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Physical Activity and Screen Time Trajectories in Adolescents

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Physical Activity and Screen Time Trajectories in Adolescents

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Résumé

Introduction : Seulement 7% des Canadiens de 17 ans et moins pratiquent 60 minutes d'activité physique modérée à vigoureuse quotidiennement. La majorité dépasse le temps d'écran quotidien recommandé de deux heures. Plusieurs études transversales indiquent que les deux comportements évoluent indépendamment et ne seraient que faiblement corrélés.

Objectifs et hypothèses : Les objectifs de ce mémoire est d'identifier des trajectoires d'activité physique et des trajectoires de temps devant l'écran durant l'adolescence, par sexe, et de décrire la distribution des individus selon l'appartenance simultanée aux deux trajectoires. Nos hypothèses stipulent que des trajectoires différentes seront observées pour les deux sexes et que les deux comportements ne s'influenceront pas.

Méthodes : Les données proviennent d'une étude prospective de 1294 adolescents de la région de Montréal, recrutés en 1999 à l'âge de 12-13 ans. Des questionnaires ont été remplis en classe à chaque 3 mois, de la première à la cinquième année du secondaire. Des modélisations de trajectoires de groupe ont identifié des trajectoires d'activité physique et de temps devant l'écran. Une modélisation de trajectoires jointes a rapporté des probabilités d'appartenance aux trajectoires des deux variables.

Résultats : Cinq groupes ont été identifiés pour les trajectoires d'activité physique pour les deux sexes. Quatre groupes ont été identifiés pour les garçons et 5 pour les filles concernant le temps passé devant l'écran. 57% des garçons et 46% des filles ont fait des activités physiques pendant 6-7 jours par semaine, durant toute l'adolescence. Toutes les trajectoires de temps devant l'écran accumulent plus de deux heures d'écran quotidiennement. Les probabilités conditionnelles suggèrent une relation entre l'activité physique et le temps devant l'écran.

Conclusion : Le développement de l'activité physique et du temps devant l'écran est hétérogène durant l'adolescence. Leur coévolution doit être prise en compte par les professionnels en santé publique.

Mots-clés : Activité physique, temps devant l'écran, comportements sédentaires, adolescence, modélisation de trajectoires, études longitudinales

Abstract

Introduction: Only 7% of Canadians age ≤ 17 years engage in the recommended 60 minutes or more of moderate-to-vigorous physical activity (PA) daily. Further, most youth surpass the recommended screen time maximum of 2-hours daily. Many cross-sectional studies suggest that PA and screen time are only weakly correlated and that they evolve independently.

Objectives and hypotheses: The first objective of this MSc thesis was to model PA and screen time trajectories during adolescence, in boys and girls. The second objective was to describe the distribution of participants according to concurrent membership in the two sets of trajectories. Our hypotheses were that trajectories differ by sex and that PA trajectories are independent of screen time trajectories.

Methods: Data were drawn from an ongoing longitudinal study of 1294 adolescents age 12-13 years recruited in 1999-2000 in 10 Montreal-area high schools. Self-report questionnaires were completed during class time, every 3 months from grade 7 to 11. Group-based trajectory modeling identified PA and screen time trajectories. Joint trajectory models provided membership probabilities in both PA and screen time trajectories.

Results: Five groups of PA trajectories were identified in both sexes. Four and five screen time trajectory groups were identified in boys and girls, respectively. Half (57%) of boys and 46% of girls engaged in PA 6-7 days weekly during the entire 5-year follow-up. All screen time trajectories were above the recommended 2-hours daily. Conditional probabilities suggested weak associations between PA and screen time.

Conclusion: Patterns of PA and screen time are heterogeneous during adolescence. Their co-evolution may need to be considered by public health practitioners.

Keywords: physical activity, screen time, sedentary behaviours, adolescence, trajectory modeling, longitudinal studies

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Abbreviations

GBTM: Group-Based Trajectory Modeling

ICC: Intraclass correlation

MET: Metabolic equivalent

MVPA: Moderate-to-vigorous physical activity

NDIT: The Nicotine Dependence in Teens study

PA: Physical activity

SBRN: Sedentary Behavior Research Network

WHO: World Health Organisation

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Chapter 1: Introduction

Noncommunicable or chronic disease is a major public health challenge worldwide. In 2012, chronic diseases were responsible for 68% of all deaths, with close to half being premature deaths under age 70 years (1). In 2016, 7 of the 10 leading causes of death in Canada were chronic diseases (2) including malignant neoplasms, heart disease and diabetes mellitus. Most premature noncommunicable diseases are preventable (1) through action on three modifiable risk factors including physical inactivity, unhealthy diet, and tobacco use (3), and research over many decades has demonstrated that these risk factors often manifest early in life during childhood or adolescence.

1.1 Early Determinants of Chronic Disease

Adolescent health lays the foundations for adult health. It is estimated that at least 70% of premature adult deaths are linked to behaviours initiated and reinforced during adolescence (4), and adolescence is increasingly viewed as a critical phase in the life course for achieving lifelong health potential (5). During adolescence, an individual acquires the physical, cognitive and social fundamentals for lifelong health and well-being. However it is also a period during which poor lifestyle habits can be acquired and consolidate, and associated health problems begin to emerge (5). While risk behaviours manifest during adolescence, they may still be amenable to change with appropriate interventions and favorable built environments (6). It is generally accepted that public health interventions to prevent unhealthy lifestyle behaviors, should be implemented early in the life course, before these behaviors become entrenched.

1.2 Physical Activity and Sedentary Behaviour in Childhood

A small number of common modifiable risk factors are responsible for most chronic diseases (3). In 2009, the World Health Organization (WHO) identified that physical inactivity is responsible for increasing the risk of chronic disease, and that it is the fourth leading risk for mortality globally. Physical activity (PA) has been studied extensively over the last 60 years, and evidence of its positive influence on health is irrefutable (7, 8). Scientific reports have

repeatedly shown that most youth are not sufficiently active, and that more than half of their waking hours are spent in sedentary behaviours such as watching television and playing on the computer (9, 10). It is now well-established that sedentary behaviours are associated with poor health (11-13) in both adults and youth (14), and it is becoming increasingly recognized as distinct from PA. Although promising in terms of shedding light on chronic disease prevention, the link between PA and sedentary behaviour in youth is not well-understood.

1.3 Purpose

The purpose of this thesis is to describe the natural course of PA and screen time (as a proxy measure of sedentary behaviour) during adolescence. This will be accomplished using Group-Based Trajectory Modeling (GBTM) of data drawn from an ongoing 20-year longitudinal study of adolescents. This thesis includes seven chapters. Chapter 2 presents a comprehensive literature review on existing knowledge on PA and screen time. Chapter 3 describes the specific objectives of this research and related hypotheses. Chapter 4 describes the adolescent sample from which the data were drawn (i.e., the NDIT (Nicotine Dependence in Teens) study). Results are presented in manuscript format in Chapter 5. Chapter 6 presents an in-depth discussion of the results and Chapter 7 concludes the thesis.

Chapter 2: Literature Review

This chapter presents an overview of the literature pertaining to the research project and its objectives. First, it will detail the current state of the knowledge on PA, beginning with its definition, components, and current guidelines in youth. Then, the epidemiology of physical inactivity in children will be described, including a depiction of risk factors for physical inactivity and its impact on health. Third, it will detail current knowledge on sedentary behaviours such as screen time. The association between PA and screen time will be examined and finally, the methodology for group-based trajectory modeling (GBTM) and its relevance to this research study will be described.

2.1 Physical Activity

2.1.1 Definition

According to the World Health Organization, PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure, which can be measured in kilojoules or, more commonly, in kilocalories (15). Although often used interchangeably in the literature, the term "exercise" is defined as a subset of PA that is planned, structured, and repetitive, and that aims to improve or maintain one or more components of "physical fitness" (16). "Physical fitness" is also not synonymous with PA - it is a set of attributes that people have or achieve (16). Thus, PA is any type of movement and every person engages in PA during their daily life. However, the amount of PA engaged in is subject to personal choice. It is influenced by numerous environmental and social factors and thus can vary substantially across individuals and over time. (16).

2.1.2 Components of Physical Activity

PA is a complex behaviour that can be categorized and measured in different ways. Four dimensions have been identified as relevant in describing PA including:

i) Type: Mode of PA participation, which can take many forms (strength, aerobic, flexibility, etc.) (7).

ii) Duration: Length of time the activity is performed, generally expressed in minutes (7).

iii) Frequency: Number of times during a certain time period the activity is performed (7).

iv) Intensity: Rate at which the activity is performed, or the effort required to perform the activity (7). PA intensity categories are based on metabolic equivalents (METs), which are multiples of resting metabolic rate (17). A low intensity PA is one of less than 3 METs, a moderate intensity PA is of 3 to 6 METs, and a vigorous intensity PA is one above 6 METs (18).

These dimensions are all important in formulating recommendations and guidelines for PA at a population level. For example, participation in different types of PA targeting endurance, flexibility and strength is important in achieving optimal health (19). Observational studies also demonstrate a dose-response relationship between PA levels and health - differences in health risks are observed between groups of individuals varying from least to most fit (19).

2.1.3 Current Physical Activity Guidelines for Youth

Burgeoning understanding of the impact of PA on health has fuelled development of guidelines and recommendations by different entities across the world. In 2002 at the 57th World Health Assembly of the WHO, growing concerns about non-communicable disease and shifts in the prevalence of chronic disease were translated into formal statements. The Organization urged state members to develop, implement, and evaluate actions that promote individual and community health through healthy diet and PA (8). Countries and legal entities followed shortly thereafter with guidelines and recommendations on PA and active living;

initially, most focused on adults since children and adolescents were viewed as healthier and naturally more active than adults (20).

In 2005, a systematic review of the literature sponsored by the U.S. Centers for Disease Control and Prevention and undertaken by a multidisciplinary expert panel, concluded that school-age youth should engage in 60 minutes or more of moderate to vigorous PA (MVPA) daily that is developmentally appropriate and enjoyable (21). A second systematic review in 2008 by the U.S. Department of Health and Human Services made the same recommendation based on substantial data indicating that important health benefits can be attained when children and youth participate in 60 or more minutes of MVPA daily (22).

In 2016, the Canadian Society for Exercise Physiology released the Canadian 24-hour movement guidelines, which is the first evidence-based set of guidelines to address movement during an entire day (23). Age-specific recommendations are presented for the early years (age 0-4 years), children and youth (5-17), young and middle-aged adults (18-64), and for older adults (65 or older). Once again, children and adolescents between ages 5 and 17 are encouraged to accumulate at least 60 minutes of MVPA daily, involving a variety of aerobic activities. The guidelines also suggest that vigorous PA as well as muscle and bone strengthening activities should each be engaged in at least 3 days weekly (23).

2.1.4 Physical Inactivity in Children

Physical inactivity is the 4th leading cause of death accounting for more than 3 million preventable deaths worldwide (24). The Global School-Based Student Health Survey obtained estimates from 105 countries and showed that 80% of 13-15-year-olds do not accumulate 60 minutes of MVPA daily and that girls are less active than boys (25).

Since 2007, the Canadian Health Measures Survey has collected data using objective PA measures in Canadian youth. During its first cycle of data collection from 2007-09, only 7% of children and adolescents met the recommended 60 minutes of MVPA daily on at least 6 of 7 days weekly, although 33% achieved a weekly average of 60 minutes daily (26). A newer

study in which the 2nd and 3rd waves of data collection were combined to examine levels of PA in youth from 2009-13, showed that 36% of children and youth met the daily 60-minute MVPA recommendations from the Canadian 24-Hour Movement Guidelines for Children and Youth (9). Almost half (47.6%) of children age 5-11 met the recommendations, compared to only 24.4% of youth age 12-17. Almost double the percentage of boys met the recommendations compared to girls (46.8% vs. 24.6%) (9). The new guidelines allow for normal day-to-day variation in PA levels by using *average* daily MVPA, and not setting a threshold of 60 minutes of MVPA on at least 6 days of the week (23).

In Québec in 2013-14, 44% of youth age 12-17 years attained the recommended leisure PA recommendations (51% of boys vs. 35% of girls). Since 1994, only girls made gains in PA time daily (10). PA levels in Québec are comparable to those in Ontario and the Prairies, but greater than those in the Atlantic provinces (10).

Low levels of PA throughout life increase the risk of numerous diseases including diabetes mellitus, hypertension, coronary artery disease, stroke, osteoporosis, and certain cancers (27). Attaining and maintaining recommended PA levels in youth improves physical and mental health (10) in the short- and long-term (19, 28). The evidence is strong for the many beneficial effects of PA during childhood and adolescence, including effects on musculoskeletal and cardiovascular health, adiposity in overweight youth and blood pressure regulation (21).

2.1.5 Measurement of Physical Activity

High-quality exposure assessments are essential to identify associations, to quantify the magnitude of observed associations and to describe dose-response relationships, when appropriate (29). Studies of PA need valid, feasible, and reliable measures (30). The most practical and appropriate measure of PA and PA patterns is direct observation (31). Validation studies comparing direct observation scores with heart rate or oxygen consumption show correlations that range from $r = 0.61$ to 0.91 and these techniques attain satisfactory levels of inter-observer agreement (31). However, the heavy response burden, the high cost and the

potential reactivity of study participants make this a less feasible method in population-based studies (30).

Objective techniques to measure PA include heart rate monitors, pedometers, and accelerometers (31). With these objective measures, PA should ideally be measured for a period of time representative of habitual activity level, with minimal discomfort to the participant, and using a low-cost system allowing it to be implemented in large-scale studies (32). Heart rate monitors rely on the relationship between heart rate and oxygen consumption (VO_2). However, this relationship is not robust at low PA levels (31). Also, a variety of psychological and environmental factors can influence heart rate and affect the results. Pedometers are electronic devices used to estimate mileage or number of steps walked over a period of time (31). They permit estimating distances walked, energy expended in movement, and activity intensity (33). Pedometers are estimated to be 97% accurate in counting steps, but are less accurate in estimating distances and even less so for energy expenditure (33).

Accelerometers assess bodily motion resulting from movement and PA (33). Worn on the waist, they are designed to measure ambulatory activity. They continually (i.e., each second or each minute) record accelerations and transform them into a signal referred to as "counts" (31). Accelerometers can measure accelerations in a single (i.e., vertical) plane or in three planes of movement (i.e., vertical, horizontal, and lateral) (33). The advantage of accelerometers is that they continuously record movement and lack of movement, providing a detailed output of daily activity intensity (33). The monitors are small and unobtrusive, making them comfortable to wear. They are also re-useable (31). However, one of the main limitations is that they cannot identify the type of PA performed or provide any descriptive information about the activity (32). Wear time per day in children is usually less than 24h, because compliance with wearing the accelerometer is affected by the size, shape, attachment method, site of attachment as well as instructions for use (34).

Subjective techniques for estimating PA rely on responses either directly from the child or indirectly from a proxy respondent such as a parent or teacher. They rely on an individual's ability to recall their activities over a set period of time and/or they record in real-

time, activities throughout the day (33). These self-report instruments are inexpensive, easy to administer, and provide information about PA type, duration, and context (33). Self-report, including diaries, standardized written questionnaires and structured interviews, is typically the method of choice with older children because of its low cost (17). PA logbooks or diaries are used by the participant to keep a record of all activities as they are occurring and to record details on the type and duration of activities during a defined period of time (33). However, these subjective measurements are prone to recall error, deliberate misrepresentation and other biases that have been shown to occur with children (31). Very young children may not be able to complete diaries themselves, but adolescents have better cognitive abilities. Questionnaires administered by trained interviewers may improve the accuracy of data provided by children, but the physical presence of an interviewer could influence the responses (31). Proxy-reports of children's PA provided by a parent or teacher avoid errors related to children's cognitive limitations, but validation studies suggest that parents do not always provide accurate assessments of the PA levels of their children (31).

As discussed above, a variety of measurement methods exist to assess PA levels and no one method is perfect. Evidence of validity and reliability exists for several instruments, but each method has pros and cons and all need to be continually improved to create accurate assessments of PA.

2.2 Sedentary Behaviour

2.2.1 Definition and Distinction from Physical Inactivity

While PA has been investigated over the last 60 years, interest in sedentary time and sedentary behaviours has developed in the last ten years only (35). In 2017, the Sedentary Behavior Research Network (SBRN) reached consensus on an appropriate definition of sedentary behaviour as any waking behavior characterized by an energy expenditure $\leq$ 1.5 METs while in a sitting, reclining or lying posture (35). This definition incorporates both energy expenditure and posture. Some researchers suggest that unique considerations are needed in assessing energy expenditure in youth, especially in younger children (36).

However, one study with whole-room calorimetry measures of 40 young children (mean age: 5.3 years) demonstrated that common sedentary activities in children are consistent with this recent consensus definition (37). In 2012, the SBRN suggested in a letter to the editor that, in order to avoid confusion and inappropriate use of the terms, “physical inactivity” be used specifically to describe individuals who do not undertake sufficient amounts of MVPA and do not meet current recommendations. This comment started the movement towards considering PA and sedentary behaviours as distinct entities. These new definitions are incorporated into a new conceptual model of movement-based terminology arranged around a 24-hour period (23) (Figure 1). The association between sedentary behaviors and PA is described in Section 2.3.

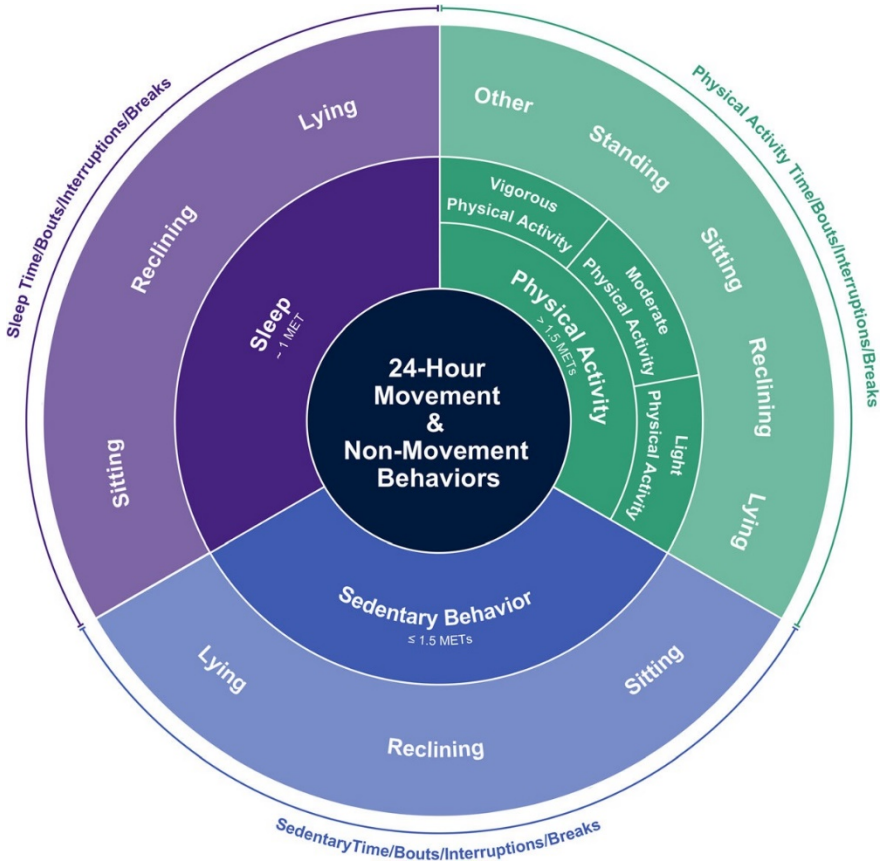

Figure 1. Conceptual model of movement-based terminology based on a 24-hour period (23).

