Baseline BMI*winter			0.08 (0.08)			-0.06 (0.05)
Random effects (variance components):						
Level 1 variance						
Within-person	133.95 (2.24[b])***	96.06 (1.75)***	96.02 (1.75)***	74.77 (1.21)***	55.65 (0.98)***	55.64 (0.98)***
Level 2 variances						
Intercept	182.32 (11.84)***	217.88 (14.62)***	217.90 (14.63)***	99.95 (6.95)***	116.99 (7.50)***	116.61 (7.48)***
Linear term		32.45 (3.31)***	32.33 (3.30)***		16.08 (1.64)***	16.04 (1.63)***
Quadratic term		4.54 (0.59)***	4.55 (0.59)***		2.65 (0.32)***	2.63 (0.32)***
Cubic term		0.70 (0.16)***	0.70 (0.16)***		0.47 (0.08)***	0.46 (0.08)***
Overall R^2 †		0.283	0.283		0.256	0.256
Change in R^2 ‡			0.000			0.000
Deviance	61374.6	60048.7	60044.8	60690.1	59443.8	59438.9
AIC	61380.6	60082.7	60090.8	60696.1	59477.8	59484.9
BIC	61393.5	60155.7	60189.6	60709.1	59551.9	59585.1

Note. [§] Models based on n=541 (7727 observations) males, n=576 (8248 observations) females; *** p<0.001; ** p<0.01; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

Depression

The depression score was introduced to both the males' and females' base models to examine whether trajectories of subjects differed with varying levels of depression (Table 4.9). Figure 4.18 displays no evidence of non-linearity in the effect of depression score on physical activity in males. Models using quadratic terms (not reported here) confirmed this conclusion. Therefore, we retained depression scores as a continuous variable with only a linear term for males.

The addition of depression scores in the males' physical activity base model revealed a significant fixed effect for depression and improved goodness of fit statistics (Table 4.9; page 110), suggesting that depression influenced the age-related physical activity trajectories in males.

Figure 4.18. Non-linearity testing of depression scores, in males.

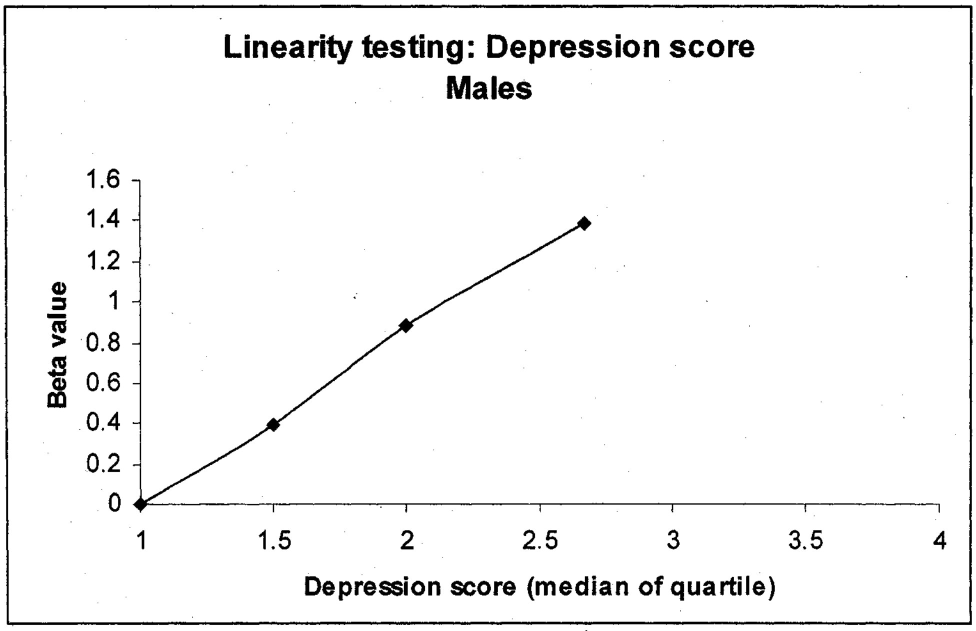


Table 4.9. Parameter estimates and standard errors for physical activity models including depression score, by sex among adolescents aged 12-17 years.§

	Males' model				Females' model			
Parameter and Fit Statistic	Level-1 base model	Depression (fixed effect)	Depression (interactions)	Depression (fixed/random effect)	Level-1 base model	Depression (fixed effect)	Depression (interactions)	Depression (fixed/random effect)
Fixed effects:								
Intercept (Status at 14.5 years)	23.62 (0.66)***	21.54 (0.81)***	19.93 (0.92)***	21.99 (0.80)***	20.13 (0.48)***	18.71 (0.63)***	18.14 (0.72)***	18.80 (0.61)***
Depression		1.24 (0.28)***	2.15 (0.37)***	0.92 (0.33)**		0.65 (0.19)***	0.91 (0.25)***	0.59 (0.21)**
Age	-1.96 (0.31)***	-1.97 (0.31)***	-1.70 (0.67)*	-1.99 (0.31)***	-2.27 (0.22)***	-2.36 (0.22)***	-1.74 (0.57)**	-2.34 (0.23)***
Age^2	-0.59 (0.13)***	-0.65 (0.13)***	0.49 (0.32)	-0.61 (0.13)***	-0.58 (0.09)***	-0.59 (0.09)***	-0.30 (0.25)	-0.59 (0.09)***
Age^3	0.24 (0.07)***	0.26 (0.07)***	-0.08 (0.17)	0.26 (0.07)***	0.42 (0.05)***	0.43 (0.05)***	0.38 (0.15)**	0.42 (0.05)***
Fall	-0.63 (0.28)*	-0.70 (0.28)*	-0.65 (0.28)*	-0.68 (0.27)*	-1.25 (0.20)***	-1.29 (0.20)***	-1.31 (0.20)***	-1.26 (0.20)***
Winter	-3.49 (0.27)***	-3.56 (0.27)***	-3.55 (0.27)***	-3.57 (0.27)***	-2.67 (0.20)***	-2.70 (0.20)***	-2.71 (0.20)***	-2.67 (0.20)***
Age * Depression			-0.15 (0.33)				-0.29 (0.23)	
Age^2* Depression			-0.63 (0.16)***				-0.13 (0.11)	
Age^3* Depression			0.18 (0.08)*				0.03 (0.06)	
Random effects (variance components):								
Level-1 variance								
Within-person	95.68 (1.70)***	95.36 (1.70)***	95.04 (1.69)***	93.77 (1.70)***	56.49 (1.00)***	56.32 (0.98)***	56.25 (0.98)***	55.68 (0.99)***
Level-2 variances								
Intercept	217.12 (14.12)***	216.60 (14.08)***	217.77 (14.15)***	197.10 (20.20)***	124.86 (7.67)***	125.18 (7.69)***	125.27 (7.69)***	106.22 (12.22)***
Linear term	33.49 (3.29)***	33.52 (3.28)***	33.79 (3.29)***	33.39 (3.29)***	17.94 (2.02)***	18.13 (1.92)***	18.30 (1.94)***	19.02 (2.02)***
Quadratic term	5.13 (0.62)***	5.16 (0.62)***	5.36 (0.64)***	5.10 (0.63)***	2.80 (0.33)***	2.78 (0.33)***	2.80 (0.33)***	2.77 (0.33)***
Cubic term	0.82 (0.16)***	0.83 (0.16)***	0.85 (0.16)***	0.82 (0.16)***	0.58 (0.13)***	0.60 (0.11)***	0.62 (0.11)***	0.66 (0.12)***
Depression				10.70 (3.08)***				3.29 (1.42)*
Overall R^2†	0.287	0.289	0.292	0.301	0.253	0.255	0.256	0.264
Change in R^2‡		0.003	0.007	0.020		0.013	0.013	0.014
Deviance	63006.2	62986.7	62970.7	62944.7	63588.1	63576.6	63571.0	63544.7
AIC	63040.2	63022.7	63012.7	62990.7	63622.1	63612.6	63613.0	63590.7
BIC	63114.3	63101.2	63104.3	63091.0	63697.6	63692.5	63706.2	63692.9

Note. § Models based on n=578 (8105 observations) males, n=627 (8798 observations) females; *** $p<0.001$; ** $p<0.01$; * $p<0.05$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

Three fixed effects were added to assess interactions between depression score and each of the three age effects.

This model revealed a non-significant interaction between depression scores and age, suggesting that depression does not have an effect on the linear effects of physical activity trajectories in males. The BIC statistic was also higher than the model including a fixed effect only.

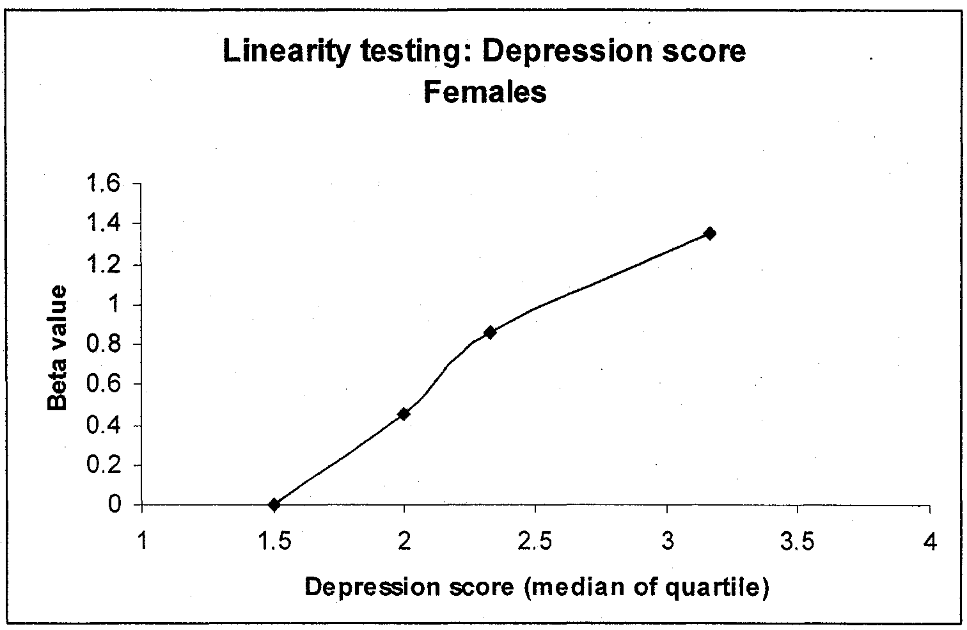
A random component associated with depression scores was added to the model with a fixed effect only. The significant random effect suggests that males displayed heterogeneity in the effects of depression on physical activity participation. This model had the greatest improvement in goodness of fit statistics. In addition, the change in R^2 of the within-person variance from the base model shows that depression scores explain an additional 2% of the variation in physical activity levels in males. Overall, this model accounts for 30.1% of the within-subject variation in physical activity; 1.7% of this variation comes from inclusion of the random effect associated with depression scores.

In females, Figure 4.19 displays no evidence of non-linearity in the effects of depression scores on physical activity. Models using quadratic terms (not reported here) confirmed this conclusion. Therefore, we retained depression scores as a continuous variable with only a linear term for females.

The significant fixed effect for depression (included in the females' base model) suggests that depression scores influenced the age-related physical activity trajectories in females (Table 4.9; page 110). Inclusion of interaction terms between depression scores and each of the three age effects were not significant and increased the goodness of fit statistics, suggesting that depression scores do not have an effect on the linear, quadratic, or cubic effects of physical activity trajectories in females.

Inclusion of a random component, however, was significant, suggesting that females displayed heterogeneity in the effects of depression scores on physical activity participation. The deviance and AIC (goodness of fit) statistics were considerably lower than the model including a fixed effect only; the BIC increased by 0.4 over the linear model, but was nearly equivalent given the addition of five more parameters.

Figure 4.19. Non-linearity testing of depression scores, in females.



In addition, the change in R^2 of the within-person variance over the base model shows that depression scores explained an additional 1.4% of the variation in physical activity levels in females. Overall, this model accounts for 26.4% of the within-subject variation in physical activity; 1% of this variation comes from inclusion of the random effect associated with depression scores.

Stress

The stress score (a continuous measure) was introduced to both the males' and females' base models to examine whether trajectories of subjects differed with varying levels of depression (Table 4.10). Figure 4.20 shows some evidence of non-linearity in the effect of stress scores on physical activity in males. The goodness of fit statistics for each non-linear model (including a quadratic term; including terms for each quartile) confirms that the degree of non-linearity is minor: each shows improvements in the goodness of fit statistics from the base model, but the goodness of fit was worse than the model including a fixed effect (linear term) only (data not shown). We thus retained stress scores as a continuous variable with only a linear term for males.

