Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

______________________________ ______________

Sara Hanson Date

Trajectories of activity and sleep through adolescence and body composition at age 18 years: Birth to Twenty Plus

By

Sara K. Hanson

Doctor of Philosophy
Nutrition and Health Sciences

____

Aryeh D. Stein
Advisor

____

Solveig A. Cunningham
Committee Member

____

Terryl J. Hartman
Committee Member

____

Felipe Lobelo
Committee Member

____

Shane A. Norris
Committee Member

Accepted:

____

Lisa A. Tedesco, Ph.D.
Dean of the James T. Laney School of Graduate Studies

____

Date

Trajectories of activity and sleep through adolescence and body composition at age 18 years: Birth to Twenty Plus

By

Sara K. Hanson
M.S. San Diego State University

Advisor: Aryeh D. Stein, Ph.D.

An abstract of

A dissertation submitted to the Faculty of the

James T. Laney School of Graduate Studies of Emory University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in Nutrition and Health Sciences

2020

Abstract

Trajectories of activity and sleep through adolescence and body composition at age 18 years: Birth to Twenty Plus

By Sara K. Hanson

Background: Adolescent physical activity, sedentary behavior and sleep are modifiable behaviors that have been linked to body composition, but prospective data on these behaviors following up to adulthood are rare, particularly in low and middle-income countries. South Africa has one of the highest prevalences of overweight and obesity in Sub-Saharan Africa, with 39% of men and 69% of women affected.

Aim: This dissertation has 2 aims. First to add to the very limited longitudinal data on physical activity, sedentary behavior and sleep change with time from adolescents living in Africa. Second, to offer new insights into the current overweight and obesity epidemic in South Africa by examining the association of these adolescent behaviors with body composition at age 18 years.

Methods: We analyzed data from the Birth-to-Twenty Plus Cohort (Bt20+), a longitudinal study of children in Soweto, Johannesburg, South Africa. We performed Latent Class Growth Analysis to group participants into distinct classes based on common longitudinal trajectories of minutes per week spent in informal activity, organized sports, walking to and from school, sedentary behavior, school-night sleep and weekend sleep from ages 12-17 years. We used group-based multi-trajectory modeling to summarize overall physical activity patters in terms of the 3 physical activity domains. We used general linear models to investigate the associations of adolescent physical activity, sedentary behavior and sleep with anthropometry and body composition at age 18 years.

Results: The majority of males (82%) and all females failed to meet the World Health Organization (WHO) physical activity recommendation for adolescents of 60 minutes of moderate-vigorous intensity physical activity per day. While most experienced a declining overall physical activity pattern, 29% of the sample in males and 17% of the sample in females were consistently active throughout adolescence. Being consistently physically active and getting more sleep per night throughout adolescence was associated with more favorable body composition at age 18 years in urban South African males. Being more sedentary over adolescence was associated with less favorable anthropometric measurements in urban South African females.

Conclusion: Adolescent physical activity, sedentary behavior and sleep are modifiable behaviors that may be contributing to the prevalence of overweight and obesity in urban South African adults.

Trajectories of activity and sleep through adolescence and body composition at age 18 years: Birth to Twenty Plus

By

Sara K. Hanson

M.S., San Diego State University

Advisor: Aryeh Stein, Ph.D.

A dissertation submitted to the Faculty of the

James T. Laney School of Graduate Studies of Emory University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in Nutrition and Health Sciences

2020

Table of Contents

Part 1. Introduction, Literature Review, and Methodology

1 Chapter 1: Introduction……1
  1.1 Rationale……2
  1.2 Aims and Objectives……3
    1.2.1 Overall Aim
    1.2.2 Specific Objectives
  1.3 Conceptual Model and Theoretical Framework……5
  1.4 Dissertation Overview and Structure……6
2 Chapter 2: Literature Review……7
  2.1 Adolescence……7
    2.1.1 Physical Growth and Sexual Maturation
    2.1.2 Brain Development and Psychosocial Changes
    2.1.3 Impact of Adolescent Health Across the Life-course
  2.2 Overweight and Obesity……8
    2.2.1 Global Overweight and Obesity
    2.2.2 Low and Middle-Income Countries
    2.2.3 South Africa
    2.2.4 Modifiable Risk Factors of Overweight and Obesity
  2.3 Physical Activity……10
  2.4 Sedentary Behavior……13
  2.5 Sleep……14
  2.6 Key Questions Still Outstanding……17
  2.7 References for Chapters 1 and 2……19
3 Chapter 3: Overview of Methodological Approaches……25
  3.1 Study Setting and Design……25
  3.2 Dissertation Data……26
    3.2.1 Primary Exposures and outcomes
    3.2.2 Participant characteristics, predictors and covariates
    3.2.3 Inclusion and Exclusion
  3.3 Statistical Analyses……31
    3.3.1 Trajectory Analyses
      3.3.1.1 Latent Class Growth Analysis
      3.3.1.2 Group Based Dual Trajectory Modeling
    3.3.2 Overall Analysis Plan
  3.4 References for Chapter 3……36

Part 2: Empirical Chapters

4 Chapter 4. Longitudinal patterns of Physical Activity, Sedentary Behavior and Sleep in Urban South African Adolescents, Birth-To-Twenty Plus Cohort……40
  4.1 Abstract……42
  4.2 Background……43
  4.3 Methods……44

4.4 Results………49
4.5 Discussion………52
4.6 Conclusion………58
4.7 References………59
4.8 Tables and Figures…………………………………………………………………………………………………63
5 Chapter 5: Adolescent Physical Activity, Sedentary Behavior and Sleep in Relation to Body Composition at Age 18 years in Urban South Africa, Birth-To-Twenty Plus Cohort ………………………..84
5.1 Abstract……86
5.2 Background……87
5.3 Methods……88
5.4 Results………91
5.5 Discussion………95
5.6 Conclusion………99
5.7 References……100
5.8 Tables and Figures ………………………………………………………………………………………………103
Part 3: Discussion and Implications
6 Chapter 6: Discussion…………………………………………………………………………………………..116
6.1 Consolidated Findings…………………………………………………………………………………………..116
6.2 Overall Story………………………………………………………………………………………………………118
6.3 Strengths and Limitations ……………………………………………………………………………………… 122
6.4 Future Research…………………………………………………………………………………………………123
6.5 Public Health Implications……………………………………………………………………………………124
6.6 Conclusions……..125
6.7 References for chapter 6………………………………………………………………………………………126

List of Figures

Figure 1.1. Conceptual diagram: Physical activity, sedentary behavior and sleep across adolescence, childhood predictors and adult adiposity/ body composition outcomes……………………………………………5

Figure 3.2. Pre-determined list of informal activities deemed common among South African children……..29

Figure 3.3. Representation of a growth mixture model with covariates (adapted from Jung and Wickrama, 2008) ……………………………………………………………………………………………………..32

Figure 3.4. Overall analysis plan of dissertation………………………………………………………………………….35

Figure 4.1. Physical activity trajectories through adolescence by domain and sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ………………………………………………………………………………69

Figure 4.2 Sedentary behavior and sleep trajectories through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ……………………………………………………………………………..70

Figure 4.3 Multi-trajectory groups of physical activity domains through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ………………………………………………………………71

Figure 4.4. Multi-trajectory groups of movement behavior domains through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ………………………………………………………72

Supplemental figure 4.1. Flow chart depicting the final sample of eligible participants included in the analysis of physical activity patterns in adolescence, Birth to Twenty Plus Cohort, Johannesburg, South Africa ……82

Supplemental Figure 5.1. Trajectories of physical activity and sedentary behavior from Latent Class Growth Analysis, Bt20+…………………………………………………………………………………………………… 110

Supplemental Figure 5.2. Flow chart depicting the final sample of eligible participants included in the analysis, Bt20+ ………112

List of Tables

Table 3.1. Data collection details for primary exposures and outcome, Bt20+ Cohort……………….……..27

Table 3.2. Data collection details for participant characteristics, potential predictors, and covariates, Bt20+ Cohort ……………………………………………….………………………………………………………………..30

Table 4.1 Characteristics of the study sample by sex, Birth-to-Twenty Plus cohort, Johannesburg, South Africa ……………………………………………………………………………………………………….………..……..63

Table 4.2 Duration of physical activity, sedentary behavior and sleep behaviors through adolescence, by sex, Birth-to-Twenty Plus cohort, Johannesburg, South Africa ………………………………………….………….64

Table 4.3. Relative risk ratios and 95% confidence intervals for predictors of trajectory class membership, Birth-to-Twenty Plus cohort, Johannesburg, South Africa ………….…………………………..66

Table 4.4. Relative risk ratios and 95% confidence intervals for predictors of physical activity multi-trajectory groups, Birth-to-Twenty Plus cohort, Johannesburg, South Africa ……………………………….68

Supplemental Table 4.1. Latent Class Growth Analysis model fit for physical activity by domain and sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ………………………………………………….73

Supplemental Table 4.2 Latent Class Growth Analysis model fit for sedentary behavior and sleep by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa …………………………………………………..75

Supplementary Table 4.3 Sedentary behavior trajectory class membership across physical activity trajectories in males, Birth to Twenty Plus Cohort, Johannesburg, South Africa …………………….…….76

Supplemental Table 4.4. Sedentary behavior trajectory class membership across physical activity trajectories in females, Birth to Twenty Plus Cohort, Johannesburg, South Africa ……………..………..77

Supplemental Table 4.5. Sleep trajectory class membership across physical activity trajectories in males, Birth to Twenty Plus Cohort, Johannesburg, South Africa ………………………….………………….78

Supplemental Table 4.6. Sleep trajectory class membership across physical activity trajectories in females, Birth to Twenty Plus Cohort, Johannesburg, South Africa ……………………………………………..79

Supplemental Table 4.7. Multi-trajectory analysis model fit statistics for physical activity domains by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa ……………………………………..……………80

Supplemental Table 4.8. Multi-trajectory analysis model fit statistics for physical activity domains, sedentary behavior and sleep by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa …….81

Table 5.1. Characteristics of participants by sex, Bt20+ ……………………………………………………………103

Table 5.2. Mean anthropometric and body composition measures at 18y by adolescent movement behavior trajectories, Bt20+………………….……………………..…………………………….………………105

Table 5.3. Regression coefficients (B) and 95% CI for anthropometric and body composition measures at 18y, adjusted, Bt20+ ……………………………………………………………………………………………107

Supplemental table 5.1. Comparison of characteristics of the study sample by data available and sex, Bt20+ ……..113

Table 6.1 Consolidated findings …………………………………………………………………………………………..116

Part 1: Introduction, Literature Review and Methodology

Chapter 1: Introduction

1.1 Rationale

Adolescence is the transitional stage between childhood and adulthood. This dynamic phase of human development is marked by rapid physical growth, sexual maturation, brain development and psychosocial changes. The current generation of people ages 10-24 years is the largest in human history and makes up nearly a quarter of the world's population [1]. However, because adolescents typically have low mortality and chronic disease rates, this population has often been neglected in global health research and policy [2]. The second *Lancet* Series on adolescent health concluded that "Failure to invest in the health of the largest generation of adolescents in the world's history jeopardizes earlier investments in maternal and child health, erodes future quality and length of life, and escalates suffering, inequality, and social instability [3]."

Of the 1.8 billion adolescents in the world, roughly 90% live in low and middle-income countries (LMICs) [1, 2]. Currently, LMICs are experiencing greater increases in overweight and obesity relative to high-income countries [4]. As the burden of overweight and obesity in LMICs continues to rise, there is a need for research on modifiable risk factors that could aid in prevention strategies [5]. However, longitudinal data on modifiable risk factors in adolescence are rare, especially in low and middle-income countries. Specifically, the Lancet Physical Activity Series Working Group described the lack of data for changes in physical activity with time in adolescents in LMICs as "worrying" and highlights a severe lack of data from African countries [6]. Further, The Child Health and Nutrition Research Initiative reported that Identifying variables that predicted physical activity patterns among adolescents in LMICs was the highest priority research question regarding physical activity [7].

Since South Africa's political transformation in 1994, the country has undergone a period of rapid urbanization, globalization and socioeconomic change with concurrent rising rates of overweight and obesity [8, 9]. Currently, the prevalence of overweight and obesity in South Africa (39% in men and 69% in women), is one of the highest in Sub-Saharan Africa, rivaling rates in developed countries [10]. The Birth-to Twenty Plus Study (Bt20+) is the largest and longest running study of adolescent health and development in Africa, and one of the few large-scale longitudinal studies in the world [11]. Findings from this study have been used to inform major policy decision in South Africa and offer valuable insight into developmental trajectories of health in a rapidly developing nation. Data on physical activity, sedentary behavior and sleep, all modifiable risk factors for overweight and obesity, have been collected from Bt20+ participants at multiple time-points across adolescence. However, until now, these data have not been analyzed.

1.2 Aims and Objectives

1.2.1 Overall Aims

This dissertation has two overall aims. First, it aims to add to the very limited longitudinal data on physical activity, sedentary behavior and sleep change with time from adolescents living in Africa. Second, it aims to offer new insights into the current overweight and obesity epidemic in South Africa. These insights relating to modifiable risk factors, may help inform targeted overweight and obesity prevention strategies in South Africa.

1.2.2 Specific Objectives

The specific objectives of this dissertation are as follows:

1. Describe longitudinal patterns of different domains of physical activity, sedentary behavior and sleep throughout adolescence and identify childhood socio-ecological predictors of these adolescent behaviors.
    a. Identify distinct sex-specific trajectories of informal activity, organized sports, walking to and from school, sedentary behavior, school-night sleep and weekend sleep from ages 12-17 years.
    b. Identify overall adolescent physical activity patterns by grouping multiple domains of physical activity together in one model.
    c. Examine how adolescent physical activity, sedentary behavior and sleep track/ group together over time.
    d. Assess the association of childhood socio-ecological variables at the individual, maternal and household level with adolescent physical activity, sedentary behavior and sleep trajectories and trajectory groupings.

2. Assess the association of longitudinal patterns of adolescent physical activity, sedentary behavior and sleep with anthropometry and body composition at age 18 years.
    a. Assess associations of longitudinal patterns of adolescent physical activity, sedentary behavior and sleep with BMI, waist-circumference, fat mass index, lean mass index and percent body fat at age 18 years.
    b. Assess association of overall adolescent physical activity pattern with BMI, waist-circumference, fat mass index, lean mass index and percent body fat at age 18 years.

1.3 Conceptual Model and Theoretical Framework

The World Health Organization (WHO) has emphasized the importance of adopting a life-course approach to address non-communicable diseases (NCDs), including obesity [12]. This approach aims to understand current patterns of health and disease by investigating long-term effects of physical and social exposures during key stages of life from preconception through adulthood [12]. Life-course models for NCD risk have highlighted the importance of the adolescent period for interventions to reduce risk in current and future generations [12]. Taking this approach allows for the prevention and control of disease through the identification of high-risk groups earlier in life [12]. A conceptual diagram showing a life-course approach to conceptualize how socioecological predictors and adult adiposity and body composition are related to adolescent physical activity, sedentary behavior and sleep trajectories is shown in figure 1.1.

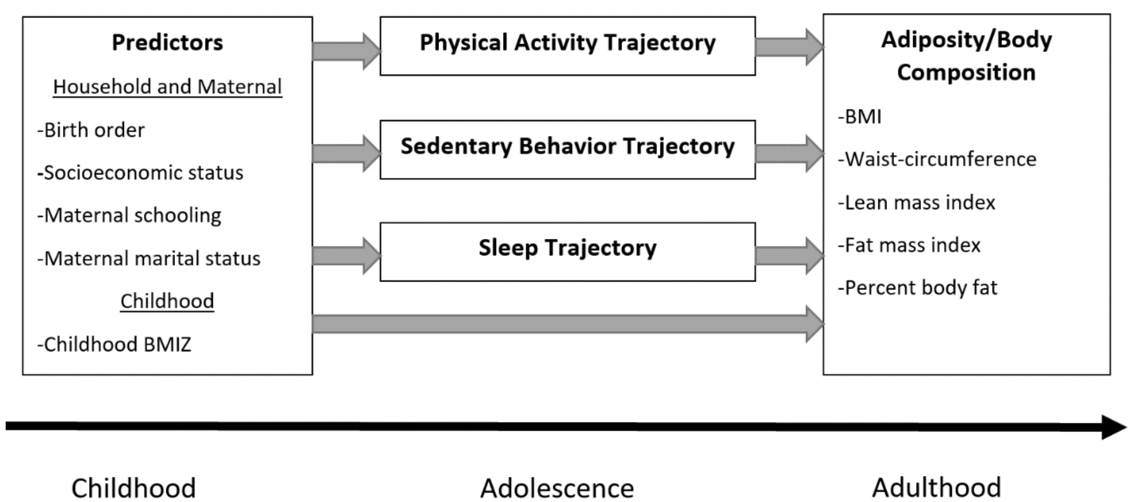


Figure 1.1. Conceptual diagram: Physical activity, sedentary behavior and sleep across adolescence, childhood predictors and adult adiposity/ body composition outcomes.