2.2.2 Components of Sedentary Behaviour

Behaviors classified as sedentary include computer use, watching television, playing video games, driving, reading, socializing, work, and public transport (33). A recent study on 1513 children age 10 years showed that boys spent 57% and girls spent 44% of their reported sedentary time in screen-based sedentary behaviours (38). A second study with older children (ages 13-14 years) showed that the most common sedentary activities for boys were (in order of weekly time): TV-viewing; homework; playing computer/video games; motorised transport; and behavioural hobbies (e.g., playing a musical instrument) (39). The most common sedentary activities for girls were (in order of weekly time): TV-viewing; homework; motorised transport; sitting and talking; and shopping/hanging out in town (39). Sedentary pursuits occur in a sporadic and widely varied manner throughout the day, making it difficult to measure and characterize (40). Researchers generally rely on global or proxy measures (i.e., car time, sitting time, indoor time, screen time) to capture sedentary behaviours (40). School-based sedentary behaviours and activities such as homework or transport have little flexibility in terms of potential modification (38). From a health promotion perspective, a focus on screen-based leisure-time sedentary behaviours may be appropriate because it is more amenable to intervention (38).

2.2.3 Current Screen time Guidelines for Youth

In 2010, the contribution of sedentary behaviours to disease risk was recognized as a research gap by the WHO in their global recommendations on PA for health (7). Until then, public health agencies worldwide focused solely on PA recommendations and interventions even though evidence suggesting sedentary behaviours may have profound independent effects on health was accumulating (41). In 2011, Canada released the first evidence-based sedentary behaviour guidelines for children and youth in the world, based on an extensive literature review (41), and many other countries followed shortly thereafter. In 2016, the Canadian 24-hour Movement Guidelines for Children and Youth updated its recommendations and suggested engaging in no more than 2-hours of recreational screen time daily and limiting sitting for extended periods (23).

2.2.4 Sedentary Behaviour in Children

At the time of implementation of the Canadian 24-hour Movement Guidelines for Children and Youth in 2016, it was estimated that only 49.3% of Canadian children age 5 to 17 met the screen time recommendations of 2-hours maximum daily (9). Boys accumulate more screen time daily than girls (9). The Canadian Health Measures Survey estimates that youth spend 8.5 hours sedentary every day (42). In Québec, adolescents age 12-17 spend 9 hours daily in sedentary activities including watching television and using electronic devices (10).

In both cross-sectional and longitudinal studies, sedentary behaviours (as distinct from physical inactivity) influence body weight in children. A study using data from the NDIT (Nicotine Dependence in Teens) study (i.e., the same dataset used in this current thesis) showed that even low levels of screen time increase the risk of a higher percent body fat if screen time increases during adolescence. However, the risk decreases if screen time decreases over time, suggesting a potential for positive effects of intervention during adolescence (43). In a systematic review of all studies examining relationship between sedentary behaviours and health outcomes in children and youth (5-17 years of age), watching TV for more than 2-hours daily was associated with unfavorable body composition, decreased fitness, lower scores for self-esteem and pro-social behaviour, and decreased academic achievement (44). Another review incorporating both cross-sectional and longitudinal studies reported that too much sedentary time is associated with obesity in youth, insulin sensitivity, clustered metabolic risk, and lower cardio-respiratory fitness in youth, but not with impaired lipid profiles or increased blood pressure (11).

2.2.5 Measurement of Sedentary Behaviour

Methods of assessing sedentary behaviours are similar to those for PA and can be categorized into subjective and objective measures (29). Subjective methods of measuring screen time document these activities in self-reports (29). Questionnaires are the most common method used in research. These can be self-administered, administered in-person or

in telephone interviews, or data can be collected in diaries. Self-report questionnaires measuring screen time have focused primarily on TV-viewing, but rarely report the validity or reliability of the measures (45). Diaries can be used to obtain more detailed assessment of sedentary behaviours and to capture its multi-faceted nature (29). These subjective methods have the same advantages and limitations as those described above for PA.

More recent studies now include multiple screen-based activities (i.e., computer use, time spent playing video games) which reflect the ever-changing nature of digital media and technology (46). One study examining the convergent construct validity of two self-report measures of sitting time against accelerometer-measured screen time suggested that a single-item measure (i.e., TV time alone) underestimates total sitting time compared to a domain-specific questionnaire (47), and that the estimation of total sitting time is improved by summing times across different domains (47). There are also reports suggesting that adults and children recall screen activities better on weekdays than weekends, which may relate to greater variability in activity patterns on weekend days (29). Gunnell et al. examined whether screen time assessments that change over time (i.e., researchers modify indicators to include new screen-based devices in more recent data collections) to reflect technological advancements, accurately measure screen time (46). The team demonstrated that across data collections spanning 4 years, 76% of screen time indicators had similar meaning, were answered on similar metrics (i.e., participants responded similarly to the response scales across cycles), and had similar sources of error (46). They concluded that screen time can be measured across time despite changes in the indicators.

As described above, accelerometers are widely used to objectively measure PA and are more and more frequently used to measure sedentary behaviours. Sedentary behaviours can be studied through the accumulation of low movement counts at pre-determined cut points by the accelerometer (29). One study examining the minimum number of days of accelerometer monitoring needed to estimate PA and sedentary behaviours in children, reported that three days of monitoring yielded 73% reliability in the estimates (48). Studies often include at least one weekend day in accelerometer monitoring (48).

2.3 Association Between Sedentary Behaviour and Physical Activity

2.3.1 Current State of the Literature

Prior to creation of a formal definition by the SBRN and recent sedentary behaviour research, it was common to classify an individual as 'sedentary' when he/she had low PA levels. It was assumed (with little evidence) that PA and sedentary behaviour had an inverse and causal relationship. In 2000, Owen et al. were among the first to suggest that sedentary behaviours such as screen time can coexist, but also compete with PA. They described the importance of exploring sedentary behaviour as a unique attribute (49).

In 2002, Marshall et al. examined this relationship by investigating clustering of activities among children age 11 to 15 (50). They observed that the correlation between sedentary behaviours and PA was small and positive ($r = 0.22$). Disputing the assumptions that they are inversely related and confirming Owen's claims, two of the three clusters included youth who were sufficiently physically active, but who were also dependent on technology-based entertainment such as TV-viewing and computer use, especially in boys. In addition, youth reporting low levels of PA also reported low sedentary behaviour levels. These and other studies (51, 52) do not support the tenets of the 'displacement hypothesis', which claims that TV time is directly related to time spent in other activities including PA (i.e., the more time spent watching TV, the less time a person will devote to other activities such as PA).

Several other studies only partially confirm the claims of the 'displacement hypothesis'. A meta-analysis of 163 articles (over 80% of which were cross-sectional) examined the association between sedentary behaviour and PA in children and adolescents and reported a small but significant negative association between the two variables. Although the direction of the association is consistent with the 'displacement hypothesis', its small magnitude does not support the premise that activities are substituted (53). This result is also contrary to those of Marshall et al. (50), who reported a positive correlation between sedentary behaviours and PA. A recent review of published studies on sedentary behaviours among

adolescents and its influence on body composition did not find any evidence suggesting that sedentary behaviour displaces PA (54).

Because sedentary behaviours and PA coexist in adolescents (i.e., both high, both low, any other combination of levels) but are only weakly correlated, the question arises as to whether these behaviours have independent effects on health. Studies show inconsistent results. A systematic review including all study types (observational studies, randomized controlled trials and other intervention studies) examining how different levels of PA, sedentary time, and sleep were related to health indicators in children and youth age 5 to 17 suggested that the optimal combination in regard to adiposity and cardiometabolic health was high PA/high sleep/low sedentary behaviour (55). The most injurious combination was low PA/low sleep/high sedentary behaviour. High PA/low sedentary behaviour was associated with better health compared to low PA/high sedentary behaviour (55). The authors suggested the presence of synergy between PA and sedentary behavior.

Numerous studies demonstrate independent effects of PA and sedentary behaviours on risk factors, with the effects of PA (and especially MVPA) generally stronger than those of sedentary behaviour. A cross-sectional study in a large sample of adolescents (n = 200,615 participants) across 39 countries did not report consistent associations between screen-based activities and PA across gender or geographical location (56). A cross-sectional study of 1862 British children age 9-10 found inverse associations between time spent in PA and measures of adiposity, independent of objectively measured sedentary time and other covariates (52). However, the association between sedentary time and adiposity was attenuated after adjustment for MVPA and other covariates. This suggests that MVPA may be more closely associated with adiposity and other cardio-metabolic risk factors than sedentary time. Chaput et al., in a prospective cohort of 536 children with at least one obese biological parent, reported that high levels of MVPA were associated with significantly lower values of several cardiometabolic risk factors (i.e., waist circumference, fasting triglycerides, diastolic BP, higher values of HDL cholesterol), independent of sedentary time. However, objectively measured sedentary time was only significantly associated with diastolic blood pressure, and the association was no longer significant after adjustment for MVPA (57). Analyses from the

European Youth Heart Study cohort of 1,092 children showed that TV-viewing was not correlated with PA ($r = 0.013$, $p = 0.58$), even after adjustment for covariates. TV-viewing was not associated with adiposity after adjustment for PA, but association between PA and fasting insulin, glucose, triglyceride, systolic blood pressure and diastolic blood pressure remained statistically significant after adjustment for TV-viewing and adiposity (58).

2.3.2 Gaps in Knowledge

MVPA and sedentary behaviours are now widely accepted as separate entities with distinct effects on health. The independent effects of MVPA and screen time are actively under study, and published articles to date report mixed findings of their effects on multiple health outcomes such obesity and high blood pressure. The correlation between MVPA and screen time is not clear. Some articles report weak positive correlations, others show a correlation in the opposite direction, and some find no correlation. Research on sedentary behaviours, and more specifically, on screen time, is still in its infancy. In adolescent studies its effects on health appear to be less potent than those of MVPA. However further research is needed to assess this in-depth. Finally, screen time and PA are behaviours that change during adolescence, but most articles assessing the association between MVPA and screen time are cross-sectional limiting causal inference, identification of predictors of change, and describing long-term evolution of the behaviours. More longitudinal studies are needed. In a systematic review of 230 articles assessing the association between sedentary behavior and PA in children and adolescents, only 21 were longitudinal in design (53). Thus, prospective research on SB in adolescents remains limited (59).

2.4 Group-Based Trajectory Modeling (GBTM)

GBTM is a statistical procedure applied to longitudinal data to identify subgroups within a population with distinctive developmental trajectories. The method is usually used to describe the progression of a phenomenon, whether behavioral, biological or physical, over age or time (60). It is an application of the finite mixture modeling, where the statistical model specifies that the population comprises a mix of a finite number of groups (61). Several

statistical methods exist to model evolution of behaviors. However, they differ in the technical assumptions about the distribution of trajectories in the population. GBTM assumes that there may be clusters of distinct developmental trajectories in the population, whereas other methods such as latent class analysis assumes a continuous distribution of population parameters and thus that the population distribution of trajectories varies continuously across individuals (61). These assumptions will influence the product of the analysis in important ways.

GBTM is a powerful statistical method for summarizing and portraying complex patterns in longitudinal datasets (61), which can be applied to behaviours such as PA and ST. This method has been used to identify PA trajectories in adults as well as in special population subgroups (62-65). Janz et al. used the method to identify sex-specific PA trajectories in an adolescent population and then tested them for their effect on bone strength (66). Kwon et al. used data from the National Growth and Health Cohort study to identify PA and TV-viewing trajectories among girls during adolescence (67). They identified four PA trajectories. Most girls in the common "PA decreasing pattern" concurrently developed an increasing pattern of TV-viewing over the 9-year follow-up. However, 87.7% of girls in the "maintaining high" PA trajectory developed a decreasing pattern of TV-viewing, findings which do not support that TV-viewing and PA are independent behaviors. Finally, a study emanating from the Cardiovascular Risk in Young Finns Study identified five PA trajectories in 3596 adolescents followed up for 31 years, although no sedentary behavior trajectories were reported (68).

There are fewer studies on screen time than PA trajectories, and even fewer in adolescents. One study from a prospective birth cohort study in Australia with a 15-year follow up, identified three distinct TV-viewing trajectories using latent class analysis (69). TV-viewing from childhood into early adulthood was a relatively stable behavior in most participants, although one-third were members of an increasing TV-viewing time trajectory that tracked into early adulthood (69). Prolonged periods of TV-viewing over the 15-year study were associated with a higher body fat percentage in women and the association was not attenuated by PA levels.

2.5 Summary

PA research has evolved considerably in the last several decades and researchers have generally adopted a new vision of movement. Sedentary behaviour is no longer viewed as one end of the PA spectrum and is now recognized as different from physical inactivity. An adolescent can be very active but still accumulate large amounts of screen time daily, supporting the premise that PA and sedentary behavior are separate and distinct entities that could have unique effects on health. PA and sedentary behaviour have a weak correlation in adolescent populations and their independent effects on health outcomes are not fully understood. Because PA and sedentary behaviour are highly variable behaviours during adolescence, increasing in some contexts and decreasing in others, examining their co-evolution during adolescence offers potential to expand understanding of these two behaviors. Trajectory modeling techniques take advantage of the longitudinal nature of some databases and can depict the co-evolution of PA and sedentary behavior over time.

Chapter 3: Objectives and Hypotheses

The aim of this MSc thesis was to describe the co-evolution of PA and screen time during adolescence. There are two specific objectives:

1. **To describe the concurrent natural course of PA and screen time during adolescence, by developing sex-specific group-based trajectories for each behaviour.**
   The literature review reveals important differences between sexes in PA and screen time. Our hypotheses were that boys and girls have distinct PA and screen time trajectories, and that boys have higher levels of PA and screen time than girls.

2. **To describe the association between PA trajectory membership and screen time trajectory membership.**
   We hypothesized that membership in PA and screen time trajectories will not covary. More specifically, cross-tabulations and conditional probabilities obtained from joint trajectory modeling will show that the variables do not associate one with the other over time.

Chapter 4: Methods

This thesis comprises a secondary analysis of data originating from the NDIT cohort. This chapter describes the study in terms of design, sampling and variables. It then presents the analytical sample and data analysis plan.

4.1 Data source: NDIT Study

4.1.1 Study Design and Sampling

The NDIT study is an ongoing longitudinal investigation of 1294 adolescents conducted in or near Montreal, Québec (70). Its main purpose is to describe the natural course of cigarette smoking and nicotine dependence in adolescents and to investigate the range of individual-level and contextual risk factors for cigarette smoking (70). NDIT data collection also included parent and school administrator self-report questionnaires, collection of blood and/or saliva samples from participants and their parents for DNA genotyping, and direct observations of school neighbourhoods (i.e., environmental scans) (70). Data collection in NDIT allows for other topics of interest in relation to adolescent health to be investigated including among others, obesity, blood pressure, PA, team sports, sedentary behavior, diet, genetics, alcohol and drug use, sleep and mental health (70).

Participant recruitment for NDIT began in 1999 using a school-based sampling strategy. Thirteen high schools were selected purposively in the greater Montreal area to include a mix of French- and English-language schools; urban, suburban and rural schools; and schools located in high, moderate and low socioeconomic status neighbourhoods. (70). School boards and school principals provided consent with assurance that the school would participate over five years (so that the students could be followed from grade 7 to 11) (70). Of the 13 high schools, two were excluded due to low parental consent and one was excluded because school administrators could not assure continued participation. The final number of schools retained was 10. All grade 7 (Secondary 1) students from the 10 high schools were invited to participate (n = 2325) and 1294 (56%) agreed to participate.

Self-report questionnaires were completed by participants during class time in autumn 1999 in nine schools, and in autumn 2000 in one school (Table 1). Follow-up questionnaires were completed during class time every 3 months during the 10-month school year for 5 years thereafter (i.e., for the entire duration of high school for students recruited at the beginning of grade 7). The follow-up during high school thus comprised 20 cycles (Figure 2), all of which are used in the current thesis. Participants continued their involvement in NDIT after graduation from high school, with completion of self-report questionnaires in 2007-08 when they were age 20 years on average (cycle 21), and in 2011-12 when they were age 24 years on average (cycle 22). The 23rd data collection cycle is currently underway (participants are now age 30 years on average). Cycle 21-23 data are not used in this thesis.

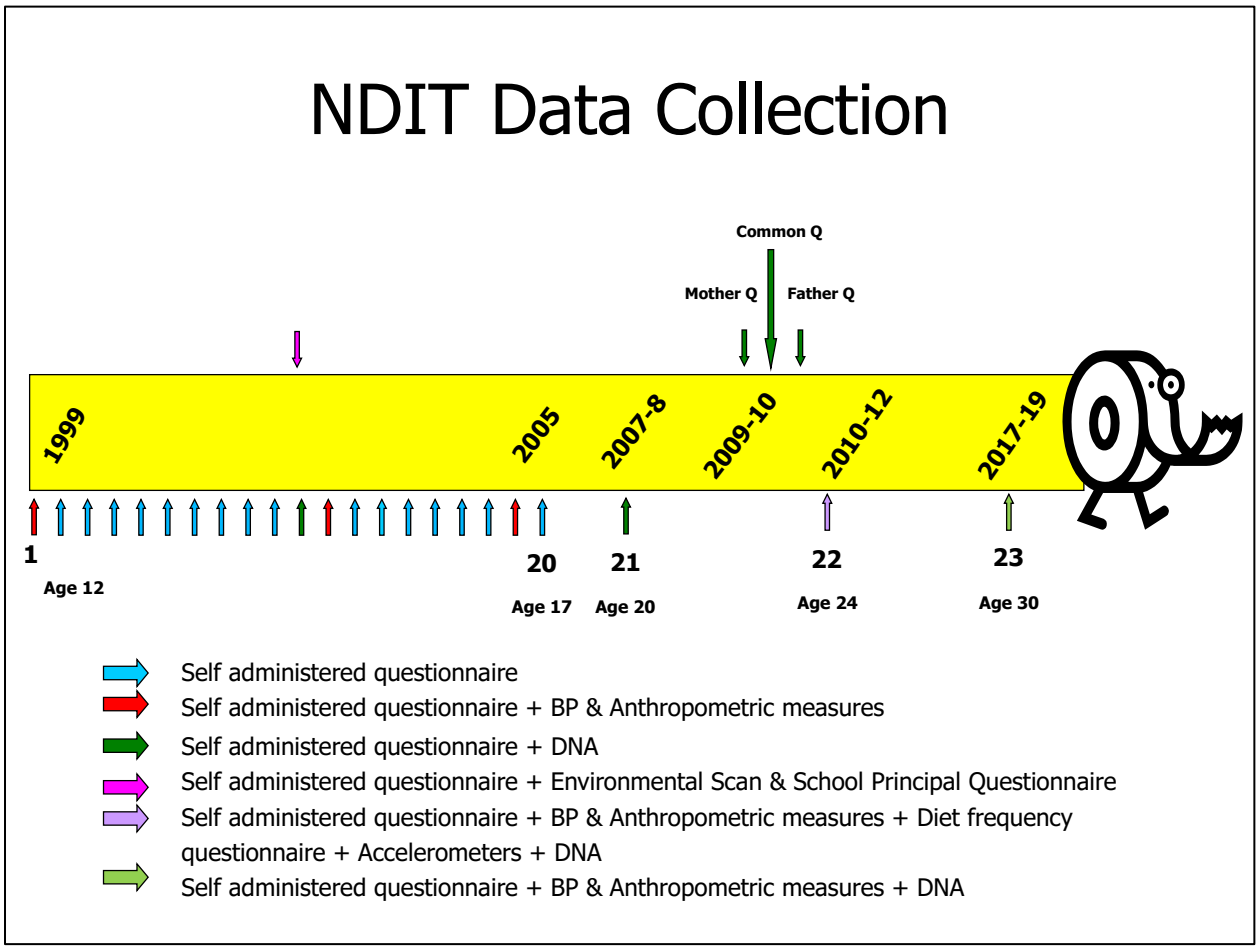

Figure 2. NDIT data collection cycles, 1999 to 2019 (70)

Table 1. Dates when the first and last school were surveyed at each survey cycle and the within-survey time range.