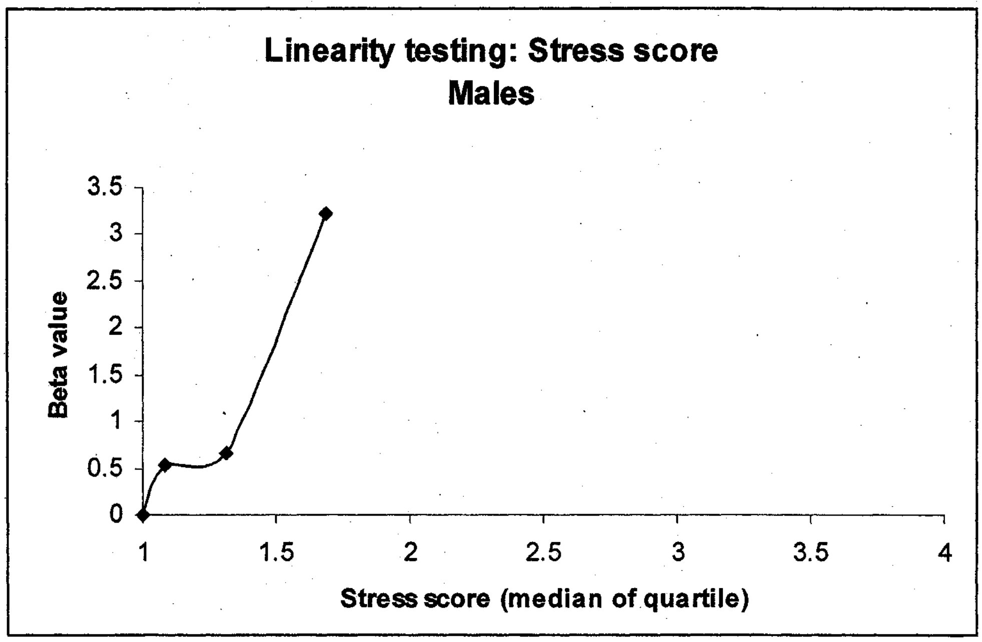
The addition of stress scores in the males' physical activity base model revealed a significant fixed effect for stress and improved goodness of fit statistics, suggesting that stress influenced the age-related physical activity trajectories in males. Three fixed effects were added to assess interactions between stress scores and each of the three age effects. This model revealed a non-significant interaction between stress scores and age, suggesting that stress

Table 4.10. Parameter estimates and standard errors for physical activity models including stress score, by sex among adolescents aged 12-17 years.§

	Males' model				Females' model			
Parameter and Fit Statistic	Level-1 base model	Stress (fixed effect)	Stress (interactions)	Stress (fixed/random effects)	Level-1 base model	Stress (fixed effect)	Stress (interactions)	Stress (fixed/random effects)
Fixed effects:								
Intercept (Status at 14.5 years)	23.59 (0.65)***	18.20 (0.94)***	16.62 (1.09)***	18.32 (1.05)***	20.07 (0.48)***	15.33 (0.72)***	14.17 (0.82)***	15.64 (0.73)***
Stress / Quartile2		4.23 (0.53)***	5.46 (0.68)***	4.13 (0.69)***		3.13 (0.36)***	3.89 (0.44)***	2.89 (0.44)***
Age	-1.95 (0.31)***	-1.83 (0.30)***	-1.64 (0.91)	-1.85 (0.30)***	-2.24 (0.22)***	-2.32 (0.22)***	-0.19 (0.67)	-2.25 (0.22)***
Age^2	-0.56 (0.13)***	-0.59 (0.13)***	0.77 (0.45)	-0.58 (0.13)***	-0.58 (0.09)***	-0.58 (0.09)***	0.02 (0.29)	-0.58 (0.09)***
Age^3	0.24 (0.07)***	0.22 (0.07)***	-0.24 (0.23)	0.22 (0.07)***	0.41 (0.05)***	0.40 (0.05)***	0.15 (0.16)	0.39 (0.05)***
Fall	-0.58 (0.27)*	-0.56 (0.27)*	-0.55 (0.27)*	-0.52 (0.27)	-1.20 (0.20)***	-1.20 (0.20)***	-1.22 (0.20)***	-1.18 (0.20)***
Winter	-3.49 (0.27)***	-3.53 (0.27)***	-3.51 (0.27)***	-3.51 (0.27)***	-2.62 (0.20)***	-2.64 (0.20)***	-2.63 (0.20)***	-2.60 (0.20)***
Age * Stress			-0.15 (0.66)				-1.42 (0.41)***	
Age^2* Stress			-1.06 (0.33)**				-0.38 (0.18)*	
Age^3* Stress			0.35 (0.17)*				0.18 (0.10)	
Random effects (variance components):								
Level-1 variance								
Within-person	95.43 (1.69)***	94.95 (1.68)***	94.67 (1.68)***	92.73 (1.68)***	56.67 (0.99)***	56.08 (0.97)***	55.95 (0.97)***	54.84 (0.97)***
Level-2 variances								
Intercept	214.85 (13.98)***	212.17 (13.81)***	212.58 (13.83)***	248.89 (31.81)***	125.24 (7.68)***	123.37 (7.57)***	123.09 (7.56)***	110.09 (7.20)***
Linear term	32.14 (3.18)***	31.33 (3.11)***	31.46 (3.12)***	31.30 (3.11)***	17.54 (1.95)***	17.82 (1.89)***	17.67 (1.88)***	16.42 (1.84)***
Quadratic term	4.97 (0.61)***	4.82 (0.60)***	4.99 (0.61)***	4.70 (0.59)***	2.80 (0.33)***	2.68 (0.32)***	2.68 (0.32)***	2.58 (0.32)***
Cubic term	0.78 (0.16)***	0.75 (0.15)***	0.77 (0.15)***	0.72 (0.15)***	0.56 (0.12)***	0.60 (0.11)***	0.61 (0.11)***	0.56 (0.11)***
Stress term				45.58 (11.49)***				27.37 (5.46)***
Overall R^2†	0.283	0.286	0.288	0.303	0.248	0.256	0.258	0.273
Change in R^2‡		0.005	0.008	0.028		0.010	0.013	0.032
Deviance	63088.8	63025.9	63015.0	62962.7	63720.6	63644.3	63621.3	63551.7
AIC	63122.8	63061.9	63057.0	63008.7	63754.6	63680.3	63663.3	63597.7
BIC	63196.9	63140.4	63148.5	63109.0	63830.1	63760.2	63756.6	63699.9

Note. § Models based on n=578 (8122 observations) males, n=627 (8815 observations) females; *** p<0.001; ** p<0.01; * p<0.05; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

Figure 4.20. Non-linearity testing of stress scores, in males.



does not have an effect on the linear effects of physical activity trajectories in males (Table 4.10). The BIC statistic was also higher that the model including a fixed effect only.

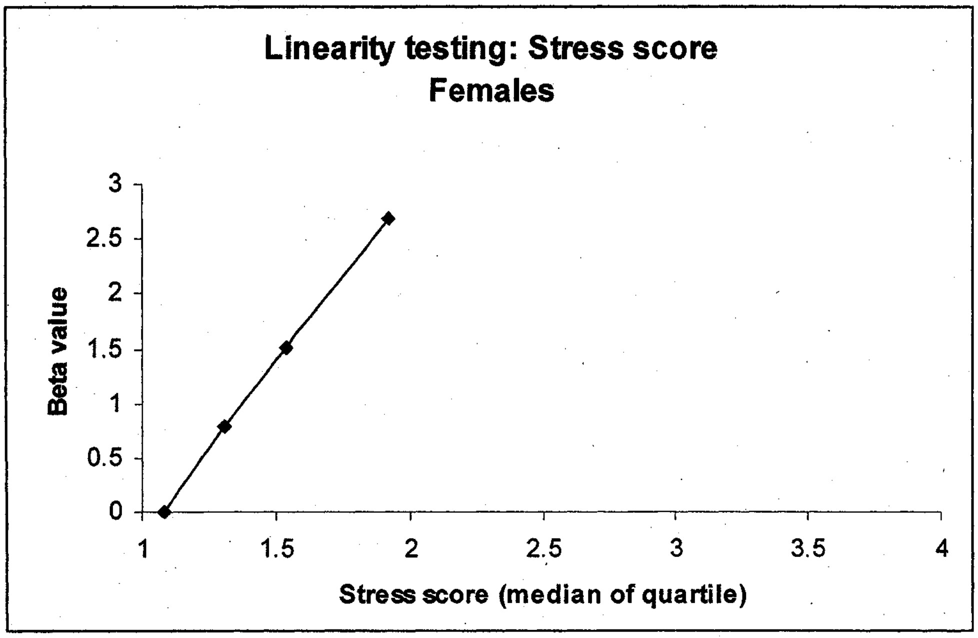
A random component associated with stress scores was added to the model with a fixed effect only. The significant random effect suggests that males displayed heterogeneity in the effects of stress on physical activity participation. This model had the greatest improvement in goodness of fit statistics. The change in R^2 of the within-person variance from the base model shows that stress scores explain an additional 3% of the variation in males' physical activity levels. Overall, this model accounts for 30.3% of the within-subject variation in physical activity in males; 2.3% of this variation can be attributed to inclusion of the random effect associated with stress scores.

In females, Figure 4.21 displays no evidence of non-linearity in the effect of stress scores on physical activity in females. Models using quadratic terms (not reported here) confirmed this conclusion. We thus retained stress scores as a continuous variable with only a linear term for females.

The addition of a fixed effect for stress scores substantially improved the fit of the model (Table 4.10; page 114); significance of the fixed effect suggests that stress influenced the age-related physical activity trajectories in females. Three fixed effects were added to assess interactions between stress scores and each of the three age effects. This model revealed a non-significant interaction between stress scores and age^3, suggesting that stress does not have an effect on the cubic effects of physical activity trajectories in females. The goodness of fit statistics improved from the model including a fixed effect only.

The addition of a random component associated with stress scores to the model including a fixed effect only revealed a significant random effect, suggesting that females displayed heterogeneity in the effects of stress on physical activity participation. This model had the greatest improvement in goodness of fit statistics, even over the model including the interactions between stress scores and each age effect. The change in R^2 of the within-person variance from the base model shows that stress scores explain an additional 3% of the variation in physical activity levels in females.

Figure 4.21. Non-linearity testing of stress scores, in females.



Overall, this model accounts for 27.3% of the within-subject variation in females' physical activity; 2% of this variation comes from inclusion of the random effect associated with stress scores.

TV-watching

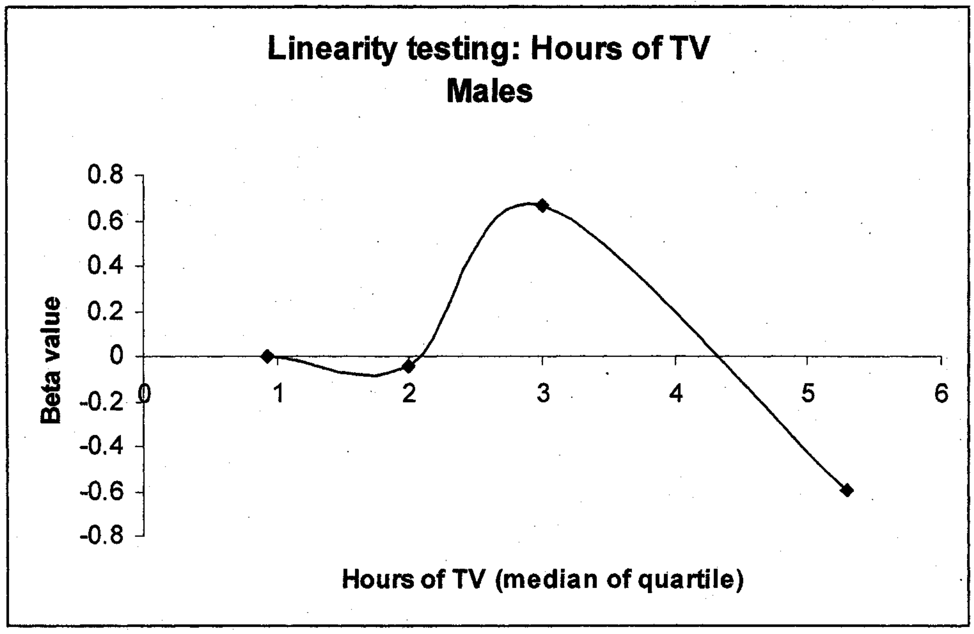
TV-watching (a continuous measure) was introduced to the both the males' and females' base models to examine whether trajectories of subjects differed with varying amounts (in hours per day) of TV-watching (Table 4.11). Figure 4.22 shows evidence of non-linearity in the effect of hours of TV-watching on males' physical activity. Therefore, for males, we can not retain hours of TV-watching as a linear variable. Both of the non-linear models that were assessed in males revealed a significant fixed effect for TV-watching but neither improved

Table 4.11. Parameter estimates and standard errors for physical activity models including hours of TV-watching, by sex among adolescents aged 12-17 years.§

Parameter and Fit Statistic	Males' model			Females' model	
	Level-1 base model	Hours of TV (continuous; linear & quadratic terms)	Hours of TV (categorical; quartiles)	Level-1 base model	Hours of TV (continuous; fixed effect)
Fixed effects:					
Intercept (Status at 14.5 years)	23.49 (0.65)***	22.57 (0.77)***	23.40 (0.72)***	20.13 (0.48)***	19.16 (0.53)***
Hours of TV / Quartile 2		0.39 (0.19)*	-0.04 (0.40)		0.38 (0.08)***
Hours of TV^2 / Quartile 3		-0.02 (0.01)	0.67 (0.51)		
Quartile 4			-0.60 (0.27)		
Age	-1.90 (0.31)***	-1.83 (0.31)***	-1.87 (0.31)***	-2.26 (0.22)***	-2.17 (0.22)***
Age^2	-0.59 (0.13)***	-0.57 (0.13)***	-0.58 (0.13)***	-0.58 (0.09)***	-0.57 (0.09)***
Age^3	0.24 (0.07)***	0.23 (0.07)***	0.24 (0.07)***	0.42 (0.05)***	0.41 (0.05)***
Fall	-0.60 (0.27)*	-0.60 (0.27)*	-0.60 (0.27)*	-1.24 (0.20)***	-1.24 (0.20)***
Winter	-3.52 (0.27)***	-3.55 (0.27)***	-3.54 (0.27)***	-2.65 (0.20)***	-2.70 (0.20)***
Random effects (variance components):					
Level-1 variance					
Within-person	94.84 (1.69)***	94.72 (1.68)***	94.76 (1.68)***	55.87 (1.01)***	55.68 (0.97)***
Level-2 variances					
Intercept	215.00 (14.00)***	215.99 (14.07)***	215.33 (14.03)***	126.42 (7.79)***	126.02 (7.76)***
Linear term	33.63 (3.28)***	33.65 (3.28)***	33.56 (3.27)***	18.09 (2.14)***	18.13 (1.95)***
Quadratic term	4.92 (0.60)***	4.95 (0.60)***	4.92 (0.60)***	2.90 (0.34)***	2.88 (0.34)***
Cubic term	0.80 (0.16)***	0.80 (0.16)***	0.80 (0.16)***	0.61 (0.14)***	0.62 (0.12)***
Overall R^2 †	0.288	0.289	0.288	0.257	0.259
Change in R^2 ‡		0.001	0.001		0.003
Deviance	63007.0	63001.4	63001.5	63461.5	63440.3
AIC	63041.0	63039.4	63041.5	63495.5	63476.3
BIC	63115.1	63122.2	63128.6	63570.8	63556.0

Note. § Models based on n=576 (8116 observations) males, n=620 (8790 observations) females; *** $p<0.001$; ** $p<0.01$; * $p<0.05$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

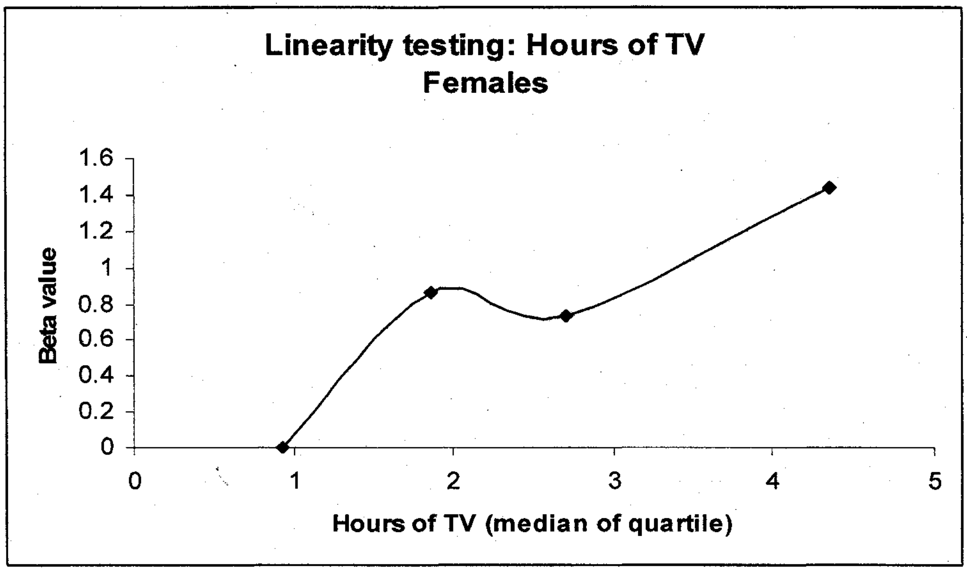
Figure 4.22. Non-linearity testing of time spent watching TV, in males.



the fit of the model. Consequently, there was no evidence to suggest that hours of TV-watching influenced the age-specific trajectories of physical activity in males.