1.4 Dissertation Overview and Structure

This dissertation has 2 empirical chapters. The first empirical chapter describes the patterns of physical activity, sedentary behavior and sleep throughout adolescence in urban South Africa and creates trajectories and multi-trajectory groups to characterize these behaviors. This chapter also identifies early-life factors that predict these adolescent behavioral trajectories. The second empirical chapter builds on the findings from the first chapter and investigates the associations of the adolescent physical activity sedentary behavior and sleep trajectories with body composition (BMI, waist-circumference, fat mass index, lean mass index and percent body fat) in young-adulthood.

Chapter 2: Literature Review

2.1. Adolescence

2.1.1 Physical Growth and Sexual Maturation

The physical and sexual maturation that occurs during adolescence are the result of the hormonal changes surrounding puberty [13]. As a child reaches puberty, the brain initiates a cascade of physiologic changes in the hypothalamic-pituitary-gonadal (HPG), adrenal, and growth hormone axes [13]. During puberty there is an acceleration in height velocity that peaks during the adolescent growth spurt. Physical growth during this period accounts for about 20% of final adult height [13].

Adolescence is also characterized by sexually dimorphic changes in body composition and regional fat distribution [14]. While both males and females gain lean mass throughout adolescence, males accrue lean mass at a much faster rate and for a longer duration than females [14]. The young-adult amount of lean mass is attained at age 15-16 years in females, but age 19-20 years in males [14]. Further, females tend to accrue fat mass throughout adolescence, while fat mass in males tends to remain constant [14, 15]. Despite the increase in lean mass in females, there is a decrease in percent lean mass and an increase in percent body fat due to the greater rate of increase in fat mass [15]. The increase in percent body fat seen in females during adolescence is related to menstrual function, as 17% body fat is required for initiation of menstruation and 22% for maintenance [16].

2.1.2 Brain Development and Psychosocial Changes

There are distinct neurodevelopmental changes that occur during adolescence [17]. These changes across brain systems result in a series of shifts in how the brain takes in, integrates and retains information [17]. Early to mid-adolescence is marked by the formation of specific brain connections that may potentiate new forms of motivation and learning [17]. Adolescence has also been described as a period of “social re-orientation” marked by a growing desire for autonomy, social acceptance and individual identity [18]. These observed alterations in adolescent behavior have been linked to developmental changes in brain physiology in the social information processing network [18]. These neurodevelopmental changes and related alterations in social behavior are what makes adolescence a critical time to shape learning and behavior [17, 18].

2.1.3 Impact of Adolescent Health Across the Life-course

The health-related behaviors that lead to overweight and obesity and the major non-communicable diseases in adulthood usually begin or are reinforced during adolescence [19]. The WHO estimates that 70% of premature deaths in adults worldwide are the result of behaviors that originated in adolescence [20].

It is well recognized that investments in the first two-years of life can have profound impact on later-life health [21, 22] However, it has been suggested that investments during the adolescent years could yield triple dividends; impacting not only current and later-life health, but also the health of future generations [23]. Many of the processes that shape early-life growth and development originate well before conception. Adolescence is the start of reproductive life and a time of male and female gamete maturation [24]. Exposures during this time including substance abuse, nutrition, physical activity and obesity may disrupt gamete production [24].

2.2 Overweight and Obesity

2.2.1 Global Overweight and Obesity

Overweight and obesity are becoming increasingly important global health concerns [25]. Globally, the prevalence of overweight and obesity has nearly doubled since 1980, reaching close to 37% in men and 38% in women [4]. Overweight and obesity in children and adolescents is also becoming a worldwide crisis [4]. From 1980-2013, the global prevalence of combined overweight and obesity in people under age 20 years increased by 47% [4]. Childhood weight status has been shown to track into adulthood and strongly predicts adult obesity [26, 27]. Excess weight can substantially increase the risk of non-communicable diseases (NCDs) including cardiovascular disease [28], type II diabetes, cancer [29], high blood pressure [30] and stroke [31]. While NCDs were not addressed in the Millennium Development Goals (MDGs), the 2030 Agenda for Sustainable Development recognized NCDs as a major challenge for sustainable development [32].

2.2.2 Low and Middle-Income Countries

LMICs are experiencing greater increases in overweight and obesity relative to high-income countries [10]. Fueled by urbanization, globalization, industrialization, economic growth, many low and middle-income countries are experiencing an epidemiological transition characterized by a shifting burden from infectious to non-communicable diseases [33] and a nutrition transition characterized by a shift from traditional diets to more processed/Westernized diets and increasingly sedentary lifestyles [34]. The rise in inactivity is thought to mainly be a result of occupational changes from labor intensive-to more sedentary professions, technological advancements and increased use of motorized transport [35-40].

2.2.3 South Africa

The prevalence of overweight and obesity in South Africa is one of the highest in Sub-Saharan Africa, with 39% of men and 69% of women being overweight or obese [10] Since it’s political transformation in 1994, South Africa has undergone a period of rapid urbanization, globalization and socioeconomic change [41]. Related to these changes, South Africa has seen rising rates of overweight and obesity in both children and adults [8, 42]. Black African women in South Africa are the most affected, with an obesity prevalence of 41%, compared to 9% in Black African males and 31% in white females [43]. The adoption of a more westernized sedentary lifestyle with urbanization and increasing physical inactivity have been shown to be major contributors the rising obesity rates in urban South Africa [42, 44, 45].

2.2.4 Modifiable Risk Factors of Overweight and Obesity

Risk factors for overweight and obesity can be categorized as modifiable and non-modifiable [46]. Modifiable risk factors are largely due to lifestyle/behavior and include (among others) physical activity, sedentary behavior and sleep patterns [46]. Non-modifiable risk factors for overweight and obesity include age, sex, race/ethnicity and genetics [46]. Given the rising rates of overweight and obesity worldwide, there is a need to understand the associated modifiable risk factors as they may be critical levers for public health interventions to curb the epidemic.

2.3 Physical Activity

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure [47]. The WHO estimates that annually, about 2 million deaths worldwide are attributable to physical inactivity [48]. This modifiable behavior plays an important role in the prevention of overweight and obesity [49]. There are several pathways by which physical activity influences obesity rate and weight gain including increasing daily energy expenditure, decreasing fat mass, maintaining or increasing muscle/lean mass, maintaining or increasing basal metabolic rate, and increasing psychosocial well-being [49].

Adolescent physical activity is influenced by a diverse set of factors [50]. A socioecological approach that models the relationships between individuals and their social and physical environments is commonly used to explain physical activity behaviors [50]. A review in the Lancet Physical Activity Series identified ethnicity, self-efficacy, perceived behavioral control and support for physical activity as determinants, and sex, age, parental education, parental/family support and several psychosocial variables as correlates of adolescent physical activity [51]. Sex, age and SES have been shown to be the most consistent correlates of physical activity in LMICs, but the findings are largely from studies in adults and differences between cultures and country level patterns may exist [51]. A study from rural South Africa shows female gender and lower socioeconomic status to be associated with lower physical activity [52]. In a sub-set of Bt20+ participants, children from homes with two parents, higher socioeconomic status, and more educated mothers were more physically active than children from homes with one parent, lower SES, and mothers with lower levels of schooling [53].

Apart from socio-economic factors, childhood weight status may be associated with adolescent physical activity level. Cross-sectional studies have found overweight or obese children to be less physically active than children of healthy weight status [54, 55]. A recent longitudinal study from the B-PROACT1V study in Southwest England found no difference in activity level at age 6 by BMI category, but that differences in activity level between children who were overweight or obese and children who were a healthy weight emerged over time by age 11 [56].

The existence of an age-related decline in physical activity throughout adolescence has been well established in high-income countries [57, 58]. A systematic review and pooled analysis by Dumith et al. reports a mean decline of 7% per year in physical activity level from ages 10-19 years and infers a 60-70% global physical activity change throughout adolescence [57]. This decline may be attributed to a decline in the number of physical activities rather than the time spent in each activity [57]. Further, there is conflicting evidence on the type/ domain of activity that declines, with some studies describing a reduction in organized sports participation [59], and others describing a reduction in non-organized sports participation [60]. The decline in physical activity throughout adolescence occurs in both males and females, but studies have consistently shown the decline to be more rapid in females [59, 61, 62]. While most longitudinal studies on adolescent physical activity are from high-income countries, in the

1993 Pelotas Birth Cohort from Brazil, a LMIC, there was also a significant decline in physical activity between ages 11 and 18 years, particularly in females [63].

Physical activity tracks from adolescence to adulthood, which suggests that promotion of physical activity should begin in early life [64, 65]. Data on the relationship between adolescent physical activity and overweight in adolescence are inconsistent [66]. However, some studies have shown a beneficial effect of adolescent physical activity on adult health outcomes. Using data from the Amsterdam Growth and Health Longitudinal Study, Twisk et al. found strong evidence of an inverse relationship between adolescent physical activity, physical fitness and body fatness (measured by sum of skin folds) at age 32 years [67, 68]. Similarly, there is evidence from the Cardiovascular Risk in Young Finns Study that persistent physical activity from ages 12-18 is related to lower body fatness (measured by sub-scapular skinfold) in young-adult females [69]. Similarly, with data from the Young Finns Study, researchers showed that both participants who were decreasingly active and persistently inactive from youth to adulthood were more likely to be obese adults compared to those who were persistently active [68]. The researchers also found that maintaining a high level of physical activity from youth to adulthood was associated with lower risk of abdominal obesity in women, but not in men [69]. Using data from the Northern Finland Birth Cohort of 1966, researchers found that becoming inactive during the transition from adolescence to adulthood was associated with overweight in males and overall obesity in males and females, with more severe abdominal obesity in females [70]. In contrast, findings from the Oslo Youth Study show that while physical fitness at age 13 was related, leisure time physical activity at age 13 years was not related to BMI at ages 25, 33 or 40 years [71]. In the Norwegian study, unlike the studies from the Dutch and Finnish cohorts, adolescent physical activity was not examined longitudinally. The 4 aforementioned studies were all from high-income European countries with primarily white participants, and had methodological limitations surrounding their measure of adiposity/body composition. However, using data from the 1993 Pelotas Cohort, Ramires et al.

examined physical activity throughout adolescence and detailed body composition measured by DXA at age 18 years. In this Brazilian cohort, consistent physical activity throughout adolescence was associated with greater lean mass in both males and females, and that vigorous physical activity was associated with less fat mass in males [72].

2.4 Sedentary Behavior

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure of ≤1.5 Metabolic Equivalents (METs) while in a sitting or resting posture [73]. Research and public health interventions among adolescents have typically focused on increasing physical activity [74]. However, a 2011 systematic review by Tremblay et al. suggests that higher sedentary behavior (i.e. too much sitting), independent low physical activity (i.e. too little exercise), is associated with adverse health outcomes [75]. The review found that more than 2 hours of sedentary behavior per day was related to unfavorable body composition, decreased fitness, lower self-esteem and social behavior, and lower academic performance in adolescents [75]. A 2016 update to this review suggested that different types of sedentary behavior in adolescents may have varied impacts on different health outcomes [76].

As with physical activity, the socioecological model is often used to structure research on correlates and determinants of sedentary behavior [50, 77]. A 2011 review of prospective studies by Uijtdewiligen et al. reported insufficient evidence for determinants of sedentary behavior in children and adolescents [78]. However, in a 2016 review using a socio-ecological perspective, Stierlin et al. found that age and weight status were determinants of sedentary behavior in youth [79]. The researchers also reported evidence of associations between higher household SES, lower neighborhood SES, more depressive symptoms and African-American race, and higher sedentary behavior in youth. The study found inconsistent or no evidence for the association of most social determinants (e.g. parental education and number of siblings) with sedentary behavior in youth [79]. In a study from rural South Africa, researchers found female gender, lower socioeconomic status, pubertal development and higher maternal education to be associated with higher sedentary time [80].

Sedentary behaviors in childhood and adolescence have been shown to track into adulthood [81]. Longitudinal studies have linked sedentary time in childhood and adolescence to adult overweight and obesity. Researchers from New Zealand found that higher weeknight TV viewing between ages 5 and 15 years was associated with higher BMI at age 26. Further, that 17% of overweight at age 26 can be attributed to watching TV for more than 2 hours during childhood and adolescence [82]. In a follow-up of the 1970 British Birth Cohort, investigators found that mean daily hours of TV viewing on weekends at age 5 years predicted higher BMI and 30 years [83]. The methods used in the previously described longitudinal studies did not allow for heterogeneity in the variation of TV watching over time. However, using latent class analysis in an Australian birth cohort, McVeigh et al. identified subsets of participants with consistently higher, increasing, and consistently lower screen-time over 15 years throughout childhood and adolescence. Males with initially lower screen time in childhood had lower percent body fat than males with consistently higher screen time. Females with initially lower and consistently lower screen time had lower percent fat than females with consistently higher screen time [84].

2.5 Sleep

Adolescent sleep health has been recognized and a growing public health concern, with many countries reporting high incidence of sleep disturbance among youth [85, 86]. A meta-analysis of 41 surveys from around the world provides evidence of a world-wide delayed sleep-wake behavior pattern in adolescents [85]. The authors of this study note that not much is known about the sleep patterns of adolescents in Africa, and that cultural factors could contribute to differences in sleep patterns [85].

Changes in sleep are a normal part of adolescent development [87]. Across populations, older adolescents have an increased preference for evening activities, go to bed later and sleep less than younger adolescents [88, 89]. Some of the changes in sleep throughout adolescence are associated with pubertal development and thought to be a result of the effects of gonadal hormones on the homeostatic drive for sleep (sleep pressure) and circadian system [90, 91]. The shift in circadian rhythm is known as sleep phase delay, and results in adolescents going to bed later [90, 91]. Other changes, including the decline in sleep slow wave activity and the delta power of non-rapid eye movement sleep are thought to be linked to age, maturation and reorganization of the adolescent brain, rather than pubertal development [92].

In addition to biological mechanisms, there are numerous psychosocial factors that affect sleep patterns in adolescents [93]. These psychosocial factors may interact with the biological regulatory processes and contribute to the sleep phase delay and decline in sleep duration across adolescence [93]. An increased desire for autonomy displayed by self-selected bedtimes may lead to a delay in the timing of sleep [93, 94]. Evening light from increased screen time and greater access to technology of older adolescents, may cause a phase specific delay to circadian rhythm and lead to delayed sleep [95]. A systematic review of studies published from 1999-2014 found that screen time was adversely associated with sleep outcomes and led to shortened duration and delayed timing of sleep [96]. Increasing academic pressure and stress in secondary school may also contribute to later bedtimes, and when combined with early school start times, contributes to shorter sleep duration [97].

Household and family level factors have also been related to adolescent sleep patterns [98, 99]. Studies on the association between household-level economic disadvantage and sleep have shown that lower SES is associated with shorter sleep duration in adolescents [98, 99]. Proposed reasons for this include unfavorable sleep environments such as noisy home conditions, shared bedrooms and uncomfortable temperatures, as well as pre-sleep worries [100]. Researchers found that in an ethnically diverse, low income population, adolescents whose parents had post-secondary education had shorter sleep duration than those whose parents had not completed secondary school [101].

Sleep and physical activity are thought to reciprocally influence each other through multiple physiological and psychosocial factors [102]. Physical activity may influence sleep through the interaction with circadian rhythm, metabolic, immune, thermoregulatory, vascular, mood and endocrine effects [102]. Regular moderate-to-vigorous physical activity has been associated with increased total sleep time and sleep quality in adolescents [103]. A meta-analysis on the relationship between physical activity and sleep from mid-adolescence to early adulthood found that adolescents engaging in higher levels of physical activity are more likely to experience good sleep, however most-evidence was from cross-sectional studies [104]. Flipping the equation around, daytime sleepiness resulting from insufficient sleep is thought to lead to physical inactivity [105]. A study in Australian adolescents found that adolescents who were late to bed and late to rise were 1.77 times more likely to have low levels of MVPA and 2.92 times more likely to have higher screen-time than early bed/early rise adolescents[106].

Short sleep duration has been identified as a risk factor for overweight and obesity in both children and adults [107-109]. In a meta-analysis of 26 studies in adults and 19 studies in children, Cappuccio et al. reported a pooled odds ratio for short sleep duration and obesity of 1.55 (95% CI: 1.42-1.68) in adults and 1.89 (95%CI: 1.46-2.43) in children [109]. Additionally, a meta-analysis of 11 longitudinal studies, comprising 24,821 participants by Fatima, Doi and Mamun found that children and adolescents sleeping for short durations had twice the risk of being overweight or obese compared to those who slept for long durations [110]. Longitudinal sleep studies on adolescents in LMICs are sparse, but using data from the 1993 Pelotas Birth Cohort, investigators found that females who increased sleep duration over adolescence had higher BMI, fat mass index and fat-free mass index at age 18 years than those who consistently got adequate sleep [111].