Survey Cycle	Study Year	Date of first school surveyed[a]	Date of last school surveyed[a]
1	1	October 4, 1999 (September 20, 2000)	February 17, 2000 (September 27, 2000)
2		January 27, 2000 (January 26, 2001)	April 11, 2000 (February 12, 2001)
3		March 10, 2000 (March 1, 2001)	June 5, 2001 (March 23, 2001)
4		May 2, 2000 (May 24, 2001)	May 25, 2000 (May 30, 2001)
5	2	September 22, 2000 (November 12, 2001)	November 14, 2001 (November 16, 2001)
6		December 6, 2000 (February 4, 2002)	February 7, 2001 (February 14, 2002)
7		February 20, 2001 (N/A)	April 4, 2001 (N/A)
8		May 2, 2001 (May 6, 2002)	June 7, 2001 (May 6, 2002)
9	3	September 26, 2001 (October 21, 2002)	November 27, 2001 (October 21, 2002)
10		December 10, 2001 (January 20, 2003)	January 22, 2002 (February 6, 2003)
11		March 12, 2002 (March 21, 2003)	April 11, 2002 (April 4, 2003)
12		April 30, 2002 (May 12, 2003)	May 22, 2002 (May 26, 2003)
13	4	September 24, 2002 (October 7, 2003)	October 24, 2002 (January 9, 2004)
14		December 10, 2002 (January 19, 2004)	February 13, 2003 (February 2, 2004)
15		March 11, 2003 (March 24, 2004)	May 2, 2003 (April 15, 2004)
16		April 30, 2003 (April 27, 2004)	May 28, 2003 (May 19, 2004)
17	5	September 23, 2003 (October 5, 2004)	November 7, 2003 (October 13, 2004)
18		December 4, 2003 (December 15, 2004)	February 25, 2004 (December 17, 2004)
19		March 9, 2004 (March 8, 2005)	April 22, 2004 (March 15, 2005)
20		May 4, 2004 (May 10, 2005)	June 11, 2004 (May 17, 2005)

[a]Nine schools were recruited and began follow-up in the 1999-2000 school year. The first set of dates are for these 9 schools. A 10th school joined the study in 2000-2001. Dates in parentheses are for the 10th school.

4.1.2 Study Variables

For this thesis, two variables from the NDIT Study were used: PA (number of days weekly that participants were physically active), and screen time (number of hours of screen time weekly). Except for sex, no other variables were used in the trajectory modeling.

4.1.2.1 Number of Days Active Weekly

In each of the 20 survey cycles, data on PA were collected with a question adapted from the 7-day Physical Activity Recall Checklist (17). Participants were asked: *Now think about the physical activities that you did last week from Monday to Sunday outside your regular school gym class. For each activity that you did for 5 minutes or more at one time, mark an "X" to show the day(s) on which you did that activity.* Participants were then presented with a list of 29 physical activities commonly engaged in by adolescents in Montreal and were instructed to mark an X for each day of the previous week on which they engaged in that activity (Table 2).

Table 2. 7-day Physical Activity Recall Checklist, NDIT 1999-2005

	Mon	Tues	Wed	Thur	Fri.	Sat.	Sun.
Bicycling to school, bicycling to do errands, going for a bicycle							
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)[a]							
Indoor chores (mopping, vacuuming, sweeping)[a]							
Mixed walking/running/jogging							
Walking[a]							
Running/jogging							
Other(s)							

[a]Activities not retained in the trajectory analyses.

The 29 physical activities represented a mix of activities of low, moderate or vigorous intensity. 'Walking' was not retained for the trajectory analyses because almost all participants reported walking every day. 'Indoor chores' and 'outdoor chores' were also excluded because they are considered to be nonleisure, nondiscretionary activities (71). Most PA recommendations for youth focus on leisure-time PA (which is amenable to change) and exclude physical activity during physical education classes at school and other nondiscretionary activities (10). The remaining 26 activities were all of moderate (i.e., 3-6 METs (18)) or vigorous (i.e., >6 METs (18)) intensity. The 5-minute threshold used in the 7-day recall is supported by findings that PA engaged in for at least 5 minutes protects against obesity in youth (73, 74). Number of days active weekly was computed as the sum of the number of days weekly when participants reported engaging in at least one of the 26 activities. For example, a value of "0" indicates that the participant did not engage in any of the 26 activities on any day of the week. A value of "2" indicates that the participant reported at least one PA on 2 of the past 7 days. This PA indicator does not incorporate duration, intensity or mode of PA.

During the first cycle of the NDIT study, the PA recall was administered twice in two weeks among 76 students in one school. The correlation between reported PA levels was $r = 0.73$ (72). The 3-day test-retest reliability reported in the original 7-day Physical Activity Recall Checklist was $r = 0.74$ and correlated with accelerometer data at $r = 0.34$ (17). Intraclass correlation coefficients (ICC) for 'Number of days active weekly' were calculated to determine

the extent to which students within the same school resemble each other. Elevated ICCs would indicate that PA levels for participants from the same school are correlated. ICCs were below 0.2 in all survey cycles, which suggests low correlations between PA values across students within the same school. Thus we can use these data without correcting for the cluster sampling structure of the study.

4.1.2.2 Weekly Screen time

At each of the 20 cycles, participants were asked: *How many hours of television (including video movies) do you usually watch in a single day? If the answer is zero, write "0" in the box. If the answer is less than ½ hour, write "LT ½",* and *How many hours do you usually play video or computer games, or use Internet in a single day? If the answer is zero, write "0" in the box. If the answer is less than ½ hour, write "LT ½".* Participants were provided with boxes to record the number of hours they engaged in these activities on weekends and on weekdays. To harmonize with other similar studies on screen time (46), responses were capped at a maximum value of 5 hours per day (i.e., recoded as "≥ 5 hours per day"). Weekly screen time was computed as the weighted sum of the number of hours of both television and computer time for weekdays and weekend days: (5 * weekday TV time) + (2 * weekend TV time) + (5 * weekday computer time) + (2 * weekend computer time). ICC were calculated again for this variable and correlations at all survey cycles were very low ($r < 0.01$).

4.2 Analytical Sample and Attrition

Participants were retained for analysis if they had provided PA and screen time data on ≥ 3 occasions across the 20 data collection cycles; participants with < 3 observations do not contribute meaningful information for trajectory modeling (75). A total of 50 participants contributed data in < 3 cycles, and therefore 1244 of the 1294 (96%) were retained for analyses. Table 3 presents the number of observations available at each cycle for these 1244 participants.

Two-thirds (65%) of the 1294 participants remained in the study until the 20th cycle (end of high school), although not all participants completed all 20 cycles. Reasons for not continuing in NDIT included moved to a non-participating school, no time and no longer interested (70).

Table 3. Number of observations missing in each cycle among eligible participants[1]

	Cycle																			
	1	2	3	4[a]	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Boys (n = 597)																				
Days active	27	32	26	338	70	70	135	115	115	126	136	124	162	167	167	172	205	219	230	236
Screen time	44	46	46	342	75	74	137	121	114	129	139	125	167	168	164	173	187	199	201	210
Girls (n = 647)																				
Days active	30	37	48	372	74	80	159	155	114	125	137	133	171	175	177	191	244	253	257	252
Screen time	48	56	58	373	81	84	166	156	117	132	142	143	174	180	178	191	194	198	205	197

[a]Data were not collected in 6 of 10 schools in cycle 4.

Table 4 presents baseline data comparing participants included and excluded from the analytical sample. Excluded participants were older on average at baseline than those included. Weekly screen time was higher among participants retained, and this result was close to statistical significance (p=0.07).

[1] Not all participants participated in all 20 cycles. Some participants joined NDIT after the first few data collection cycles were completed.

Table 4. Baseline (cycle 1) characteristics of included and excluded participants, NDIT 1999-2000

	Included participants (n=1244)	Excluded participants (n=50)	p-value
Age, y, mean (SD)	12.7 (.51)	13.4 (1.11)	**< 0.001**
Missing	0	1	
Male, %	48	53	0.486
Missing	0	0	
Single-parent family[a], %	9	13	0.483
Missing	62	10	
Born in Canada, %	92	86	0.249
Missing	0	1	
Mother has some university-level education[a], %	55	70	0.354
Missing	276	40	
Number of days active weekly, mean (SD)	4.9 (.07)	5 (.40)	0.838
Missing	57	10	
Weekly screen time (hr), mean (SD)	26.5 (.43)	21.6 (2.4)	0.069
Missing	92	11	

[a]Parental reports of data from the parent questionnaires.

Missing values were high for mother's level of education, because only some parents (46% of mothers and 37% of fathers of all NDIT adolescent participants) completed the parent questionnaires in 2009-10.

4.3 Data Analysis

4.3.1 GBTM

Group-based trajectories for PA and screen time were modeled in boys and girls separately. The time metric to estimate all trajectories was cycle (1 to 20). However, to ease interpretation, median age at each cycle was used as the x-axis in trajectory plots.

GBTM requires the analysis to choose among four distributions for the variable to be modelled: censored normal, Poisson and zero-inflated Poisson, and Bernoulli (61). In the case of the 'number of days active weekly' variable, we are in the presence of count data; examination of the data distribution with histograms, however, informs us that the data do not present with a Poisson distribution (see Appendix C for histograms of the PA variable at cycles 1, 10 and 20),

and this type of model would not be appropriate. It can be best described as a discrete variable with a large number of values at its maximum (7 days weekly). In the case of the 'Weekly Screen time' variable, the distribution is continuous with a wide range (exceeding 70-hours weekly) (see Appendix D for histograms of the screen time variable at cycles 1, 10 and 20). Thus, for both variables, the censored normal distribution has been determined as the most appropriate form for estimating trajectory parameters, especially given that the model using the censored normal distribution is robust to departure from the normal distribution (Bobby Jones, July 4, 2019). The GBTM is the product of maximum likelihood estimation, which is a modification of the normal distribution but in which the data values are forced to take values in between the interval specified with minimum and maximum values, that lie outside the range of observed data values (76).

The number of trajectories (or groups) is not decided a priori but is empirically derived by estimating models with an increasing number of trajectories (starting with 2) and selecting the model with the best fit. In regards with the objectives of the study, we considered models containing between 2 and 5 trajectory groups. The number of trajectories that best fit data is identified based on the Bayes factor, estimated from the Bayesian Information Criterion (BIC) as ~2x(ΔBIC) (61, 76). The model which minimizes the Bayes factor is determined to be the optimal model. Second, the selected model is simplified through modifications in the order of the polynomials for each trajectory group (which determine its flexibility). Terms that did not attain significance level at .05 were omitted so that the trajectory was estimated with lower-order polynomials, while assuring that these modifications do not majorly affect the shape of the curves. The estimation provides posterior probabilities for each individual and participants are assigned to the group for which their posterior probability is the highest. An average posterior probability per trajectory group over 0.70 implies a satisfactory fit of the model (61).

Trajectories were modeled in SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA) using the Proc Traj package[2] (76). Descriptive statistics and other related analyses were undertaken in SAS 9.4 and STATA 12.1 ® (College Station, Texas, USA).

4.3.2 Joint Trajectories

After modeling of PA and screen time trajectories separately, we modeled joint trajectories for both variables simultaneously (61).

The joint trajectory model can be used to analyze the connections between the developmental trajectories of two outcomes evolving simultaneously (61). It relates the two measurements but without combining them into a single metric (such as a single summary statistic), making a more effective use of the longitudinal character of the data. This model was first presented as providing a new statistical tool for analyzing two themes in developmental psychopathology, criminology, and psychiatry; however potential applications of the model extend into diverse domains.

The joint trajectory is modeled once individual trajectories for both PA and ST are determined. Using the same number of trajectory groups and orders as determined during the creation of the distinct trajectories of PA and ST, the joint trajectory model is estimated with the same statistical package and software. The joint model will provide three outputs: 1) group membership to trajectories for both measurements, which are previously obtained from the trajectory modeling of the two variables separately; 2) the probability of membership in each pair of trajectory groups (e.g., the proportion of individuals that are members of low PA and high ST trajectory groups); and 3) two sets of conditional probabilities for trajectory group membership across both variables (e.g., the probability of being in the low PA trajectory group given that the individual is part of the high ST trajectory group, and vice-versa). These conditional probabilities

[2]The GBTM procedure was performed in SAS 9.4 and STATA 12.1, both supporting the Proc Traj package. Inconsistent outputs and results were seen between the two softwares. After consultation with Bobby Jones (Research Scientist, Department of Psychiatry, University of Pittsburgh School of Medicine, and developer of the Proc Traj package), a decision was made to pursue all trajectory modeling with the SAS 9.4 software.

are the key advantage of the joint model and provide the capacity to link two distinct but theoretically related measurements (77).

4.4 Ethical Considerations

For all adolescent participants, one parent or legal guardian signed a consent form (Appendix A). Participation is entirely voluntary, and participants could choose to stop being part of the study at any time without providing a reason and without consequences. Post-high school, participants were given monetary compensation for their involvement in the study.

This project is an add-on to an existing study which has received ethics approval from the Montreal Department of Public Health Ethics Review Committee, the McGill University Faculty of Medicine Institutional Review Board, the Ethics Research Committee of the Centre de recherche du Centre hospitalier de l'Université de Montréal and the University of Toronto (See Appendix B).

Chapter 5: Results

5.1 Manuscript Presentation and Contribution

This chapter includes a manuscript entitled *Joint trajectories of physical activity and screen time during adolescence.* The journal targeted for publication is the *International Journal of Behavioral Nutrition and Physical Activity*. As first author, the candidate played a central role in all aspects of manuscript preparation. She refined the objectives, conducted all the analyses and wrote the manuscript. Marie-Pierre Sylvestre and Jennifer O'Loughlin supervised the analyses and reviewed and edited the manuscript.

5.2 Manuscript

Title: Joint trajectories of physical activity and screen time during adolescence

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Number of tables: 3

Number of figures: 3

Supplementary data: 10

Abstract

Introduction: Physical activity relates positively to adolescent health. However only 7% of youth age ≤17 years meet the recommended 60 minutes of moderate-to-vigorous physical activity (MVPA) daily. Additionally, most adolescents exceed the recommended maximum 2 hours screen time daily. Several studies suggest that MVPA and screen time are weakly correlated and may develop independently of each other. We examined the co-evolution and association between MVPA and screen time during adolescence.

Methods: Data were drawn from a longitudinal investigation of 1294 adolescents age 12-13 recruited in 1999-2000 from all grade 7 classes in 10 Montreal-area high schools. Participants completed self-report questionnaires every 3 months during the 10-month school year, from grade 7 to 11. Sex-specific group-based joint trajectories were used to describe co-evolution of MVPA and screen time over 5 years during adolescence. Associations were examined in cross-tabulations.

Results: We identified 5 MVPA trajectories in both sexes, 4 screen time trajectories in boys and 5 screen time trajectories in girls. 57% of boys and 46% of girls reported MVPA 6-7 days per week during the 5-year study. All screen time trajectories exceeded 2 hours screen time daily. 17.2% of boys and 14.5% of girls had low screen time and stable-high MVPA trajectories. Conditional probabilities suggest associations between screen time and MVPA trajectory group memberships.

Conclusions: Developmental patterns of MVPA and screen time are heterogenous in adolescents. Public health practitioners need to take co-evolution and the association between MVPA and screen time into account in planning programs and policy.

Key Words: Physical activity, screen time, sedentary behaviour, adolescence, longitudinal study, group-based trajectory modeling.

Introduction

The World Health Organization has identified that physical inactivity increases the risk of chronic diseases including diabetes mellitus, hypertension, coronary artery disease, stroke, osteoporosis and certain cancers, and that physical inactivity is in fact, the fourth leading risk for mortality globally (1, 2). Increased understanding of the role of physical activity (PA) in health has fuelled development of PA recommendations worldwide. Initially these recommendations focused on adults since children and adolescents were viewed as healthier and naturally more active than adults (3). However a growing evidence-base has converged to suggest that school-age youth should engage in at least 60 minutes of moderate to vigorous PA (MVPA) daily (4, 5).

In spite of these guidelines, cross-sectional data from the Global School-Based Student Health Survey with estimates from 105 countries, showed that 80.3% of youth age 13 to 15 do not accumulate 60 minutes of MVPA per day, and that girls are less active than boys (6). In fact, studies consistently report gender differences in PA engagement, where adolescent girls practice less PA than adolescent boys (7). Data from the Canadian Health Measures Survey suggest that only 7% of youth age $\leq$17 years meet the Canadian recommendation of 60 minutes of MVPA per day on at least 6 of 7 days weekly, although 33% achieved a weekly average of 60 minutes daily (8). These data are concerning because PA from childhood tracks into adult life, and thus low levels of PA during childhood and adolescence may lead to physical inactivity during adulthood (9, 10).

While PA has been investigated over the last 60 years, research on sedentary behaviours has emerged only in the last decade (11). The Sedentary Behavior Research Network reached consensus on an appropriate definition of sedentary behaviour as any waking behavior characterized by an energy expenditure $\leq$1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture (11). This includes watching television, using the computer, playing video games, socializing, driving, reading, work and public transport (12). In research on children and adolescents, it is common to rely on proxy measures such as car-, sitting- or screen time, to capture sedentary behaviour (13). It may in fact be appropriate to

adopt a focus on leisure-time sedentary behaviour since other activities (i.e., at-school sedentary activity, homework) generally have little flexibility in terms of modification (14). The current Canadian 24-hour Movement Guidelines for Children and Youth suggests that children ages 5 to 17 engage in no more than two hours of recreational screen time daily (15), and 46% of boys and 52% of girls meet this recommendation (16). As for PA, gender differences in the duration, types, and effects on health of sedentary behaviours are frequently reported (17). Boys accumulate more screen time than girls (16, 17).

Prior to the creation of a formal definition, it was common to classify an individual as 'sedentary' when he/she engaged in low PA levels. Owen et al. were among the first to suggest that sedentary behaviours can coexist but also compete with PA, and they highlighted the importance of studying sedentary behaviour as unique from PA (18). The distinction is important because the risk factors and outcomes of PA and sedentary behavior might differ, and public health practice may need to address each with separate and distinct action.

Although it is generally accepted by the scientific community that PA and sedentary behaviours are unique constructs, the recent literature reports contradictory findings on the associations between the two variables. Marshall et al. reported a small positive correlation between sedentary behaviour and PA ($r = 0.22$) in children age 11 to 15 (19). In contrast, a meta-analysis covering 163 articles (20) on the association between sedentary behaviour and PA in youth, reported a small and significant negative association between the two variables. Additionally, a cross-national study of over 200,000 adolescents from 39 countries did not report consistent associations between screen-based sedentary behaviours and PA across genders and geographical locations (21). In the European Youth Heart Study of 1,092 children, TV-viewing was not correlated with PA ($r=0.013$, $p=0.58$), even after adjustment for covariates (22).