Figure 4.23 displays no evidence of a non-linear relationship between the impact of TV-watching and females' physical activity participation. Models using quadratic terms (not reported here) confirmed this conclusion. We therefore retained hours of TV as a continuous variable with only a linear term for females (Table 4.11; page 118). The significant fixed effect and the improvement in goodness of fit statistics suggest that hours of TV-watching influenced the age-related physical activity trajectories in females.

Figure 4.23. Non-linearity testing of time spent watching TV, in females.



The change in R^2 of the within-person variance from the base model shows that TV-watching in females only explained an additional 0.3% of the variation in physical activity levels. This is a minor impact although the model did suggest that higher amounts of TV-watching were associated with slightly higher levels of physical activity (0.4 activities per week). Overall, this model accounted for 26% of the within-subject variation in physical activity.

Computer/internet/video game-playing

The average time spent playing on the computer or internet, or playing video games (a continuous measure) was introduced to both the males' and females' base models to examine whether trajectories of subjects differed with varying amounts (in hours per day) of computer/internet/video game-playing (Table 4.12).

Table 4.12. Parameter estimates and standard errors for physical activity models including hours of computer/internet/video game-playing, by sex among adolescents aged 12-17 years.§

Parameter and Fit Statistic	Males' model: Level-1 base model	Males' model: Hours of video games (continuous; fixed effect)	Females' model: Level-1 base model	Females' model: Hours of video games (continuous; fixed effect)	Females' model: Hours of video games (fixed and random effects)
Fixed effects:					
Intercept (Status at 14.5 years)	23.57 (0.65)***	23.13 (0.68)***	23.57 (0.65)***	19.79 (0.50)***	19.82 (0.49)***
Hours of video games		0.19 (0.08)*		0.25 (0.08)**	0.19 (0.11)
Age	-1.93 (0.31)***	-1.94 (0.31)***	-1.93 (0.31)***	-2.32 (0.22)***	-2.25 (0.21)***
Age^2	-0.55 (0.13)***	-0.53 (0.13)***	-0.55 (0.13)***	-0.58 (0.09)***	-0.57 (0.09)***
Age^3	0.23 (0.07)***	0.23 (0.07)***	0.23 (0.07)***	0.42 (0.05)***	0.41 (0.05)***
Fall	-0.61 (0.28)*	-0.60 (0.28)*	-0.61 (0.28)*	-1.16 (0.20)***	-1.14 (0.20)***
Winter	-3.55 (0.27)***	-3.56 (0.27)***	-3.55 (0.27)***	-2.63 (0.20)***	-2.60 (0.20)***
Random effects (variance components):					
Level-1 variance					
Within-person	95.84 (1.70)***	95.76 (1.70)***	56.11 (1.00)***	56.05 (1.00)***	54.92 (0.95)***
Level-2 variances					
Intercept	215.28 (14.02)***	215.50 (14.04)***	126.69 (7.80)***	126.35 (7.78)***	121.13 (8.00)***
Linear term	33.63 (3.30)***	33.56 (3.30)***	17.65 (2.05)***	17.83 (2.04)***	17.32 (1.71)***
Quadratic term	5.06 (0.61)***	5.04 (0.61)***	2.86 (0.33)***	2.82 (0.33)***	2.63 (0.32)***
Cubic term	0.83 (0.16)***	0.83 (0.16)***	0.58 (0.13)***	0.60 (0.13)***	0.53 (0.09)***
Hours of video games term					1.51 (0.32)***
Overall R^2 †	0.287	0.281	0.254	0.254	0.269
Change in R^2 ‡ from base model		0.000		0.001	0.020
Deviance	63143.3	63137.9	63471.2	63462.8	63402.8
AIC	63177.3	63173.9	63505.2	63498.8	63448.8
BIC	63251.5	63252.4	63580.6	63578.5	63550.7

Note. § Models based on n=578 (8121 observations) males, n=621 (8790 observations) females; *** $p<0.001$; ** $p<0.01$; * $p<0.05$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model

Figure 4.24 reveals some evidence of non-linearity in the effect of computer/internet/video game-playing on physical activity in males. However, non-linear models revealed no significant fixed effects for either a quadratic term, nor for the fixed effects of each quartile; the goodness of fit statistics also increased over the base model (data not shown). We therefore retained hours of computer/internet/video game-playing as a continuous variable with only a linear term for males. Despite a significant fixed effect, a significant change in deviance and a lower AIC measure, the BIC increased over the base model. Therefore, we conclude there was no evidence to suggest that hours of computer/internet/video game-playing influenced the age-specific trajectories of physical activity in males.

Figure 4.24. Non-linearity testing of time spent playing video games, in males.

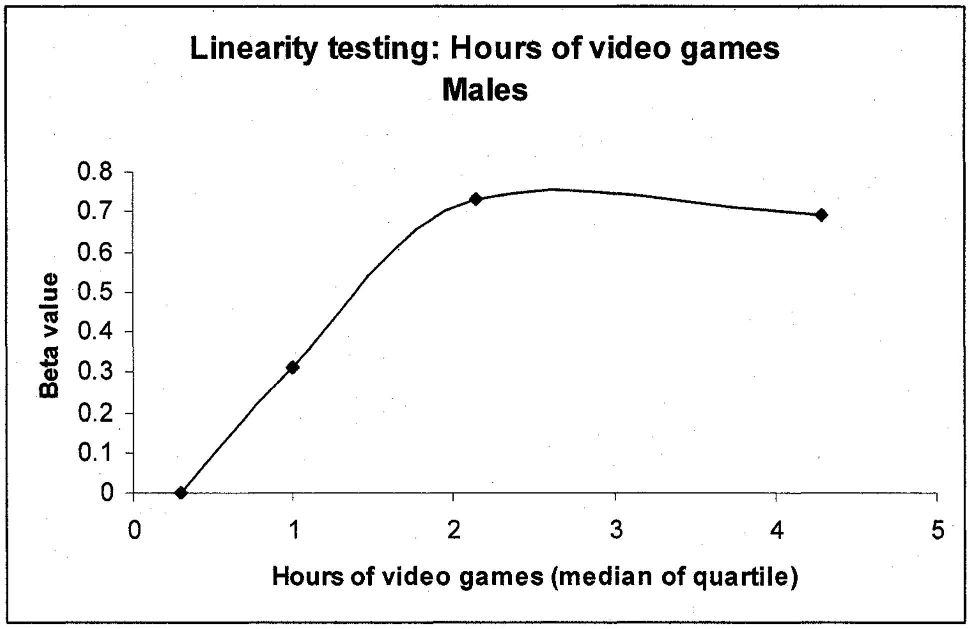
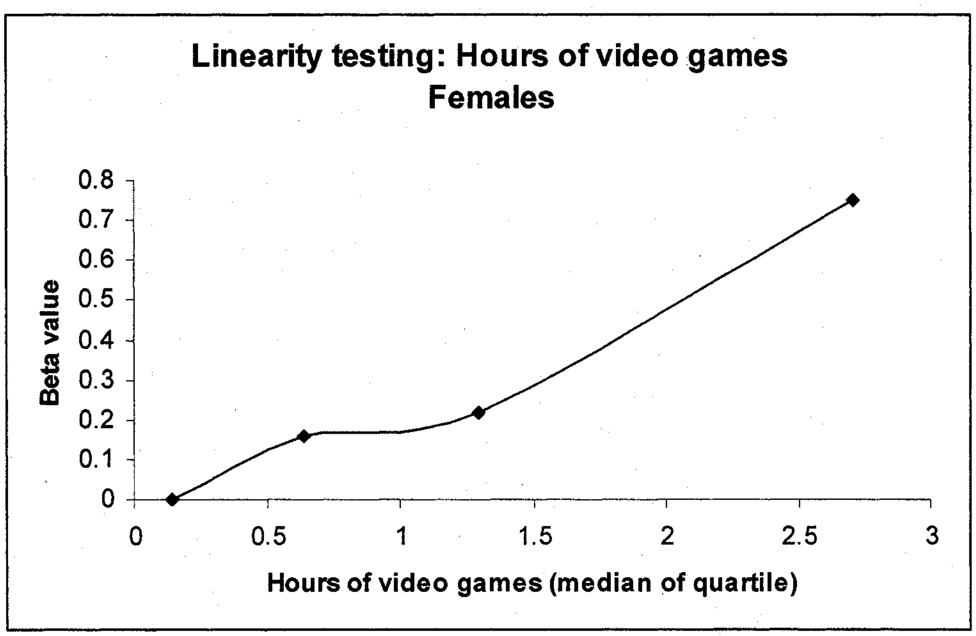


Figure 4.25 shows no evidence of a non-linear relationship between the impact of computer/internet/video game-playing and females' physical activity participation. Models using quadratic terms (not reported here) confirmed this conclusion. We therefore retained hours of TV as a continuous variable with only a linear term for females.

As shown in Table 4.12 (on page 121), the fixed effect for computer/internet/video game-playing was significant. However, when a random effects term was added to the model, the fixed effect was no longer significant, but the goodness of fit statistics were much lower than the model including a fixed effect only.

Figure 4.25. Non-linearity testing of time spent playing video games, in females.



Additionally, the significant random effect suggests that the impact of computer/internet/video game-playing on physical activity for females displays important heterogeneity.

The change in R^2 of the within-person variance from the base model shows that computer/internet/video game-playing in females only explained an additional 2% of the variation in physical activity levels. This is a minor impact although the model did suggest that higher amounts of computer/internet/video game-playing were associated with slightly higher levels of physical activity (0.2 activities per week). Overall, this model accounts for 26.9% of the within-subject variation in physical activity; 2% of this variation comes from inclusion of the random effect associated with hours of computer/internet/video game-playing.

Alcohol use

Alcohol use in the past three months was introduced to both the males' and females' base models to examine whether trajectories of subjects differed by alcohol use (those who drink at least once per month vs those who do not drink at least once per month) (Table 4.13). In males, the fixed effect for alcohol use was significant, suggesting that alcohol use influenced the age-related physical activity trajectories in males. The addition of a random component associated with alcohol use, however, showed a greater improvement in the goodness of fit statistics. Furthermore, the random component was significant, suggesting that males displayed heterogeneity in the effects of alcohol use on physical activity

Table 4.13. Parameter estimates and standard errors for physical activity models including alcohol use, by sex among adolescents aged 12-17 years.§

	Males' model			Females' model		
Parameter and Fit Statistic	Level-1 base model	Drinking (fixed effect)	Drinking (fixed and random effects)	Level-1 base model	Drinking (fixed effect)	Drinking (fixed and random effects)
Fixed effects:						
Intercept (Status at 14.5 years)	23.56 (0.65)***	23.07 (0.66)***	23.04 (0.67)***	20.10 (0.48)***	19.63 (0.49)***	19.65 (0.47)***
Drinking		1.54 (0.36)***	1.43 (0.42)***		1.27 (0.26)***	1.26 (0.26)***
Age	-1.97 (0.31)***	-2.12 (0.31)***	-2.08 (0.32)***	-2.26 (0.21)***	-2.42 (0.22)***	-2.44 (0.22)***
Age^2	-0.57 (0.13)***	-0.57 (0.13)***	-0.54 (0.13)***	-0.58 (0.09)***	-0.56 (0.09)***	-0.56 (0.09)***
Age^3	0.24 (0.07)***	0.24 (0.07)***	0.24 (0.07)***	0.41 (0.05)***	0.41 (0.05)***	0.41 (0.05)***
Fall	-0.61 (0.27)*	-0.64 (0.27)*	-0.68 (0.27)*	-1.22 (0.20)***	-1.25 (0.20)***	-1.27 (0.20)***
Winter	-3.49 (0.27)***	-3.53 (0.27)***	-3.54 (0.27)***	-2.66 (0.20)***	-2.71 (0.20)***	-2.73 (0.20)***
Random effects (variance components):						
Level-1 variance						
Within-person	95.88 (1.69)***	95.65 (1.68)***	93.32 (1.69)***	56.79 (0.97)***	56.60 (1.00)***	56.34 (1.00)***
Level-2 variances						
Intercept	214.38 (13.93)***	213.01 (13.85)***	216.73 (13.84)***	125.23 (7.68)***	124.29 (7.63)***	114.00 (7.49)***
Linear term	33.11 (3.23)***	33.16 (3.24)***	34.86 (3.39)***	17.40 (1.78)***	17.54 (1.99)***	18.84 (1.88)***
Quadratic term	4.94 (0.60)***	4.95 (0.60)***	4.92 (0.61)***	2.86 (0.33)***	2.81 (0.33)***	2.65 (0.32)***
Cubic term	0.80 (0.16)***	0.80 (0.16)***	0.83 (0.16)***	0.55 (0.10)***	0.56 (0.13)***	0.65 (0.10)***
Drinking term			20.62 (5.19)***			2.10 (2.14)
Overall R^2 †	0.286	0.287	0.306	0.252	0.254	0.258
Change in R^2 ‡		0.002	0.027		0.003	0.005
Deviance	63927.7	63909.2	63875.0	64262.7	64238.3	64209.7
AIC	63961.7	63945.2	63921.0	64296.7	64274.3	64255.7
BIC	64035.8	64023.7	64021.3	64372.2	64354.3	64357.8

Note. § Models based on n=579 (8226 observations) males, n=627 (8888 observations) females; *** $p<0.001$; ** $p=0.01$; [a] standard error of the fixed effect; [b] standard error of the variance component; † compared to unconditional means model; ‡ compared to base model participation. The change in R^2 from the base model's within-subject variance shows that alcohol use explains an additional 2.7% of the variation in physical activity levels in males. Overall, this model accounts for 30.6% of the within-subject variation in physical activity; 2.4% of this variation can be attributed to inclusion of the random effect for alcohol use.