2.6 Key Questions Still Outstanding

Despite several years since the Lancet Physical Activity series and subsequent calls for more evidence and data particularly from Africa, significant gaps in the literature still exist:

1. While physical activity, sedentary behavior and sleep have been the subject of many cross-sectional studies in children, few studies have examined these behaviors longitudinally over the adolescent years of life [6]. Of the few existing longitudinal studies, none are from Africa. How physical activity sedentary behaviors and sleep change over time in an adolescent African population is unknown.
2. It is unknown whether South African youth tend to meet/exceed the recommended amounts of physical activity, sedentary behavior and sleep over adolescence.
3. Studies on the correlates of physical activity in LMICs have largely focused only on adult populations [51]. Factors that consistently predict adolescent physical activity levels in LMICs have not been established.
4. The existence of an age-related decline in physical activity throughout adolescence has been well established in high-income countries [57, 58]. However, overall adolescent physical activity patterns among African adolescents have not been explored.
5. Physical activity, sedentary behavior and sleep have been shown to reciprocally influence each other in studies using compositional data analysis methods and objectively measured data. How these behaviors track together over time when assessed via retrospective interview is unknown.
6. Longitudinal studies have linked physical activity, sedentary behavior and sleep in childhood and adolescence to overweight and obesity in adulthood, but these findings are primarily from high-income countries. To date there have been no longitudinal studies linking these adolescent behaviors to adult adiposity and body composition in Africa. Whether or not adolescent physical

activity, sedentary behavior and sleep are contributing to the current overweight and obesity epidemic in South Africa is unknown.

References for Chapters 1 and 2

1. UNFPA: **State of the World's Population. The power of 1.8 billion-adolescents, youth and the transformation of the future.**
2. Dick B, Ferguson BJ: **Health for the world's adolescents: a second chance in the second decade.** *J Adolesc Health* 2015, **56:**3-6.
3. Resnick MD, Catalano RF, Sawyer SM, Viner R, Patton GC: **Seizing the opportunities of adolescent health.** *Lancet* 2012, **379:**1564-1567.
4. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany EC, Biryukov S, Abbafati C, Abera SF, et al: **Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013.** *Lancet* 2014, **384:**766-781.
5. Sallis JF, Owen N, Fotheringham MJ: **Behavioral epidemiology: a systematic framework to classify phases of research on health promotion and disease prevention.** *Ann Behav Med* 2000, **22:**294-298.
6. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U: **Global physical activity levels: surveillance progress, pitfalls, and prospects.** *Lancet* 2012, **380:**247-257.
7. Nagata JM, Ferguson BJ, Ross DA: **Research Priorities for Eight Areas of Adolescent Health in Low- and Middle-Income Countries.** *Journal of Adolescent Health* 2016, **59:**50-60.
8. Chopra M, Lawn JE, Sanders D, Barron P, Abdool Karim SS, Bradshaw D, Jewkes R, Abdool Karim Q, Flisher AJ, Mayosi BM, et al: **Achieving the health Millennium Development Goals for South Africa: challenges and priorities.** *Lancet* 2009, **374:**1023-1031.
9. Lundeen EA, Norris SA, Adair LS, Richter LM, Stein AD: **Sex differences in obesity incidence: 20-year prospective cohort in South Africa.** *Pediatr Obes* 2016, **11:**75-80.
10. Chen T, Wu Z, Shen Z, Zhang J, Shen X, Li S: **Sleep duration in Chinese adolescents: biological, environmental, and behavioral predictors.** *Sleep Med* 2014, **15:**1345-1353.
11. Richter L, Norris S, Pettifor J, Yach D, Cameron N: **Cohort Profile: Mandela's children: the 1990 Birth to Twenty study in South Africa.** *Int J Epidemiol* 2007, **36:**504-511.
12. Jacob C M BJ, Barker M, Cooper C, Hanson M: **The Importance of a Life Course Approach to Health: Chronic Disease Risk from Preconception through Adolescence and Adulthood.** *World Health Organization* 2017, White Paper.
13. Chulani VL, Gordon LP: **Adolescent growth and development.** *Prim Care* 2014, **41:**465-487.
14. Rogol AD, Roemmich JN, Clark PA: **Growth at puberty.** *Journal of Adolescent Health* 2002, **31:**192-200.
15. Dai S, Labarthe DR, Grunbaum JA, Harrist RB, Mueller WH: **Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years. Project HeartBeat!** *Am J Epidemiol* 2002, **156:**720-729.
16. Frisch RE: **Body fat, menarche, fitness and fertility.** *Hum Reprod* 1987, **2:**521-533.
17. Dahl RE, Allen NB, Wilbrecht L, Suleiman AB: **Importance of investing in adolescence from a developmental science perspective.** *Nature* 2018, **554:**441-450.
18. Nelson EE, Leibenluft E, McClure EB, Pine DS: **The social re-orientation of adolescence: a neuroscience perspective on the process and its relation to psychopathology.** *Psychol Med* 2005, **35:**163-174.
19. Organization WH: **Health for the world's adolescents: a second chance in the second decade.** Geneva2014.

20. World Health Organization: **Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks.** 2009.
21. Woo Baidal JA, Locks LM, Cheng ER, Blake-Lamb TL, Perkins ME, Taveras EM: **Risk Factors for Childhood Obesity in the First 1,000 Days: A Systematic Review.** *Am J Prev Med* 2016, **50:**761-779.
22. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M, Ezzati M, Grantham-McGregor S, Katz J, Martorell R, Uauy R: **Maternal and child undernutrition and overweight in low-income and middle-income countries.** *Lancet* 2013, **382:**427-451.
23. George C Patton SMS, John S Santelli, David A Ross, Rima Afifi, Nicholas B Allen, Monika Arora, Peter Azzopardi, Wendy Baldwin, Christopher Bonell, Ritsuko Kakuma, Elissa Kennedy, Jaqueline Mahon, Terry McGovern, Ali H Mokdad, Vikram Patel, Suzanne Petroni, Nicola Reavley, Kikelomo Taiwo, Jane Waldfogel, Dakshitha Wickremarathne, Carmen Barroso, Zulfiqar Bhutta, Adesegun O Fatusi, Amitabh Mattoo, Judith Diers, Jing Fang, Jane Ferguson, Frederick Ssewamala, Russell M Viner: **Our Future: A Lancet Commission on Adolescent Health and Wellbeing.** *The Lancet*, **387:**2423-2478.
24. George C. Patton CAO, Vegard Skirbekk, Richard Saffery, Mary E. Wlodek, Peter S. Azzopardi, Marcin Stonawski, Bruce Rasmussen, Elizabeth Spry, Kate Francis, Zulfiqar A. Bhutta, Nicholas J. Kassebaum, Ali H. Mokdad, Christopher J. L. Murray, Andrew M. Prentice, Nicola Reavley, Peter Sheehan, Kim Sweeny, Russell M. Viner, Susan M. Sawyer: **Adolescence and the next generation.** *Nature* 2018**:**458-466.
25. WHO: *Global status report on non-communicable diseases 2014, World Health Oganization.* Geneva2014.
26. Singh AS, Mulder C, Twisk JW, van Mechelen W, Chinapaw MJ: **Tracking of childhood overweight into adulthood: a systematic review of the literature.** *Obes Rev* 2008, **9:**474-488.
27. Parsons TJ, Power C, Logan S, Summerbell CD: **Childhood predictors of adult obesity: a systematic review.** *Int J Obes Relat Metab Disord* 1999, **23 Suppl 8:**S1-107.
28. Ortega FB, Lavie CJ, Blair SN: **Obesity and Cardiovascular Disease.** *Circ Res* 2016, **118:**1752-1770.
29. Garg SK, Maurer H, Reed K, Selagamsetty R: **Diabetes and cancer: two diseases with obesity as a common risk factor.** *Diabetes Obes Metab* 2014, **16:**97-110.
30. Kotsis V, Stabouli S, Papakatsika S, Rizos Z, Parati G: **Mechanisms of obesity-induced hypertension.** *Hypertens Res* 2010, **33:**386-393.
31. Strazzullo P, D'Elia L, Cairella G, Garbagnati F, Cappuccio FP, Scalfi L: **Excess body weight and incidence of stroke: meta-analysis of prospective studies with 2 million participants.** *Stroke* 2010, **41:**e418-426.
32. Nations U: **General Assembly Resolution A/RES/70/1. Transforming Our World, the 2030 Agenda for Sustainable Development.** 2015.
33. Santosa A, Wall S, Fottrell E, Hogberg U, Byass P: **The development and experience of epidemiological transition theory over four decades: a systematic review.** *Glob Health Action* 2014, **7:**23574.
34. Popkin BM: **The nutrition transition in low-income countries: an emerging crisis.** *Nutr Rev* 1994, **52:**285-298.
35. Gidlow C, Johnston LH, Crone D, Ellis N, James D: **A systematic review of the relationship between socio-economic position and physical activity.** *Health Educaton* 2006, **65:**338-367.
36. Popkin BM: **Technology, transport, globalization and the nutrition transition food policy.** *Food Policy* 2006, **31:**554-569.
37. Dumith S, Hallal P, Reis R, 3rd KH: **Worldwide prevalence of physical inactivity and its association with human development index in 76 countries.** *Prev Med* 2011, **53:**24-28.

38. Katzmarzyk P, Mason C: **The physical activity transition.** *J Phys Act Health* 2009, **6:**269-280.
39. Draper C, Basset S, de Villiers A, Lampert E, Group HW: **Results From South Africa's 2014 Report Card on Physical Activity for Children and Youth.** *Int J Behav Nutr Phys Act* 2014, **11:**S98-S104.
40. Bell A, Ge K, Popkin B: **The road to obesity or the path to prevention: motorized transportation and obesity in China.** *Obes Res* 2002, **10:**277-283.
41. Yach D, Cameron N, Padayachee N, Wagstaff L, Richter L, Fonn S: **Birth to ten: child health in South Africa in the 1990s. Rationale and methods of a birth cohort study.** *Paediatr Perinat Epidemiol* 1991, **5:**211-233.
42. Sartorius B, Veerman LJ, Manyema M, Chola L, Hofman K: **Determinants of Obesity and Associated Population Attributability, South Africa: Empirical Evidence from a National Panel Survey, 2008-2012.** *PLoS One* 2015, **10:**e0130218.
43. 2016 SADaHS: **Key Indicators Report.** Statistics South Africa; 2017.
44. Kruger HS, Venter CS, Vorster HH, Margetts BM: **Physical inactivity is the major determinant of obesity in black women in the North West Province, South Africa: the THUSA study. Transition and Health During Urbanisation of South Africa.** *Nutrition* 2002, **18:**422-427.
45. Micklesfield LK, Lambert EV, Hume DJ, Chantler S, Pienaar PR, Dickie K, Puoane T, Goedecke JH: **Socio-cultural, environmental and behavioural determinants of obesity in black South African women.** *Cardiovasc J Afr* 2013, **24:**369-375.
46. Hruby A, Hu FB: **The Epidemiology of Obesity: A Big Picture.** *PharmacoEconomics* 2015, **33:**673-689.
47. Caspersen CJ, Powell KE, Christenson GM: **Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research.** *Public Health Rep* 1985, **100:**126-131.
48. Organization WH: **Global strategy on diet, physical activity and health.** Geneva2004.
49. Strasser B: **Physical activity in obesity and metabolic syndrome.** *Ann N Y Acad Sci* 2013, **1281:**141-159.
50. F. Sallis J, Owen N, Fisher E: *Ecological Models of Health Behavior.*2008.
51. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW: **Correlates of physical activity: why are some people physically active and others not?** *Lancet* 2012, **380:**258-271.
52. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman S, Norris SA: **Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates.** *BMC Public Health* 2014, **14:**40.
53. McVeigh J, Norris S, de Wet T: **The relationship between socio-economic status and physical activity patterns in South African children.** *Acta Paediactr* 2004, **93:**982-988.
54. Cooper AR, Goodman A, Page AS, Sherar LB, Esliger DW, van Sluijs EMF, Andersen LB, Anderssen S, Cardon G, Davey R, et al: **Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD).** *The international journal of behavioral nutrition and physical activity* 2015, **12:**113-113.
55. van Sluijs EMF, Skidmore PML, Mwanza K, Jones AP, Callaghan AM, Ekelund U, Harrison F, Harvey I, Panter J, Wareham NJ, et al: **Physical activity and dietary behaviour in a population-based sample of British 10-year old children: the SPEEDY study (Sport, Physical activity and Eating behaviour: environmental Determinants in Young people).** *BMC public health* 2008, **8:**388-388.
56. Jago R, Salway R, Emm-Collison L, Sebire SJ, Thompson JL, Lawlor DA: **Association of BMI category with change in children's physical activity between ages 6 and 11 years: a longitudinal study.** *International journal of obesity (2005)* 2020, **44:**104-113.
57. Dumith SC, Gigante DP, Domingues MR, Kohl HW, 3rd: **Physical activity change during adolescence: a systematic review and a pooled analysis.** *Int J Epidemiol* 2011, **40:**685-698.

58. Sallis JF: **Age-related decline in physical activity: a synthesis of human and animal studies.** *Med Sci Sports Exerc* 2000, **32:**1598-1600.
59. Telama R, Yang X: **Decline of physical activity from youth to young adulthood in Finland.** *Med Sci Sports Exerc* 2000, **32:**1617-1622.
60. van Mechelen W, Twisk JW, Post GB, Snel J, Kemper HC: **Physical activity of young people: the Amsterdam Longitudinal Growth and Health Study.** *Med Sci Sports Exerc* 2000, **32:**1610-1616.
61. Kimm SY, Glynn NW, Obarzanek E, Kriska AM, Daniels SR, Barton BA, Liu K: **Relation between the changes in physical activity and body-mass index during adolescence: a multicentre longitudinal study.** *Lancet* 2005, **366:**301-307.
62. Sherar LB, Esliger DW, Baxter-Jones AD, Tremblay MS: **Age and gender differences in youth physical activity: does physical maturity matter?** *Med Sci Sports Exerc* 2007, **39:**830-835.
63. Azevedo MR, Menezes AM, Assuncao MC, Goncalves H, Arumi I, Horta BL, Hallal PC: **Tracking of physical activity during adolescence: the 1993 Pelotas Birth Cohort, Brazil.** *Rev Saude Publica* 2014, **48:**925-930.
64. Telama R: **Tracking of physical activity from childhood to adulthood: a review.** *Obes Facts* 2009, **2:**187-195.
65. Hallal PC, Victora CG, Azevedo MR, Wells JC: **Adolescent physical activity and health: a systematic review.** *Sports Med* 2006, **36:**1019-1030.
66. Rauner A, Mess F, Woll A: **The relationship between physical activity, physical fitness and overweight in adolescents: a systematic review of studies published in or after 2000.** *BMC Pediatr* 2013, **13:**19.
67. Twisk JW, Kemper HC, van Mechelen W: **The relationship between physical fitness and physical activity during adolescence and cardiovascular disease risk factors at adult age. The Amsterdam Growth and Health Longitudinal Study.** *Int J Sports Med* 2002, **23 Suppl 1:**S8-14.
68. Twisk JW, Kemper HC, van Mechelen W: **Tracking of activity and fitness and the relationship with cardiovascular disease risk factors.** *Med Sci Sports Exerc* 2000, **32:**1455-1461.
69. Raitakari OT, Porkka KV, Taimela S, Telama R, Rasanen L, Viikari JS: **Effects of persistent physical activity and inactivity on coronary risk factors in children and young adults. The Cardiovascular Risk in Young Finns Study.** *Am J Epidemiol* 1994, **140:**195-205.
70. Tammelin T, Laitinen J, Nayha S: **Change in the level of physical activity from adolescence into adulthood and obesity at the age of 31 years.** *Int J Obes Relat Metab Disord* 2004, **28:**775-782.
71. Kvaavik E, Tell GS, Klepp KI: **Predictors and tracking of body mass index from adolescence into adulthood: follow-up of 18 to 20 years in the Oslo Youth Study.** *Arch Pediatr Adolesc Med* 2003, **157:**1212-1218.
72. Ramires VV, Dumith SC, Wehrmeister FC, Hallal PC, Menezes AM, Goncalves H: **Physical activity throughout adolescence and body composition at 18 years: 1993 Pelotas (Brazil) birth cohort study.** *Int J Behav Nutr Phys Act* 2016, **13:**105.
73. Network SBR: **Letter to the Editor: Standardized use of the terms "sedentary" and "sedentary behaviours".** *Appl Physiol Nutr Metab* 2012, **37:**540-542.
74. Spanier PA, Marshall SJ, Faulkner GE: **Tackling the obesity pandemic: a call for sedentary behaviour research.** *Can J Public Health* 2006, **97:**255-257.
75. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, Goldfield G, Gorber SC: **Systematic review of sedentary behaviour and health indicators in school-aged children and youth.** *Int J Behav Nutr Phys Act* 2011, **8:**1-22.
76. Carson V, Hunter S, Kuzik N, Gray CE, Poitras VJ, Chaput JP, Saunders TJ, Katzmarzyk PT, Okely AD, Connor Gorber S, et al: **Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update.** *Appl Physiol Nutr Metab* 2016, **41:**S240-265.

77. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF: **Adults' sedentary behavior determinants and interventions.** *Am J Prev Med* 2011, **41:**189-196.
78. Uijtdewilligen L, Nauta J, Singh AS, van Mechelen W, Twisk JW, van der Horst K, Chinapaw MJ: **Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies.** *Br J Sports Med* 2011, **45:**896-905.
79. Stierlin AS, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy MH, Kennedy A, O'Donoghue G, Chastin SF, De Craemer M: **A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study.** *Int J Behav Nutr Phys Act* 2015, **12:**133.
80. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman SM, Norris SA: **Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates.** *BMC Public Health* 2014, **14**.
81. Smith L, Gardner B, Hamer M: **Childhood correlates of adult TV viewing time: a 32-year follow-up of the 1970 British Cohort Study.** *J Epidemiol Community Health* 2015, **69:**309-313.
82. Hancox RJ, Milne BJ, Poulton R: **Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study.** *Lancet* 2004, **364:**257-262.
83. Viner RM, Cole TJ: **Television viewing in early childhood predicts adult body mass index.** *J Pediatr* 2005, **147:**429-435.
84. McVeigh J, Smith A, Howie E, Straker L: **Trajectories of Television Watching from Childhood to Early Adulthood and Their Association with Body Composition and Mental Health Outcomes in Young Adults.** *PLoS One* 2016, **11:**e0152879.
85. Gradisar M, Gardner G, Dohnt H: **Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep.** *Sleep Med* 2011, **12:**110-118.
86. Owens J, Adolescent Sleep Working G, Committee on A: **Insufficient sleep in adolescents and young adults: an update on causes and consequences.** *Pediatrics* 2014, **134:**e921-e932.
87. Colrain IM, Baker FC: **Changes in sleep as a function of adolescent development.** *Neuropsychol Rev* 2011, **21:**5-21.
88. Thorleifsdottir B, Bjornsson JK, Benediktsdottir B, Gislason T, Kristbjarnarson H: **Sleep and sleep habits from childhood to young adulthood over a 10-year period.** *J Psychosom Res* 2002, **53:**529-537.
89. Yang CK, Kim JK, Patel SR, Lee JH: **Age-related changes in sleep/wake patterns among Korean teenagers.** *Pediatrics* 2005, **115:**250-256.
90. Hagenauer MH, Perryman JI, Lee TM, Carskadon MA: **Adolescent changes in the homeostatic and circadian regulation of sleep.** *Dev Neurosci* 2009, **31:**276-284.
91. Carskadon MA, Vieira C, Acebo C: **Association between puberty and delayed phase preference.** *Sleep* 1993, **16:**258-262.
92. Ringli M, Huber R: **Developmental aspects of sleep slow waves: linking sleep, brain maturation and behavior.** *Prog Brain Res* 2011, **193:**63-82.
93. Carskadon MA: **Sleep in adolescents: the perfect storm.** *Pediatr Clin North Am* 2011, **58:**637-647.
94. Short MA, Gradisar M, Wright H, Lack LC, Dohnt H, Carskadon MA: **Time for bed: parent-set bedtimes associated with improved sleep and daytime functioning in adolescents.** *Sleep* 2011, **34:**797-800.
95. Ogunleye AA, Voss C, Sandercock GR: **Delayed bedtime due to screen time in schoolchildren: importance of area deprivation.** *Pediatr Int* 2015, **57:**137-142.
96. Hale L, Guan S: **Screen time and sleep among school-aged children and adolescents: a systematic literature review.** *Sleep Med Rev* 2015, **21:**50-58.

97. Jakobsson M, Josefsson K, Jutengren G, Sandsjö L, Högberg K: **Sleep duration and sleeping difficulties among adolescents: exploring associations with school stress, self-perception and technology use.** *Scandinavian journal of caring sciences* 2019, **33:**197-206.
98. Marco CA, Wolfson AR, Sparling M, Azuaje A: **Family socioeconomic status and sleep patterns of young adolescents.** *Behav Sleep Med* 2011, **10:**70-80.
99. El-Sheikh M, Bagley EJ, Keiley M, Elmore-Staton L, Chen E, Buckhalt JA: **Economic adversity and children's sleep problems: multiple indicators and moderation of effects.** *Health Psychol* 2013, **32:**849-859.
100. Bagley EJ, Kelly RJ, Buckhalt JA, El-Sheikh M: **What keeps low-SES children from sleeping well: the role of presleep worries and sleep environment.** *Sleep Med* 2015, **16:**496-502.
101. Zapata Roblyer MI, Grzywacz JG: **Demographic and Parenting Correlates of Adolescent Sleep Functioning.** *J Child Fam Stud* 2015, **24:**3331-3340.
102. Chennaoui M, Arnal PJ, Sauvet F, Leger D: **Sleep and exercise: a reciprocal issue?** *Sleep Med Rev* 2015, **20:**59-72.
103. Kubitz KA, Landers DM, Petruzzello SJ, Han M: **The effects of acute and chronic exercise on sleep. A meta-analytic review.** *Sports Med* 1996, **21:**277-291.
104. Lang C, Kalak N, Brand S, Holsboer-Trachsler E, Puhse U, Gerber M: **The relationship between physical activity and sleep from mid adolescence to early adulthood. A systematic review of methodological approaches and meta-analysis.** *Sleep Med Rev* 2016, **28:**32-45.
105. Master L, Nye RT, Lee S, Nahmod NG, Mariani S, Hale L, Buxton OM: **Bidirectional, Daily Temporal Associations between Sleep and Physical Activity in Adolescents.** *Scientific reports* 2019, **9:**7732-7732.
106. Olds TS, Maher CA, Matricciani L: **Sleep duration or bedtime? Exploring the relationship between sleep habits and weight status and activity patterns.** *Sleep* 2011, **34:**1299-1307.
107. Bayon V, Leger D, Gomez-Merino D, Vecchierini MF, Chennaoui M: **Sleep debt and obesity.** *Ann Med* 2014, **46:**264-272.
108. Miller MA, Kruisbrink M, Wallace J, Ji C, Cappuccio FP: **Sleep Duration and Incidence of Obesity in Infants, Children and Adolescents: A Systematic Review and Meta-Analysis of Prospective Studies.** *Sleep* 2018.
109. Cappuccio FP, Taggart FM, Kandala NB, Currie A, Peile E, Stranges S, Miller MA: **Meta-analysis of short sleep duration and obesity in children and adults.** *Sleep* 2008, **31:**619-626.
110. Fatima Y, Doi SA, Mamun AA: **Longitudinal impact of sleep on overweight and obesity in children and adolescents: a systematic review and bias-adjusted meta-analysis.** *Obes Rev* 2015, **16:**137-149.
111. Schafer AA, Domingues MR, Dahly DL, Meller FO, Goncalves H, Wehrmeister FC, Assuncao MC: **Sleep Duration Trajectories and Body Composition in Adolescents: Prospective Birth Cohort Study.** *PLoS One* 2016, **11:**e0152348.

Chapter 3: Overview of Methodological Approaches

3.1 Study Setting and Design

Birth-to-Twenty Plus (BT20+) is an interdisciplinary investigation following individuals residing in Soweto-Johannesburg, South Africa [1]. Soweto, which stands for South Western Township, is an urban area approximately 15km outside of the Johannesburg Central Business District. The area came into existence mainly to accommodate displaced Black South Africans from Johannesburg after the passing of a racial segregation policy on residential areas by the South African Apartheid government in 1950 [2].

In 1990, the greater Johannesburg area had a population of about 3.5 million and spanned approximately 200 km^2[3]. Rapid unplanned urbanization led to high population growth and left many residents with limited health care and other social amenities [4]. It was anticipated that this rapid urbanization would have a profound impact on the health and development of resident children [4]. The original intent of the BT20+ Cohort, initially knows as the Birth-to-Ten Cohort, was to track the growth, health, well-being and educational progress of urban South African children across the first decade of their life [1, 4]. After the first 10 years, the study transitioned towards answering specific questions related to risk associated with life-style, including sexual and reproductive disorders, bone health, cardiovascular disease and diabetes and became known as the Birth-to-Twenty Cohort [3]. Now known as BT20+, the cohort is the largest and longest running study of adolescent health and development in Africa, and one of the few large-scale longitudinal studies in the world [1].

BT20 participants, part of the first cohort growing up in a democratic South Africa, are colloquially referred to as Mandela's Children for the proximity of their births to February 11, 1990, the date of Nelson Mandela's release from prison [1]. Pregnant women who were at a gestational age of 26 to 40 weeks and expected to deliver between April and June 1990 were recruited through public antenatal clinics [5]. All singleton children born to Soweto-Johannesburg residents and residing in the area for at least six months were eligible for inclusion [1]. The rational for this requirement was the large number of women who would came from rural areas to deliver babies in the city and then return home [1]. Children were identified from the compulsory official birth notification forms completed by clinic/hospital personnel or from clinic/hospital records [5].

According to records, 5,460 births occurred in the study area during the 7-week enrollment period. Of these births, 3,273 children met the cohort entry criteria of remaining in the study area for at least 6 months, and were enrolled in the study [5]. The sample is representative of urban South Africa; 78% black and approximately equal numbers of male (49%) and female (51%) participants [1]. The cohort has had a relatively low attrition rate of 30% over 20 years, with nearly 2,300 participants still in contact with the study. The majority of attrition cases occurred in the first few years of the study, primarily due to migration out of the study area [1, 6].

3.2 Dissertation Data

Data for the Bt20+ Cohort have been collected at 22 time points from antenatal to young-adulthood with the most extensive waves of data collection occurring in early childhood (age 5 years), pre-puberty (age 7-8 years), puberty (age 12 years), post-puberty (age 15 years), late adolescence (age 17 years) and young-adulthood (age 22-24 years). This dissertation utilized data from the adolescent years (ages 12-17 years) and early/young-adulthood (age 18 years).

3.2.1 Primary exposures and outcomes

Physical activity, sedentary behavior and sleep were self-reported using a questionnaire developed to be appropriate for South African children and validated in a South African population [7]. Informal activity includes physical activity during school breaks or outside of school, and not part of a sports team or club, such as skipping, traditional games and playing with a ball. Due to a change in questionnaire format in the year 13 data collection cycle related to the shift to secondary school, we did not include informal activity at age 12 in our analyses. Physical education was defined as any exercise class supervised by a teacher during school time. School sport was defined as any extra-mural sport organized by the school; club sport was defined as any private extra-mural sport, for example, club soccer. Active transportation was defined as walking or biking to and from school, however few participants reported using bicycles, so we included only time spent walking in analyses. Details on data collection for primary exposures and outcomes of interest are presented in table 2.1.

Table 3.1 Data collection details for primary exposures and outcome, Bt20+ Cohort

Category	Instrument/method	Variables	Ages/time points measured
Physical activity	Retrospective interview	Physical activity over the past 12 months in multiple domains: informal/play activity, physical education, school sports, club sports, active transportation	12, 13, 14, 15, 17-18y
Sedentary behavior	Retrospective interview	Sedentary activities before or after school including watching TV and videos; reading, drawing, homework; playing a musical instrument; playing video/computer games; and internet surfing	12, 13, 14, 15, 17-18y
Sleep	Retrospective interview	What time the respondent went to bed and woke up on school-nights and weekends/holidays	13, 14, 15, 17-18y
Anthropometry	Standard protocols	Height (cm), weight (kg), BMI (kg/m^2), waist-circumference (cm)	All time points
Body composition	Dual-energy X-ray absorptiometer (DXA)	Whole body lean tissue (g), whole body fat tissue (g), percent body fat (%)	18y

We calculated informal activity minutes per week by summing the minutes spent per day in each of the three most frequent activities. At ages 13, 14 and 15 years respondents were asked to choose from a pre-determined list of activities common to South African youth (figure 2.2). At age 17 years respondents were free to list any 3 informal activities. We calculated physical education minutes per week by multiplying the reported number of classes per week by the reported number of minutes per class. We created a composite measure of organized sport by combining reported minutes per week of school sports and club sports. For each reported sport we calculated the reported minutes per week or practices and competitions using the following formula:

$$\frac{minutes}{week}_{sport1} = \left[\left(\frac{practices}{week}_{sport1} x \frac{minutes}{practice}_{sport1}\right) + \left(\frac{competitions}{week}_{sport1} x \frac{minutes}{competition}_{sport1}\right)\right]$$

To account for seasonality of sports, we then multiplied the reported minutes per week of each sport by the reported months per year the sport was played. This value was used to calculate average minutes per week over the 52-week year. We then summed the reported number of minutes per week across all reported sports. Because duration of competition was not included in the questionnaire, we inferred a value for each sport based on sport-specific rules (e.g., rugby has two 40-minute halves). If a sport had no rules governing the duration of competition (e.g., gymnastics or tennis), we inferred a duration of 60 minutes. To better represent moderate-vigorous intensity physical activity (MVPA) participation, only sports with a metabolic equivalent (MET) value ≥3 based on the Compendium of Physical Activity for Youth were included [8]. Walking to and from school minutes per week was calculated as the sum of minutes per day spent walking to school and minutes per day spent walking home, multiplied by 5 days per week. We calculated total sedentary behavior minutes per week by summing the reported time spent per day (Monday to Sunday) in each of the activities. We calculated the minutes of sleep per night on school days and weekends/ holidays as the difference between the time the participant reported going to bed and the time the participant reported waking up. Because bedtime and wake time were recorded as categorical variables at age 13, we did not include these data in our analyses.

Informal activities
Do you engage in any physical activity during **school breaks** or **outside school**, for example riding a bike, playing in the street or yard? **NOT** activity as part of a sports team or club. Tick the three most frequent activities that you do, and time spent on each activity.

Activity	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Riding a bike							
Playing with a ball							
Skipping							
Hop scotch							
Dibeke (tin game)							
Bhati (tennis ball game)							
Mgusha (panty hose game)							
Skateboarding/ roller-skating							
Other (list)							

Figure 3.2 Pre-determined list of informal activities deemed common among South African children

3.2.2 Participant characteristics, predictors and covariates

We selected potential predictors and covariates *a priori* using a socio-ecological approach, including factors at the individual, maternal and household level [9-12] Socio-ecological models provide a framework for understanding factors that promote or hinder health behaviors and focuses on the social and physical environments in addition to individual characteristics[11]. Our selected predictors were household assets (proxy for SES), maternal schooling, mother's marital/ union status, and parity. Details on data collection for participant characteristics, potential predictors and covariates are presented in table 3.2.

Table 3.2 Data collection details for participant characteristics, potential predictors, and covariates, Bt20+ Cohort

Category	Instrument/method	Variables	Ages/time points measured
Individual (birth)	Birth notification forms or hospital records	Birth order	Birth
Individual (child)	Standard protocols	BMI Z-score	7/8 or 9 y
Maternal variables	Retrospective interview	Maternal schooling (matriculated/ did not matriculate)), marital status (in union/ not in union)	7/8y
Household variables	Retrospective interview	Household physical assets (proxy for SES): score based on mother's /caregiver's response yes/no for home type, home ownership, electricity in the home, and ownership of a television, car, refrigerator, washing machine, and phone. Divided into quintiles.	7/8y

Household physical assets were used as a proxy for socio-economic status. Making use of methods developed by Sheppard et al., a validated standardized questionnaire based on the Demographic and Health survey for developing countries (available at http://www.dhsprogram.com/) was used to calculate an asset score using variables for home type, home ownership, electricity in the home, and ownership of a television, car, refrigerator, washing machine, and phone[13]. Mothers were asked whether they had the asset in question (yes/no). The affirmative answers were tallied and then categorized into quintiles. We dichotomized the variables for mother's schooling to 1=matriculated from secondary school, 0=did not matriculate, mother's marriage/union status to 1=in union (married), 0= not in union (single, divorced/separated, widowed), and birth order to 1=firstborn, 0= not firstborn.

3.2.3 Inclusion and exclusion

All analyses will be restricted to Black African participants, due to low study retention in the other ethnic groups [3]. Trajectories in Empirical Chapter 1 will be generated from participants with at least 2 measures of physical activity, sedentary behavior and sleep. At least 2 time points are needed to ensure model stability in Latent Class Growth Analysis (as described in section 3.3.1.1) [14]. Analyses for Empirical Chapter 2 will be limited to participants who meet the criteria for Empirical Chapter 1 and have either anthropometric (BMI and waist circumference) or detailed body composition (fat mass, lean mass and percent body fat) data at age 18 years.

3.3 Statistical Analyses

We stratified all analyses by sex due to well-established sex differences in adolescent physical activity levels [15-18] and previously described sex differences in adolescent fat mass and lean mass accrual.

3.3.1 Trajectory Analyses

3.3.1.1 Latent Class Growth Analysis

We used Latent Class Growth Analysis (LCGA) in MPlus 7.3 (Muthén & Muthén) to group participants into distinct classes based on common longitudinal trajectories of informal activity, physical education, organized sports, walking to and from school, sedentary behavior, school-night sleep and weekend sleep. LCGA is a type of Growth Mixture Modeling (GMM) where it is assumed that the estimated variance and covariance of the growth factors within each class are fixed to zero [14]. The benefits of fixing the within-class variances to zero are less computational burden and the clearer identification of classes [14]. LCGA takes a “person-centered” as opposed to a “variable-centered” analyses approach and is recommended when a single growth curve may not describe the variables of interest in the population adequately [14].