Results are also inconsistent on the independent effects of PA and sedentary behaviours on health outcomes. The European Youth Heart Study did not find that TV-viewing was associated with adiposity after adjustment for PA, but the association between

PA and fasting insulin, glucose, triglyceride, systolic and diastolic BP remained significant after adjustment for TV-viewing and adiposity (22). In a longitudinal study of 536 children with at least one obese biologic parent, Chaput et al., reported that, independent of sedentary time, high MVPA levels were associated with lower levels of cardiometabolic risk factors including waist circumference, fasting triglycerides, diastolic blood pressure (BP) and HDL cholesterol. Further, objectively measured sedentary time was associated with diastolic BP only, and the association was no longer significant after adjustment for MVPA (23).

Most of the current research assessing the association between the PA and sedentary behavior are cross-sectional, so that their co-evolution over time is unknown. Because lifestyle behaviours appear to track from childhood into adult life, understanding their change over time is crucial in creating appropriate and effective interventions (24). As a first step towards better understanding the extent to which and how PA and sedentary behavior are distinct and separate constructs, we used group-based trajectory modeling to examine the co-evolution and association between MVPA and screen time (i.e., as a measure of sedentary behaviour) during adolescence.

Methods

Data were drawn from the Nicotine Dependence in Teens (NDIT) study, a longitudinal investigation of 1294 adolescents recruited in grade 7 (ages 12-13) in 1999-2000 from 10 public high schools in or near Montreal (25). Schools were selected purposively to include a mix of French and English schools; urban, suburban, and rural schools; and schools from high, moderate, and low socioeconomic status neighbourhoods (25). In-class self-report questionnaires were administered every 3 months during the 10-month school year from grade 7-11, for a total of 20 data collection cycles.

The study was approved by the Montreal Department of Public Health Ethics Review Committee, the McGill University Faculty of Medicine Institutional Review Board, the Ethics Research Committee of the Centre de recherche du Centre hospitalier de l'Université de Montréal and the University of Toronto.

Study variables

PA data were collected using a question adapted from the 7-day Physical Activity Recall Checklist (26): "*Now think about the physical activities that you did last week from Monday to Sunday outside your regular school gym class. For each activity that you did for 5 minutes or more at one time, mark an "X" to show the day(s) on which you did that activity."* Participants were presented with a list of 29 physical activities (Appendix 1) commonly engaged in by adolescents in Montreal and were instructed to mark an X for each day of the previous week when each activity was done. The 3-day test-retest reliability reported in the original 7-day Physical Activity Recall Checklist instrument by Sallis et al. was $r = 0.74$ and the measure correlated with accelerometer data at $r = 0.34$ (26). During the first cycle of NDIT, the PA question was administered twice in two weeks among 76 students in one school. The test-retest correlation coefficient was $r = 0.73$ (27). For the current analysis, "walking" was not retained because almost all participants reported walking daily. Indoor and outdoor chores were also excluded because they are generally nonleisure and nondiscretionary activities (28). The remaining 26 activities were of moderate (i.e., 3-6 (METs) (29)) or vigorous intensity (i.e., >6 METs (29)). The number of days being active per week was computed as the sum of the number of days in the past week when participants reported engaging in at least one of the 26 activities.

Screen time was measured in cycles 1-20 in four items. At each cycle, participants reported hours usually spent watching television and playing video or computer games, or using the Internet, for week days (Monday-Friday) and weekend days (Saturday-Sunday). To harmonize with other similar studies on screen time (30), responses were capped at a maximum value of 5 hours per day (i.e., responses above 5 hours per day were recoded as "5 hours or more"). Weekly screen time was calculated as the weighted sum of the number of hours of both television and computer time for weekdays (multiplied by 5) and weekend days (multiplied by 2).

Data Analysis

Group-based trajectory modeling (GBTM) is an application of finite mixture modelling applied to longitudinal data to identify subgroups within a population with distinctive

developmental trajectories (31). The modeling strategy consists of determining the optimal number of trajectories, estimating their shape, obtaining individual posterior probabilities for group memberships and then assigning individuals to the group for which their posterior probability is the highest (32). In the current analysis, we modeled sex-specific trajectories separately for PA and screen time and used the survey cycle (1 to 20) as the time axis, although median age at each cycle was used as the x-axis on the plots presented to ease interpretation. In order to contribute meaningful information for trajectory modeling, participants with fewer less than 3 time points for PA or screen time were excluded from analysis (33).

For both variables, we considered 2 to 5 trajectory groups and selected the optimal number using the Bayes Factor, approximated from the Bayesian Information Criterion (BIC) as ~2x(ΔBIC) (31, 34). Starting values for parameters were generated randomly. In the case where the Bayes Factor would not identify an optimal number of groups, such that it continued to improve as more groups were added, the selection was determined based on evaluation of the model that best illustrated the distinctive developmental patterns while maintaining model parsimony (31). Models were fitted using third order polynomials and then simplified by removing high order terms that did not attain statistical significance level at $p \leq 0.05$. Models with a mean probability per trajectory group greater than 0.70 were considered to have a satisfactory fit (31).

Second, a joint trajectory model was developed once individual trajectories for both PA and screen time were identified (35). The joint model used the parameters from the trajectory modeling of the two variables separately to estimate joint and conditional probabilities. Specifically, the joint models provided estimates of the probability of membership in each pair of trajectory groups (e.g., the proportion of individuals in low PA and high screen time trajectory groups) and two sets of conditional probabilities for trajectory group membership across both variables (e.g., given membership in the high screen time trajectory group, the probability of membership in the low PA trajectory group, and vice-versa).

Trajectories analyses were undertaken in SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA) using the Proc Traj package (34). Descriptive statistics and cross-tabulations were undertaken in SAS 9.4 and STATA 12.1 ® (College Station, Texas, USA).

Results

Fifty participants (3.9%) has fewer than three observations for PA and screen time and were excluded from the analysis. A total of 1244 participants (547 boys and 647 girls) were retained for trajectory modeling. Table 1 presents descriptive statistics from the baseline cycle by sex.

Table 1. Selected characteristics of NDIT participants by sex in cycle 1, NDIT, 1999-2000

	Boys (*n*=597)	Girls (*n*=647)	*p*
Age, y, mean (SD)	12.8 (0.5)	12.7 (0.5)	**0.010**
Born in Canada, %	92.3	92.3	0.988
Single-parent family, %	7.7	10.6	0.092
Participant is an only child, %	36.9	34.5	0.380
Mother has some university education, %	48.8	40.9	**0.014**
BMI, kg/m^2, mean (SD)	20.1 (3.7)	20.0 (3.9)	0.4012

Values in bold are significant at p = 0.05.

Trajectories in boys

PA

A 5-group model of PA trajectories was retained in boys (Figure 1a). The average posterior probability for the five groups ranged from 80-93%. Based on current PA recommendations that youth should engage in at least 60 minutes of MVPA daily (3, 4) and to facilitate presenting the results, we characterized the five trajectory groups into three "higher risk" PA trajectories including early decreasers (i.e., 5-6 active days per week in early cycles, sharply decreasing to 2-3 active days per week; *n*=63; 10.6%); later decreasers (6 active days per week decreasing slowly to 3 days per week; *n*=57; 9.5%); and stable-low PA (i.e., 2-3

active days per week; *n*=61; 10.2%). The "lower risk" PA trajectory groups included increasers (i.e., steadily increasing from 4 to 5 active days per week (*n*=78; 13.1%), and stable-high PA (i.e., ~6 active days per week (*n*=338; 56.6%)).

Screen Time

A 4-group model of screen time was identified in boys (Figure 1b). Average posterior probabilities for the four groups were all above 89%. Trajectories of screen time were all relatively stable over the course of adolescence, with slight decreases in later cycles. Trajectories included very-high screen time (i.e., 40-50 hours per week; *n*=119; 19.9%); high screen time (i.e., ~35 hours per week; *n*=197; 33%); moderately-low screen time (i.e., ~22 hours per week; *n*=186; 31.2%); and low screen time (i.e., ~15 hours per week; *n*=95;15.9%). In all four trajectories, the average number of screen time hours was above the recommended two hours per day (i.e., 14 hours per week) and therefore all the trajectories were considered "high risk".

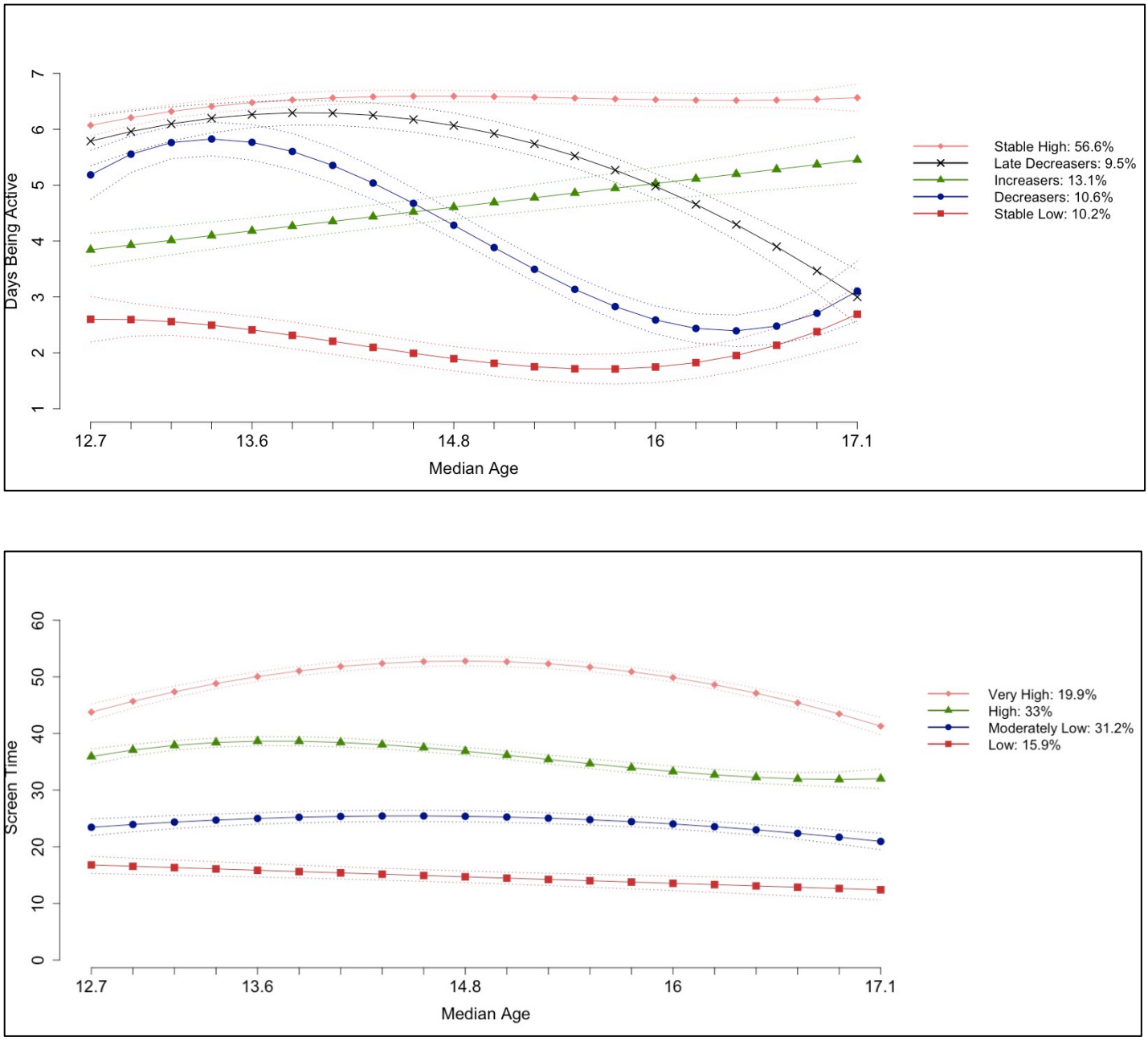

Figure 1. Five-year trajectories of number of days per week being physically active (top) and number of screen time hours per week (bottom) in boys. For ease of interpretation, median age at each cycle was used to label the x-axis.

Table 2a illustrates the joint probabilities of simultaneously belonging to one PA trajectory and one screen time trajectory group. In boys, the most populated joint probabilities were moderately-low screen time and stable-high PA (17.2%) and high screen time and stable-high PA (15.0%) (Table 2a). Only 1.6% of boys had low screen time and stable-low PA levels; 9.3% simultaneously belonged to the very high screen time and stable-high PA trajectory group.

Tables 2b shows the probability of membership in each PA group conditional on screen time group (e.g., given membership in the very high screen time group, 16.1% of boys were members of the early decreasing PA trajectory group), and Table 2c illustrates the probability of membership in each screen time group conditional on PA group. These sets of conditional probabilities are directly related to the respective PA and screen time group percentages (e.g., all conditional probabilities for the stable-high PA group are high because most participants are part of this PA trajectory group). For table 2b, results across PA trajectories were summed for the "higher risk" and for the "lower risk" trajectories. If PA and screen time are independent, similar trends in the distributions of conditional probabilities would be observed. Higher risk PA trajectories tended to have relatively higher probabilities conditional on the two highest screen time trajectories (i.e., ~42% for the two highest, 27.9% and 33.7% for the two lowest screen time trajectories). The two lower risk PA trajectories (and especially the stable-high PA group) tended to have higher probabilities conditional on the two low screen time groups (72.1% and 66.3%). Similarly, the two highest screen time trajectories had higher conditional probabilities given membership in the higher risk PA trajectories (Table 2c). The moderately-low screen time trajectory had higher conditional probabilities given membership in the lower risk PA groups. However mixed results were observed for the lowest screen time trajectory (i.e., was not informative for PA group membership).

Table 2: Joint (a) and conditional (b and c) probabilities of PA and screen time in boys (n=597), NDIT 1999-2005

a) Joint probabilities of membership in PA and screen time trajectories						
Screen time trajectories	n	Physical activity trajectories				
		Higher risk			*Lower risk*	
		Early decreasers (n=63) %	Later decreasers (n=57) %	Stable-low PA (n=61) %	Increasers (n=78) %	Stable-high PA (n=338) %
Very high screen time	119	3.2	2.7	2.6	2.1	9.3
High screen time	197	5.8	4.6	3.6	4.2	15.0
Moderately-low screen time	186	2.4	3.4	2.6	4.6	17.2
Low screen time	95	1.2	2.8	1.6	1.3	9.7

b) Membership in PA trajectories, given membership in screen time trajectories								
Screen time trajectories	n	Physical activity trajectories						
		Higher risk				*Lower risk*		
		Early decreasers (n=63) %	Later decreasers (n=57) %	Stable-low PA (n=61) %	*Total higher risk %*	Increasers (n=78) %	Stable-high PA (n=338) %	*Total lower risk %*
Very high screen time	119	16.1	13.3	13.2	*42.6*	10.6	46.7	*57.3*
High screen time	197	17.4	13.8	10.9	*42.1*	12.8	45.2	*58.0*
Moderately-low screen time	186	8.0	11.2	8.7	*27.9*	15.2	56.9	*72.1*
Low screen time	95	7.4	16.6	9.7	*33.7*	7.9	58.4	*66.3*

c) Membership in screen time trajectories, given membership in PA trajectories					
Physical activity trajectories	n	Screen time trajectories			
		Very high screen time (n=119) %	High screen time (n=197) %	Moderately-low screen time (n=186) %	Low screen time (n=95) %
Higher risk					
Early decreasers	63	25.5	45.6	19.1	9.8
Later decreasers	57	19.9	34.2	25.3	20.6
Stable-low PA	61	25.2	34.5	24.9	15.4
Lower risk					
Increasers	78	17.4	34.6	37.4	10.7
Stable-high PA	338	18.2	29.3	33.5	19.0

Trajectories in girls

PA

A 5-group PA trajectory model was retained in girls (Figure 2a). The average posterior probabilities in the five trajectory groups were all above 82%. Based on current PA recommendations that youth should engage in at least 60 minutes of MVPA daily (3,4), we characterized three trajectories as "higher risk" including the stable-low PA trajectory (i.e., ~2.5 active days per week, n=90; 13.9%); the low-decreasers (i.e., from 3 to 1 active day per week, n=60; 9.3%); and the high-decreasers (i.e., from 5 to 2 active days per week, n=96; 14.8%). We characterized the remaining two trajectories as "lower risk" including the stable-moderate PA trajectory (~4.5 active days per week, n=105; 16.2%) and the stable-high PA trajectory (~6 active days per week, n=296; 45.8%).

Screen time

As 5-group screen time trajectory model was retained in girls. All average posterior probabilities were above 87%. Trajectories were characterized as: increasing then stable high screen time (i.e., from 40 to 50 hours per week, n=60; 9.3%); decreasing screen time (i.e., from ~38 to ~20 hours per week, n=87; 13.5%); increasing screen time (i.e., from ~22 to ~32 hours per week, n=92; 14.2%); stable-moderate screen time (i.e., ~20 hours per week, n=236; 36.5%); and stable-low screen time (i.e., 14 hours per week, n=172; 26.6%). Screen time was above the recommended two hours per day, or 14 hours per week, in all five trajectories.

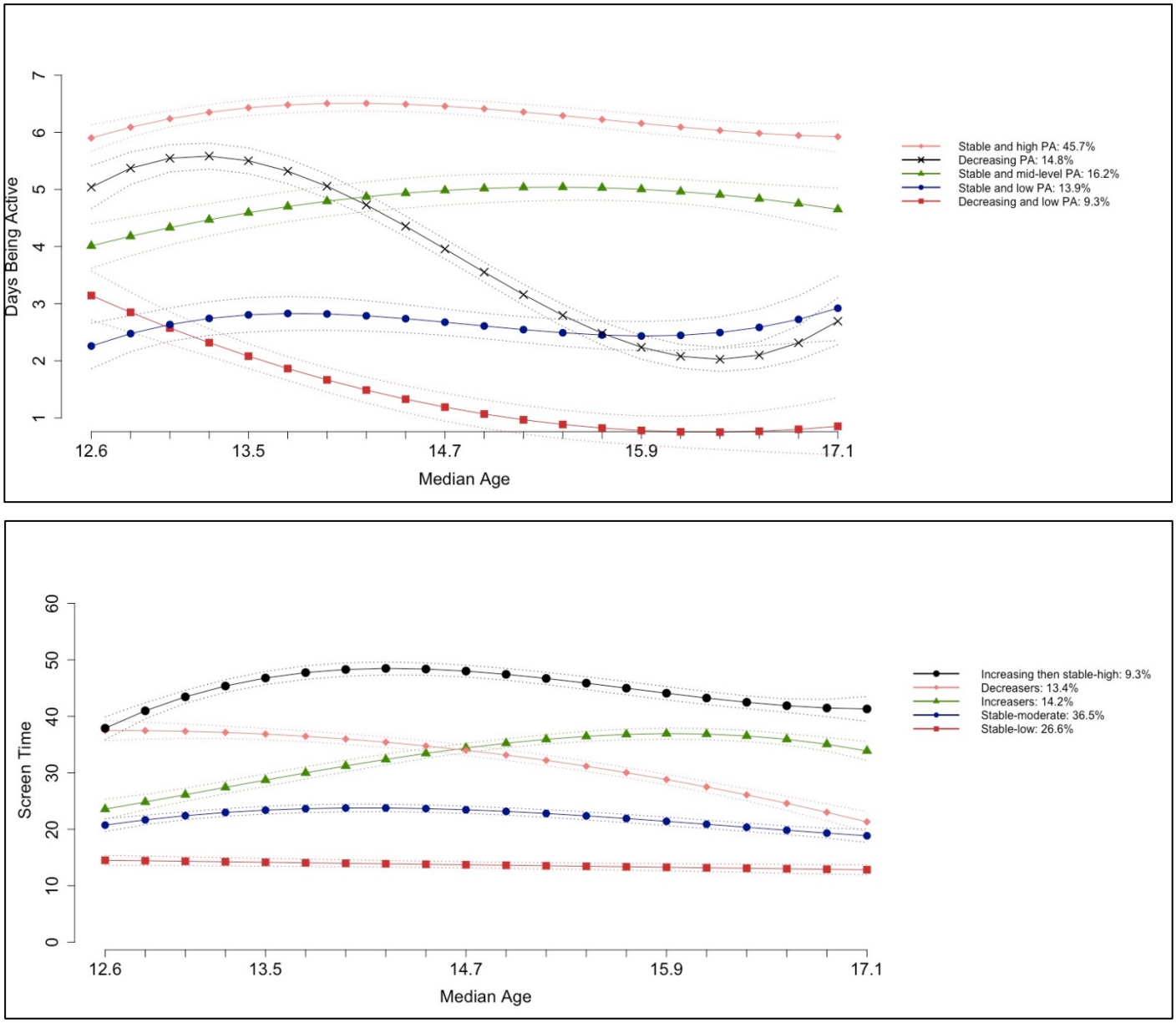

Figure 2. Five-year trajectories of number of days per week being physical active (top) and number of hours of screen time per week (bottom) in girls. For ease of interpretation, median age at each cycle was used to label the x-axis.