In females, the fixed effect for alcohol use was significant, suggesting that alcohol use influenced the age-related physical activity trajectories in females. The random component associated with alcohol use, however, was not significant, suggesting that females did not display heterogeneity in the effects of alcohol use on physical activity participation. Furthermore, the goodness of fit statistics improved greater in the model including a fixed effect term only, based mainly on the BIC statistic (Table 4.13; page 125). The change in R^2 from the base model's within-subject variance shows that alcohol use in females explains only an additional 0.3% of the variation in their physical activity levels. But overall, this model accounts for 25.4% of the within-subject variation in physical activity in females.

Cigarette smoking

Cigarette smoking was introduced to both the males' and females' base models to examine whether trajectories of subjects differed by smoking status (those who smoke every day vs those who do not smoke every day) (Table 4.14). For both males and females, neither model produced a significant fixed effect for cigarette smoking, nor did the goodness of fit statistics improve.

Table 4.14. Parameter estimates and standard errors for physical activity models including cigarette smoking, by sex among adolescents aged 12-17 years.§

Parameter and Fit Statistic	Males' model			Females' model	
	Level-1 base model	Smoking (fixed effect)	Smoking (fixed and random effects)	Level-1 base model	Smoking (fixed effect)
Fixed effects:					
Intercept (Status at 14.5 years)	23.54 (0.66)***	23.62 (0.66)***	23.62 (0.66)***	20.11 (0.48)***	20.14 (0.48)***
Smoking		-1.43 (0.84)	-1.73 (0.99)		-0.19 (0.46)
Age	-1.97 (0.31)***	-1.94 (0.31)***	-1.92 (0.31)***	-2.25 (0.21)***	-2.24 (0.21)***
Age^2	-0.57 (0.13)***	-0.58 (0.13)***	-0.57 (0.13)***	-0.58 (0.09)***	-0.58 (0.09)***
Age^3	0.24 (0.07)***	0.24 (0.07)***	0.24 (0.07)***	0.41 (0.05)***	0.41 (0.05)***
Fall	-0.59 (0.27)*	-0.58 (0.27)*	-0.58 (0.27)*	-1.24 (0.20)***	-1.24 (0.20)***
Winter	-3.46 (0.27)***	-3.46 (0.27)***	-3.46 (0.27)***	-2.66 (0.20)***	-2.66 (0.20)***
Random effects (variance components):					
Level-1 variance					
Within-person	95.67 (1.69)***	95.69 (1.69)***	95.05 (1.69)***	56.78 (0.97)***	56.78 (0.97)***
Level-2 variances					
Intercept	216.26 (14.06)***	216.00 (14.04)***	220.12 (14.42)***	125.45 (7.70)***	125.43 (7.70)***
Linear term	32.98 (3.24)***	32.87 (3.23)***	32.35 (3.24)***	17.42 (1.76)***	17.36 (1.76)***
Quadratic term	5.06 (0.61)***	5.03 (0.61)***	5.07 (0.62)***	2.78 (0.32)***	2.78 (0.32)***
Cubic term	0.81 (0.16)***	0.80 (0.16)***	0.79 (0.16)***		0.54 (0.10)***
Smoking term			42.94 (19.66)*		
Overall R^2†	0.286	0.286	0.291	0.251	0.251
Change in R^2‡		0.000	0.006		0.000
Deviance	63507.4	63504.5	63489.7	64015.3	64015.1
AIC	63541.4	63540.5	63535.7	64049.3	64051.1
BIC	63615.5	63619.0	63635.9	64124.7	64131.0

Note. § Models based on n=578 (8172 observations) males, n=625 (8856 observations) females; *** p<0.001; ** p<0.01; * p<0.05; [a] standard error of the fixed effect; [b] standard error of the variance component; †compared to unconditional means model; ‡compared to base model

Inclusion of a random component associated with cigarette smoking in males was significant; however, the goodness of fit statistics were higher than the base model. Therefore, there was no evidence that cigarette smoking influenced the age-specific trajectories of physical activity in either males or females.

Summary of differences in predictors for males and females

In general, the age-related physical activity trajectories for both males and females were influenced by similar predictors. None of the demographic/biological predictors were significant in either sex, yet depression and stress (psychological/emotional predictors) were positively associated with physical activity trajectories in both sexes. The only behavioural attribute that was significantly associated with physical activity trajectories in both sexes was alcohol use (positively); sedentary behaviours were positively associated with physical activity trajectories in females only.

Each of these predictors may have shown a different effect if included in a multivariate model, but this thesis was a preliminary study of physical activity trajectories in this data set, and intended to examine the relationships of each predictor independently, in order to lay the groundwork for future studies using the NDIT data.

CHAPTER FIVE: DISCUSSION

The objectives of this thesis were to describe trajectories of physical activity in adolescents from age 12 to 17 years, and to identify factors that influenced the shape of these trajectories. In addition, differences between males and females in trajectory patterns were investigated. Our analyses revealed that physical activity levels through adolescence can be described as complex, curvilinear patterns that are influenced by time-varying factors (some in atypical directions) including symptoms of depression and stress, and sedentary behaviours. Marked differences were noted in the trajectories of males and females: males were more active than females at all ages, but activity levels in males decreased at a faster rate. Factors that influenced physical activity trajectories in both sexes included: depression scores, stress scores, and alcohol use; sedentary behaviours (TV-watching, computer/internet/video game-playing) were predictive of physical activity patterns among females only. Country of birth of the subject and his/her parents, BMI at baseline, and smoking were not associated with physical activity trajectories in either sex.

Physical activity trajectories through adolescence

Our analysis revealed an overall trajectory pattern best described by a cubic function. Specifically, physical activity levels increased from age 12, peaked at approximately age 13.5, decreased to age 16.5, and then began to increase again to age 17. This suggests that physical activity behaviours of adolescents are complex since they in fact fluctuate through adolescence. The declines observed from age 14 to 16 years are consistent with declines observed in most longitudinal studies of physical activity in this age group.[25-27;52-54;57] However, no study to date has documented increases in physical activity participation from age 12 to 14, and several studies report that declines are in fact, most pronounced at these ages.[26;28] One possible explanation for the increases observed in our study is that secondary schools often provide a broader range of sports and fitness activities than elementary schools,[59] and subjects in this study had just entered secondary school (grade 7). Students may have taken advantage of the increased availability of sports and physical activity opportunities as they entered high school. Alternatively, students may have actively sought out opportunities for social interaction through intramural or extramural sports, in order to establish new friendships and participate in new social circles.

Increases in physical activity after age 16 have been observed in other studies.[27;28] Van Mechelen et al.[28] for example reported a 5% increase in total habitual activity in both males and females from age 16 to age 21, most notably in time spent in "other" activities (including physical activity at work or school, active transportation, household activities, shopping, and leisure time activities other than sports activities). Other studies have reported increases in specific types of activities during the late-adolescent years, such as low-intensity activities.[53;100] The increase in participation observed in this analysis may be specific to low-intensity and/or "other" activities (such as indoor/outdoor chores). NDIT data could be used in further analyses to investigate if increases in physical activity are due to stable and/or increased participation in only a few specific activities, rather than a general increase in activities overall. It is possible that adolescents in this age group prefer certain types of activity, such as individual sports (i.e., running, swimming) rather than team sports (i.e., basketball, hockey). Participation in team sports tends to be more stable over time in males than participation in individual sports, although the reverse has been observed among females.[25] Better understanding of preferences for certain types of activities may help in the conceptualization and development of intervention strategies targeted to young males and females.

Sex differences in physical activity trajectories

One major finding in this analysis is that physical activity trajectories differed between males and females. Consistent with previous studies,[25;26;28;29;53;55;57] males were more active than females at all ages. Also consistent, males decreased at a faster rate than females.[25;26;53;55;57] The cubic curve, however, was more prominent in females. At age 16.5, physical activity levels among females increased, whereas the rate of decline in physical activity decreased among males. Additional waves of NDIT data (after 4.5 years) may show that activity levels among females eventually exceed activity levels among males, as has been reported in previous studies.[26;28] It is possible that physical activity patterns are more stable for males during adolescence than for females, as Janz et al.[101] found in a similar population.

Individual differences in physical activity trajectories

The finding that physical activity follows a cubic pattern during adolescence was based on the overall sample trajectory (i.e., the fixed effects). We also found evidence for substantial within- and between-subject heterogeneity in the trajectories. That is, subjects display different patterns of change in physical activity levels as they grow older. These differences impact on the average level of physical activity as well as on the pattern of change over time. This study was unable to characterize the heterogeneity in more detail. Available predictor variables provide some explanation of the differences but still left considerable unexplained heterogeneity. Future analyses might use cluster or similar methods to identify groups of subjects displaying more homogeneous trajectories, particularly to examine between-subject differences in physical activity trajectories.

No prior study has considered the presence of individual (within-subject) differences in trajectories. But this important finding indicates there is considerable variation in physical activity behaviours in adolescents. Several factors may contribute to unstable physical activity patterns during adolescence within-subjects. According to Freud[102] and Erikson,[103] the adolescent years are marked by transitions and changes. In particular, external changes in life events (e.g., entering and leaving high school, entry into the work force) may affect the pattern of physical activity participation during adolescence,[64] due to increased role/responsibilities and social demands.[104] Unfortunately, NDIT data do not capture the period of transition into secondary school, nor the period post-secondary school, and therefore these transitions should not directly influence the physical activity trajectories in this sample. However, entry into the work force and other increased role/responsibilities and social demands (e.g., dating/relationships, tests/exams, peer pressure) may have variable effects on different individuals, which could potentially result in heterogeneity in physical activity participation. To consider two extremes, an individual (with potentially effective coping strategies) may adjust well to busy schedules, in which case their physical activity patterns would be relatively stable because they are able to continue with established behaviours. On the other hand, an individual (with potentially poor coping strategies) may struggle with greater time demands, resulting in unstable physical activity due to the inability to maintain common behaviours when time is limited. These differences in coping mechanisms may contribute to within-subject heterogeneity in physical activity patterns through adolescence.

Within-subject heterogeneity may also be a result of changes in motivation sources. Shephard[8] reports that during adolescence, cues or role models for an active lifestyle shift from the parent or coach to the peer group. Therefore, individuals with athletic peers may have higher physical activity than individuals with few or no athletic peers. There was no information in the NDIT to explore this relationship.

Seasonal differences

Data collection waves at approximate two-month intervals allowed assessment of seasonal variation in physical activity levels. Consistent with other studies,[38;66;105] activity levels were highest in the spring, lower in fall and lowest in winter. Warmer temperatures and longer daylight hours in spring[66] likely contribute to higher levels of participation in physical activities. Declines in the fall and winter may relate in part to weather and to higher demands of schoolwork during the winter months. Aaron et al.[25] assessed the stability of year-round activities versus seasonal activities in subjects aged 12-15 years, and reported that over four years, year-round activities were more stable than seasonal activities. Strategies to promote physical activity need to include ways for adolescents to maintain activity levels throughout the year, particularly during the winter season.

The finding that number of physical activities declined to a greater extent among males during the winter months is unexpected; the reason for this difference is unclear.

Explaining individual differences in physical activity trajectories – predictor analyses

Another unexpected finding was that both depression and stress had significant, positive effects on physical activity trajectories in both sexes. To date three longitudinal studies have reported no association,[14;35;70] although two cross-sectional studies reported that depression was inversely associated with physical activity.[72;73] However, the measures of depression used in these cross-sectional studies encompassed indicators of anxiety, and it is possible that the inverse association[72;73] reflected a combination of the effects of depression and anxiety (i.e., high levels of anxiety might have a strong negative relationship with physical activity). Norris et al.[14] found that subjects who participated in a ten-week, high-intensity training program had significantly lower anxiety scores than subjects who participated in a moderate-intensity training program. However, there were no significant differences between anxiety scores in the high- or moderate-intensity training groups and the flexibility training or control groups.[14]

Results for two longitudinal studies[14;34] suggest a significant, negative relationship between stress and physical activity. One intervention study examined the effects of physical activity by level of intensity, and a significant, inverse relationship was observed only among those in the high-intensity training group (no relationship was found for those in the moderate-intensity or flexibility training groups, or in the control group).[14] In a female-only sample, Reynolds et al.,[34] found a significant, inverse relationship at 4 months of follow-up, that was no longer apparent at 16 months.

Due to limited evidence regarding the relationship between physical activity and both depression and stress, the positive associations found in this study are neither confirmatory nor contradictory of existing evidence. It may be that adolescents with depression symptoms participate to a greater extent in physical activity or alternatively, that participation leads to more depression symptoms. Paluska et al.[106] suggest for example that excessive physical activity may lead to overtraining, which may in turn lead to symptoms of depression.

Adolescents can be exposed to many stressors such as pressure to excel at school, family difficulties, stresses associated with physical maturation, and peer pressure, that may relate to the positive association between stress and physical activity. Commitments to sports teams or competitive sports may be an additional source of stress if they result in less time to focus on other activities. If sports are competitive, there may be increased pressure to perform well. Alternatively, it is possible that high levels of stress result in higher activity levels, as a stress-coping mechanism. Exercise may shift a person's focus away from everyday stressors, allowing a temporary escape from the burdens of life.[104] Future studies should examine the natural course of physical activity in relation to both depression and stress.

There were significant random components associated with both depression and stress, indicating substantial inter-individual variation in the effects on physical activity participation. Heterogeneity in the relationship between stress, depression and physical activity would need to be considered.

The positive association between physical activity participation and sedentary behaviours observed among females is inconsistent with previous research. However, the magnitude of the association was small (an increase of 0.4 activities per week for each hour of TV-watched per day and 0.2 activities per week for each hour of increased computer/internet/video game-playing). Furthermore, given that each sedentary activity added little explanatory variance in activity levels (TV-watching only accounted for 0.3% of the within-person variance, computer/internet/video game-playing accounted for 0.2%), it is unlikely that this relation is clinically meaningful. In fact, significance may simply relate to the increased statistical power associated with large sample sizes. Previous cross-sectional studies have reported an inverse relationship between sedentary behaviours and physical activity in females,[32] males,[62] and both sexes;[33] one longitudinal study found no association.[35] However, a positive relationship was reported in two cross-sectional studies of younger children (aged 9-13 years[107] and 9-15 years[108]). It is conceivable that individuals with high levels of activity watch more TV perhaps because they are less interested in school work. It is also possible that individuals who remember and report participation in numerous physical activities also have a tendency to recall and report more sedentary behaviour.[108]

Alcohol use was positively associated with physical activity levels in both males and females. This is consistent with one cross-sectional study in youth;[76] and also with studies of adults.[65] Physical activity participation can provide opportunities for a social interchange and use of alcohol is often an integral part of post-activity social gatherings.[65] The adolescent population in this analysis is below the legal drinking age in Quebec. However, 50% of males and 53% of females at age 17 reported that they had consumed alcohol (the proportion was lower at younger ages; 14% of males and 12% of females reporting drinking at age 12).