If a population is homogeneous, it can be described by a single growth curve. However, if a population is heterogeneous, it may be best to use growth mixture modeling techniques. In LCGA (and other GMM methods), intra-individual change over time can be described as a function of class membership. The likelihood of belonging to a specific class, is determined by similarity in initial values of the observed variable (intercept) and change in the observed variable over time (slope). The primary goal of LCGA is to estimate the probability of belonging to a particular class, or development pattern, over time. The growth mixture model, as described by Jung and Wickrama, is depicted in figure 3.3 [14]. The diagram consists of trajectory of longitudinally measured observed variable T, with an intercept of I and a slope of S. This is summarized into a categorical class variable, C. Predictors or covariates are represented by X, and the outcome variable is represented by Y/U.

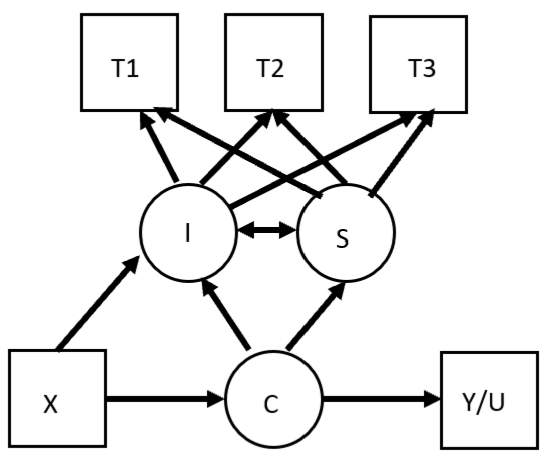


Figure 3.3 Representation of a growth mixture model with covariates (adapted from Jung and Wickrama, 2008 [14])

The LCGA approach can identify individuals whose behaviors may deviate from the norm, or represent a greater health risk, for example, those in a declining physical activity trajectory. Characteristics of these individuals can then be compared to a those in a normal or "healthy" referent group, for example, those in a consistently high physical activity trajectory. Predictors of unfavorable trajectories can be determined. Additionally, trajectory membership can be used to predict a distal health outcome later in life, for example, adult obesity.

MPlus handles missing data using the expectation-maximization algorithm with the assumption that the data are missing at random [19]. This uses the full information maximum likelihood estimation with missing values by using estimation to integrate all available information based on missing at random assumptions [19]. This approach used in MPlus prevents potential biases that result from not including participants with missing data [19].

The first step of LCGA is to determine the optimal number of latent classes [14]. We did this using Bayesian Information Criteria (BIC), entropy, the Lo-Medell-Rubin-Likelihood Ratio Test (LMR-LRT), and the Bootstrap Likelihood Ratio Test (BLRT) [14]. The best model was considered the one with the lowest BIC value, highest entropy significant Lo-Medell-Rubin-Likelihood Ratio Test (LMR-LRT) and significant Bootstrap Likelihood Ratio Test (BLRT) [14]. In addition to model fit indices, we also considered the percentage of participants per class, parsimony, theoretical justification and interpretability [14]. We employed a restriction requiring at least 5% per class to avoid small group sizes. After establishing the number of trajectory classes, participants were assigned to a class based on the individual's maximum posterior probability [14].

3.3.1.2 Group-Based Multi-Trajectory Modeling

To summarize overall physical activity pattern, we performed group-based multi-trajectory modeling. This modeling technique is designed to identify latent clusters of individuals following similar trajectories over multiple indicators of an outcome (e.g. overall physical activity pattern throughout adolescence as measured by informal activity trajectory, organized sports trajectory and walking to and from school trajectory) [20]. This method allowed us to define a multi-trajectory “group” in terms of trajectories from the 3 physical activity domains. The first step in group-based multi-trajectory modeling is choosing the best model [20, 21]. We did this using a two-stage model selection process as described by Nagin, 2005 [21]. In the first stage, we determined the optimal number of groups based on BIC and ability to distinguish between groups [20, 21]. The preferred model had the lowest BIC and distinct groupings of trajectories (i.e. not two groups looked the same) [20, 21]. In the second stage, we determined the preferred order of the polynomial defining the shape of each trajectory, given the number of groups selected in the first stage [20, 21]. We also used group-based multi-trajectory modeling to see if the sedentary behavior and school-night sleep trajectories tracked over time with the 3 physical activity domains. We employed the same methods described above but added sedentary behavior and sleep to the model. We conducted the group-based multi-trajectory analysis using a plug-in for Stata version 14 downloaded from http://www.andrew. cmu.edu/user/bjones/traj [20].

3.3.2 Overall Analysis Plan

This aims of this dissertation were carried out in a series of steps detailed in figure 3.4.

Step 1

-Compile physical activity, sedentary behavior and sleep data from ages 12-17 years

-Calculate minutes per week (physical activity domains, sedentary behavior) and minutes per night (sleep) at each time point

Step 2

-Choose optimal number of classes for LCGA using BIC, entropy, LMR-LMT, BLRT, and percentage per class

-Choose the optimal number of groups for multi-trajectory models using BIC and ability to distinguish between groups

-Choose the polynomial order that best fits multi-trajectory model

Step 3

-Record each individual's posterior probability of belonging to specific trajectories and multi-trajectory groups

-Assign membership to trajectories and multi-trajectory groups based on posterior probabilities

Step 4 (output for Empirical Chapter 1)

-Describe adolescent physical activity, sedentary behavior and sleep trajectories and multi-trajectory groups from step 4

-Relate *a priori* selected childhood socio-ecological predictors to adolescent trajectories and multi-trajectory groups using multinomial logistic regression

Step 5 (output for Empirical Chapter 2)

-Relate adolescent trajectories and multi-trajectory groups from step 4 to BMI and waist-circumference at age 18 using generalized linear models

-Use significant predictors identified in step 4 as covariates (if also thought to be related to anthropometric and body composition outcomes)

Figure 3.4 Overall analysis plan of dissertation

References for Chapter 3

1. Richter L, Norris S, Pettifor J, Yach D, Cameron N: **Cohort Profile: Mandela's children: the 1990 Birth to Twenty study in South Africa.** *Int J Epidemiol* 2007, **36:**504-511.
2. Mesthrie US: **Tinkering and Tampering: A Decade of the Group Areas Act (1950–1960).** *South African Historical Journal* 1993, **28:**177-202.
3. Richter LM, Norris SA, De Wet T: **Transition from Birth to Ten to Birth to Twenty: the South African cohort reaches 13 years of age.** *Paediatr Perinat Epidemiol* 2004, **18:**290-301.
4. Yach D, Cameron N, Padayachee N, Wagstaff L, Richter L, Fonn S: **Birth to ten: child health in South Africa in the 1990s. Rationale and methods of a birth cohort study.** *Paediatr Perinat Epidemiol* 1991, **5:**211-233.
5. Richter LM, Yach D, Cameron N, Griesel RD, de Wet T: **Enrolment into Birth to Ten (BTT): population and sample characteristics.** *Paediatr Perinat Epidemiol* 1995, **9:**109-120.
6. Richter LM, Panday S, Norris SA: **Factors influencing enrolment: A case study from Birth to Twenty, the 1990 birth cohort in Soweto–Johannesburg.** *Eval Program Plann* 2009, **32:**197-203.
7. McVeigh J, Norris S, Cameron N, Pettifor J: **Criterion validity and test-retest reliability of a physical activity questionnaire in South African primary school aged children.** *J Sports Med* 2012**:**43-48.
8. Butte N, Watson K, Ridley K, Zakeri I, McMurray R, Pfeiffer K, Crouter S, Hermann S, Bassett D, Long A, et al: **A Youth Compendium of Physical Activities Codes and Metabolic Intensities.** *Med Sci Sports Exer* 2018, **50:**246-456.
9. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW: **Correlates of physical activity: why are some people physically active and others not?** *Lancet* 2012, **380:**258-271.
10. Uijtdewilligen L, Nauta J, Singh AS, van Mechelen W, Twisk JW, van der Horst K, Chinapaw MJ: **Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies.** *Br J Sports Med* 2011, **45:**896-905.
11. F. Sallis J, Owen N, Fisher E: *Ecological Models of Health Behavior.*2008.
12. Muthuri SK, Onywera VO, Tremblay MS, Broyles ST, Chaput JP, Fogelholm M, Hu G, Kuriyan R, Kurpad A, Lambert EV, et al: **Relationships between Parental Education and Overweight with Childhood Overweight and Physical Activity in 9-11 Year Old Children: Results from a 12-Country Study.** *PLoS One* 2016, **11:**e0147746.
13. Sheppard ZA, Norris SA, Pettifor JM, Cameron N, PL. G: **Approaches for assessing the role of household socioeconomic status on child anthropometric measures in urban South Africa.** *American journal of human biology* 2009, **21:**48-54.
14. Jung T, Wickrama KAS: **An introduction to latent class growth analysis and growth mixture modeling.** *Social and Personality Psych Compass* 2008, **2:**302-317.
15. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman S, Norris SA: **Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates.** *BMC Public Health* 2014, **14:**40.
16. Marques A, Carreiro da Costa F: **Levels of physical activity of urban adolescents according to age and gender.** *International Journal of Sports Science* 2013, **3:**23-27.
17. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U: **Global physical activity levels: surveillance progress, pitfalls, and prospects.** *Lancet* 2012, **380:**247-257.
18. Dumith SC, Gigante DP, Domingues MR, Kohl HW, 3rd: **Physical activity change during adolescence: a systematic review and a pooled analysis.** *Int J Epidemiol* 2011, **40:**685-698.
19. Muthen BO, Muthen LK: **MPlus User's Guide. 1998-2012, Seventh Edition.**
20. Nagin D, Jones B, Passos V, Tremblay R: **Group-based multi-trajectory modeling.** *Statistical Methods in Medical Research* 2016**:**0962280216673085.

21. Nagin DS: *Group-based modeling of development.* Cambridge, MA: Harvard University Press; 2005.

Part 2: Empirical Chapters

Empirical Chapter 1

Chapter 4

Longitudinal Patterns of Physical Activity, Sedentary Behavior and Sleep in Urban South African Adolescents, Birth-To-Twenty Plus Cohort

Longitudinal Patterns of Physical Activity, Sedentary Behavior and Sleep in Urban South African Adolescents, Birth-To-Twenty Plus Cohort [a]

Sara K. Hanson[1,2], Lisa K. Micklesfield[2], Felipe Lobelo[3], Solveig A. Cunningham[3], Terryl J. Hartman[3,4], Shane A. Norris[2,3], Aryeh D. Stein[3,4]

[1]Doctoral Program in Nutrition and Health Sciences, Laney Graduate School, Emory University, Atlanta, GA,

[2]MRC/Wits Developmental Pathways for Health Research Unit, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa,

[3]Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA

[4]Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA

Author email addresses: sara.hanson@emory.edu, lisa.micklesfied@wits.zc.za felipelobelo@emory.edu, sargese@emory.edu, tjhartm@emory.edu, shane.norris@wits.ac.za, Aryeh.stein@emory.edu

Corresponding author: Aryeh D Stein, Aryeh.stein@emory.edu

[a] Manuscript published as: Hanson SK, Munthali RJ, Micklesfield LK, Lobelo F, Cunningham SA, Hartman TJ, Norris SA, Stein AD: Longitudinal patterns of physical activity, sedentary behavior and sleep in urban South African adolescents, Birth-To-Twenty Plus cohort. *BMC Pediatr* 2019, 19:241.

4.1 Abstract

Background: Adolescence is a critical phase of human development that lays the foundation for health in later life. Of the 1.8 billion adolescents in the world, roughly 90% live in low and middle-income countries. Yet most longitudinal studies of adolescent physical activity, sedentary behavior, and sleep come from high-income countries. There is a need for a better understanding of these behaviors to inform obesity and chronic disease prevention strategies.

Aim: The aim of this study is to identify longitudinal patterns and associations between physical activity, sedentary behavior and sleep in urban South African adolescents.

Methods: We analyzed data from the Birth-to-Twenty Plus Cohort (Bt20+), a longitudinal study of children in Soweto, Johannesburg, South Africa. Behaviors were self-reported annually between ages 12 and 17 y. We used Latent Class Growth Analysis to group participants into classes based on common longitudinal trajectories of time spent in informal physical activity, organized sports, walking to and from school, sedentary behavior, and school-night and weekend sleep, respectively. We performed group-based multi-trajectory modeling to identify latent clusters of individuals who followed similar trajectories of informal physical activity, organized sports and walking to and from school, and who followed similar trajectories of these three domains together with sedentary behavior and sleep.

Results: The large majority of males (82%) and all females failed to meet the World Health Organization (WHO) physical activity recommendation for adolescents of 60 min of moderate-vigorous intensity physical activity per day. The physical activity domains clustered together in three multi-trajectory groups that define individuals' overall physical activity pattern. While two patterns indicated decreases in physical activity throughout adolescence, one pattern, including 29% of the sample in males and 17% of the sample in females, indicated higher levels of activity throughout adolescence. Sedentary behavior and sleep trajectories did not cluster together with the physical activity domains.

Conclusion: Most adolescents in this South African population did not meet WHO recommendations for physical activity. In this population, trajectories of sedentary behavior and sleep were independent of physical activity.

Keywords: Adolescence; Low or middle income country; Physical activity; Sedentary behavior; Sleep.

4.2 Background

Adolescence is a critical phase of human development between childhood and adulthood that lays the foundation for later life health [1, 2]. The current generation of people aged 10–24 years is the largest in human history and makes up nearly a quarter of the world's population. [3] However, because adolescents typically have low mortality and chronic disease rates, this population has until recently been relatively neglected in global health research and policy [4, 5]. The recent releases of the World Health Organization (WHO) Recommendations on Adolescent Health and the Lancet Commission on Adolescent Health and Wellbeing have focused interest on adolescent health [6, 7].

Health-related risk behaviors (e.g., physical activity, dietary habits, initiation of smoking) adopted during adolescence can have substantial effects on later health, including increased risk of obesity, coronary heart disease, diabetes, some cancers and premature death [8–10]. Globally, an estimated 80% of 13–15 year-olds do not meet the current WHO physical activity recommendation of 60 min of moderate to vigorous intensity physical activity per day [6, 9, 11]. In the last decade, sedentary behavior has been identified as its own health risk, independent of physical activity [12, 13], and the majority of children and adolescents exceed the recommendations of 2 h or less of screen time daily [14–16]. Insufficient sleep in adolescence is recognized as a serious health risk, yet data from multiple countries suggest that most adolescents are sleeping fewer hours than the 8–10 h that they need [17–20]. There is increasing interest in considering the set of movement behaviors as whole rather than considering them separately [21, 22].

Of the 1.8 billion adolescents in the world, roughly 90% live in low- or middle-income countries (LMICs) [3, 4]. Many LMICs are experiencing an epidemiological transition characterized by a shifting burden from infectious to non-communicable diseases [23]. As the burden of non-communicable diseases in LMICs continues to rise, there is a need for research on modifiable risk factors that could better inform prevention strategies [24]. However, longitudinal data on modifiable risk factors spanning adolescence are rare. Specifically, the Lancet Physical Activity Series Working Group highlights a severe lack of data from Africa [11, 20].

Since South Africa's political transformation in 1994, the country has undergone rapid urbanization, globalization and socioeconomic change [25]. An increasing prevalence of overweight and obesity and shifts in dietary patterns in urban South African youth have been observed [26, 27]. Patterns of physical activity, sedentary behavior and sleep may be contributing to the high prevalence of overweight and obesity, but these behaviors in urban South African adolescents remain unexplored. Therefore, the aims of this study are to describe longitudinal patterns of physical activity, sedentary behavior and sleep in urban South African adolescents and identify factors that predict these patterns.

4.3 Methods

<u>Study sample</u>

We analyzed data from participants in the Birth-to-Twenty Plus Cohort (Bt20+), a longitudinal study of singleton children born between April and June 1990 in Soweto and in Johannesburg, South Africa. Detailed information on the cohort is provided elsewhere [28, 29]. Singleton children born in public hospitals to Soweto or Johannesburg residents and residing in the area for at least 6 months after the birth were eligible for inclusion. Of all 5449 births notified in the study area, 3,273 met the residency eligibility criterion and were recruited. Most attrition occurred in the first few years of the study, primarily due to migration out of the study area [30]. At inception the cohort was 78% Black African, with approximately equal numbers of males (49%) and females (51%); attrition was higher for White cohort members [31]. Ethical approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects (approval ID #M010556). Written participant assent and caregiver permission to participate in the study were obtained at each wave.

Assessment of movement behaviors

Physical activity and sedentary behavior were self-reported at ages 12, 13, 14, 15, 16 and 17/18 years using a questionnaire developed for South African children and validated in a South African population (Additional file 1) [32]. Respondents were asked to report about frequency and duration of informal physical activity, physical education at school, school sports, club sports and active transportation on a typical week over the past 12 months. Informal physical activity includes physical activity during school breaks or outside of school and not part of a sports team or club, such as skipping, traditional games and playing with a ball; respondents were asked to report on the duration of the three most frequent activities. Due to changes in the wording of the questionnaire between age 12 and age 13, we did not include informal physical activity at age 12 in our analyses. Physical education was defined as any exercise class supervised by a teacher during school time. School sport was defined as any extramural sport organized by the school; club sport was defined as any private extramural sport. Active transportation was defined as walking or biking to and from school; as few participants reported using bicycles, we included only time spent walking in our analyses. Questions regarding sedentary behavior included time spent watching television and videos; reading, drawing and homework; playing a musical instrument; playing video/computer games, and internet surfing, before and after school. At ages 13, 14, 15, 16 and 17/18 years, respondents reported the times they went to bed and woke up on school nights and weekends/holidays, from which we calculated hours of sleep. No information was solicited on quality of sleep.