The highest proportion of girls (14.5%) were conjointly members of the stable-high PA and stable-low screen time trajectories (Table 3a). Following closely, 14.3% were members of the stable-high PA and stable-moderate screen time trajectories. The proportion of girls in all other conjoint trajectories ranged from 0.8% to 7.2%.

The lower risk PA trajectories were comprised of 68% and 57% of girls assigned to the stable-low and stable-moderate screen time groups. (Table 3b). However, contrary to the other trends observed, 61% of girls in the increasing screen time group were also members of the lower risk PA trajectory groups. Conditional to membership to the lowest risk PA trajectories (i.e., stable-moderate and stable-high PA), the highest proportion of girls were members of the stable-moderate and stable-low screen time trajectories (Table 3c). Given membership in a higher risk PA trajectory, the highest proportion of girls were members of the stable-moderate screen time trajectory (Table 3c).

Table 3: Joint (a) and conditional (b and c) probabilities of PA and screen time in girls (n=647), NDIT 1999-2005

a) Joint probabilities of membership in PA and screen time trajectories						
Screen time trajectories	n	Physical activity trajectories				
		Higher risk			*Lower risk*	
		Low decreasers (n=60) %	High decreasers (n=96) %	Stable-low PA (n=90) %	Stable-moderate (n=105) %	Stable-high PA (n=296) %
Increasing then stable high screen time	60	1.2	1.3	0.8	1.9	4.1
Increasing screen time	92	1.2	1.8	2.8	3.4	5.8
Decreasing screen time	87	2.3	2.6	2.1	1.4	5.0
Stable-moderate screen time	236	3.6	7.2	4.2	5.7	14.3
Stable-low screen time	172	1.5	3.4	3.9	4.1	14.5

b) Membership in PA trajectories, given membership in screen time trajectories								
Screen time trajectories	n	Physical activity trajectories						
		Higher risk				*Lower risk*		
		Low decreasers (n=60) %	High decreasers (n=96) %	Stable-low PA (n=90) %	Total higher risk	Stable moderate (n=105) %	Stable-high PA (n=296) %	Total lower risk
Increasing then stable high screen time	60	13.2	13.5	8.4	35.1	20.8	44.2	65.0
Increasing screen time	92	8.1	12.1	18.6	38.8	22.8	38.4	61.2
Decreasing screen time	87	17.3	19.8	15.5	52.6	10.2	37.2	47.4
Stable-moderate screen time	236	10.3	20.4	12.1	42.8	16.2	41.0	57.2
Stable-low screen time	172	5.4	12.4	14.2	32.0	15.0	53.0	68.0

c) Membership in screen time trajectories, given membership in PA trajectories						
Physical activity trajectories	n	Screen time trajectories				
		Increasing then stable high screen time (n=60) %	Increasing screen time (n=92) %	Decreasing screen time (n=87) %	Stable-moderate screen time (n=236) %	Stable-low screen time (n=172) %
Higher risk						
Low decreasers	60	12.4	12.4	23.4	36.6	15.1
High decreasers	96	7.7	11.2	16.2	44.0	20.9
Stable-low PA	90	5.7	20.3	15.0	30.9	28.2
Lower risk						
Stable-moderate	105	11.7	20.7	8.3	34.3	25.0
Stable-high PA	296	9.4	13.2	11.3	32.8	33.3

Sex Differences

We observed similarities and differences in the trajectories and joint probabilities across sexes. 5 groups were determined for the PA variable in both boys and girls, however not all trajectories followed a similar evolution. In boys, the PA trajectories were composed of two stable, one increasing, and two decreasing patterns. The girls' PA trajectories were composed of two stable and two decreasing patterns. In both cases, a large part of the sample was part of the stable-high PA group (56.6% of boys and 45.7% of girls), maintaining PA levels on 6-7 days of the week throughout adolescence.

The screen time trajectory groups were all stable across the follow-up period for boys, while we observed increasing and decreasing patterns for girls. All four screen time groups for boys were present at higher screen time levels than the girls' screen time groups. All screen time trajectories for both sexes were above the recommended daily 2 hours limit (or 14 hours weekly).

Examination of the joint probabilities showed a more consistent relationship among PA and screen time for boys than it did for girls. For boys, individuals had higher probabilities of belonging to higher risk PA trajectories when they were members of higher screen time

trajectories. Similarly, the lower risk PA trajectories had higher probabilities when conditional on the lower screen time groups. Inversely, similar conclusions were made for screen time group membership conditional on PA. For girls, the conditional probabilities between PA and screen time were inconsistent. While individuals in the lower risk PA groups had higher probabilities given membership to lower ST groups, 61.0% of girls in the increasing screen time group were also members of the lower risk PA trajectories.

Figure 3 illustrates the distribution of individuals across all possible combinations of PA and screen time trajectories, for boys (left) and girls (right).

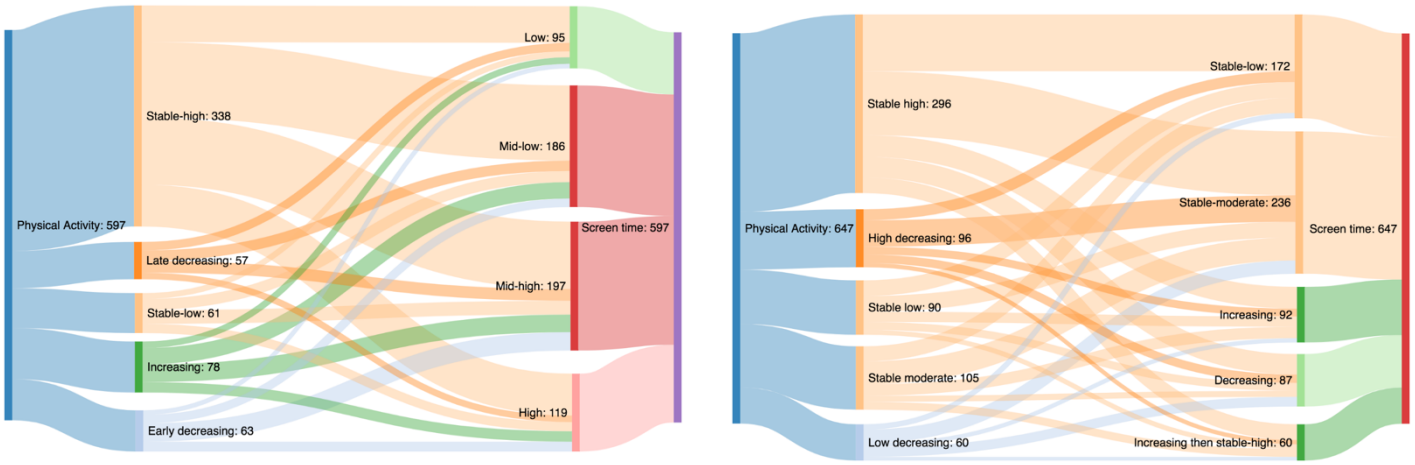

Figure 3. Sankey diagrams illustrating simultaneous PA and screen time group membership, for boys (left) and girls (right).

Discussion

We examined the association between PA and screen time in boys and girls, adding to the literature on whether and how these behaviours co-evolve and inter-relate during adolescence. Using group-based trajectory modeling, we identified five PA and four screen time trajectory groups in boys. In girls, five groups were identified for both PA and screen time. 17.2% of boys and 14.5% were jointly members of a lower screen time trajectory group and a stable-high PA trajectory group. Conditional probabilities suggested that PA and screen time are interdependent.

In contrast to our study, Janz et al (36), in a longitudinal study of bone health during childhood (530 participants followed from age 5 to 17 years), used latent class modeling of accelerometer-measured MVPA to identify three decreasing MVPA trajectories in both girls and boys. Kwon et al (37) used group-based trajectory modeling and identified four distinct PA trajectories in 2,155 adolescent girls (followed from age 10 to 19 years). Two trajectories suggested that PA levels were maintained during adolescence and two suggested decreasing PA levels. We replicated the trajectory shapes identified by Kwon et al., but also identified a fifth group of stable-high PA in girls. The two decreasing trajectories identified by Kwon et al. represented 62.6% of the sample, whereas our decreasing trajectories represented only 24.1% of girls. Rovio et al (38) used group-based trajectory modeling to identify a 5-group model of PA trajectories in both sexes combined (1753 participants followed from age 3 to 18 years). Three trajectories showed maintained PA levels, one showed decreasing and one showed increasing PA levels. The most populated trajectory was the 'persistently low active' group (51.4%); in this current cohort, 24% of participants in both sexes were members of the stable-low PA group.

Challenging the PA literature which generally portrays notable declines in PA during adolescence, our PA trajectories suggest that 57% of boys and 46% of girls maintain PA on at least 6 of 7 days weekly during adolescence. An additional 13% of boys increased PA from 4 to 5 days per week over the five years of high school. Data from the Canadian Health Measures Survey (2007 to 2015) indicate that 7% of youth accumulated at least 60 minutes of MVPA on 6 out of 7 days (current recommendation), and 33% achieved a weekly average of

at least 60 minutes daily. This current study examined PA levels through the number of days being active per week, where "being active" represented the involvement in at least one moderate-to-vigorous PA for at least 5 minutes. The 5-minute threshold used in the self-reported question is supported by findings that PA engaged in for at least 5 minutes protects against obesity in youth (39, 40). It is possible that children remain engaged in that specific PA for longer than 5 minutes, although that information is not collected. The frequency of PA is also not collected. This question is based on the 7-day Physical Activity Recall Checklist, with demonstrated test-retest reliability and validity (26). This checklist incorporates PA of many different types, which has been put forward as an important way to increase PA sustainability in children. A study done on a cohort of 756 youth from New Brunswick, Canada, has shown that early sport samplers (i.e., elevated involvement in unorganised PA and low involvement in organised PA) had a higher likelihood of long-term involvement in PA. In contrast, early sport specialization (i.e., involvement in organised PA such as sports teams) lead to a higher risk of dropping out of sports (41). In this study, examining youth PA levels through the lens of "days being active" has shown that most children are active and remain active over adolescence. With the incorporation of various PA activities in the metric, it may portray a more global and inclusive view of youth PA levels. These results should be taken into consideration by PA recommendations in order to better sustain PA during adolescence.

Two other studies have reported screen time trajectories comparable to those observed in this study. Kwon et al. (37) identified two decreasing and two increasing TV-viewing trajectories in a sample of Caucasian and African American girls, contrasting our findings which showed two stable, two increasing, and one decreasing trajectory in girls. Using group-based trajectory modeling, da Silva et al (42) identified three stable screen time trajectories (both sexes combined), in a longitudinal prospective study conducted among 3382 participants of the 1993 Pelotas (Brazil) Birth Cohort, followed at ages 11, 15, and 18 years. Our results may differ from those of da Silva et al. because we report screen time hours on both week- and weekend-days, whereas da Silva et al. reported weekday screen time only, which could be lower since most children attend school during the week.

Further, in contrast to the Canadian 24-hour Movement Guidelines for Children and Youth which state that, from combined data collected between 2009 and 2013, 49.3% of youth met the daily screen time recommendation of less than 2 hours (16), all screen time trajectories in both sexes in the NDIT sample were above the recommended level. Consistent with the literature showing that adolescent boys report more screen time (16), all four screen time trajectories in boys were stable at higher values of weekly screen time than the five trajectories in girls. Today's generation of adolescents have grown up and live with screen-based technology, and this has shown to influence various health outcomes (43). As well, this and other sedentary behaviours need to be addressed distinctly from interventions targeting PA levels, because sedentary behaviours and PA are distinct concepts (18).

Few studies report conditional probabilities between screen time and PA trajectories. In this study, the conditional probabilities suggest that screen time and PA may co-vary over time. Only Kwon et al (37) studied probabilities of TV-viewing trajectory groups conditional on PA trajectory - 88% of girls in the high PA trajectory were members of the two decreasing TV-viewing trajectories, whereas 86% of girls in the 'decreasing from moderate PA' trajectory were members of one of the two increasing TV-viewing trajectories. Similar results were observed in NDIT girls; most members in the stable-low and stable-moderate screen time groups were members of the lower risk PA trajectories. Both Kwon et al and the current study suggest interrelationships between PA and screen time, although the direction and intensity of the association especially over time, remains understudied. This study has shown that overall, individuals with low levels of screen time also have increasing or stable-high levels of PA, which is encouraging.

Limitations of the study included use of self-report PA and screen time data (44). Self-report measures are inexpensive and easy to administer, but prone to recall error, deliberate error and difficulties quantifying and categorising behaviours. This is especially true among children for whom activities can be more sporadic (44). Data were collected from 1999 to 2005, which may not reflect PA or screen time levels in adolescents today. However, Canadian data from nationwide surveys suggest that since 1994, only girls made modest gains in PA levels (8, 45). In addition, Gunnell et al. demonstrated that longitudinal screen time

assessments remain accurate despite changes in technology (30). Although selected schools included a mix of schools serving students with differing sociodemographic profiles, the results of this study may not be generalizable to adolescents in other populations. For example, 92% of participants were born in Canada, and it is possible that PA and screen time levels differ among students born in other countries. The results would likely also generalize to students in urban settings but less so to rural settings where the opportunities for PA may differ. Students living in rural areas could manifest different PA or screen time trajectories over the course of adolescence. Our examination of the association between PA and screen time did not consider covariates (other than sex) or potential confounders. Finally, the group-based trajectory modeling method has limitations - PA and screen time groups only provide an approximation of a more complex underlying reality of the two behaviours (31). While GBTM offers a convenient method to summarize longitudinal patterns identified in a dataset, it does not necessarily imply that these trajectories constitute real entities that individuals do not deviate from.

Conclusion

PA and sedentary behaviours are now seen as unique constructs. We identified sex-specific heterogeneous PA and screen time trajectories during adolescence and identified that the two behaviours influence one another over time. Public health practitioners need to take the co-evolution and the association between MVPA and screen time into account in planning programs and policy.

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5.3 Additional Results

This section contains additional results not detailed in the manuscript. It includes statistical information on trajectory model selection and sensitivity analysis.

5.3.1 Trajectory Selection

We decided to formally test models containing between 2 and 5 groups. To obtain more complete information to better inform our decision in selecting a parsimonious model, the models were computed with up to 8 groups, to observe the changes in the trajectories (graphically) and in Bayes Factors (statistically).

5.3.1.1 PA Trajectories in Boys

In computing models up to 8 groups (all cubic), the Bayes Factor declined significantly with a 6-group model (Bayes Factor = 7.10). (Appendix G – Supplementary Table 1). A Bayes factor < 10 is not large enough to support incorporation of an additional group (61). Thus, a 5-group model was retained. For three of the five trajectories, the cubic order was not significant at p = 0.05, so that the model was simplified until it attained significance. The final model contained 3 cubic groups, one quadratic group, and one linear group. Modifications in the order of polynomials did not alter the trajectory shapes. The average posterior probabilities (APP) for each group were 0.80-0.93 (Table 5).

Table 5. Average Posterior Probabilities (APP) by PA trajectory for the final model (boys), NDIT 1999-2005

PA Trajectory	Polynomial Order	APP
1	Cubic	0.93
2	Cubic	0.89
3	Linear	0.80
4	Cubic	0.86
5	Quadratic	0.86

5.3.1.2 Screen Time Trajectories in Boys

Examination of plots as number of groups increased up to 4 suggested that all trajectories were stable over time in a 'rainbow' distribution (Appendix G – Supplementary Figure 2). With addition of a 5th group, one curve increased and one decreased. The Bayes Factor increased with the addition of the 5th group, and therefore a 4-group model was retained (Appendix G – Supplementary Table 2). Three of the 4 groups with cubic order polynomials did not attain significance and were simplified to quadratic. One of the groups was simplified further to a linear order. Thus, the final model included 4 groups with one cubic order, two quadratic orders, and one linear order. All APPs were satisfactory (Table 6).

Table 6. Average Posterior Probabilities (APP) by screen time trajectory for the final model (boys)

Trajectory	Polynomial Order	APP
1	Linear	0.93
2	Quadratic	0.90
3	Cubic	0.94
4	Quadratic	0.95

5.3.1.3 PA Trajectories in Girls

In computing models up to 8 groups, the Bayes Factor declined significantly when reaching a 6-group model (Appendix G – Supplementary Table 3). Thus, a 5-group model was retained. For two of the five trajectories, the cubic order was not significant at $p = 0.05$, so that the model was simplified to a quadratic order where it attained significance. The APP for each group were 0.83-0.91 (Table 7).

Table 7. Average Posterior Probabilities (APP) by PA trajectory for final model (girls)

Trajectory	Polynomial Order	APP
1	Quadratic	0.89
2	Cubic	0.84
3	Quadratic	0.83
4	Cubic	0.91
5	Cubic	0.89

5.3.1.4 Screen Time Trajectories in Girls

In this round of model selection, the Bayes Factor continued to decrease from a model to the next, while still remaining large enough to support the addition of groups. Because we decided to limit our models to a maximum of 5 groups, and because there was no statistical reason or graphical indication to select a model with 2, 3, or 4 groups, a 5-group model was selected (Appendix G – Supplementary Table 4 and Supplementary Figure 6). Two groups did not attain statistical significance at a cubic order of polynomial and were simplified further to a quadratic order. All APPs were satisfactory (Table 8).