Smoking was not a significant predictor of age-related physical activity trajectories. Others have found a significant (inverse) relationship, but measures of smoking status differ across studies. Aarnio et al.[69] grouped subjects into regular smokers, occasional smokers (including quitters) and non-smokers. Pate et al.[76] classified subjects as smokers if they had smoked in the past 30 days. Kimm et al.[54] categorized subjects as smoker if they responded yes to "smoked daily", "almost daily", or "weekly". We re-ran our analysis broadening our definition of smokers to include subjects who had smoked once or a couple of times each week (rather than smoked everyday), with no substantive changes in the results.

None of the candidate demographic or biological predictor variables (i.e., subject's country of birth, parent's country of birth, baseline BMI) influenced age-related physical activity levels in either males or females. In contrast, O'Loughlin et al.[109] found that country of birth was a strong predictor of physical activity in a younger study population (i.e., students in grades 4 and 5). BMI has been reported to be a significant predictor of physical activity, but only in females.[31;34;54] Consistent with this current analysis however, the majority of studies report no association.[32;35;62;77]

Proportion of variability explained in physical activity trajectories

Just over 27% of the within-person variance in physical activity was explained by a cubic change trajectory, controlling for season. The inclusion of time-varying predictors added minimal explanatory variance (at its highest, a 3% increase in explained variance with the addition of stress to the models for males and females). A multivariate model would likely explain a greater percent of the within-person variance. It is plausible that important predictors were not considered in this analysis.

Limitations

This analysis is subject to several limitations. First, this was a secondary analysis of an existing database, the study and the primary objective of which was not related to physical activity. The variables available for analysis were limited to those collected in the context of the original objectives. Other predictor variables that may have influenced age-related trajectories in male and female adolescents that were not assessed in the NDIT Study include puberty,[56] illicit drug use,[76;110] parent/friend/teacher support,[29;31;35] barriers to physical activity,[31;32;35] and availability of resources in the home, school, or neighbourhood environment.[29;62;63]

There were, however, a number of potential predictors that were measured but could not be analyzed due to exclusion criteria used in this analysis. For example, questions were asked in collection cycles 7 and 11 on self-esteem. Self-esteem has been associated, both positively and negatively, with levels of physical activity.[13;33] Data were collected in cycles 7 and 12 on chronic health problems (asthma, for example may explain limited physical activity levels in subjects with this problem). Finally subjects were asked in cycles 11 and 12 about their academic performance; an exploration of the relationship between academic performance and physical activity participation may have provided an interesting perspective. However, data on these variables were collected in only two collection waves and therefore were excluded as potential predictor variables.

Social factors, such as family and peer influences, were not assessed in the NDIT questionnaire. Social factors have been examined in previous studies and have provided useful predictive information.[60;64;65]

Another limitation is that the measure of physical activity used in this thesis did not assess duration of participation. It measured instead, frequency of participation in activities in which the subjects participated for a minimum of five-minutes. It is unlikely that participation in physical activities for as little as five minutes results in health benefits or in habit-forming behaviours. Without consideration of the duration of participation, the total time spent participating in physical activity cannot be assessed. In addition, self-report measures are prone to overestimation of physical activity participation, an effect which can be exacerbated if the questionnaire provides a checklist of activities[41] (as in the NDIT Study).

The omission of socioeconomic status (SES) as a predictor variable is a limitation, because higher SES is associated with higher levels of physical activity.[31;54;69;70;74]

Another limitation is that our analysis examined the influence of candidate predictors on physical activity trajectories univariately; a multivariate model was not developed, and therefore the analysis could not identify independent predictors of activity levels (i.e., the impact of specific factors in the presence of other factors), and it neglected the necessity to control for confounding effects.

Because we did not compare the characteristics of subjects retained in the study with those who were excluded (due either to dropping-out or to missing data), selection bias cannot be ruled out. External generalizability may also be limited because subjects were recruited in a convenience sample and the baseline response was 56%. Measurement error may also have been present because the data were collected in self-reports by adolescents, which are subject to recall bias and overestimation of activity participation.[41] Finally, due to the nature of longitudinal studies, repeated questionnaires may alter behaviour with respect to initiating health-related changes.[111] This is unlikely in NDIT, however, because the primary purpose was to measure nicotine dependence symptoms and tobacco exposure.

Strengths

There are a number of strengths in this study as well. First and foremost, the long-term, prospective design allowed for the assessment of physical activity patterns (developmental trajectories) through adolescence. In addition, the time-interval between assessments was approximately two months (during the school year), which provided great detail on how physical activity levels change in this age group. This represents a significant improvement over previous longitudinal studies that are limited by short follow-up periods and long time intervals between assessments. The short time-intervals between data collection waves also allowed for the assessment of seasonality as a predictor of physical activity. Data on candidate predictors were collected using the same assessment methods at each of the 18 data waves. The sample size was large, composed of 1206 subjects and 17,172 data points over the 4.5-year study period.

The analytic approach used in this thesis (i.e., the multilevel model for change) permitted modeling changes over time for each person in the sample, and allowed assessment of how these changes varied across subjects.[83] Consequently, we were able to assess the degree to which both within- and between-person values differed from population average values in this age group. No published study to date has reported physical activity trajectories in adolescents using such sophisticated analyses.

Suggestions for future research

Understanding patterns of physical activity during adolescence is important for identifying youth at risk for inactivity as adults, as well as for developing effective interventions aimed at promoting increased levels of activity. Longitudinal studies that collect data repeatedly at short time intervals over long follow-up periods, can accurately describe the pattern of physical activity behaviours, particularly if the data are modeled using sophisticated regression (trajectory) analysis.

Results of this analysis show that, although physical activity declines through adolescence, there are periods in which activity levels may increase. Future research should identify factors that contribute to this rise in activity. Do adolescents participate in more organized sports through these ages? Are the activities primarily individual sports since organized sports may not be readily available in late-adolescence? Is the increase in activities specific to low-intensity activities rather than moderate or vigorous activities? Knowledge of these factors can help shape physical activity promotion strategies.

Changes in levels of activity observed in this analysis relates to changes in frequency of participation. However, without a measure of duration of physical activity, it is not possible to assess whether duration of participation changes. It might be useful to group activities according to intensity (i.e., using the Compendium of Physical Activities,[51] a classification tool to measure energy costs for specific activities) to determine if increases were specific to low-intensity activities. The NDIT questionnaire assessed participation in school sports teams and participation in sports and/or lessons outside of school; it would be interesting to describe trajectories (and possibly even identify predictors of change) in these specific activities.

There is limited evidence regarding factors that influence age-related changes in physical activity during adolescence. More longitudinal studies are needed to examine the relationships between health-related behaviours, and in particular, how these behaviours change over time and influence the pattern of physical activity through adolescence. Furthermore, knowledge of the determinants of physical activity can provide the basis to develop more effective interventions, especially if these determinants are amenable to intervention and can be targeted for change.[60]

NDIT data could be stratified by school to ascertain if students in English or French-language schools have differing activity patterns.

French and English schools may differ in terms of the physical activity curriculum. If patterns differ according to language, interventions may need to be tailored to account for these factors. The influence of socioeconomic factors should also be assessed.

Physical activity is determined or influenced by a variety of factors.[64] Multivariate models should be developed using NDIT and other data to identify independent influences on physical activity trajectories. The direction of association between the predictors and physical activity may change in the presence of other factors, and undoubtedly, these factors are interrelated.

Due to the heterogeneity in trajectories observed in this study, future studies should identify subgroups of adolescents with distinctive developmental trajectories. Subject characteristics can then be identified to determine their effect on trajectory membership.

Future research must also focus on identifying factors that increase physical activity. Activity preferences and recruitment strategies that can be used to make activity participation more appealing for adolescents should be a high priority.

Considering the limited generalizability with the NDIT, it is hopeful that other researchers will take the many strengths of these data and apply them to other longitudinal studies with greater generalizability, perhaps in a population-based sample. Furthermore, careful consideration of other health-related behaviours that may be associated with physical activity over time need to be examined.

Conclusion

This study has implications for the conceptualization and development of programs to promote physical activity, further analysis of NDIT and other data, and future monitoring of physical activity in Canada. The adolescent years are a time when independence is established. Lifestyle habits developed during this life stage are likely to be constant for many years.[112] It is essential that we prevent declines in physical activity levels during adolescence, and that we identify factors that promote healthy levels of participation in physical activity.[113] Effective physical activity promotion interventions aimed at adolescents may have the potential to prevent inactivity in adulthood, the onset of chronic diseases in later life, and the economic burden these health problems will eventually have on the health care system in Canada.

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APPENDICES

Appendix A. Summary of longitudinal and cross-sectional studies measuring predictors/correlates of physical activity in adolescents

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
Longitudinal studies:					
Comparison of barriers self-efficacy and perceived behavioral control for explaining physical activity across 1 year among adolescent females. Motl et al.,[52] 2005	• FEMALES in 8th grade at baseline from 12 high schools (and associated middle schools) in South Carolina • n=1038 (856 baseline, 853 FU)	• 3-Day Physical Activity Recall (3DPAR) • Duration of study: 1 year; (baseline in spring semester of 1999, FU in spring semester of 2000)	• Structural equation modeling (SEM) performed using full-information maximum likelihood (FIML)	• Barriers • self efficacy • perceived behavioural control • baseline MPA / baseline VPA	• Baseline self efficacy predictive of baseline MPA (beta= .34) and baseline VPA (.17) • baseline perceived behavioural control predictive of baseline VPA (.25) and FU VPA (.15) • baseline MPA predictive of FU MPA (.39) • baseline VPA predictive of FU VPA (.36)
Tracking of physical activity and aerobic power from childhood through adolescence. McMurray et al.,[37] 2003	• 3rd and 4th-grade students at baseline (1990) from the Cardiovascular Health in Children Study (CHIC) recruited from 21 elementary schools in North Carolina • n=791 (males: n=404; females: n=387)	• Physical activity survey that listed 32 different activities commonly performed and how often they completed each activity • Duration of study: 7 years; (FU annually to approximately 16 years of age)	• ANOVA for gender comparisons • Mixed model ANOVA for time trends by race and sex	• Sex • Race (black vs white)	• Females had significantly lower activity scores than males • No significant differences between race within gender and year

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
Factors associated with changes in physical activity. Neumark-Sztainer et al.,[35] 2003	• Subjects were FEMALES in grades 9-12 who were overweight or at risk of overweight because of low levels of PA from 6 high schools in Minneapolis/St. Paul area • n=201	• Modified version of the Leisure Time Exercise Questionnaire • Duration of study: 8 months (Baseline Sept. 2000, FU Jan. 2001, FU April 2001)	• Changes in outcome were fit by linear regression • Backward elimination with manual choice until only significant variables remained in model	• Personal factors: self-acceptance, self-worth, athletic competence, physical appearance, body satisfaction, depressive mood, benefits of PA, enjoyment of PA, self-efficacy to be physically active, BMI, age, race/ethnicity • Behavioural factors: watching TV, time constraints • Socioenvironmental factors: support for PA, cost/lack of resources for PA	• Factors associated with change in VPA during the study period included time constraints (estimated extra VPA in min/wk -32) and social support for PA (estimated extra PA in min/wk 28); associations with self-worth (estimated extra PA in min/wk 11) marginally significant • Time constraints (estimated extra MPA in min/wk -20) and self-efficacy (estimated extra PA in min/wk 17) were associated with change in moderate PA • Factors associated with change in MVPA over time include time constraints (estimated extra MVPA in min/wk -53), support for PA (estimated extra PA in min/wk 35), and self-worth (though only of marginal significance; estimated extra PA in min/wk 19)
Associations of health related behaviour, social relationships, and health status with persistent physical activity and inactivity: a study of Finnish adolescent twins. Aarnio et al.,[69] 2002	• 16-year old (twins) at baseline from the Central Population Registry of Finland • n=4906 (2254 males, 2652 females)	• Questionnaire - assessed the frequency of leisure time PA outside school • Duration of study: 3 years; (Baseline within 1 month of 16th birthday, FU 1 month after 17th birthday, again within 6 months of 18th birthday)	• Logistic regression - first independently, then multivariate • Final sex-specific model performed with those variables that remained significant in group-wise	• Health-related behaviours: smoking, alcohol consumption, use of dietary fats (measured by type of spread put on bread), breakfast eating habits • Social relationships: kind of school (academically oriented HS, vocational, others), school grade	• Persistently active MALES – non-smoking (ref grp, Odds Ratio regular smoking 0.20), regular breakfast eating (ref grp, OR once a week 0.23), attending a gym (ref grp, vocational school OR 0.46; other alternatives OR 0.40), mother's SES upper level (ref grp, self-employed OR 0.25), good perceived current health (very good ref grp, good/avg OR 0.47) • Persistently active FEMALES – non-smoking (ref grp, regular smoking OR 0.52), regular breakfast eating habits (ref grp, once a week OR 0.62), non-use of spreads on bread (ref grp, butter OR 0.39, margarine OR 0.45), attending a gym (ref grp, vocational school

Study title/ Reference	Study Population	Measure of PA/ Method	Statistical Analysis	Independent variables	Main Findings
			analysis • Those that answered at all 3 questionnaires that their frequency of PA was 4-5 times per week were classified as persistent exercisers	compared with class average, SES of parents • Health status: own perception of current health, BMI	OR 0.46; other alternative schools OR 0.33), good perceived current health (ref grp, poor OR 0.37, good/avg OR 0.56)
Decline in physical activity in black females and white females during adolescence. Kimm et al.,[54] 2002	• FEMALES aged 9-10 years at baseline from the National Heart, Lung, and Blood Institute Growth and Health Study recruited from school districts outside Berkeley, CA, and Cincinnati, OH; large health maintenance organization in Washington, DC • n=2379 females (1213 Black,	• Habitual Activity Questionnaire (HAQ) • Duration of study: 10 years; (FU annually until ages 18-19 years)	• Generalized estimating equations to determine whether changes in activity scores from study year 1 to study year 5 differed from those from study year 5 to study year 8 (only used data from first 8 study years because median HAQ scores fell to zero for black	• Household income (ref grp: $40000 or more) • parental level of education (4+ yrs of college) • Number of parents in household (2 parents) • BMI from each successive FU interval • HAQ score from each successive FU interval • pregnancy (never pregnant) (examined for years 5-8) • smoking (non-smoker) (examined for years 5-8)	• Household income not significant • Predictors of decline from years 1-5 in black females: BMI (effect size - represents change in HAQ score in MET-times/week: -0.17) and HAQ (-0.79) scores from each successive FU interval • Predictors of decline from years 1-5 in white females: parental level of education – high school or less (-4.34) and some college (-2.53), BMI (-0.21) and HAQ (-0.82) from each successive FU interval • Predictors of decline from years 5-8 in black females: parental level of education – high school or less (-1.28), some college (-0.99), ever pregnant (-1.91), BMI (-0.08) and HAQ (-0.43) from each successive FU interval • Predictors of decline from years 5-8 in white females: parental level of education – high school or less (-1.80), some college (-1.57), single-parent household (-1.27), cigarette smoking (-1.89), BMI (-0.08) and HAQ (-0.35) from each successive FU interval