We calculated informal physical activity minutes by summing the minutes spent per week in each of the three most frequent activities. We calculated physical education minutes by multiplying the reported number of classes per week by the reported number of minutes per class. We created a composite measure of organized sport by combining reported minutes per week of school sports and club sports. We inferred duration of competition for each sport based on sport-specific rules (e.g., rugby has two 40-min halves). If a sport had no rules governing the duration of competition (e.g., gymnastics or tennis), we inferred a duration of 60 min. We then summed the reported number of minutes per week across all reported sports. To better represent moderate-vigorous intensity physical activity (MVPA) participation, only sports with a metabolic equivalent (MET) value ≥3 based on the Compendium of Physical Activity for Youth were included [33]. Walking minutes per week was calculated as the sum of minutes per day spent walking to and from school, multiplied by 5 days per week. Intensity of walking was not reported, and we did not include this walking in our estimate of MVPA. We calculated total sedentary behavior minutes per week by summing the reported time spent per day in each of the activities.

Predictors of movement behaviors

We selected potential predictors a priori, including factors at the individual, maternal and household level [34–37]. All these variables were collected by questionnaire administered to the mother at recruitment into the cohort or at child age 7/8 y. Covariates include socio-economic status (SES) at child age 7/8 years, mother's schooling at child age 7/8 y (matriculated from secondary school, did not matriculate), mother's marital/union status at child age 7/8 y (in union, not in union) and whether the child was first-born or not. These variables have been identified as correlates of physical activity and sedentary behavior in childhood in a subset of Bt20+ participants and in adolescence in rural South Africa [38, 39]. Household physical assets at age 7/8 were used as a proxy for socio-economic status (SES). A validated standardized questionnaire based on the Demographic and Health survey for developing countries was used to calculate an asset score [40]. Mothers were asked about home type, home ownership, electricity in the home, and ownership of a television, car, refrigerator, washing machine, and phone. The resulting score was categorized into quintiles.

Inclusion and exclusion

We restricted analyses to participants who were Black African due to low numbers of the other ethnic groups. Analyses were further restricted to participants who had physical activity, sedentary behavior and sleep data for at least two data points between the ages of 12 and 17/18 years to ensure model stability.

Statistical analyses

We stratified all analyses by sex due to well-established sex differences in adolescent physical activity levels [11, 39, 41, 42]. We conducted a sensitivity analysis by comparing SES asset quintile, mother's education, mother's marital /union status, mother's age at delivery, and parity, between participants who met inclusion criteria (Black African ethnicity and ≥ 2 data points) and participants who did not meet inclusion criteria, using chi-square tests. Descriptive summary data are presented as 25th percentile (Q1), median (Q2) and 75th percentile (Q3) for time spent in physical activity, sedentary behavior and sleep (Table 1).

We used Latent Class Growth Analysis (LCGA) to group participants into distinct classes based on common longitudinal trajectories of informal physical activity, physical education, organized sports, walking to and from school, sedentary behavior, school-night sleep or weekend sleep. LCGA is a type of Growth Mixture Modeling where it is assumed that the estimated variance and covariance of the growth factors within each class are fixed to zero [43]. We used full information maximum likelihood estimation to integrate all available information based on missing at random assumptions [44].

We determined the optimal number of latent classes using Bayesian Information Criterion (BIC), entropy, the Lo-Medell-Rubin-Likelihood Ratio Test (LMR-LRT) and the Bootstrap Likelihood Ratio Test (BLRT) [43]. The best model was considered the one with the lowest BIC value, highest entropy significant LMR-LRT, and significant BLRT. In addition to model fit indices, we also considered the percentage of participants per class, parsimony, theoretical justification and interpretability [43]. We implemented a restriction requiring at least 5% per class to avoid small group sizes. After establishing the number of trajectory classes, we assigned participants to a class based on the individual's maximum posterior probability. Because we determined there to be only one physical education trajectory class in both males and females, we did not include this domain in subsequent analyses. We explored the relationships between individual trajectory classes across domains using chi-square tests. We identified predictors of trajectory class membership for each movement behavior using multinomial logistic regression. We conducted the LCGA in MPlus 7.3 [44] and the logistic regression in Stata version 14. We set significance at $p < 0.05$.

To describe overall movement behavior patterns, we performed multi-trajectory modeling. This modeling technique is designed to identify latent clusters, or multi-trajectory "groups," of individuals following similar trajectories over multiple indicators of an outcome [45]. We examined two sets of multi-trajectory models: (1) overall physical activity - informal physical activity, organized sports and walking to and from school; and (2) overall movement behavior defined by the 3 physical activity domains, sedentary behavior and school-night sleep. For both overall physical activity and overall movement behavior, we chose the preferred multi-trajectory model using a two-stage model selection process. In the first stage, we determined the number of multi-trajectory groups based on BIC model fit statistics, practical interest and ability to distinguish between groups. In the second stage, we determined the preferred order of the polynomial defining the shape of each trajectory, given the number of groups selected in the first stage [46]. We compared characteristics of the multi-trajectory groups using chi-square tests, and identified predictors of multi-trajectory group membership using multinomial logistic regression. We conducted the multi-trajectory analysis using a plug-in for Stata version 14 [45].

4.4 Results

These analyses included 1,414 participants (of whom 745 were female), representing 43% of the source population. A flow chart depicting the final sample of eligible participants included in the analyses is provided in Supplemental Figure 4.1. Based on information collected at age 7/8 years, 29% of males and 31% of females had mothers who matriculated from secondary school, 29% of males and 36% of females had mothers who were married/in a union and 38% of males and 41% of females were firstborn (Table 4.1). There were no significant differences in study characteristics between males included in the analytic sample and males excluded for lack of movement behavior data. Among females, there was a significantly higher percentage of mothers in a union at child age 7/8 years, and a significantly lower percentage of first-born children in those who were excluded compared to those who were included.

<u>Identification of trajectories</u>

Duration of all forms of physical activity decreased over adolescence, while sedentary behavior increased and duration of weekend sleep remained stable, in both males and females (Table 4.2). School night sleep decreased across adolescence in males but remained stable in females.

We identified 2 trajectories for informal physical activity for males, with one (93% of the sample) showing a steady decrease in physical activity from age 13–18 years and the other showing a steady increase (Figure 4.1). In females, we also identified two informal physical activity trajectories with one (95% of the sample) showing a steady decrease and the other showing a decrease followed by a sharp increase at age 16 years. For organized sports, we identified 3 trajectories for males: consistently low (82%), increasing (11%) and decreasing (8%) and two for females, representing no participation (89%) or some participation in organized sports from age 12. We identified 2 trajectories of walking to and from school, lower (representing 82 and 75% of males and females, respectively) and higher.

For sedentary behavior, we identified 3 trajectories in males, showing steady lower (78%), steady higher (10%) and increasing (12%) and 2 trajectories in females, increasing (92%) and steady higher (Figure 4.2). For school-night sleep, we identified 4 trajectories in males and 3 trajectories in females. For weekend sleep, we identified 3 trajectories for males and 4 trajectories for females. Model fit statistics of individual trajectories are provided in Supplemental Tables 4.1 and 4.2.

Associations between trajectories

In males, the distribution of the sedentary behavior trajectories was independent of the distributions of all the physical activity domain trajectories (Supplemental Table 4.3). In females, the distribution of the sedentary behavior trajectories differed across the distribution of the walking to and from school trajectories ($p = 0.04$) but was independent of the distributions of the informal physical activity and organized sport trajectories (Supplemental Table 4.4). In both males and females, the distributions of school-night sleep trajectories and weekend sleep trajectories differed across the distribution of sedentary behavior trajectories ($p < 0.001$ and $p = 0.002$). The distribution of the school-night sleep trajectories differed by the distribution of the walking to and from school trajectory in females but not in males ($p = 0.001$) (Supplemental Tables 4.5 and 4.6).

Predictors of trajectory class membership

Informal physical activity: Being in a higher SES quintile was associated with higher likelihood of being in the steady increasing trajectory compared to the steady decreasing trajectory among males (Relative Risk Ratio (RRR) =1.48 95% CI: 1.11–1.98) (Table 4.3).

Walking to and from school: Being in a higher SES quintile and having a mother who matriculated from secondary school were each associated with lower likelihood of being in the higher trajectory compared to the lower trajectory in males (RRR = 0.81 95% CI: 0.66–0.98 and RRR = 0.55 95% CI: 0.33–0.99) and females (RRR = 0.68 95% CI 0.58–0.81 and RRR = 0.47 95% CI: 0.28–0.80).

Sedentary behaviors: Among males, having a mother who matriculated from secondary school was associated with higher likelihood of being in the increasing trajectory compared to the steady lower trajectory (RRR = 1.82 95% CI: 1.02–3.25).

Sleep: In adjusted models, having a mother who matriculated from secondary school was associated with over two times the likelihood of being in the 8 h per night trajectory and over three times the likelihood of being in the 7 h per night trajectory compared to the 9 h per night trajectory in males and lower likelihood of being in the 9 h per night trajectory compared to the 8 h per night trajectory (RRR = 0.82 95% CI: 0.70–0.95 and RRR = 0.46 95% CI: 0.30–0.72) in females.

None of these variables were associated with informal physical activity or sedentary behavior trajectories in females or with organized sport and weekend sleep trajectories in either males or females.

Multi-trajectory modeling

Overall physical activity: We identified 3 multi-trajectory groups for males and for females (Figure 3). In both male and female multi-trajectory groups 1 and 3, informal physical activity and organized sport trajectories declined throughout adolescence. The main distinguishing characteristic between groups 1 and 3 was the level of walking to and from school. Group 2 maintained higher levels of both informal physical activity and organized sports than groups 1 and 3 and had a walking to and from school trajectory similar to group 3. Group 1, representing 23% of the sample in males and 32% of the sample in females, respectively, can be described as “Decreasing Activity, non-walkers”, group 2 (29 and 17%, respectively) as “Active, walkers” and group 3 (48 and 51%, respectively) as “Decreasing activity, walkers.” Model fit statistics of the physical activity multi-trajectory groups are shown in Supplemental Table 4.7.

Higher SES quintile and having a mother who matriculated from secondary school were each associated with increased likelihood of being in group 1 (“Decreasing Activity, non-walkers”) compared to group 3 (“Active, walkers”) but were not associated with risk of being in group 3 (“Decreasing activity, walkers” compared to group 2 in either males or females (Table 4.4).

Multi-trajectory modeling of all movement behaviors

Overall movement behaviors: We identified 4 multi-trajectory groups for males and 2 for females (Figure 4.4). Model fit statistics are shown in Supplemental Table 4.8. In males, the most notable distinctions between the multi-trajectory groups were seen among the 3 physical activity trajectories, with the sedentary behavior and sleep trajectories in each group being nearly identical. In females, the primary distinction between multi-trajectory groups related to walking to and from school, with the other trajectories showing minimal differences between the two groups.

4.5 Discussion

Given the increasing prevalence of overweight and obesity throughout childhood and adolescence in South Africa [26], there has been interest in exploring modifiable lifestyle factors. This study identified distinct sex-specific trajectories of movement behaviors in a cohort of urban South African adolescents.

The patterns of overall physical activity trends, as described by the physical activity multi-trajectory groups, were similar between males and females in this study population, though the amounts of both informal physical activity and organized sports were higher in males. Overall physical activity decreased from age 12 to 17 years. This is consistent with findings from high-income countries [42]. However, we identified groups of both males and females (29 and 17%, respectively) who showed a pattern of maintaining physical activity across adolescence. Understanding what sets these individuals apart may provide valuable information for intervention research and forms the basis for future research.

The WHO recommends that adolescents get 60 min of moderate to vigorous intensity physical activity per day [6]. In our study, organized sports can be considered as a proxy for MVPA, and 82% of males and 100% of females failed to meet these recommendations throughout adolescence. An additional 8% of males met the recommendation in early adolescence but then declined below the recommendation by age 14 years. In contrast, 11% of males did not meet the recommendation in early adolescence but increased their activity to meet the recommendation after age 15 years. Among females, 89% did not participate in any organized sports throughout adolescence. Even in the remaining 11% who did participate in organized sports, none met the recommended duration.

Physical activity behavior is multi-dimensional and influenced by a diverse set of factors [47]. Among the males in our study, participants in a higher asset quintile (a proxy for SES) were more likely to be in the increasing informal physical activity trajectory than the decreasing trajectory. This association was not seen in females. Male adolescents from higher SES families may have fewer household responsibilities than males from lower SES families and females, giving them more free time for play and leisure-time activities. Both males and females from a higher asset quintile were more likely to be in the trajectory that represented lower walking to and from school, which may be indicative of family car ownership or greater access to transportation options. Asset quintile was not related to categorization into organized sports trajectory in either males or females. Micklesfield et al. in rural South African adolescents and McVeigh et al. in a younger subset of this cohort, reported that lower SES was associated with less time spent in school and club sports [38, 39]. Older youth living in an urban setting may have more access to school and club sports than the rural and younger participants in the previously described studies.

Research and public health interventions among adolescents have typically focused on increasing physical activity [48]. However, higher sedentary behavior (i.e. too much sitting), independent of physical activity, is associated with adverse health outcomes [49]. In our study, every sedentary behavior trajectory showed sedentary behavior durations over 2 h per day.

Adolescent sedentary behaviors have been shown to track over time, but most previous studies have used methods that did not assume population heterogeneity [50, 51]. Two studies from high –income country settings that followed participants from ages 5 to 19/20 years demonstrated that sedentary behavior was stable in some participants during the adolescent years of the studies but increased or decreased over time in others [52, 53]. We found a similar pattern in this South African birth cohort, with trajectories of both stable and increasing sedentary time in males and females. We however did not observe a trajectory that decreased over time.

Adolescent sleep has been recognized as a public health concern, with many countries reporting high prevalence of sleep disturbance among youth [20], but little is known about the sleep patterns of adolescents in Africa. In our study, all but the smallest trajectories of males (5%) and females (7%) met the National Sleep Foundation's guideline for adolescents of 8–10 h of sleep per day [54], but we lack information about the quality of this sleep. In contrast, a 2002 cross-sectional study by Reid et al. in urban South African adolescents reported a total sleep time of just over 7 h, high percentages of daytime napping and sleepiness during school, suggesting insufficient sleep [55]. Unlike most studies of adolescent sleep from around the world, we did not find a decline in sleep time through adolescence [20, 56].

Prior research has found a positive association between SES and sedentary behavior in LMICs [38, 39, 57]. We found no association between asset quintile and sedentary behavior trajectories, but that males whose mothers matriculated from secondary school had higher likelihood of being in the steeper increasing trajectory for sedentary time compared to the consistently lower trajectory. Additionally, we found that higher maternal schooling was associated with being in the lower school-night sleep trajectories in both males and females, consistent with other findings in a low-income setting [58]. Adolescents with more educated parents may be more likely to have smartphones and computers with access to Wi-Fi. They may also receive more academic pressure at home, and therefore may spend more time doing homework, a component of sedentary behavior. Further, these adolescents may delay bedtime trying to complete homework and therefore sleep for a shorter duration.

To our knowledge, this is the first study to use multi-trajectory modeling to represent the associations between multiple physical activity domains in adolescents. This approach allowed us to identify domain-specific patterns while still assessing overall physical activity. In both males and females, those who decreased time spent in organized sports throughout adolescence also decreased informal physical activity, and those who maintained higher levels of organized sports maintained higher levels of informal physical activity. This finding adds to the evidence that organized sport participants are more physically active overall than non-participants and supports the need for strategies to increase and maintain organized sport participation rates [59, 60].

Consistent with our single trajectory analysis, adolescents with higher SES were more likely to be in the “decreasing activity, non-walkers” category compared to the “decreasing activity, walkers”. SES was not associated with being in the “active, walker” group compared to the “decreasing, activity walker” group, indicating that the association between SES and physical activity multi-trajectory group is driven by the walking trajectory. While we did not see an association between birth order and individual trajectories, first-born females were less likely to be an “active, walker” than a “decreasing activity, walker.” This could be due to greater household responsibilities (perhaps having to help look after younger siblings) and therefore less time for play and sports in first-born female children.

Sedentary behavior has been viewed as displacing physical activity and as an independent health risk behavior [61]. Results from studies linking sedentary behavior and physical activity levels have been mixed [62]. We found that females who reported initially lower sedentary behavior reported more walking to and from school. The longer time spent walking may mean less time for sedentary activities once at home. The lack of relation between sedentary behavior and informal physical activity and organized sports in both males and females suggests that sedentary time was not displacing these activities.