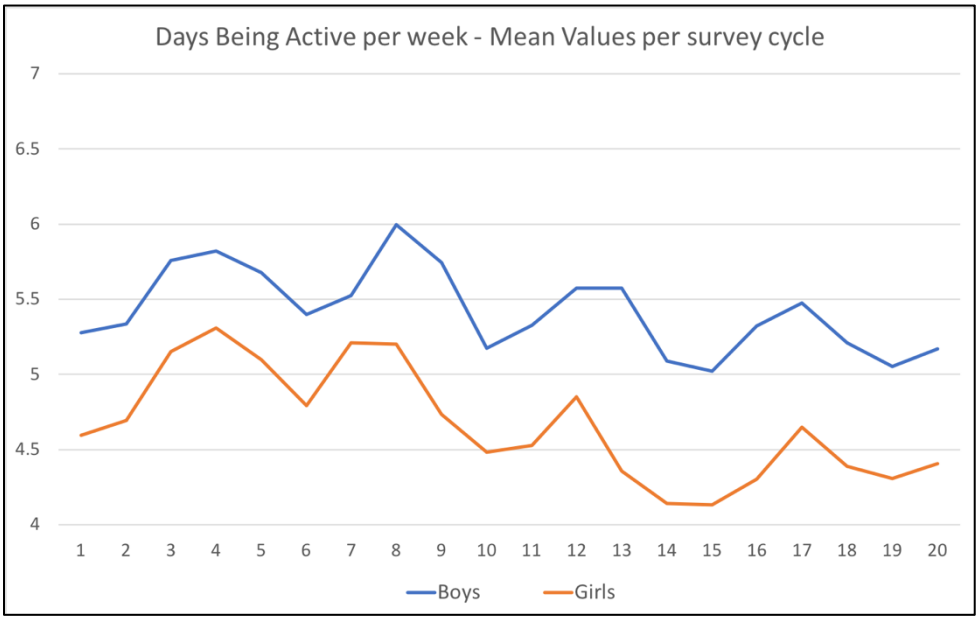
Table 8. Average Posterior Probabilities (APP) by screen time trajectory for final model (girls)

Trajectory	Polynomial Order	APP
1	Linear	0.94
2	Cubic	0.89
3	Cubic	0.90
4	Quadratic	0.87
5	Cubic	0.94

5.3.2 Sensitivity Analyses: Seasonality

The literature suggests that seasonality and weather conditions influence PA levels. PA generally decreases during the winter months and increases in the summer (86-88). In a cross-sectional study of 1,332 adults (87), poor weather was a barrier to PA and associated with an increase in sedentary behaviour.

Because NDIT data collection occurred every 3 months, seasonality could have affected both PA and screen time. Figure 3 illustrates the mean values of both PA and screen time variables in boys and girls during the 20 cycles of data collection. Each year (4 cycles, 3 months between each cycle; Table 1 for the dates of data collection at each cycle), PA declined during the winter months and increased during warmer months. A similar pattern was apparent for screen time, although less pronounced.



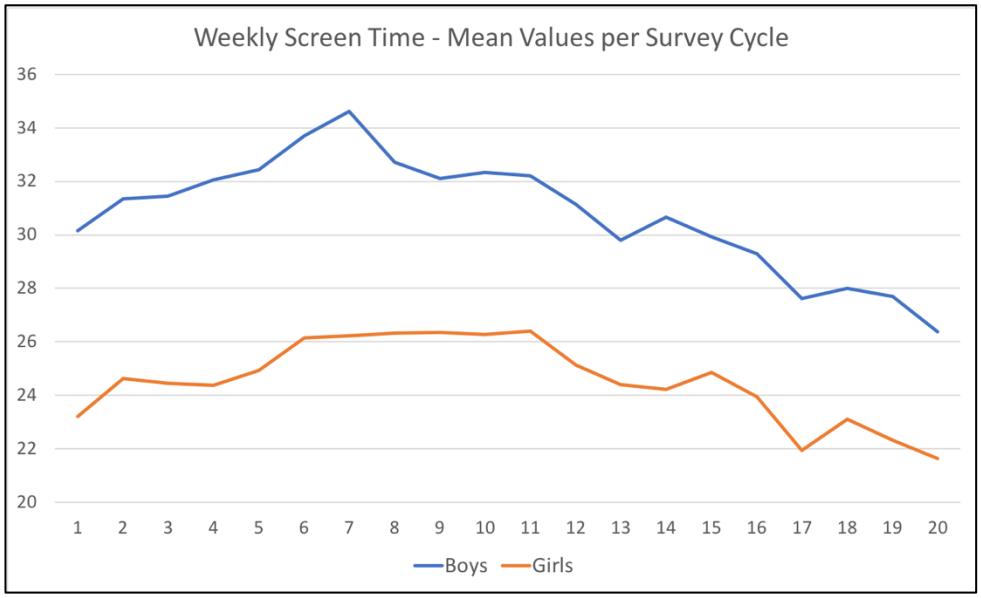


Figure 3. Mean values of number of days active weekly (top) and screen time (bottom) variables, by sex, NDIT 1999-2005.

All 20 cycles were retained in the trajectory modeling to maximize the number of data points available and to make trajectories more flexible and parsimonious. We repeated the analyses using a new time metric that combined the 4 cycles each year to create a yearly value, thereby diminishing any seasonality effect. The trajectories for both PA and screen time were the same as in the main analysis, for both boys and girls suggestive that seasonality did not influence the group-based trajectories obtained.

Chapter 6: Discussion

6.1 Summary and Interpretation of Findings

The objective of this MSc thesis was to describe the co-evolution of PA and screen time during adolescence. We used sex-specific GBTM to describe the natural course of each of screen time and PA, and then we assessed the conjoint association between membership in PA and screen time trajectories.

6.1.1 Physical Activity and Screen Time Trajectories

In the first step of the two-step trajectory modeling procedure, we identified five PA groups and four screen time groups in boys, and five groups for both PA and screen time in girls. To facilitate interpretation and based on current PA recommendations for youth to engage in at least 60 minutes of MVPA daily (20, 21), the early decreasing, later decreasing and the stable-low trajectory groups in boys were labelled "higher risk." The "lower risk" group included the increasing and stable-high trajectory groups. Half of boys (56.6%) were members of the stable-high PA group, who maintained high PA levels on 6 of 7 days during adolescence.

The five PA trajectory groups identified in girls were of similar shape and group size, except that an increasing PA trajectory was detected in boys, but not in girls. Rather, a third stable moderate PA trajectory was observed in girls. Three trajectories were classified as "higher risk" including stable-low, low-decreasing and high-decreasing groups in girls. The remaining two "lower risk" PA trajectories were stable-moderate and stable-high PA. Similar to boys, 45.8% of girls maintained a stable-high PA trajectory during high school.

A four-group model of screen time trajectories was identified for boys. These trajectories reflected a "rainbow" distribution in which all trajectories were relatively stable over time. All four trajectories were above the recommended 2-hours screen time daily, so all were "high risk".

The 5-group screen time model suggested more variability in girls. We identified one increasing and one decreasing screen time trajectory, in addition to three stable trajectories. As in boys, screen time levels in all trajectories were above the recommended 2-hours daily.

6.1.2 Joint Trajectory Modeling

The second part of the two-step trajectory modeling procedure allowed us to conclude that PA and screen time influence one another over time, contesting the hypothesis that these behaviors evolve independently. Examination of conditional and joint probabilities obtained from the joint trajectory model suggested that PA group membership influenced membership in specific screen time trajectory groups, and vice-versa. The most important findings were that higher risk PA trajectories tended to have higher probabilities conditional on higher screen time trajectories. Similarly, higher screen time trajectories had higher probabilities conditional on membership in higher risk PA trajectories. Finally, lower risk PA trajectories had higher probabilities given membership in lower screen time trajectories. These trends were observed in both boys and girls.

The most common combination in terms of joint probabilities was low screen time and a stable-high PA. However, participants were distributed across all possible combinations of PA and screen time, suggesting that their co-evolution in adolescents is generally heterogeneous. As well, this provides further consolidating evidence that PA and sedentary behaviours are unique constructs.

Physical activity and sedentary behaviours, and their co-existence, is a highly active field of study. We contribute meaningful information that shows how higher levels of PA generally present with lower levels of screen time, and similarly, lower levels of PA present with higher levels of screen time. The current published literature is still unsure on how, and if, these behaviours are associated. A meta-analysis from 33 youth studies has found that the relationship between screen time and physical activity is small but negative (89). Another systematic review and meta-analysis of 163 studies (in children and adolescents) has found a small, negative association between PA and sedentary behaviours, an association authors consider generally

weak and with limited relevance to public health (53). Small inverse associations were also observed for specific sedentary behaviours and PA, such as internet use, screen time, and TV viewing (53). Increased understanding of the association between PA and sedentary behaviours is relevant from a public health perspective because it is important to know if interventions targeting change in one behaviour are associated with levels of a second behaviour. This could inform the development of policy and programs on whether separate interventions for PA and screen time are needed."

Our findings have also shown an inverse relationship between PA and screen time group membership, supporting these reviews. Although these results are in line with the displacement theory (where sedentary behaviours take time away from other activities such as PA), they only partially support it because we have found various possible combinations of PA and screen time, including those where both are present in high and low amounts. Also, it is possible that a child engaged in PA while watching a screen, such as a tablet or a phone, suggesting that they may not be mutually exclusive. Because our results describe all possible combinations of PA and screen time, we consider PA and screen time (and other sedentary behaviours) to have a complex interplay that needs to be studied further from all possible angles.

6.2 Strengths and Limitations

6.2.1 NDIT

This thesis comprised a secondary analysis of data originating in the NDIT Study. The 1294 adolescents followed over 5-years during high school, combined with dense data collection every 3 months, provided an excellent dataset for trajectory modeling. To date, few studies have examined PA and screen time behaviours during adolescence conjointly in a longitudinal study design (90). We therefore bring to the literature new insight on the co-evolution of the two behaviours, at a time when it is generally accepted that PA and sedentary behaviours represent distinct entities, although their co-evolution and relationship are understudied.

6.2.2. Group-Based Trajectory Modeling

GBTM was applied to the PA and screen time data in NDIT to identify subgroups in an adolescent population with distinctive longitudinal patterns. We identified sub-groups of boys and girls that apparently evolve similarly in their levels of PA and screen time over time.

GBTM is a widely accepted statistical procedure with robust scientific foundations. Over the last decade, GBTM has been used in many studies across a wide variety of topics. The technique takes advantage of the longitudinal nature of many datasets to portray information in graphic form, thus extending the data beyond correlation analyses and summary statistics. With the expansion of GBTM to perform joint trajectory analyses, we were able to describe the co-evolution of PA and screen time across time using conditional and joint probabilities. The number of groups identified was data-derived by model estimation and selection since no prior hypotheses or decisions were made.

GBTM involves decision-making throughout model selection, but this process is poorly standardized. Interpretation of results and decision-making can vary widely across researchers resulting in differing findings that can impede comparison of results (91). To overcome this issue, van de Schoot et al. (91) developed a set of Guidelines for Reporting on Latent Trajectory Studies (GRoLTS) in 2016. The GRoLTS is a list of 16 items recommended to be included in publications using trajectory modeling. In order to assure that our results can be replicated, we included the GRoLTS items in the manuscript including those related to statistical decision-making. These are described in Appendix E.

The GBTM technique does have critics who focus on the limitations of the method. As mentioned above, studies of the same behavior for example, obtain different results in their trajectory modeling. In addition to decision-making in the statistical procedure, differences can be due to the nature of the sample, power, timing and length of follow-up, number of measurement occasions, and how the behaviour is measured. In addition, the GBTM technique functions under the assumption that individuals are members of only one among several trajectory groups (of PA and screen time in this thesis). It is possible, however, that there are no

distinct trajectory groups (92). The screen time trajectories observed in boys showed a "rainbow" distribution of trajectories, which could portray a continuous developmental situation. One previous study also showed three parallel screen time trajectories (84), but another study did not (67). These conflicting results raise concerns about whether GBTM captures the underlying reality and they support that more research on GBTM as well as replication of GBTM results using a standardized approach is required.

Finally, GBTM yields statistical estimates that only approximate a more complex reality of how PA and screen time co-evolve over time. They are *expected* trajectories which may not actually exist. There is no "true" number of trajectory groups because that is not the overarching objective; the aim is to identify a model as parsimonious as possible that represents the primary features of the distribution of data (61). However, that groups of individuals follow a similar pattern of evolution over time is certainly possible.

Other methods of modeling trajectories exist, such as hierarchical modeling (93) and latent growth mixture modeling (94, 95). These are alternatives to the GBTM but share the same purpose: to explain differences across population members in their developmental course, through trajectories. The aim of hierarchical modeling is to estimate a mean trajectory, while accounting for individual fluctuations in slopes and intercept (61). It does not identify homogeneous subgroups of similar trajectories like GBTM and latent growth mixture modelling do. GBTM can be viewed as a special case of latent growth mixture models in which the variance parameters measuring the variability within the trajectory groups are set to zero. Hence, in GBTM the trajectories are assumed homogeneous while in more general latent growth mixture models they are estimated. However, latent growth mixture models are computationally more demanding, and tend to have convergence problems because of the number of parameters to estimate.

6.2.3 Self-Report Questionnaires

The NDIT study collected data in self-report questionnaires. This method of data collection is widely used because it is quick, easy to administer and relatively inexpensive. In this study, the self-reported questionnaires were administered every 3 months during class time. Repeated administration of the same questions may improve the accuracy and consistency of responses. However, participants may have incorrectly reported their levels of PA and screen time, which can lead to a non-differential information bias. Self-report is also prone to recall bias, especially in youth. In the context of PA and screen time measurements, the advantages and disadvantages of this method were described in detail in Chapter 2.

This study could be replicated, and the trajectories validated, with objective PA measures. In the context of GBTM, using objectively measured PA data could facilitate replication across studies. Heart rate monitoring, accelerometry, and other similar objective measures are considered to be high-quality tools in assessing PA (34), but cannot inform the researcher on the different types of activities engaged in by the participant. Screen time could be assessed through the "lack of PA" from accelerometry data, which calls for a complementary subjective assessment of behaviours, for example through journaling (e.g. the participant could note the activities he/she engaged in during the day, which can complement the objective measurements). Thus, a combination of objective and subjective assessments of PA and screen time would provide excellent data to model group-based trajectories in future studies.

6.3 Implications

PA is important to the physical, psychological, social and cognitive health of school-age youth (28, 96), and the negative effect of sedentary behaviour including screen time, on health is increasingly acknowledged (97). There is agreement in the scientific community that PA and sedentary behaviours are separate entities, and that individuals can accumulate different levels of one independent of the other. This perspective argues against the displacement hypothesis, since those with PA high levels can also accumulate high screen time. Recent research (90) identifies a need for unique 'typologies' of PA and sedentary

behaviours across the activity spectrum, and this thesis contributes directly to this gap in knowledge.

Studying co-evolution of PA and screen time during adolescence is highly relevant because unhealthy behaviour patterns often develop and consolidate during this period (90). Identifying adolescent sub-groups with similar higher risk 'typologies' could be efficient from a public health perspective if these sub-groups can be targeted with early preventive intervention (90).

Joint trajectory modeling yielded conditional probabilities for all possible combinations of PA and screen time, demonstrating heterogeneity in these behaviours. Identifying that higher PA generally presented with lower screen time and vice-versa may be encouraging for more general public health interventions but may not be sufficient for effectiveness. To obtain best results, public health messages targeting adolescents may need to consider multi-faceted approaches that recognize these combinations (e.g., targeting PA only, while ignoring screen time may miss the mark). In addition to aiming for high PA and low screen time as the ideal combination, maintenance of healthy PA and screen time levels throughout adolescence could also translate into important health and economic benefits (98). Finally, we identified distinct trajectories in boys and girls. Future public health initiatives may need to consider whether these differences warrant creating or adapting interventions that take these differences into account.

6.4 Future Directions

To facilitate comparison and critical appraisal of research findings, researchers should endeavor to use and report standard procedures when modeling trajectories, using the GRoLTs checklist (91) for example. Several studies suggest that sedentary behaviours have their origins in early childhood (48, 99). Future research could examine PA and screen time trajectories beginning in elementary school to provide insight into whether and how early these behaviors consolidate into stable patterns. Investigation of the predictors and outcomes of the conjoint trajectories identified herein could be a fruitful avenue of research, as would in-

depth study of the association between PA and screen time in large samples of adolescents. Finally, the Canadian 24-hour Movement Guidelines for Children and Youth incorporate suggestions on sleep (23). Future trajectory research could incorporate data on sleep in addition to PA and sedentary behaviour, and link the natural course of these three entities conjointly to health outcomes in youth (100).

Chapter 7: Conclusion

This Masters' thesis contributes new knowledge on the co-evolution of PA and screen time in adolescence, by identifying trajectories of these behaviors and examining their relationship. More specifically, it presents models with 5 PA trajectories in both sexes, 4 screen time trajectories in boys and 5 screen time trajectories in girls, through the application of GBTM. 57% of boys and 46% of girls reported PA engagement on 6-7 days per week during the 5-year stud, while everyone was part of screen time trajectories above 2 hours per day (or 14 hours per week). Going further with a joint trajectory modeling, we identified sets of conditional probabilities linking the PA and screen time groups in both sexes. It was observed that individuals from higher risk PA trajectories tended to have higher probabilities conditional on higher screen time trajectories. Similarly, individuals from lower screen time trajectories had higher probabilities given membership to lower risk PA trajectories.

The results of this work support the premise of PA and screen time, and other sedentary behaviours, being distinct concepts but interdependent. Both PA and screen time present with a heterogeneous development over time, and the two variables influence one another during adolescence. This study joins the up-and-coming literature on the "sedentary behaviour epidemiology" movement. In fact, many changes in the science of movement are currently occurring, and especially for youth. The Canadian 24-Hour Movement Guidelines for Children and Youth is a first-of-its-kind vision of movement integrating PA, sedentary behaviour, and sleep, giving guidance on how the 24-hour period should be constituted for optimal youth health (23).

The heterogeneity of PA and screen time, their interdependence, and the gender differences all need to be taken into account by public health practitioners into account in planning effective programs and policy targeting adolescents.

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Appendix A: NDIT Parental Consent Form

RÉGIE RÉGIONALE
DE LA SANTÉ ET DES
SERVICES SOCIAUX
DE MONTRÉAL-CENTRE

November 18, 1999

MCGILL UNIVERSITY STUDY ON NICOTINE DEPENDENCE IN TEENS

Investigators: J. O'Loughlin, PhD., G. Paradis, MD, P. Clarke, PhD., J. Hanley, PhD, R. Tyndale, PhD., J. DiFranza, MD

Dear Parent/Guardian:

The Public Health Directorate of Montréal-Centre in collaboration with McGill University, and the Universities of Toronto and Massachusetts, is undertaking a 3-year study among Secondary I students in 12-15 Montreal high schools to study how smoking becomes an established habit in certain adolescents. All Secondary I students in your child's school have been asked to participate because we need to study children who smoke, as well as children who do not smoke. The ultimate purpose of this research is to help us develop more effective strategies to prevent the onset of smoking in children, as well as to help youth who want to quit smoking. In addition, this study will examine the relationship between smoking, weight, and blood pressure during adolescence. The study has 2 parts:

Part I - In the next few weeks, our research team will visit your child's classroom. Two interviewers will administer a 45-minute in-class questionnaire to all students about their smoking experiences. The interviewers will visit your child's class again 3-4 months later and every 3-4 months after that for the next 3 years (in Secondary I, II and III) to re-administer the questionnaire in order to collect updated information on the students' smoking experiences. Trained technicians will measure your child's height, weight, skinfold thickness, waist circumference and blood pressure once a year. All data will be stored in locked storage areas at the Public Health Directorate.

Part II - An important aspect of this study is to investigate if genetic factors are involved in smoking uptake. To explore this possibility, we will collect a blood sample from each student for genetic analysis. During data collection in March 2002, a nurse will draw 10 ml of blood (2 teaspoons) for genetic analysis. The samples will be analyzed and stored at the University of Toronto, which specializes in this type of genetic analysis. The blood samples will be labeled only by number and the results of the genetic test will remain completely confidential. A master list linking the child and the identification number will be stored securely at the Public Health Directorate. Only the principal investigator and the project coordinator will have access to the list. This list will be destroyed at the end of the study. It will be impossible to provide any individual results of the genetic testing to anyone because they will never be linked to a particular name. After the list is destroyed, all blood samples will be completely anonymous. The samples will be stored for a maximum of ten (10) years for future genetic analysis exclusively related to smoking.