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
	1166 white)		females by year 8)		
Psychosocial correlated of PA and sedentary leisure habits in young adolescents: The Teens Eating for Energy and Nutrition at School Study. Schmitz et al.,[70] 2002	• 7th grade students at baseline (age range 11-15 years) from 16 schools (with lower income populations) in the Twin Cities, Minnesota • n=3878 at baseline; n=3798 at FU	• Questionnaire - assessed whether they were physically active (outside of school) 3 times a week for at least 20 minutes at a time • Duration of study: 8 months; (baseline fall 1998; FU in spring of 1999)	• General Linear Mixed Model • Separate analysis for males and females. • Initial models included linear and quadratic terms for each continuous independent variable of interest – provided an indication of any nonlinear relationships that might exist in the data	• Demographic and SES variables: sex, DOB, race, participation in free/reduced meal program at school, number of parents they live with, highest level of education for mother and father, number of parents who work full-time • Depression (CES-D, higher scores more depressed) • Spirituality • Future expectations • Parenting style (authoritative vs non-authoritative) • Importance student places on health, appearance, and achievement • Perceived academic rank compared to other students • If expect to finish college	• MALES – PA significantly higher in Caucasian and multiethnic students compared to Asian and "other" , PA higher in males who lived in homes where at least one parent was working and homes where a mother was present; non-authoritative (mother) parenting style and perceived academic rank • FEMALES – PA higher with parents' education level, authoritative (mother) parenting style, value on health, appearance and achievement scale, and perceived academic rank • NOTE: Authoritative parenting style sets clear boundaries for the child while remaining responsive to the child's needs and rights; fosters child competence, self-esteem, and academic achievement; a non-authoritative parent is intrusive and controlling, provides little support for the child's individuation
Changes in common activities of 3rd	• Students in grades 3 and 4 at baseline	• Questionnaires - asked subjects to indicate the	• Weighted least squares to assess	• Activities most participated (vigorous vs	• FEMALES: from ages 8-11, AA females reported doing more intense activities than CA or other race females, but beginning at

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
through 10th graders: the CHIC Study. Bradley et al.,[56] 2000	(aged 8-11 years; 1990-91 school year) from the Cardiovascular Health in Children and Youth (CHIC) studies recruited from elementary schools from 12 counties across North Carolina • n=656 (50.5% female)	three activities they usually did most • Duration of study: 6 years; (FU annually to 9th-and 10th-grade; aged 14-17 years)	gender on activity status across time • GEE model to test whether pubertal status or race in either middle or high school significant predictors of activity status for each gender	sedentary) • by race (AA: African-American; CA: Caucasian)	ages 9-12, AA females reported more sedentary activities than other races and maintained through ages 14-17 • MALES: At young ages, AA and CA males reported similar activity patterns, but males from other races reported more intense activities until 11-14, when AA males reported more sedentary activities than CA or other races • At ages 14-17, race was a marginally significant predictor of VPA with CA females more likely to report; for males race was significant of activity status with CA more likely than AA to report vigorous activities
Determinants of exercise among children. II. A longitudinal analysis. DiLorenzo et al.,[29] 1998	• 5th and 6th grade students at baseline from a Midwestern community (Missouri) • n=54 females, n=57 males	• Structured in-home interview (Physical Activity Interview, PAI) • Parents also given a parental PA questionnaire regarding parents' exercise habits, etc. • Duration of study: 3 years; (May/June 1991 and 1994)	• Linear regression for potential predictors • Variables that did not account for at least 1% of the variance were not included • Analyses only includes those that participated in both Phases	• Child's self-efficacy for PA • Direct parental modeling • Friend and family support • Child's enjoyment of PA • Home equipment • Child's exercise knowledge • Negative indicators of PA (mother's report) • Child's interest in sports media • Mother/father's PA level	• FEMALES – mother's self-efficacy for PA (inversely; accounted for 11% of variance); mother's barriers to exercise (inverse; 6%); mother's enjoyment of exercise (inverse; 4%); child's self-efficacy for PA (5%) – model accounting for a total of 25% • MALES – child's exercise knowledge (21%)

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
				• Mother/father's self-efficacy • Mother/father – friend modeling support • Mother/father – family support, rewards/punishments, • Mother/father's enjoyment in PA • Mother/father's barriers to exercise	
Continuity and change in sporting and leisure time physical activities during adolescence. Dovey et al.,[57] 1998	• Participants were part of the Dunedin Multidisciplinary Health and Development Study (DMHDS) in New Zealand (recruited at birth from a hospital in Dunedin between April 1 1972 and March 31 1973); this study only looks at them from age 15-18 • n=775 (400 males, 375 females)	• Face to face interview consisted of the Minnesota Leisure Time Physical Activity Questionnaire • Duration of study: 3 years; (baseline at age 15 collected during 1997-1998 and FU at age 18 from 1990-1991)	• Predictors (from age 15) of subjects who participate in more than four hours a week of PA at age 18 identified by logistic regression	• "very good" self assessed health at age 15 (rather than "good", "fair" or "poor") • playing sports in a school team at age 15 (yes/no) • Reporting their fitness to be "better" than that of their peers (rather than "the same" or "worse")	• Controlling for sex, predictors of spending more than 4 hrs/wk in physical activity at age 18 were having very good self assessed health (OR=1.4), playing sport in a school sports team (OR=1.8), and judging ones fitness to be better than their peers (OR=1.7) • For MALES only, playing representative sport at age 15 (OR=2.1) and having better self assessed fitness (OR=1.7) • For FEMALES only, having better self assessed fitness (OR=1.8)

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children Crocker et al.,[66] 1997	• Students in grades 4-8 (aged 9-14 years) from the Saskatchewan Bone Mineral Accrual Study • n=200 (102 females, 98 males)	• Physical Activity Questionnaire for Older Children (PAQ-C) • Duration of study: 8 months (data collection 3 times: in fall, winter, spring)	• ANOVA with repeated measures on time • Analyses conducted on 3 groups: total sample, split age samples (<=12 yr; >=13 yr) • Only subjects that completed all 3 questionnaires included in analysis	• Sex*time • Season • Sex • Age	• Overall, significant time effect • Males more active than females • Spring activities higher than fall or winter activities (no differences between fall and winter) • By assessment period, only sex was significant at winter and spring assessments • Age and sex significant for fall assessment • Younger group more active than older group
Effects of persistent physical activity and inactivity on coronary risk factors in children and young adults Raitakari et al.,[71] 1994	• Subjects aged 12, 15 or 18 at baseline from the Cardiovascular Risk in Young Finns Study, Finland • n=561 women, n=438 men	• Participation in leisure-time PA was assessed by questionnaire • Duration of study: 6 years (baseline 1980, FU 1983, FU 1986)	• Multiple linear regression • (change calculated by subtracting the baseline value of the variable from the 1986 value) • Subjects with a PA index of >= 85 in all 3 examinations	• 6-year change in serum total cholesterol, HDL cholesterol, triglycerides, insulin, HDL cholesterol/total cholesterol ratio, and subscapular skinfold thickness; PAI, smoking habits, polyunsaturated to saturated fatty acids ratio (P/S ratio), saturated fat intake,	• Constantly active young FEMALES: lower concentrations of serum triglycerides (0.80 vs 0.97) and thinner subscapular skinfold thickness (10.5 vs 14.2) (serum insulin concentration and insulin/glucose ratio not statistically significant, but in right direction); • Constantly active young MALES: lower levels of insulin (8.07 vs 9.24), lower serum triglyceride concentration (0.92 vs 1.05), thinner subscapular skinfold thickness (9.9 vs 12.2), higher HDL cholesterol/total cholesterol ratio (0.30 vs 0.26)

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
			3 years apart were considered as constantly active (those who participated in more than 2 hours per week of intense PA)	and carbohydrate intake	
The effects of physical activity and exercise training on psychological stress and well-being in an adolescent population. Norris et al.,[14] 1992	• Students at a secondary school in Warwickshire, UK • n=14 in high-intensity group; n=15 in moderate-intensity group; n=15 in flexibility group; n=16 in control group	• students in each of the 3 training programmes participated in two sessions per week (25-30 minutes each) of that particular type of training • training intervention lasted 10 weeks	• ANCOVA	• Life events (potentially stress-inducing situations) • Illness • Perceived stress • Anxiety, depression, and hostility • Heart rate (resting, after a fitness/step test, 2-minutes after a fitness/step test) • Systolic and diastolic blood pressure	• High-intensity group had lower scores at the end of the intervention than the other 3 groups • High-intensity group had lower scores than the moderate-intensity group at end of intervention • High-intensity group had lower resting heart rates than the moderate-intensity and control groups; flexibility group had lower resting heart rates than the moderate-intensity group • After the fitness/step test, the high-intensity group had lower heart rates than the moderate-intensity group; flexibility group had lower heart rates than the moderate-intensity group • 2-minutes after the fitness/step test, the high-intensity group had lower heart rates than the moderate-intensity and control groups; flexibility group had lower heart rates than the moderate-intensity group • High-intensity group recorded lower diastolic blood pressure than the moderate-intensity group • No effects of life events, illness, depression,

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					hostility, or systolic blood pressure
Psychosocial predictors of physical activity in adolescents. Reynolds et al.,[34] 1990	• Students in grade 10 (age 14-16 years, median age 15) at baseline from the Stanford Adolescent Heart Health Program (SAHHP) – North California high schools • n=356 males & 324 females at baseline; n=283 M and n=174 at 4 months FU; n=233 M and n=141 F 16 months FU	• Self-administered questionnaires - provided 19 activities, frequency of which they participated in each activity for at least 20 minutes nonstop • Duration of study: 1.5 years; (baseline, FU at 4 months, again at 16 months)	• Stratified by gender • Hierarchical regressions with PA as dependent variable • NOTE that for self-efficacy, intention and social influence, a negative coefficient represents a positive relationship between that variable and PA	• Self-efficacy • Intention • Stress • Direct social influence • BMI Not significant for MALES at 4 months: BMI, Intention, stress, social influence. Not significant for FEMALES at 4 months: BMI, self-efficacy. Not significant for MALES at 16 months: BMI, self-efficacy, stress, social influence. Not significant for FEMALES at 16 months: baseline activity, stress, social influence.	• Significant for MALES at 4 months: baseline activity (beta = 0.20), self-efficacy (-0.51, p=0.08); accounts for 24% of variance overall (when including the non-significant variables) • Significant for FEMALES at 4 months: baseline activity (0.16), intention (-0.92), stress (-1.27), social influence (-1.00); accounts for 45% of variance overall, incl non-significant vars) • Significant for MALES at 16 months: baseline activity (0.18), intention (-0.93); accounts for 24% of variance overall (when including the non-significant variables) • Significant for FEMALES at 16 months: BMI (-0.20), self-efficacy (-0.75), intention (-0.86); accounts for 28% of variance overall, incl non-significant vars). • NOTE: see previous column for non-significant variables included in models
Cross-sectional studies:					
Relationship of vigorous physical activity to psychological distress among adolescents.	• Students in grades 7-13 (mean age 14.9 years); data from the Ontario Student Drug Use	• Questionnaire - On how many of the last 7 days did you exercise or participate in sports activities for at least 20	• Hierarchic-al multiple regression analysis	• Anxiety / depression (subscale of the General Health Questionnaire; GHQ) • Problems in social	• Anxiety / depression: in bivariate relationship, VPA beta=-0.12 (R^2 only .00); no longer significant when sex, age, and SES were in model (R^2only .05) • Problems in social functioning: in bivariate relationship, VPA beta=-0.09 (R^2only .01); beta=-0.06 when sex, age, and SES were in

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
Allison et al.,[72] 2005	Survey • n=2104 (49% male)	minutes that made you sweat and breathe hard?		functioning • Psychological distress	model (R^2only .03) • Psychological distress: in bivariate relationship, VPA beta=-0.09 (R^2only .01); beta=-0.06 when sex, age, and SES were in model (R^2only .03)
Perceived environment and physical activity in youth. Fein et al.,[63] 2004	• Students in grades 9-12 (mean age 15.5 years) in 4 high schools in rural Alberta • n=610 (62% female)	• PA outcome measure based on the Godin Leisure-Time Questionnaire	• Multiple regressions (MR) unadjusted • Hierarchic-al regression (HR)	• Sex, grade, self-efficacy, peers, family, and PE teacher relationships (block 1 in HR) • Environmental variables (perceived availability of environmental resources [home, neighbourhood, convenient facilities, and school] and importance for each of these four environments (2nd block in HR)	• Self-efficacy HR: beta=.30; • Sex HR: beta= -0.15 (males ref grp) • Availability of resources in the home: MR: beta=.15; HR: beta= 0.02 (ns) • Perceived importance of the home environment: HR: beta= 0.09 (ns) • Availability of resources in the neighbourhood environment: MR: beta=.13; HR: beta=.05 (ns) • Perceived importance of the neighbourhood environment: HR: beta= 0.01 (ns) • Availability of resources in the school environment: MR: beta=.11; HR: beta=.01 (ns) • Perceived importance of the school environment: MR: beta=.22; HR: beta=.14 • Availability of convenient facilities: HR: beta= 0.00 (ns) • Perceived importance of convenient facilities: HR: beta= 0.04 (ns) • MR: perceived availability of environmental resources explained 5% of variance, perceived importance of environmental resources explained 8% of variance • HR: 22% of variance explained from 1st block, additional 4% from 2nd block, 26% overall
The relationship between physical activity and self-image and problem behaviour	• Students (aged 14-18 years) from 9 secondary schools in West Germany	• questionnaire – assessed the degree of regular, continuous involvement in	• linear discriminant analysis • ANOVA	• Sociodemographic variables (gender, age, nationality, number of siblings, educational status) • Family variables	• Subjects in the low (endurance) activity groups (never, seldom) reported significantly more physical complaints than those in the high activity group (often, frequently) • Subjects who were regularly active reported significantly lower cigarette use