Sleep and physical activity are thought to reciprocally influence each other through multiple physiological and psychosocial factors [63]. Regular MVPA has been associated with increased total sleep time and sleep quality in adolescents [64]. Daytime sleepiness resulting from insufficient sleep may lead to physical inactivity. We found that school-night sleep trajectory membership differed across walking to and from school trajectories in both males and females but did not differ across informal physical activity or organized sport trajectories. These findings suggest a possible time displacement of sleep for walking (such as having to get up early to walk to school). We found that school-night sleep trajectory membership also differed across sedentary behavior trajectory in both males and females, with those reporting more sedentary behavior reporting less sleep. This could be due to higher use of screen-based devices at night delaying bedtimes.

While multi-trajectory modeling was useful for summarizing physical activity behaviors in this population, we had limited success modeling physical activity together with sedentary behavior and sleep. We were able to create distinct multi-trajectory groups in males, but the primary distinctions between groups were in the physical activity domains. In females, the only distinction between groups was the walking to and from school trajectory. The goal of multi-trajectory modeling is to highlight heterogeneity in the linkage between trajectories of distinct behaviors that are thought to have common underlying etiological processes [45]. Our results indicate that physical activity, sedentary behavior and sleep may have different etiological processes in this urban South African population and should be looked at as independent health risk behaviors.

Strengths and limitations

A major strength of our study was the use of longitudinal data throughout adolescence. Another strength of our study was the use of LCGA to group participants into common longitudinal trajectories of physical activity domains, sedentary behavior and sleep. The goal of LCGA is to model individual trajectories and is recommended when a single growth curve may not describe the variables of interest in the population adequately.

The use of LCGA comes with some limitations. In LCGA, class membership is inferred using a series of exploratory analyses to determine the best fitting model. The validity of LCGA may be questioned because model fit statistics may not adequately differentiate between a model with multiple latent classes and a single-class model with non-normal outcomes [65]. However, using multiple indicators of model fit strengthens the validity of our findings [66]. Both LCGA and multi-trajectory modeling assign class/group membership based on estimated posterior probabilities from a maximum likelihood analysis. Not all participants follow a trajectory/group perfectly and misclassification can occur [43, 45]. Our attempt to generate multi-trajectory groups that included physical activity, sedentary behavior and sleep had limited success, as there was not enough heterogeneity in the linkages between these behaviors in this population to identify clusters of individuals in terms of these outcomes together. The questionnaires changed slightly over time. All the measures we analyzed were self-reported, and we do not have data on intensity of informal physical activity or walking or on quality of sleep.

4.6 Conclusion

The majority of this population of South Africa adolescents did not meet WHO recommendations for physical activity and demonstrated a decline over the adolescent period. In this population, trajectories of sedentary behavior and sleep were independent of physical activity.

4.7 References for Chapter 4

1. Sawyer SM, Afifi RA, Bearinger LH, Blakemore SJ, Dick B, Ezeh AC, Patton GC. **Adolescence: a foundation for future health**. Lancet. 2012;379:1630–1640.
2. Patton George C., Olsson Craig A., Skirbekk Vegard, Saffery Richard, Wlodek Mary E., Azzopardi Peter S., Stonawski Marcin, Rasmussen Bruce, Spry Elizabeth, Francis Kate, Bhutta Zulfiqar A., Kassebaum Nicholas J., Mokdad Ali H., Murray Christopher J. L., Prentice Andrew M., Reavley Nicola, Sheehan Peter, Sweeny Kim, Viner Russell M., Sawyer Susan M. **Adolescence and the next generation.** Nature.
3. UNFPA: State of the World's Population. **The power of 1.8 billion-adolescents, youth and the transformation of the future**. 2014.
4. Dick B, Ferguson BJ. **Health for the world's adolescents: a second chance in the second decade**. J Adolesc Health. 2015;56:3–6.
5. Resnick MD, Catalano RF, Sawyer SM, Viner R, Patton GC. **Seizing the opportunities of adolescent health**. Lancet. 2012;379:1564–1567
6. WHO **. WHO recommendation on adolescent health: guidelines approved by the WHO guidelines review committee**. Geneva: World Health Organization; 2017.
7. Patton GC, Santelli JS, Ross DA, Afifi R, Allen NB, Arora M, Azzopardi P, Baldwin W, Bonell C, Kakuma R, et al. **Our future: a lancet commission on adolescent health and wellbeing**. Lancet. 2016;387:2423–2478.
8. Gore FM, Bloem PJ, Patton GC, Ferguson J, Joseph V, Coffey C, Sawyer SM, Mathers CD. **Global burden of disease in young people aged 10-24 years: a systematic analysis**. Lancet. 2011;377:2093–2102.
9. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. **Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy**. Lancet. 2012;380:219–229.
10. Hallal PC, Victora CG, Azevedo MR, Wells JC. **Adolescent physical activity and health: a systematic review**. Sports Med. 2006;36:1019–1030.
11. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. **Global physical activity levels: surveillance progress, pitfalls, and prospects**. Lancet. 2012;380:247–257.
12. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee IM, Jakicic JM. **Definition, measurement, and health risks associated with sedentary behavior**. Med Sci Sports Exerc. 2015;47:1295–1300.
13. Katzmarzyk PT. **Physical activity, sedentary behavior, and health: paralysis or paradigm shift?** Diabetes. 2010;59:2717–2725.
14. **Australia's Physical Activity & Sedentary Behaviour Guidelines for Children (5-12 years) 2014** [http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines]. Accessed 16 July 2019.
15. Tremblay MS, Leblanc AG, Janssen I, Kho ME, Hicks A, Murumets K, Colley RC, Duggan M. **Canadian sedentary behaviour guidelines for children and youth**. Appl Physiol Nutr Metab. 2011;36:59–64.
16. **Australian Health Survey: Physical Activity, 2011–12** [http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/462FBA87B642FCA4CA257BAC0015F3CE?opendocument]. Accessed 16 July 2019.
17. Wheaton AG, Olsen EO, Miller GF, Croft JB**. Sleep duration and injury-related risk behaviors among high school students--United States, 2007-2013**. MMWR Morb Mortal Wkly Rep. 2016;65:337–341.

18. Yang CK, Kim JK, Patel SR, Lee JH. **Age-related changes in sleep/wake patterns among Korean teenagers**. Pediatrics. 2005;115:250–256.
19. Millman RP. **Excessive sleepiness in adolescents and young adults: causes, consequences, and treatment strategies.** Pediatrics. 2005;115:1774–1786.
20. Gradisar M, Gardner G, Dohnt H**. Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep**. Sleep Med. 2011;12:110–118.
21. Tremblay MS, Carson V, Chaput JP, Connor Gorber S, Dinh T, Duggan M, Faulkner G, Gray CE, Gruber R, Janson K, et al. **Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep**. Appl Physiol Nutr Metab. 2016;41:S311–S327.
22. Carson V, Tremblay MS, Chaput JP, Chastin SF**. Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses**. Appl Physiol Nutr Metab. 2016;41:S294–S302.
23. Santosa A, Wall S, Fottrell E, Hogberg U, Byass P. **The development and experience of epidemiological transition theory over four decades: a systematic review.** Glob Health Action. 2014;7:23574.
24. Sallis JF, Owen N, Fotheringham MJ. **Behavioral epidemiology: a systematic framework to classify phases of research on health promotion and disease prevention**. Ann Behav Med. 2000;22:294–298.
25. Chopra M, Lawn JE, Sanders D, Barron P, Abdool Karim SS, Bradshaw D, Jewkes R, Abdool Karim Q, Flisher AJ, Mayosi BM, et al. **Achieving the health millennium development goals for South Africa: challenges and priorities.** Lancet. 2009;374:1023–1031.
26. Lundeen EA, Norris SA, Adair LS, Richter LM, Stein AD**. Sex differences in obesity incidence: 20-year prospective cohort in South Africa.** Pediatr Obes. 2016;11:75–80.
27. Feeley A, Musenge E, Pettifor JM, Norris SA**. Changes in dietary habits and eating practices in adolescents livng in urban South Africa: the birth to twenty cohort.** Nutriton. 2012;28:e1–e6
28. Richter L, Norris S, Pettifor J, Yach D, Cameron N. **Cohort profile: Mandela's children: the 1990 birth to twenty study in South Africa.** Int J Epidemiol. 2007;36:504–511.
29. Richter LM, Norris SA, De Wet T. **Transition from birth to ten to birth to twenty: the south African cohort reaches 13 years of age.** Paediatr Perinat Epidemiol. 2004;18:290–301.
30. Richter LM, Panday S, Norris SA**. Factors influencing enrolment: a case study from birth to twenty, the 1990 birth cohort in Soweto–Johannesburg**. Eval Program Plann. 2009;32:197–203.
31. Richter LM, Yach D, Cameron N, Griesel RD, de Wet T. **Enrolment into birth to ten (BTT): population and sample characteristics.** Paediatr Perinat Epidemiol. 1995;9:109–120.
32. McVeigh J, Norris S, Cameron N, Pettifor J. **Criterion validity and test-retest reliability of a physical activity questionnaire in south African primary school aged children**. J Sports Med. 2012;24:43–48.
33. Butte N, Watson K, Ridley K, Zakeri I, McMurray R, Pfeiffer K, Crouter S, Hermann S, Bassett D, Long A, et al. **A youth compendium of physical activities Codes and Metabolic Intensities**. Med Sci Sports Exer. 2018;50:246–456.
34. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW. **Correlates of physical activity: why are some people physically active and others not?** Lancet. 2012;380:258–271.
35. Uijtdewilligen L, Nauta J, Singh AS, van Mechelen W, Twisk JW, van der Horst K, Chinapaw MJ. **Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies.** Br J Sports Med. 2011;45:896–905.
36. Sallis JF, Owen N, Fisher E. **Ecological models of health behavior**. 2008.

37. Muthuri SK, Onywera VO, Tremblay MS, Broyles ST, Chaput JP, Fogelholm M, Hu G, Kuriyan R, Kurpad A, Lambert EV, et al. **Relationships between parental education and overweight with childhood overweight and physical activity in 9-11 year old children: results from a 12-country study.** PLoS One. 2016;11:e0147746.
38. McVeigh J, Norris S, de Wet T. **The relationship between socio-economic status and physical activity patterns in south African children**. Acta Paediactr. 2004;93:982–988.
39. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman S, Norris SA**. Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates.** BMC Public Health. 2014;14:40.
40. **The DHS Program. Demographic and Health Surveys** https://www.dhsprogram.com/. Accessed 16 July 2019.
41. Marques A, Carreiro da Costa F**. Levels of physical activity of urban adolescents according to age and gender.** Int J Sports Sci. 2013;3:23–27.
42. Dumith SC, Gigante DP, Domingues MR, Kohl HW., **3rd Physical activity change during adolescence: a systematic review and a pooled analysis**. Int J Epidemiol. 2011;40:685–698.
43. Jung T, Wickrama KAS**. An introduction to latent class growth analysis and growth mixture modeling**. Soc Personal Psychol Compass. 2008;2:302–317.
44. Muthen BO, Muthen LK. MPlus User's Guide. 7 1998.
45. Nagin Daniel S, Jones Bobby L, Passos Valéria Lima**,** Tremblay Richard E**. Group-based multi-trajectory modeling.** Statistical Methods in Medical **R**esearch. 2016;27(7):2015–2023.
46. Nagin DS. **Group-based modeling of development.** Cambridge, MA: Harvard University Press; 2005.
47. Bauman AE, Sallis JF, Dzewaltowski DA, Owen N. **Toward a better understanding of the influences on physical activity:** the role of determinants, correlates, causal variables, mediators, moderators, and confounders. Am J Prev Med. 2002;23:5–14.
48. Spanier PA, Marshall SJ, Faulkner GE. **Tackling the obesity pandemic: a call for sedentary behaviour research**. Can J Public Health. 2006;97:255–257.
49. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, Goldfield G, Gorber SC. **Systematic review of sedentary behaviour and health indicators in school-aged children and youth.** Int J Behav Nutr Phys Act. 2011;8:1–22.
50. Biddle SJH, Pearson N, Ross GM, Braithwaite R. **Tracking of sedentary behaviours of young people: a systematic review.** Prev Med. 2010;51:345–351. doi: 10.1016/j.ypmed.2010.07.018.
51. Francis SL, Stancel MJ, Sernulka-George FD, Broffitt B, Levy SM, Janz KF. **Tracking of TV and video gaming during childhood: Iowa bone development study**. Int J Behav Nutr Phys Act. 2011;8:100.
52. McVeigh J, Smith A, Howie E, Straker L. **Trajectories of television watching from childhood to early adulthood and their association with body composition and mental health outcomes in young adults**. PLoS One. 2016;11:e0152879.
53. Kwon S, Janz KF, Letuchy EM, Burns TL, Levy SM**. Developmental trajectories of physical activity, sports, and television viewing during childhood to young adulthood: Iowa bone development study**. JAMA Pediatr. 2015;169:666–672.
54. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, Hazen N, Herman J, Katz ES, Kheirandish-Gozal L, et al**. National Sleep Foundation's sleep time duration recommendations: methodology and results summary.** Sleep Health. 2015;1:40–43.
55. Reid A, Maldonado CC, Baker FC. **Sleep behavior of south African adolescents**. Sleep. 2002;25:423–427.

56. Schafer AA, Domingues MR, Dahly DL, Meller FO, Goncalves H, Wehrmeister FC, Assuncao MC. **Sleep duration trajectories and body composition in adolescents: prospective birth cohort study.** PLoS One. 2016;11:e0152348.
57. Mielke GI, Brown WJ, Nunes BP, Silva ICM, Hallal PC. **Socioeconomic correlates of sedentary behavior in adolescents: systematic review and meta-analysis.** Sports Med. 2017;47:61–75.
58. Zapata Roblyer MI, Grzywacz JG. **Demographic and parenting correlates of adolescent sleep functioning**. J Child Fam Stud. 2015;24:3331–3340.
59. Telford RM, Telford RD, Cochrane T, Cunningham RB, Olive LS, Davey R. **The influence of sport club participation on physical activity, fitness and body fat during childhood and adolescence: the LOOK longitudinal study.** J Sci Med Sport. 2016;19:400–406.
60. Basterfield L, Reilly JK, Pearce MS, Parkinson KN, Adamson AJ, Reilly JJ, Vella SA. **Longitudinal associations between sports participation, body composition and physical activity from childhood to adolescence.** J Sci Med Sport. 2015;18:178–182.
61. Hancox RJ, Milne BJ, Poulton R. **Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study.** Lancet. 2004;364:257–262.
62. Melkevik O, Torsheim T, Iannotti RJ, Wold B**. Is spending time in screen-based sedentary behaviors associated with less physical activity: a cross national investigation**. Int J Behav Nutr Phys Act. 2010;7:46.
63. Chennaoui M, Arnal PJ, Sauvet F, Leger D**. Sleep and exercise: a reciprocal issue?** Sleep Med Rev. 2015;20:59–72.
64. Kubitz KA, Landers DM, Petruzzello SJ, Han M. **The effects of acute and chronic exercise on sleep.** A meta-analytic review. Sports Med. 1996;21:277–291.
65. Bauer DJ, Curran PJ. **Overextraction of latent trajectory classes: much ado about nothing?** Reply to Rindskopf (2003), Muthén (2003), and Cudeck and Henly (2003) Psychol Methods. 2003;8:384–393.
66. Muthen B**. Statistical and substantive checking in growth mixture modeling: comment on Bauer and Curran (2003)** Psychol Methods. 2003;8:369–377.