Request for your consent - We are now asking for your and your child's consent for Part I of the study (the in-class questionnaire and the anthropometric measures). In February or March 2002, we will ask you separately and specifically for a consent for the blood sample. Both your school board and school principal fully support this project and have agreed that your child's class can participate. However your child's participation is completely voluntary, and it is entirely up to you and your child whether or not he/she participates. Your child can decide not to participate in the blood sample portion of the study and participate only in the questionnaires and anthropometric measures. Also, your child can withdraw from the study at any time and/or ask that his/her blood sample be destroyed before the end of the study by contacting the Project Coordinator (telephone number shown below). If you decide not to allow his/her participation, or if he/she withdraws from the study before it is completed, there will be no prejudice against your child.

Please complete the attached form to indicate whether or not your child will participate in Part I of the study, and return it to your child's teacher in the next 3 days. If you have any questions, please contact the Project Coordinator, Mrs. Elizabeth MacMillan-Davey at 528-2400 local 3976. We thank you and your child for your help in this important project.

[redacted]
Jennifer O'Loughlin, Ph.D.
Principal Investigator

[redacted]
Gilles Paradis, M.D.
Co-Investigator

Santé physique
1301, rue Sherbrooke Est
Montréal (Québec) H2L 1M3
Téléphone : (514) 528-2400
Télécopieur : (514) 528-2512
http://www.santepub-mtl.qc.ca

Hôpital général de Montréal
mandataire

DIRECTION DE LA SANTÉ PUBLIQUE
Garder notre monde en santé

RÉGIE RÉGIONALE
DE LA SANTÉ ET DES
SERVICES SOCIAUX
DE MONTRÉAL-CENTRE

MCGILL UNIVERSITY STUDY ON NICOTINE DEPENDENCE IN TEENS

Investigators: J. O'Loughlin, PhD., G. Paradis, MD, P. Clarke, PhD., J. Hanley, PhD, R. Tyndale, PhD., J. DiFranza, MD

CONSENT FORM - PART I

(In-class questionnaire and anthropometric measures)

Please complete and return this form to your child's teacher within 3 days.

Child's name:

First name (please print clearly) _____ Last name (please print clearly) _____

☐ **Yes,** my child will participate in Part I of this study (i.e. the classroom questionnaire and the measurement of height, weight, skinfold thickness, waist circumference and blood pressure).

☐ **No,** my child will not participate in this study.

PLEASE NOTE: You are <u>not</u> consenting to the blood sample at this time. You will receive a separate consent form to sign for Part II (blood sample) in February or March 2002, just before the blood sample will be taken.

Signatures

Parent's name (please print) _____ Parent's signature _____ Date _____

Child's name (please print) _____ Child's signature _____ Date _____

Santé physique
1301, rue Sherbrooke Est
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DIRECTION DE LA SANTÉ PUBLIQUE
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Appendix B: Original Ethics Approval of the NDIT Study

RÉGIE RÉGIONALE DE LA SANTÉ ET DES SERVICES SOCIAUX
DE MONTRÉAL-CENTRE

APPROBATION DU PROJET PAR LE COMITÉ D'ÉTHIQUE

Le Comité d'éthique de santé publique de la Régie régionale de Montréal-Centre a examiné le projet de recherche :

A prospective study on the natural history of nicotine dependence

Soumis par: *Madame Jennifer O'Loughlin*

Le comité d'éthique a conclu que la recherche proposée respecte les règles éthiques en santé publique définies par la Régie régionale de Montréal-Centre.

Membres du comité:

M. Denis Allard	*Agent de recherche*
Dr. Robert Allard	*Médecin*
Mme Lorraine Bernier	*Agente de recherche sociosanitaire*
Dr. Nicole-Hébert-Croteau	*Médecin-conseil*
M. Alain Gauthier	*Secrétaire général, C.S. Marguerite Bourgeois*
Mme Marie Hirtle	*Avocate*
Mme Marcelle Monette	*Conseillère à la recherche et au développement professionnel*
Mme Francine Tardif	*Sociologue consultante*
M. Claudio Zanchettin	*Professeur en philosophie*
Dr. Bernard Heneman	*Médecin-conseil et président du comité*

[redacted]

Président du comité

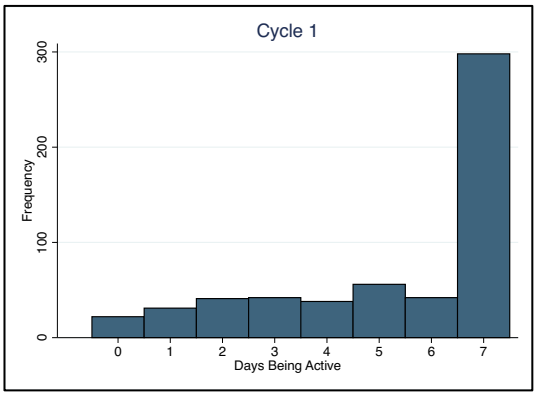
99-04-07
Date

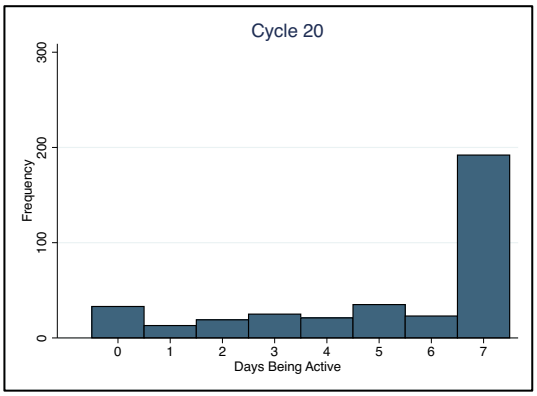
Note: Le présent certificat n'est valide que si une preuve d'acceptation du protocole pour son évaluation scientifique a été déposée auprès du comité d'éthique de la santé publique.

certifica.eth

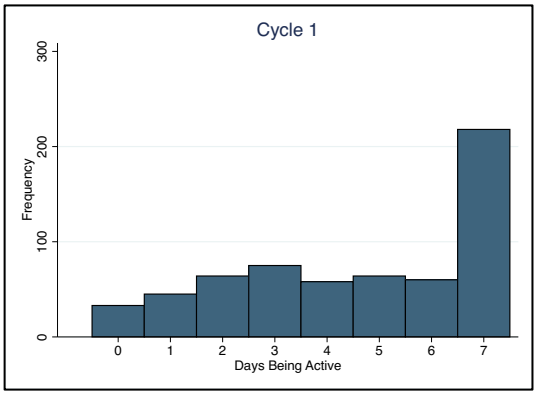
Appendix C: Histograms of the "Number of days active weekly" Variable in Cycle 1 and 20, Boys and Girls, NDIT 1999-2005

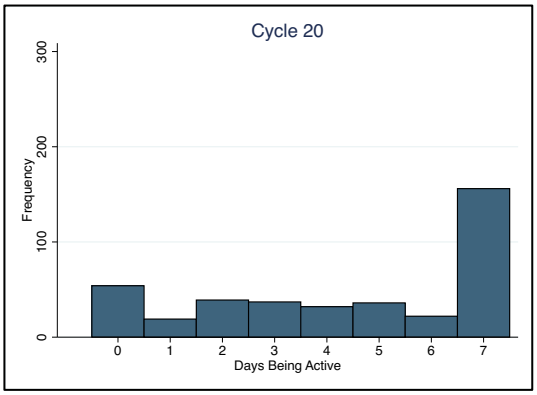
1) Boys





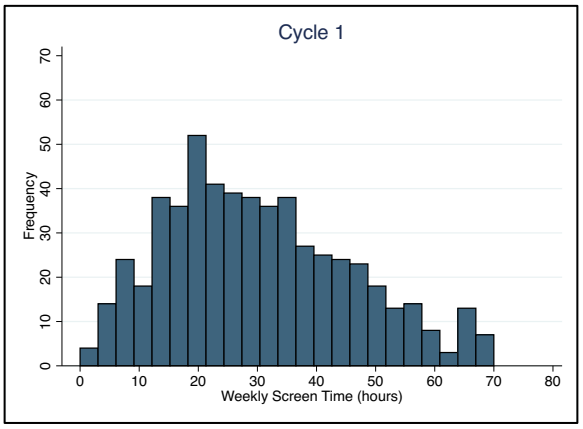
2) Girls

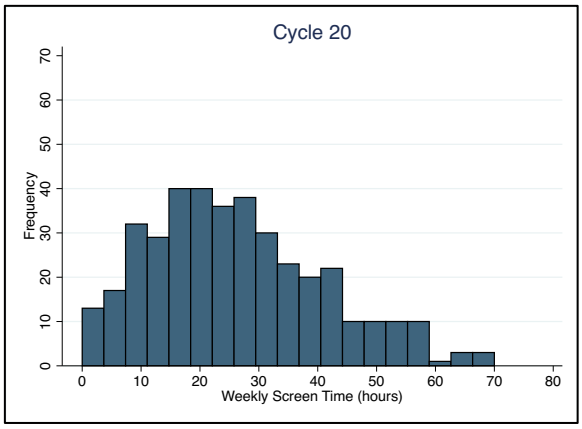




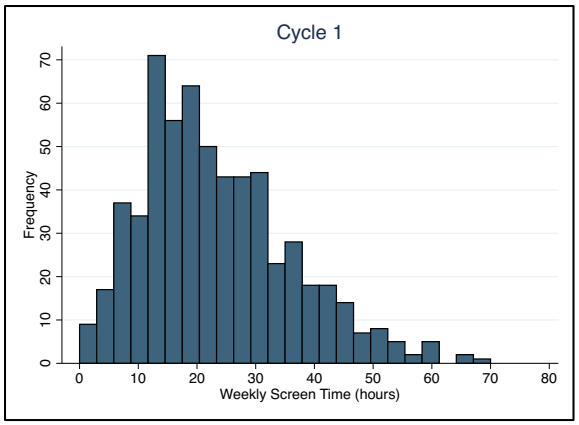
Appendix D: Histograms of the 'Weekly Screen Time' Variable in Cycle 1 and 20, Boys and Girls, NDIT 1999-2005

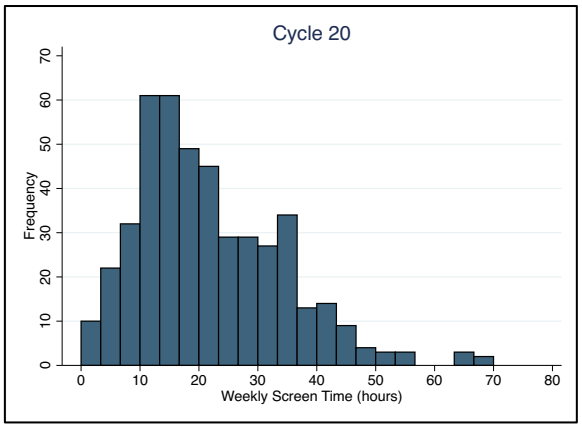
1) Boys





2) Girls





Appendix E: Items from the Guidelines for Reporting on Latent Trajectory Studies Checklist addressed in the current study, NDIT 1999-2005.

Checklist item	Reported in thesis
1. Is the metric of time used in the statistical model reported?	Yes (p.26)
2. Is information presented about the mean and variance of time within a wave?	Yes (Table 1; p.21)
3a. Is the missing data mechanism reported?	No missing data mechanism used; Eligible participants had ≥3 data points
3b. Is a description provided of what variables are related to attrition/missing data?	Yes (Table 4; p.26)
3c. Is a description provided of how missing data in the analyses were dealt with?	Yes (p.24)
4. Is information about the distribution of the observed variables included?	Yes (p.26 and Appendix D)
5. Is the software mentioned?	Yes (p.28)
6a. Are alternative specifications of within-class heterogeneity considered (e.g., LGCA vs. LGMM) and clearly documented? If not, was sufficient justification provided as to eliminate certain specifications from consideration?	No
6b. Are alternative specifications of the between-class differences in variance–covariance matrix structure considered and clearly documented? If not, was sufficient justification provided as to eliminate certain specifications from consideration?	No
7. Are alternative shape/functional forms of the trajectories described?	Yes (Appendix F)
8. If covariates have been used, can analyses still be replicated?	N/A (no covariates were used)
9. Is information reported about the number of random start values and final iterations included?	No, but is available from the authors
10. Are the model comparison (and selection) tools described from a statistical perspective?	Yes (pp. 61-64)
11. Are the total number of fitted models reported, including a one-class solution?	Yes (Appendix F)
12. Are the number of cases per class reported for each model (absolute sample size, or proportion)?	Yes (pp. 42, 45, 47, 49-50)
13. If classification of cases in a trajectory is the goal, is entropy reported?	No
14a. Is a plot included with the estimated mean trajectories of the final solution?	Yes (pp. 42, 47)

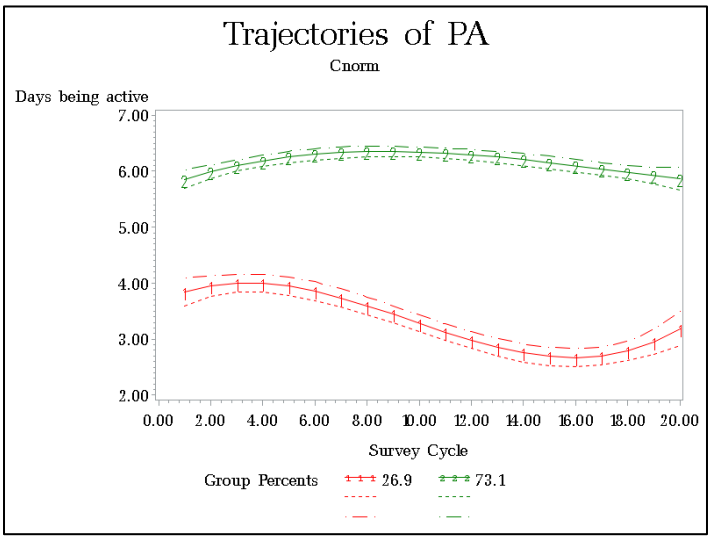
14b. Are plots included with the estimated mean trajectories for each model?	Yes (Appendix F)
14c. Is a plot included of the combination of estimated means of the final model and the observed individual trajectories split out for each latent class?	Yes (Appendix F – Supplementary Figures 3 and 6)
15. Are characteristics of the final class solution numerically described (i.e., means, SD/SE, n, CI, etc.)?	Yes (pp. 40-50)
16. Are the syntax files available (either in the appendix, supplementary materials, or from the authors)?	Yes (from the authors)

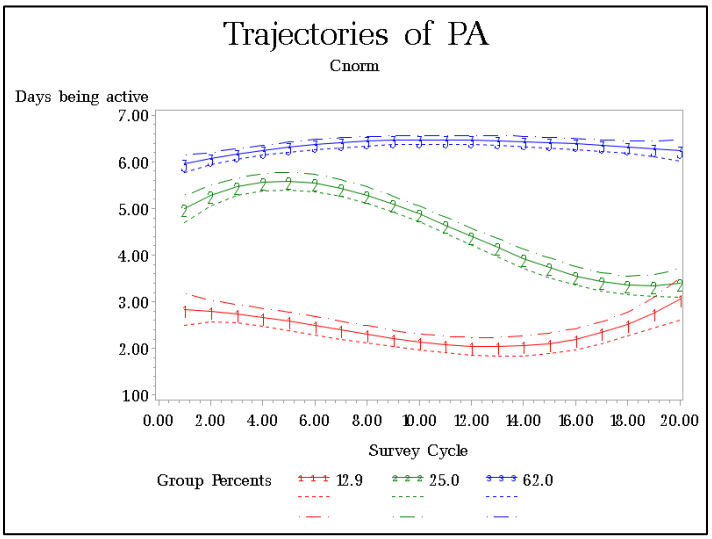
Appendix F: Supplementary Materials

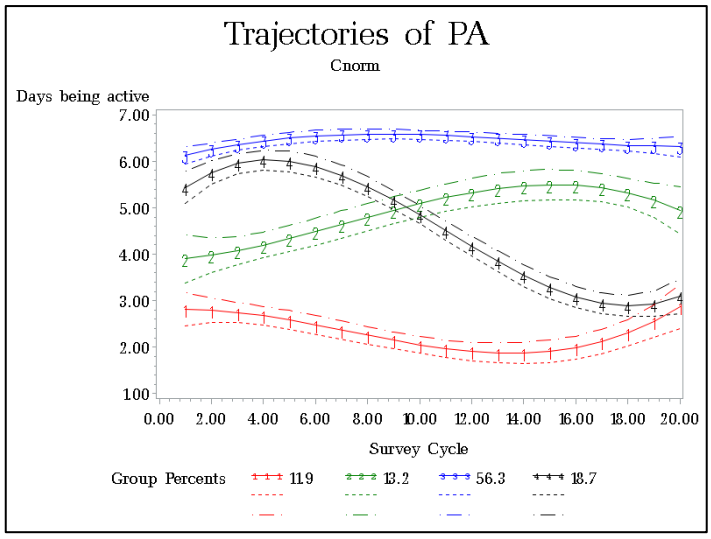
Supplementary Table 1. Bayesian Information Criteria (BIC) and Bayes Factor Values for Selection of the PA Trajectory Model, Boys, NDIT 1999-2005

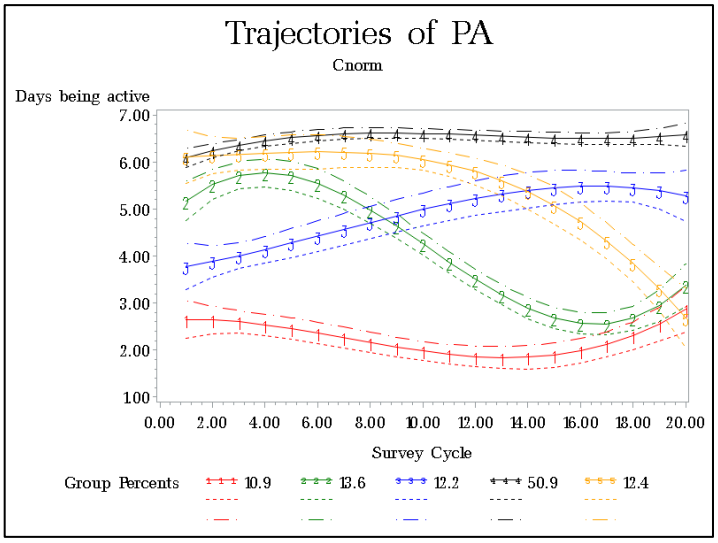
Number of groups	**BIC 1 (n=597 participants)**	**BIC 2 (n=9068 observations)**	**2 x (ΔBIC 1) ~ Bayes Factor 1**	**2 x (ΔBIC 2) ~ Bayes Factor 2**
1	-20402.44522	-20409.2467	.	.
2	-19077.93036	-19091.53331	2649.03	2635.43
3	-18757.20238	-18777.60681	641.46	627.85
4	-18644.05603	-18671.26193	226.29	212.69
5	-18582.33806	-18616.34543	123.44	109.83
6	-18578.78644	-18619.59529	7.10	-6.50
7	-18500.65428	-18548.26461	156.26	142.66
8	-18465.42035	-18519.83215	70.47	56.86

Supplementary Figure 1. Figures Depicting PA Trajectories, with Number of Groups Ranging from 2 to 5, Boys, NDIT 1999-2005