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
among adolescents. Kirkcaldy et al.,[73] 2002	• n=988 (52.8% female)	general recreational activities (running, swimming and cycling); duration ratings (never, seldom, often, always)		(self-image) • Mental well-being (social problems, anxiety/depression) • Physical health (exhaustion, gastric disorders, limb pains, circulatory problems, "colds") • Addiction/drug dependency	• Subjects who "never" engaged in endurance sports reported significantly higher cannabis use • No effect of alcohol • Regular exercise associated with higher self-image • Subjects who engaged in regular physical activity had lower anxiety/depression scores and lower social behavioural inhibition than those who were less active
Psychosocial correlates of physical activity in healthy children. Strauss et al.,[33] 2001	• Children aged 10-16 years recruited from urban and suburban families through pediatric clinics in New Brunswick • n=92 (44 males, 48 females)	• Habitual activity assessed with a biaxial accelerometer	• Multivariate regression models (controlling for sex and age) • Partial correlation coefficients reported for significant variables	• Self-efficacy; support seeking; barriers; positive alternatives • Social influences • Health beliefs; physical outcomes; social outcomes • Age • Sedentary behaviours (reading, homework, computer and video equipment use, television viewing)	• Multivariate regression found only age (partial correlation coefficient: -.50) and sedentary behaviour time (-.36) independently correlated with moderate activity levels (r^2=0.35) • Age (-.45), sex (partial correlation coefficient not provided but males more active than females), and self-efficacy [support seeking (.28), perceived barriers (.32), and perceived alternatives (.34)] significant independent correlates of high activity (r^2=0.29)
Determinants of adolescent physical activity and inactivity patterns. Gordon-Larsen et al.,[74] 2000	• Students in grades 7-12 (ages 11-19 years) from the National Longitudinal study of Adolescent Health • n=17,766 (8287	• In-home survey – collected information on participation in moderate to vigorous physical activity (MVPA) • Adolescents categorized into	• Adjusted odds ratios (AORs) for being in the 'high MVPA' group using logistic regression • NOTE: * denotes	• gender • age • total household income • maternal education • ethnic group • ethnicity*sex interaction • generation of residence in United	• Models controlled for sex, age, urban residence, SES, ethnicity, generation of residence in the U.S., presence of mother/father in household, pregnancy status, in-school status, work status, region, and month of interview • Environmental model: PE times/week: 0 (ref grp), 1-4 times (AOR=1.44), 5 times (AOR=2.21); recreation center use: don't use center (ref grp), use center (AOR=1.75); total

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	males, 9039 females)	high, medium, and low activity	significance; ns = not significant	States • urban residence • total reported incidents of serious crime per 100,000 • use of neighbourhood recreation center • number of days in an average week in PE class • employment (for pay) • region • month of interview	crime/100,000: low (ref grp), medium (AOR=.89, ns), high (AOR=.77) • Sociodemographic model: maternal education: less than high school (ref grp), high school/general education development (AOR=.93, ns), some college (AOR=1.05, ns), college degree (AOR=1.12, ns), graduate/professional degree (AOR=1.27); family income: low (ref grp), medium (AOR=1.19), high (AOR=1.43) • No effect of season
Adolescent physical activity and inactivity vary by ethnicity: The National Longitudinal Study of Adolescent Health. Gordon-Larsen et al.,[75] 1999	• Students in grades 7-12 (ages 11-19 years) from the National Longitudinal study of Adolescent Health • n=13,157 (8287 males, 9039 females)	• Questionnaire – asked about the times per week spent engaged in various PAs	• Multinomial logistic regression • Models controlled for sex, age, urban residence, SES, ethnicity, in-school status, and month of interview • Dependent variable was tertiles of MVPA: low, medium, high	• Race	• Likelihood of engaging in highest tertile of MVPA ranged from 37.9% (Asian males) to 42.2% (non-Hispanic black males) [non-Hispanic white males 42.1%, Hispanic 40.1%] • Non-Hispanic white females (25.6%) were most likely and Asian females (12.5%) least likely [non-Hispanic black 18.1%, Hispanic 18.1% • Significant interactions between race and sex: non-Hispanic black females (RR=0.43), Asian females (RR=0.41), Hispanic females (RR=0.62)
Correlates of physical activity	• Children in grades 4-12 and	• Telephone interviews to	• Significant variables in a	• Demographic: parent education,	• For BOYS in grades 7-9 (n=250): parent education (partial r=-.13, ns), single parent

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in a national sample of girls and boys in grades 4 through 12. Sallis et al.,[31] 1999	their parents • n=1504 (see Main Findings column for sample size by comparison group)	assess participation in school and nonschool sports teams and 7-day recalls of vigorous physical activity	bivariate analysis were entered into a hierarchical multiple regression analysis • Variables entered as blocks (therefore adjust R^2 for that block reported); partial correlations reported for significant variables in the model • NOTE: significant partial correlation/R^2 denoted with *	single-parent status, child's ethnicity • Child psychological and biological: BMI, body satisfaction, enjoyment of physical education, general barriers to PA, time barriers, academic grades, use of afternoon time, methods of transport to school • Social: parent PA, importance of child's PA, parent enjoyment of PA, fees paid for child activity, family support index, social barriers, parent BMI • Physical environment: access to play space, play rules, supervised programs, environmental barriers	(0.7, ns), race (white) (-.009, ns), Adj r^2 of block =.002, ns; use of afternoon time (.26), enjoy PE (.15), time barriers (-.11, ns), general barriers (-.05, ns), Adj r^2 of block=.16, family support (*.17), importance of child's PA (.06, ns), parent PA (.10, ns), social barriers (-.11, ns), parent paid fees (.18), parent PA enjoyment (.01, ns), parent BMI (-.07, ns), Adj r^2 of block=.11; environment barriers (-.01, ns), supervised programs (.03, ns), play rules (.12, ns), Adj r^2 of block=.004 (overall r^2 for model: .28) • For GIRLS in grades 7-9 (n=208) : parent education (0.07, ns), single parent (-.11, ns), race (white) (-.14, ns), Adj r^2 of block=.003, ns; use of afternoon time (.28), enjoy PE (.22), time barriers (-.16), general barriers (-.08, ns), child's BMI (-.16), school grades (.04, ns) Adj r^2 of block=.23; family support (.16), social barriers (.02, ns), Adj $r^2$of block = .01, ns; environment barriers (-.04, ns), Adj r^2 of block=-.003, ns (overall r^2 for model: .25) • BOYS gr 10-12 (n=200) : parent education (-.18), single parent (-.12, ns), race (white) (.08, ns), Adj r^2 of block=.02, ns; use of afternoon time (.20), enjoy PE (.15), time barriers (-.36), general barriers (-.12, ns), child's BMI (-.13, ns), body satisfaction (.07, ns), Adj r^2 of block=.35); family support (.15), importance of child's PA (.12, ns), social barriers (-.05, ns), parent paid fees (.23), Adj r^2 of block=.07; environment barriers (.004, ns), supervised programs (.07, ns), Adj r^2 of block=-.003, ns (overall r^2 for model: 0.43) • GIRLS gr 10-12 (n=210) : parent education (-.08, ns), single parent (-.09, ns), race (white) (-

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
					.05), Adj r^2 of block= -.01, ns; use of afternoon time (.28, ns), enjoy PE (.28), time barriers (-.13, ns), general barriers (-.24), body satisfaction (.08, ns), Adj r^2 of block=.42); family support (.38), importance of child's PA (.27), social barriers (.08, ns), parent paid fees (.13, ns), Adj r^2 of block= .17; environment barriers (-.08, ns), supervised programs (.12, ns), play rules (.06, ns), Adj r^2 of block=.005, ns (overall r^2 for model: 0.59)
Determinants of physical activity among female adolescents. Bungum et al.,[32] 1997	• High school FEMALES aged 14-18 years from South Carolina • n=852 (see Main Findings column for sample size by comparison group)	• Questionnaire - Stanford Physical Activity Recall	• Multiple regression • Only reported significant variables in the model • Modeled entire sample, and by age group (younger: 14-15 years; older: 16-18 years), and by race (Caucasian: CA; African-American: AA)	• Age • Environmental: exercise opportunity • Social factors: peer modeling, parent modeling, sports influence, friend support, family support, parental nurturing • Cognitive factors: self-efficacy, attitudes toward exercise, knowledge, normative beliefs, anticipated health benefits, barriers, socioeconomic status, television viewing, academic grades, smoking, height, weight • Participation in organized sports	• ALL girls (n=852): 2 hrs TV/night (beta=-0.27), participation in organized sports (beta=.24), age (beta= -.19), nurtured by biological father (beta=.09), attitudes toward exercise (beta = .09) (adj r^2 = .18) • CA girls (n=226): attitudes toward exercise (beta=.05) (overall adj r^2 = .14) • AA girls (n=626): participation in organized sports (beta=.23), age (beta= -.10), sports media influences (beta=-.08), nurtured by biological father (beta=.08), friend support (beta=.07) (overall adj r^2 = .12) • younger AA girls (aged 14-15 years, n=228): participation in organized sports (beta=.14), self-efficacy (beta=.13) (overall adj r^2 = .11) • older AA girls (aged 16-18 years, n=398): participation in organized sports (beta=.09), nurtured by biological father (beta=.08), enjoy VPAs (beta=.08), friend support (beta=.07), health benefits (beta=.07) (overall adj r^2 = .10) • younger CA girls (n=115): attitudes toward exercise (beta = .13), enjoy VPAs (beta=.08) (overall adj r^2 = .12) • older CA girls (n=101): participation in organized sports (beta=.12) (overall adj r^2 =

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
					.17)
Associations between physical activity and other health behaviours in a representative sample of U.S. adolescents. Pate et al.,[76] 1996	• High school students from all 50 states and D.C. from the 1990 Youth Risk Behavior Survey • n=2652 (67.2% male)	• how many of the past 14 days participated in: at least 20 minutes of hard exercise, and at least 20 minutes of light activity	• unadjusted odds ratios • multiple logistic regression (MR) controlling for age, sex, and race/ethnicit y • those who reported 6 or more days of hard and 6 or more days of light activity (in past 14 days) were classified as high active	• Sex • Age • Race/ethnicity • Smoking • Alcohol consumption • Cocaine use • Marijuana use • Injury in a physical fight • Seat belt use • Number of servings of vegetables • Number of servings of fruit • Number of sex partners • TV/video game hours per day • Kind of student • Weight perception	• Smoking: 1 or more days vs 0 days in past 30 days: OR=1.21 therefore more likely to be in the 'low active' group (but not significant); MR: OR=1.42 • Alcohol: 1 or more times vs 0 times in past 30 days: OR=0.77 therefore less likely to be in the 'low active' group; MR: significant interaction with sex: in females, OR=0.66; (not significantly) associated with PA in boys OR=1.30 • Cocaine: 1 or more times vs 0 times in past 30 days: OR=1.20 (not significant); MR: OR=1.97 (not significant) • Marijuana: 1 or more times vs 0 times in past 30 days: OR=1.35; MR: OR=1.75 • Injury in a fight: 1 or more times vs 0 times in past 30 days: OR=0.94 (not significant); MR: OR=0.90 (not significant) • Seat belt use: never/sometimes vs usually/always: OR=1.39; MR: OR=1.67 • Vegetables: 0 vs 1 or more (yesterday): OR=2.03; MR: OR=1.97 • Fruit: 0 vs 1 or more (yesterday): OR=2.64; MR: significant interactions with race: OR=3.10 for whites, OR=1.26 (not significant) for AAs, OR=2.27 for Hispanics • Sex partners: 1 or more vs 0 (in past 3 months): OR=1.27; MR: OR=1.07 (not significant) • TV/video: 3 or more vs < 3 hours (14 days after school): OR=1.51; MR: significant interaction with race: OR=1.99 for whites, OR=0.47 for AAs, OR=0.88 (not significant) for Hispanics

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
					• Kind of student: bottom/little above middle vs far above middle/best: OR=1.73; MR: OR=1.88 • Weight perception: too thin vs too fat vs about right: OR=0.98, OR=1.32; MR: OR=1.17 (not significant), OR=0.93 (not significant)
Physical activity patterns in American high school students: Results from the 1990 Youth Risk Behavior Survey. Heath et al.,[67] 1994	• High school students from all 50 states and D.C. from the 1990 Youth Risk Behavior Survey • n=11, 631 (49.6% male)	• How many of the past 14 days participated in: at least 20 minutes of hard exercise, and how many varsity or junior varsity sports teams they played on during 12 months preceding survey	• Determined differences among subgroups using confidence intervals	• Age/Grade • Sex • Race • TV-watching	• Males significantly more likely to be vigorously active than females (49.6% vs 24.7%) • VPA significantly decreased by grade for females in all 3 racial groups (white, black, Hispanic); no significant differences for males by race or grade • females in grades 11 and 12 significantly more likely to be vigorously active than female students in grade 9 (49.6% vs 24.7%); did not vary for males • females who were vigorously active were significantly less likely to watch 3 or more hours of TV per day than females who were not vigorously active (32.5% vs 40.4%); not significant for males
Psychosocial discomfort and exercise frequency: An epidemiological study of adolescents. Page et al.,[77] 1994	• Students in grades 9-12 from 12 HS in Northwestern US • n=1297 (603 females and 654 males)	• Questionnaire - frequency (days per week) of exercise hard enough to increase heart rate for 20 minutes or more	• MANCOVA	• BMI • Self-perceived physical attractiveness • Satisfaction with body weight • Grade • Loneliness • Shyness • Hopelessness	• Exercise frequency inversely associated with loneliness (r = -.13), shyness (r = -0.13), and hopelessness (r = -.14) • Positively associated with perceived attractiveness (r = .19) and satisfaction with body weight (r = .11) • Not associated with BMI or grade
Correlates of vigorous	• grades 9 and 11 • n=1622 (815	• Questionnaire - assessed	• Hierarchic-al multiple	• Social variables: family support,	• Race: MALES anglo (beta=0.00, ns); latino (beta= -0.06); FEMALES anglo (beta=0.05,

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
exercise in a predominantly low SES and minority high school population. Zakarian et al.,[62] 1994	females and 807 males)	vigorous PA performed outside of PE class	regression analyses computed separately for males and females	friend support, teacher support, coach support, family modeling, friend modeling, teacher modeling, coach modeling, neighbourhood modeling • Cognitive variables: barriers, facilities, benefits, self-efficacy, neighbourhood safety • Physiological variables: BMI, body image, number in home, year in school, Anglo, Latino, cigarettes, alcohol, hours of television, hours sleep, employed, forced to exercise, grade point average, PE attitude	ns); latino (beta= -0.02, ns) • Year in school (9th grade vs 11th grade): MALES beta=-0.18; FEMALES beta=-0.10 • Alcohol: males beta=0.00, ns, females beta=0.09, ns • Forced to exercise: males beta=0.02, ns, females beta=0.06, ns • Self-efficacy: males beta=0.17, females beta=0.19 • Friend support: males beta=0.12, females beta=-0.03 • Teacher support: males beta=0.04, ns, females beta=0.01, ns • Family modeling: males beta=0.03, females beta=0.05 • Friend modeling: males beta=0.04, females beta=0.01 • Family support: males beta=0.05, females beta=0.14 • Barriers: males beta=-0.08, females beta=-0.14 • PA benefits: males beta=0.09, females beta=0.08 • Hours sleep: males beta=-0.05, ns, females beta=-0.05 • Teacher modeling: males beta=-0.03, ns, females beta=-0.03, ns • Dislike PE: males beta=-0.03, females beta=-0.09 • Employment: males beta=0.05, ns, females beta=-0.01, ns • Body image: males beta=0.08, females beta=0.05 • Neighbourhood safety: males beta=0.02, ns, females beta=-0.06, ns • Access to recreational facilities: males

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
					beta=0.00, females beta=-0.05 • Neighbourhood modeling (how often people in the neighbourhood exercise): males beta=0.02, females beta=0.03 • Number in house: males beta=-0.03, ns, females beta=0.02, ns • Academic grades: males beta=0.02, females beta=0.00, ns • Coach support: males beta=0.02, females beta=0.06 • Coach modeling: males beta=-0.00, females beta=0.04 • Smoking: males beta=0.08, ns, females beta=-0.05, ns • BMI: males beta=0.03, ns, females beta=0.09, ns • TV-viewing: males beta=-0.03, females beta=0.03, ns • All variable for males accounted for 15.4% of variance, for females - 16.4%
The epidemiology of leisure physical activity in an adolescent population. Aaron et al.,[78] 1992	• Students in grades 7-9 in Pittsburgh • n=1175 (641 males and 604 females)	• subjects asked to indicate all activities participated in at least 10 times in past year; also recorded frequency and duration for each.	• Kruskal-Wallis nonparametric tests	• Sex • Race • Age • SES	• Males reported significantly more leisure PA than females (median 22.5 hrs/wk vs 6.6 hrs/wk), also significantly more time in hard exercise (OR=2.1 times more likely to be vigorously active) and participation in competitive athletics (OR=2.6) • White males significantly more active than nonwhite males (median 23.5 hrs/wk in leisure PA vs 18.9); same for females (7.0 vs 4.9) • Significant decrease in hrs/wk from age 12 to 14 for females only (8.9 vs 4.9) • Trend toward increased PA with higher SES in girls, but not significant (none for males)
Sociocultural	• Students in	• Questionnaire -	• Hierarchical	• Sex	• Sex [males associated with higher frequency

Study title / Reference	Study Population	Measure of PA / Method	Statistical Analysis	Independent variables	Main Findings
correlates of childhood sporting activities: Their implications for heart health. Gottlieb et al.,[68] 1985	grades 7 and 8 from 52 schools in Texas • n=2695	to determine the physical exercise and leisure activities participated in from a list of 16 activities	multiple regression	• Ethnicity • Heart Knowledge Test (assessed areas of the heart and definitions to see how much participant knew) • Father's occupation (social status measure) • Parental exercise	(beta=0.32)], ethnicity [Anglo-Americans associated with higher frequency of exercise (beta=.08), Blacks with lower exercise frequency (beta= -.06) than Mexican-Americans (ref grp)], and father's occupation [associated with higher frequency of exercise (beta= -0.04)] accounted for 5% of variance in exercise behaviour • Heart knowledge score [associated with higher exercise frequency (beta=0.10)], parental exercise [associated with higher exercise frequency (beta=0.25)], and sex-parental exercise interaction [associated with lower exercise frequency (beta=-0.18)] accounted for an additional 5% • Sex – variable most strongly related to exercise frequency, followed by parental exercise • Significant interaction between sex and parental exercise such that girls' exercise frequency increased more than boys as the number of parents exercising increased

Note. Results (main findings) are significant at $p < .05$ unless otherwise stated. ns=not significant

Appendix B. NDIT questionnaire items for variables included in this thesis

MCGILL UNIVERSITY STUDY
ON NICOTINE DEPENDENCE IN TEENS

1. In what month is your birthday?

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

2. On what day of the month is your birthday? Circle the correct day.

1	2	3	4	5	6	7	8	9	10	
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	31

3. In what year were you born?

- ☐ 1984
- ☐ 1985
- ☐ 1986
- ☐ 1987
- ☐ 1988
- ☐ Other ______________________
  Specify year

5. Are you a.....?

- ☐ Boy
- ☐ Girl

11. Were you born...?

☐ In Canada → ______________________
Name province

☐ Outside Canada → ______________________
Name country

13. Was your biologic father born...?

☐ In Canada → ______________ OR ☐ I don't know which province
Name province

☐ Outside Canada → ______________ OR ☐ I don't know which country
Name country

☐ I don't know

14. Was your biologic mother born...?

☐ In Canada → ______________ OR ☐ I don't know which province
Name province

☐ Outside Canada → ______________ OR ☐ I don't know which country
Name country

☐ I don't know

15. Now, think about the physical activities that you did last week from Monday to Sunday <u>outside</u> your regular school gym class. For each activity that you did <u>for 5 minutes or more at one time</u>, mark an "X" to show the day(s) on which you did that activity.

	Mon	Tue	We	Thu	Fri	Sat	Sun
Bicycling to school, bicycling to do errands, going for a bicycle ride							

Swimming/diving							
Basketball							
Baseball/softball							
Football							
Soccer							
Volleyball							
Racket Sports (badminton, tennis)							
Ice hockey/ball hockey							
Jump rope							
Downhill skiing, snowboarding							
Cross-country skiing							
Ice skating							
Rollerblading, skateboarding							
Gymnastics (bars, beams, tumbling, trampoline)							
Exercise / physical conditioning (push-ups, sit-ups, jumping jacks, weight-lifting, exercise machines)							
Ball-playing (dodge ball, kickball, wall-ball, catch)							
Track and field							
Games (chase, tag, hopscotch)							
Jazz/classical ballet							
Dancing (aerobic, folk, at a party)							
Outdoor play (climbing trees, hide and seek)							
Karate/ Judo/ Tai Chi/ Kung Fu							
Boxing, wrestling							
Outdoor chores (mowing, raking, gardening)							
Indoor chores (mopping, vacuuming, sweeping)							
Mixed walking / running / jogging							
Walking							
Running/Jogging							
Other(s) → Name them							

a)							
b)							
c)							

18. How many hours of television (including video movies) do you usually watch in a <u>single day</u>? ***If the answer is zero, write "0" in the box. If the answer is less than ½ hour, write "LT ½".***

On <u>weekdays</u>, I usually watch [ ] hour(s) of television <u>a day</u>

On <u>weekends</u>, I usually watch [ ] hour(s) of television <u>a day</u>

19. How many hours do you usually play video or computer games, or use the Internet in a <u>single day</u>? ***If the answer is zero, write "0" in the box. If the answer is less than ½ hour, write "LT ½".***

On <u>weekdays</u>, I usually play video or computer games .... [ ] hour(s) <u>a day</u>

On <u>weekends</u>, I usually play video or computer games .... [ ] hour(s) <u>a day</u>

20. During the <u>past 3 months</u>, how often have you...?

	Never	Rarely	Sometimes	Often
Felt too tired to do things	☐	☐	☐	☐
Had trouble going to sleep or staying asleep	☐	☐	☐	☐

Felt unhappy, sad, or depressed	☐	☐	☐	☐
Felt hopeless about the future	☐	☐	☐	☐
Felt nervous or tense	☐	☐	☐	☐
Worried too much about things	☐	☐	☐	☐

21. During the <u>past 3 months</u>, have you been worried or stressed by any of the following...?

	Not at all OR This does not apply to me	A little bit	Quite a bit	A whole lot
Your parents separating or divorcing	☐	☐	☐	☐
Loneliness	☐	☐	☐	☐
Breaking up with your boyfriend or girlfriend	☐	☐	☐	☐
Your relationship with your father	☐	☐	☐	☐
Your relationship with your mother	☐	☐	☐	☐
Your relationship with your brother(s)/ sister(s)	☐	☐	☐	☐
Your relationship with your friends	☐	☐	☐	☐
A health problem (such as acne or asthma)	☐	☐	☐	☐
Your weight	☐	☐	☐	☐
Sex	☐	☐	☐	☐
Your new family (parents remarried)	☐	☐	☐	☐
Financial problems in your family	☐	☐	☐	☐
School work	☐	☐	☐	☐

Other(s) → Please describe				
a) ______________________	☐	☐	☐	☐
b) ______________________	☐	☐	☐	☐

22. During the past 3 months, how often did you…?*

	Never	A bit to try	Once or a couple of times a month	Once or a couple of times a week	Usually every day
Drink alcohol (beer, wine, hard liquor)	☐	☐	☐	☐	☐

24. Check the one box that describes you best…

- ☐ I have never smoked a cigarette, even just a puff → *Go to question 32*
- ☐ I have smoked cigarettes (even just a puff), but not at all in the past twelve months
- ☐ I smoked cigarettes once or a couple of times in the past twelve months
- ☐ I smoke cigarettes once or a couple of times each month
- ☐ I smoke cigarettes once or a couple of times each week

* Smoking a cigar and Using chewing tobacco were also assessed in this question.

Appendix C. Results of models with physical activity transformations and exclusion of physical activity extreme values—Attempts to improve the level-1 submodel

Table C.1. Results of models using square root physical activity.

	Model		
Parameter and Fit statistic	Unconditional means model	Unconditional growth model	Base model
Fixed Effects:			
Intercept (Status at 14.5 years)	4.12 (0.04[a])***	4.12 (0.04)***	4.34 (0.04)***
Age		-0.15 (0.01)***	-0.24 (0.02)***
Age^2			-0.06 (0.01)***
Age^3			0.04 (0.004)***
Fall			-0.10 (0.02)***
Winter			-0.34 (0.02)***
Variance Components (Random Effects):			
Level-1			
Within-person variance	1.26 (0.01[b])***	1.04 (0.01)***	0.92 (0.01)***
Level-2			
Intercept variance	1.54 (0.07)***	1.52 (0.07)***	1.81 (0.08)***
Linear term variance		0.13 (0.01)***	0.27 (0.02)***
Quadratic term variance			0.04 (0.004)***
Cubic term variance			0.01 (0.001)***
Overall R^2 †		0.175	0.270
Deviance	55926.8	54219.6	53264.2
AIC	55932.8	54231.6	53298.2
BIC	55948.1	54262.2	53384.8

Notes.
*** $p<0.001$
† compared to unconditional means model
[a] standard error of the fixed effect
[b] standard error of the variance component

Table C.2. Results of models using cube root physical activity.

Parameter and Fit statistic	Model: Unconditional means model	Unconditional growth model	Base model
Fixed Effects:			
Intercept (Status at 14.5 years)	2.51 (0.02[a])***	2.51 (0.02)***	2.60 (0.02)***
Age		-0.07 (0.006)***	-0.11 (0.009)***
Age^2			-0.02 (0.004)***
Age^3			0.01 (0.002)***
Fall			-0.04 (0.009)***
Winter			-0.15 (0.009)***
Variance Components (Random Effects):			
Level-1			
Within-person	0.26 (0.003[b])***	0.22 (0.003)***	0.20 (0.002)***
Level-2			
Intercept variance	0.28 (0.01)***	0.27 (0.01)***	0.32 (0.014)***
Linear term variance		0.03 (0.002)***	0.05 (0.004)***
Quadratic term variance			0.007 (0.001)***
Cubic term variance			0.0001 (0.002)***
Overall R^2 †		0.154	0.231
Deviance	29056.9	27412.4	26640.9
AIC	29062.9	27424.4	26674.9
BIC	29078.1	27455.0	26761.5

Notes.
*** $p<0.001$; * $p<0.05$
† compared to unconditional means model
[a] standard error of the fixed effect
[b] standard error of the variance component

Table C.3. Results of models using log(physical activity + 1).

Parameter and Fit statistic	Model: Unconditional means model	Unconditional growth model	Base model
Fixed Effects:			
Intercept (Status at 14.5 years)	2.75 (0.017[a])***	2.75 (0.017)***	2.85 (0.020)***
Age		-0.08 (0.007)***	-0.12 (0.010)***
Age^2			-0.03 (0.004)***
Age^3			0.02 (0.002)***
Fall			-0.04 (0.010)***
Winter			-0.16 (0.010)***
Variance Components (Random Effects):			
Level 1			
Within-person	0.33 (0.004[b])***	0.27 (0.003)***	0.25 (0.003)***
Level 2			
Intercept variance	0.33 (0.014)***	0.33 (0.014)***	0.38 (0.018)***
Linear term variance		0.03 (0.002)***	0.06 (0.005)***
Quadratic term variance			0.009 (0.001)***
Cubic term variance			0.0009 (0.0002)***
Overall R^2 †		0.182	0.242
Deviance	32773.3	31118.5	30377.9
AIC	32779.3	31130.5	30411.9
BIC	32794.6	31161.1	30498.5

Notes.
*** $p<0.001$; * $p<0.05$
† compared to unconditional means model
[a] standard error of the fixed effect
[b] standard error of the variance component

Table C.4. Results of models excluding physical activity values greater than 84.

Parameter and Fit statistic	Model: Unconditional means model	Unconditional growth model	Base model
Fixed Effects:			
Intercept (Status at 14.5 years)	19.40 (0.32[a])***	19.44 (0.32)***	21.37 (0.37)***
Age		-1.21 (0.11)***	-1.97 (0.17)***
Age^2			-0.56 (0.07)***
Age^3			0.31 (0.04)***
Fall			-0.88 (0.16)***
Winter			-2.93 (0.16)***
Variance Components (Random Effects):			
Level 1			
Within-person	93.40 (1.05[b])***	78.07 (0.91)***	68.74 (0.85)***
Level 2			
Intercept variance	115.92 (5.09)***	115.70 (5.09)***	141.69 (6.42)***
Linear term variance		8.93 (0.56)***	20.14 (1.48)***
Quadratic term variance			3.34 (0.28)***
Cubic term variance			0.44 (0.07)***
Overall R^2 †		0.164	0.264
Deviance	128856.3	127339.0	126321.6
AIC	128862.3	127351.0	126355.6
BIC	128877.6	127381.6	126442.2

Notes.
*** $p<0.001$; * $p<0.05$
† compared to unconditional means model
[a] standard error of the fixed effect
[b] standard error of the variance component