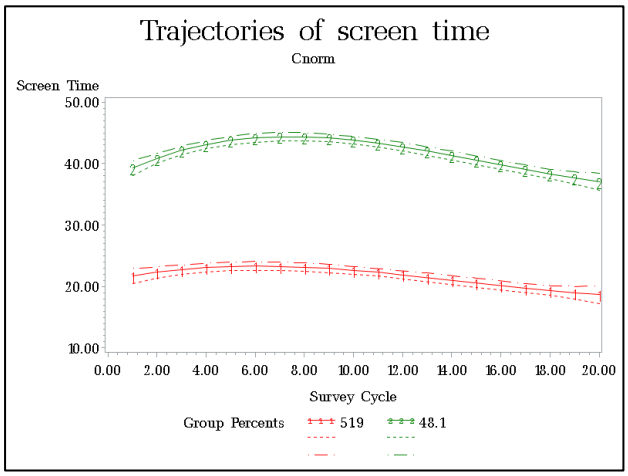


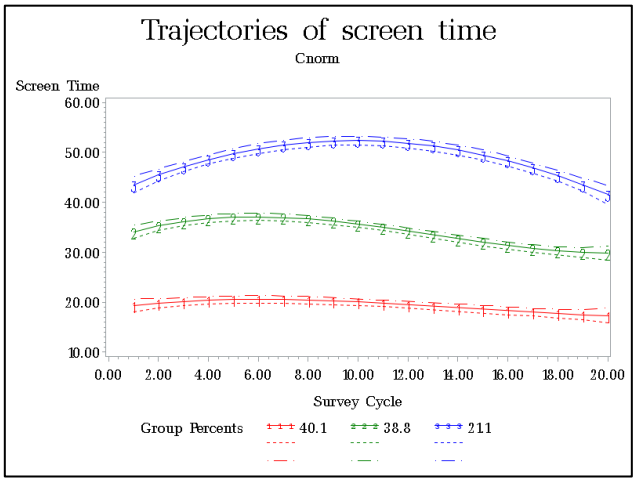


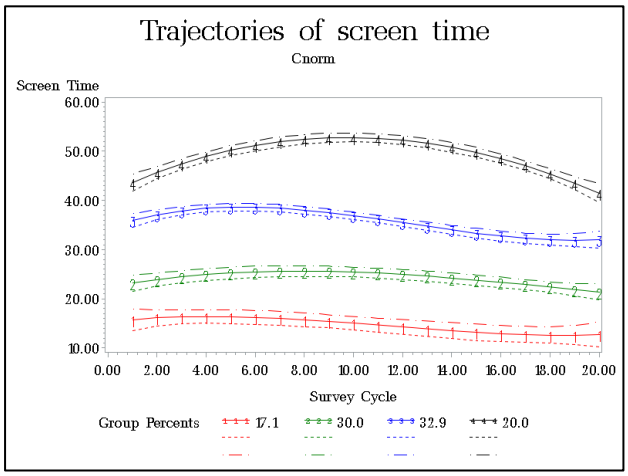
Supplementary Table 2. Bayesian Information Criteria (BIC) and Bayes Factor Values for Selection of Screen Time Trajectory Model, Boys, NDIT 1999-2005

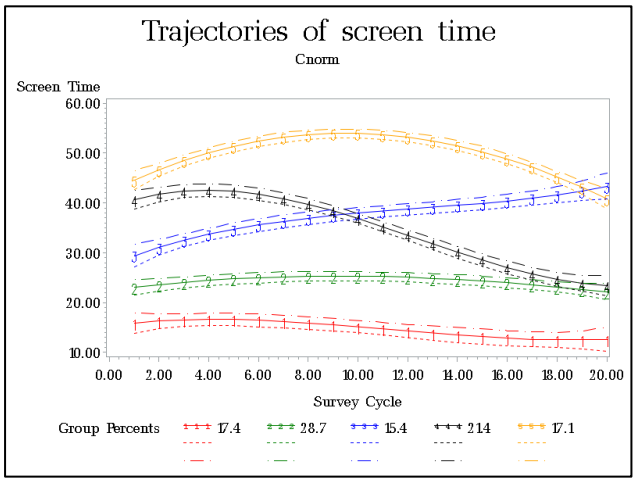
Number of groups	**BIC 1 (n=597 participants)**	**BIC 2 (n=9068 observations)**	**2 x (ΔBIC 1) ~ Bayes Factor 1[25]**	**2 x (ΔBIC 2) ~ Bayes Factor 2[25]**
1	-37836.50462	-37843.30913	.	.
2	-35843.6754	-35857.28442	3985.66	3972.05
3	-35257.18682	-35277.60034	1172.98	1159.37
4	-35067.70198	-35094.92001	378.97	365.36
5	-34854.39985	-34888.42237	426.60	413.00
6	-34788.67957	-34829.5066	131.44	117.83
7	-34725.10933	-34772.74087	127.14	113.53
8	-34655.36901	-34709.80505	139.48	125.87

Supplementary Figure 2. Figures Depicting Screen Time Trajectories, With Number of Groups Ranging from 2 to 5, Boys, NDIT 1999-2005



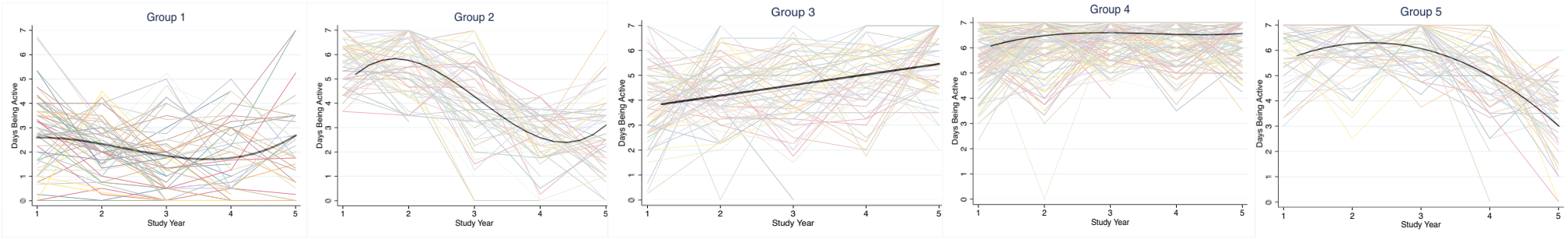




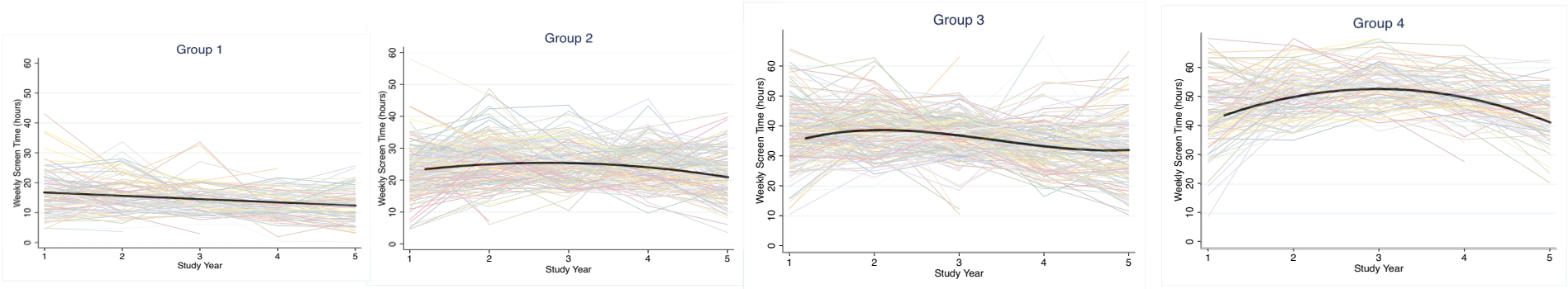


Supplementary Figure 3. Participant-Specific Trajectories of Group Members Overlapped with the Trajectory Estimated by the Final Model, Boys (Top: PA; Bottom: Screen Time), NDIT 1999-2005

PA



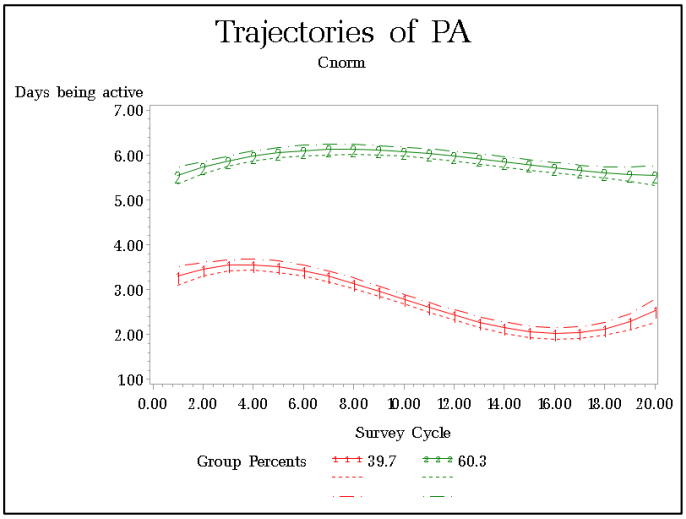
Screen Time

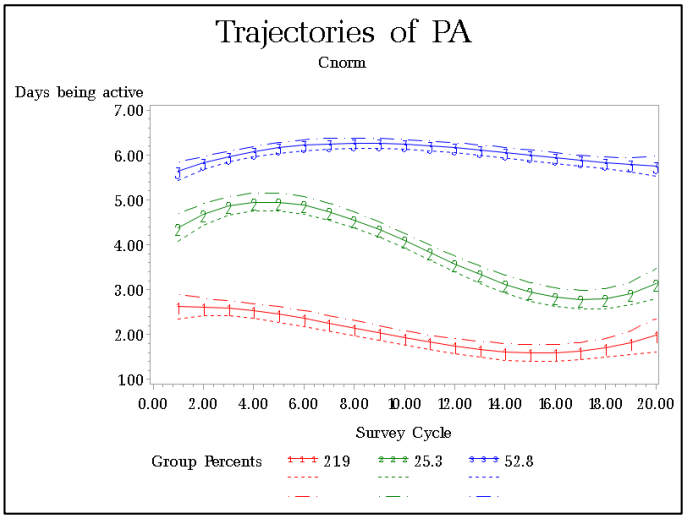


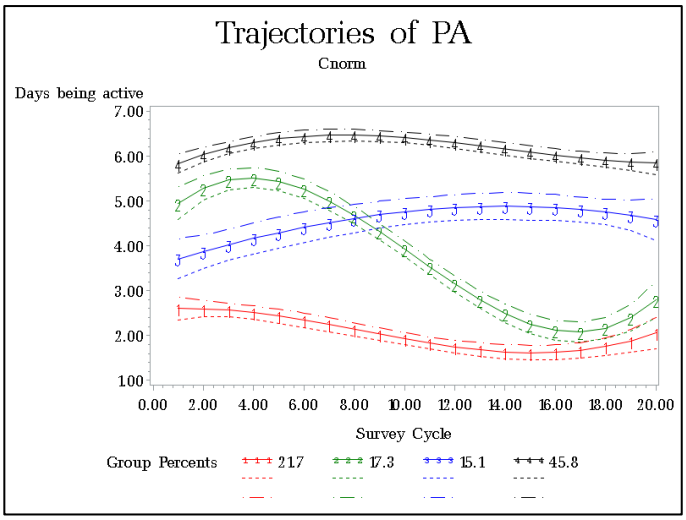
Supplementary Table 3. Bayesian Information Criteria (BIC) and Bayes Factor Values for Selection of the PA Trajectory Model, Girls, NDIT 1999-2005

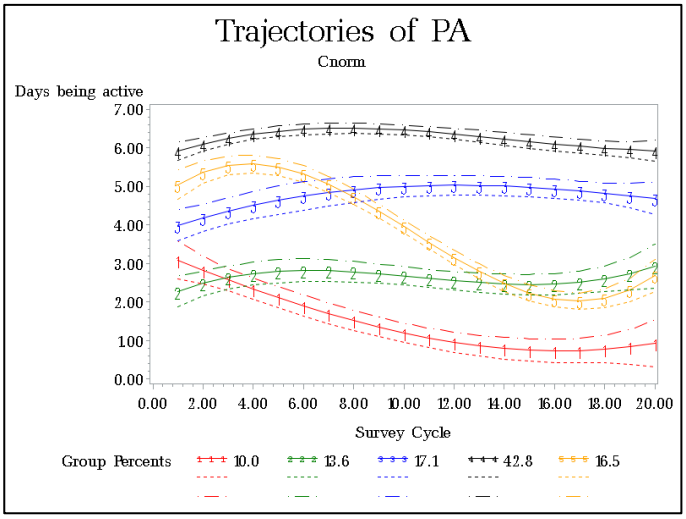
Number of groups	**BIC 1 (n=647 participants)**	**BIC 2 (n=9756 observations)**	**2 x (ΔBIC 1) ~ Bayes Factor 1[25]**	**2 x (ΔBIC 2) ~ Bayes Factor 2[25]**
1	-22926.57883	-22933.36206	.	.
2	-21148.64883	-21162.21529	3555.86	3542.29
3	-20866.13088	-20886.48056	565.04	551.47
4	-20741.01757	-20768.15049	250.23	236.66
5	-20699.06841	-20732.98455	83.90	70.33
6	-20652.42364	-20693.12301	93.29	79.72
7	-20633.05102	-20680.53362	38.75	25.18
8	-20624.99043	-20679.25626	16.12	2.55

Supplementary Figure 4. Figures Depicting PA Trajectories, with Number of Groups Ranging from 2 to 5, Girls, NDIT 1999-2005





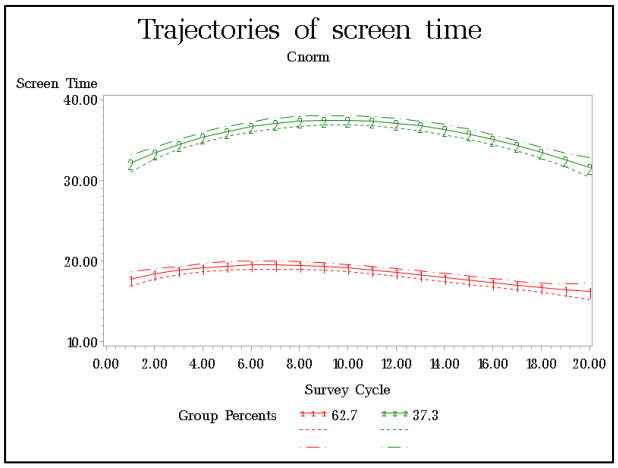


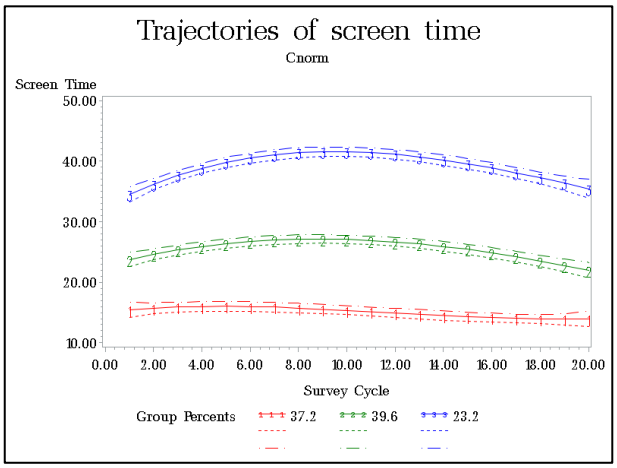


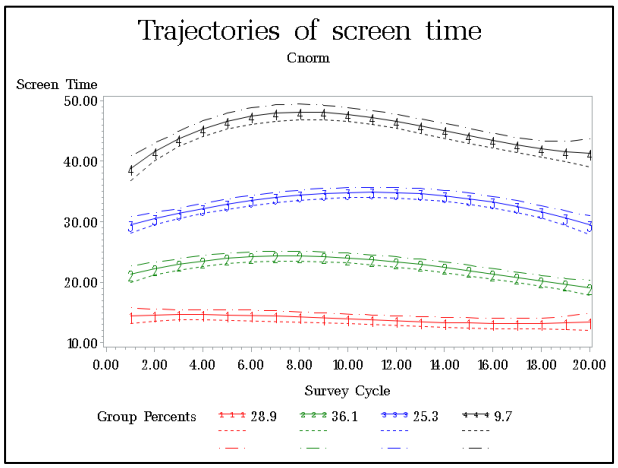
Supplementary Table 4. Bayesian Information Criteria (BIC) and Bayes Factor Values for Selection of Screen Time Trajectory Model, Girls, NDIT 1999-2005

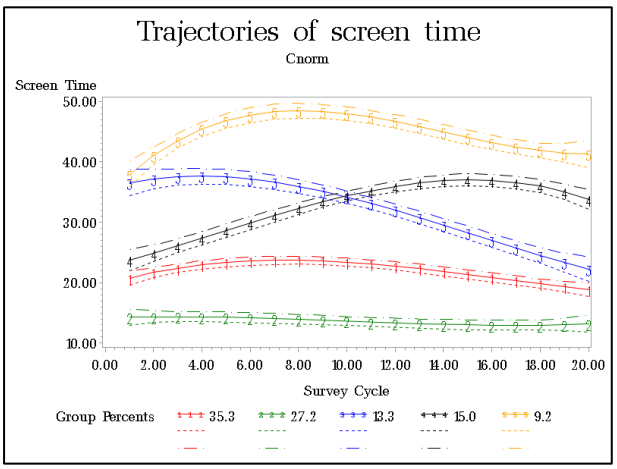
Number of groups	**BIC 1 (n=647 participants)**	**BIC 2 (n=9756 observations)**	**2 x (ΔBIC 1) ~ Bayes Factor 1[25]**	**2 x (ΔBIC 2) ~ Bayes Factor 2[25]**
1	-39376.60856	-39383.42007	.	.
2	-37262.62635	-37276.24937	4227.96	4214.34
3	-36719.78942	-36740.22395	1085.67	1072.05
4	-36472.10684	-36499.35288	495.37	481.74
5	-36285.18116	-36319.23872	373.85	360.23
6	-36174.45618	-36215.32526	221.45	207.83
7	-36096.89235	-36144.57293	155.13	141.50
8	-36060.05948	-36114.55157	73.67	60.04

Supplementary Figure 5. Figures Depicting Screen Time Trajectories, With Number of Groups Ranging from 2 to 5, Girls, NDIT 1999-2005



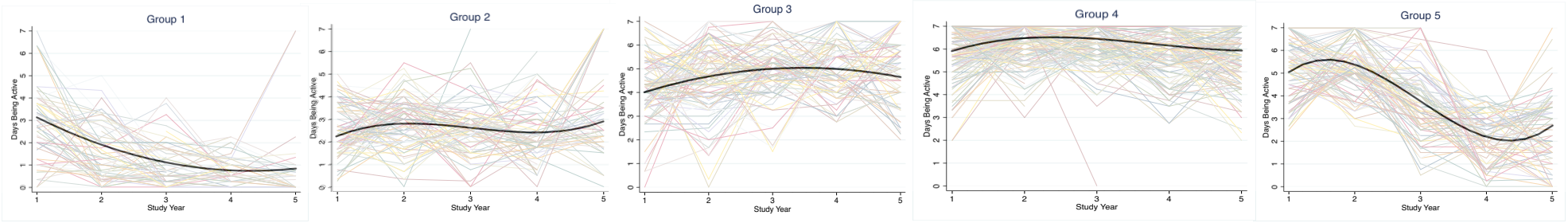






Supplementary Figure 6. Participant-Specific Trajectories of Group Members Overlapped with the Trajectory Estimated by the Final Model, Girls (Top: PA; Bottom: Screen Time), NDIT 1999-2005

PA



Screen time