4.8 Chapter 4 Tables and Figures

Table 4.1. Characteristics of the study sample by sex, Birth-to-Twenty Plus cohort, Johannesburg, South Africa

	Males			Females		
	Included [a]	Excluded	P-value	Included	Excluded	P-value
N	669	577		745	577	
SES-asset quintile, % [b]	17	22	0.19	22	28	0.19
1 (lowest)	20	19		18	22	
2	30	31		29	25	
3	22	16		19	15	
4	11	12		12	10	
5 (highest)	29	25	0.24	31	30	0.74
Mother married or in union, % [b]	29	36	0.32	36	44	0.04
Mother's age at delivery, %						
< 25 y	48	47	0.24	47	43	0.28
25–29 y	23	27		24	28	
≥30 y	29	25		29	28	
Child was first-born, %	38	33	0.05	41	32	0.001

[a] Among participants who are of Black African ethnicity, provided activity data at ≥2 time points

[b] Ascertained by interview of the mother at child age 7/8 y

Table 4.2. Duration of physical activity, sedentary behavior and sleep behaviors through adolescence, by sex, Birth-to-Twenty Plus cohort, Johannesburg, South Africa

	12 y				13 y				14 y				15 y				16 y				17 y			
	Any[a]	Q1[b]	Q2	Q3	Any	Q1	Q2	Q3	Any	Q1	Q2	Q3	Any	Q1	Q2	Q3	Any	Q1	Q2	Q3	Any	Q1	Q2	Q3
	%	Min/ wk	Min/ wk	Min/ wk	%	Min/ wk	Min/ wk	Min/ wk	%	Min/ wk	Min/ wk	Min/ wk	%	Min/ wk	Min/ wk	Min/ wk	%	Min/ wk	Min/ wk	Min/ wk	%	Min/ wk	Min/ wk	Min/ wk
Males	N = 502				N = 669				N = 634				N = 640				N = 660				N = 640			
Informal activity [c]	--	--	--	--	94	210	360	638	92	180	360	615	82	60	210	480	51	0	30	240	59	0	120	360
Physical education [c]	49	0	0	150	27	0	0	30	22	0	0	0	15	0	0	0	35	0	0	60	38	45	90	120
Organized sports [c]	84	46	186	383	81	37	138	355	66	0	92	300	46	0	0	245	41	0	0	138	43	0	0	174
Walking to/from school [c]	76	10	150	250	75	0	150	250	81	50	150	250	87	50	150	200	77	20	100	200	70	0	100	200
Sedentary behavior [d]	100	540	750	750	100	660	990	1500	100	660	990	1680	100	990	1470	1950	100	840	1335	2040	100	1050	1633	2310
School-night sleep [d]	--	--	--	--	--	--	--	--	100	480	540	570	100	480	510	570	100	480	510	540	100	450	480	540
Weekend sleep [d]	--	--	--	--	--	--	--	--	100	540	600	630	100	540	600	660	100	540	600	660	100	540	600	660
Females	N = 578				N = 745				N = 705				N = 705				N = 735				N = 702			
Informal activity [c]	--	--	--	--	90	150	275	510	82	60	210	300	62	0	60	240	30	0	0	45	21	0	0	0
Physical education [c]	47	0	0	120	35	0	0	60	25	0	0	60	20	0	0	0	36	0	0	60	31	60	90	135
Organized sports [c]	73	0	55	149	69	0	55	148	49	0	0	94	15	0	0	0	26	0	0	9	22	0	0	0
Walking to/from school l [c]	72	0	150	263	72	0	150	300	75	10	150	300	78	30	150	300	67	0	100	200	57	0	70	225
Sedentary behavior [d]	100	540	780	1080	100	750	1080	1680	100	660	1020	1680	100	1110	1740	2370	100	1020	1655	2340	100	1260	1950	2790
School-night sleep [d]	--	--	--	--	--	--	--	--	100	480	510	540	100	450	510	540	100	459	510	520	100	420	480	540
Weekend sleep [d]	--	--	--	--	--	--	--	--	100	540	600	630	100	540	600	660	100	540	600	660	100	540	600	660

[a] Respondents reporting at least 1 min per week of specific behavior
[b] Q1: 25th percentile; Q2: 50th percentile; Q3: 75th percentile
[b] Minutes per week
[d] Minutes per night

-- Module not administered

Table 4.3. Relative risk ratios and 95% confidence intervals for predictors of trajectory class membership, Birth-to-Twenty Plus cohort, Johannesburg, South Africa

Males		Females	
	RRR (95% CI)		RRR (95% CI)
Informal Physical Activity			
Class 1--- decreasing (ref)		Class 1--- decreasing (ref)	
Class 2--- increasing		Class 2--- decreasing then increase at 16 y	
SES (asset quintile)	1.48 (1.11–1.98)	SES (asset quintile)	0.95 (0.71–1.29)
mother's schooling	0.59 (0.26–1.34)	mother's schooling	1.04 (0.45–2.43)
mother's marriage/union status	0.48 (0.23–1.01)	mother's marriage/union status	0.71 (0.32–1.58)
parity	0.59 (0.28–1.24)	parity	0.70 (0.32–1.52)
Pseudo R2	0.04	Pseudo R2	0.006
Organized Sports			
Class 1--- consistently low (ref)		Class 1--- no participation (ref)	
Class 2--- increasing		Class 2--- some participation	
SES (asset quintile)	0.86 (0.68–1.10)	SES (asset quintile)	1.04 (0.84–1.30)
mother's schooling	1.53 (0.81–2.87)	mother's schooling	0.93 (0.51–1.71)
mother's marriage/union status	1.15 (0.63–2.10)	mother's marriage/union status	0.76 (0.42–1.36)
parity	1.25 (0.69–2.29)	parity	1.07 (0.62–1.86)
Class 3--- decreasing			
SES (asset quintile)	1.00 (0.75–1.33)		
mother's schooling	1.01 (0.48–2.14)		
mother's marriage/union status	0.87 (0.43–1.75)		
parity	1.31 (0.66–2.61)		
Pseudo R2	0.007	Pseudo R2	0.003
Walking to and from school			
Class 1--- lower (ref)		Class 1--- lower (ref)	
Class 2--- higher		Class 2--- higher	
SES (asset quintile)	0.81 (0.66–0.98)	SES (asset quintile)	0.68 (0.58–0.81)
mother's schooling	0.55 (0.31–0.99)	mother's schooling	0.47 (0.28–0.80)
mother's marriage/union status	0.70 (0.43–1.14)	mother's marriage/union status	1.12 (0.73–1.72)
parity	0.69 (0.42–1.14)	parity	0.84 (0.55–1.29)
Pseudo R2	0.04	Pseudo R2	0.07
Sedentary Behavior			
Class 1--- stable lower (ref)		Class 1--- increasing (ref)	
Class 2--- increasing'		Class 2--- stable higher	
SES (asset quintile)	1.08 (0.86–1.36)	SES (asset quintile)	1.29 (0.99–1.67)
mother's schooling	1.64 (0.91–2.96)	mother's schooling	1.50 (0.76–2.94)
mother's marriage/union status	1.46 (0.83–2.56)	mother's marriage/union status	1.18 (0.62–2.25)
parity	1.11 (0.63–1.98)	parity	0.78 (0.40–1.51)
Class 3--- stable higher			
SES (asset quintile)	1.06 (0.85–1.34)		
mother's schooling	1.82 (1.02–3.25)		
mother's marriage/union status	1.52 (0.87–2.65)		
parity	1.14 (0.76–2.35)		
Pseudo R2	0.02	Pseudo R2	0.03
School-night Sleep			

Class 1--- 9 h/night (ref)		Class 1---8 h/night (ref)	
Class 2--- 8 h/night		Class 2---9 h/night	
SES (asset quintile)	1.10 (0.93–1.29)	SES (asset quintile)	0.82 (0.70–0.95)
mother's schooling	2.43 (1.58–3.74)	mother's schooling	0.46 (0.30–0.72)
mother's marriage/union status	1.35 (0.90–2.02)	mother's marriage/union status	0.80 (0.54–1.18)
parity	0.70 (0.46–1.07)	parity	0.90 (0.62–1.32)
Class 3--- 10 h/night		Class 3--- 6.5 h/night	
SES (asset quintile)	0.79 (0.59–1.04)	SES (asset quintile)	1.11 (0.84–1.45)
mother's schooling	0.55 (0.20–1.50)	mother's schooling	1.18 (0.59–2.32)
mother's marriage/union status	0.76 (0.38–1.53)	mother's marriage/union status	1.10 (0.54–2.13)
parity	0.49 (0.23–1.02)	parity	1.81 (0.93–3.52)
Class 4--- 7 h/night			
SES (asset quintile)	1.40 (0.95–2.06)		
mother's schooling	3.63 (1.47–8.98)		
mother's marriage/union status	1.32 (0.55–3.17)		
parity	1.19 (0.49–2.90)		
Pseudo R2	0.05	Pseudo R2	0.04
Weekend Sleep			
Class 1--- 9.5 h/night (ref)		Class 1--- 9 h/ night (ref)	
Class 2--- 11 h/night		Class 2---10 h/night	
SES (asset quintile)	1.02 (0.83–1.24)	SES (asset quintile)	1.01 (0.87–1.17)
mother's schooling	0.56 (0.32–1.05)	mother's schooling	1.07 (0.71–1.62)
mother's marriage/union status	0.82 (0.50–1.25)	mother's marriage/union status	1.14 (0.78–1.68)
parity	0.65 (0.39–1.09)	parity	1.06 (0.73–1.54)
Class 3--- 7.5 h/night		Class 3--- 8 h/night	
SES (asset quintile)	1.30 (0.95–1.79)	SES (asset quintile)	1.10 (0.86–1.43)
mother's schooling	0.97 (0.43–2.16)	mother's schooling	1.38 (0.67–2.78)
mother's marriage/union status	1.00 (0.47–2.13)	mother's marriage/union status	1.16 (0.60–2.26)
parity	0.92 (0.43–1.97)	parity	0.90 (0.46–1.74)
		Class 4--- 11 h/night	
		SES (asset quintile)	1.04 (0.76–1.43)
		mother's schooling	1.53 (0.64–3.65)
		mother's marriage/union status	0.87 (0.38–1.97)
		parity	0.42 (0.17–1.02)
Pseudo R2	0.02	Pseudo R2	0.006

Table 4.4. Relative risk ratios and 95% confidence intervals for predictors of physical activity [a] multi-trajectory groups, Birth-to-Twenty Plus cohort, Johannesburg, South Africa

	Males			**Females**		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
	"Decreasing activity, non-walkers"	"Active, walkers"	"Decreasing activity, walkers"	"Decreasing activity, non-walkers"	"Active, walkers"	"Decreasing activity, walkers"
SES (asset quintile)	1.48 (1.22–1.81)	1.04(0.87–1.23)	(ref)	1.80 (1.51–2.14)	1.16 (0.95–1.42)	(ref)
Mother's schooling	2.39 (1.47–3.88)	1.21 (0.75–1.96)	(ref)	3.43 (2.21–5.32)	1.91 (1.08–3.37)	(ref)
Mother's marital status	1.69 (1.06–2.70)	1.21 (0.79–1.87)	(ref)	0.89 (0.57–1.38)	0.57 (0.33–0.97)	(ref)
Parity	1.49 (0.93–2.39)	1.24 (0.81–1.92)	(ref)	0.94 (0.61–1.45)	0.58 (0.34–0.97)	(ref)
Pseudo R2			0.05			0.11

[a] Overall physical activity includes informal physical activity, organized sports and walking to and from school

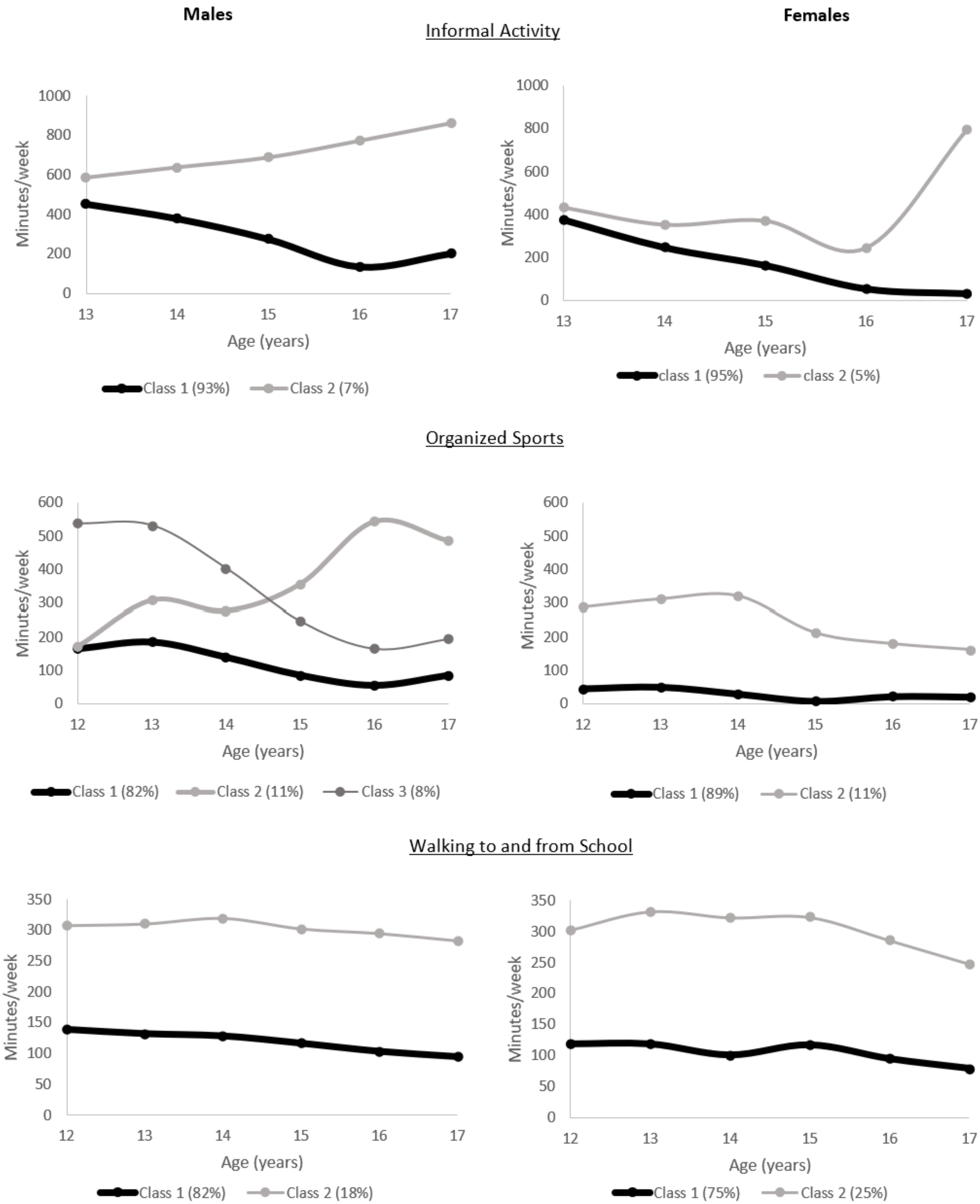


Figure 4.1. Physical activity trajectories through adolescence, by domain and sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa

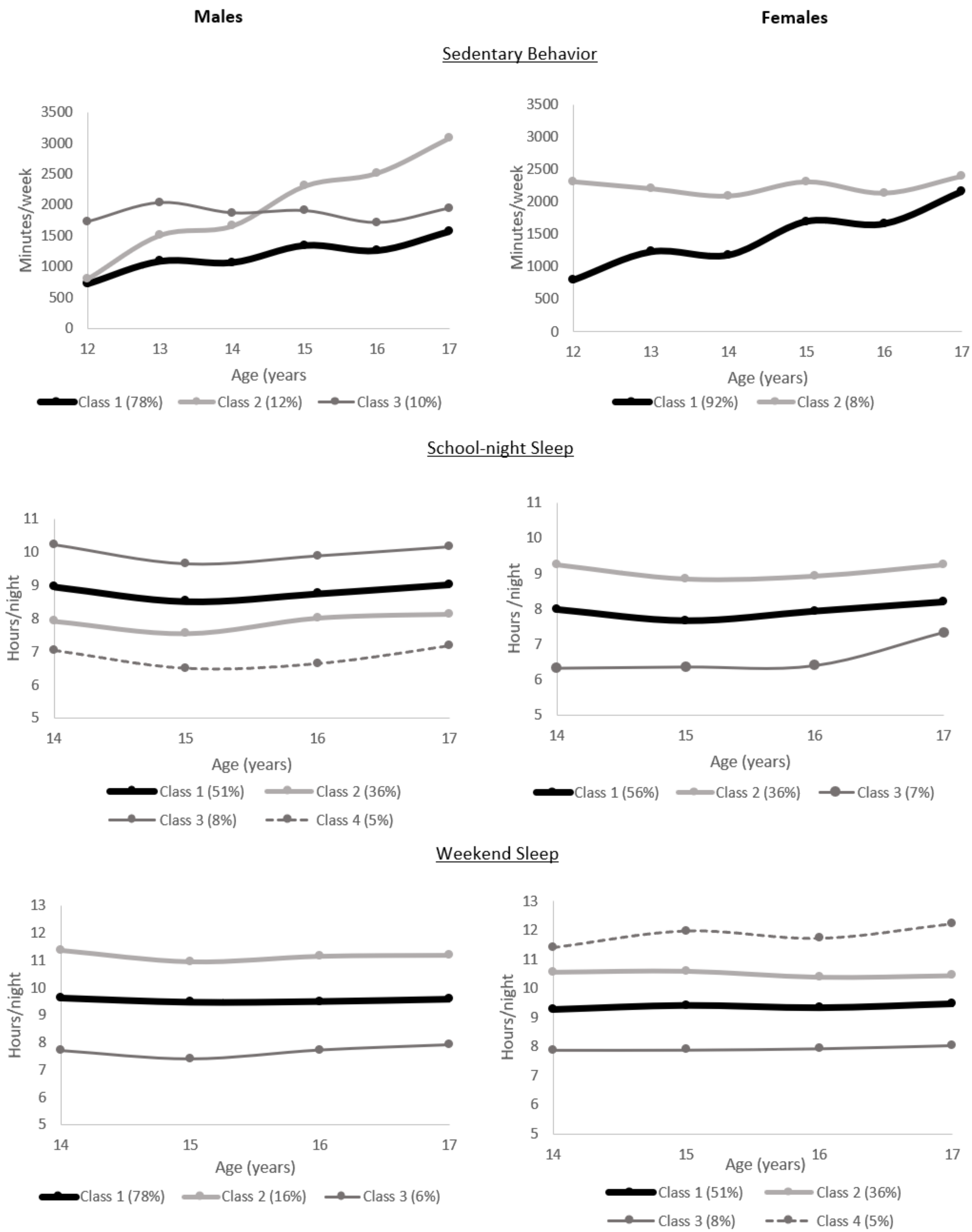


Figure 4.2. Sedentary behavior and sleep trajectories through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa

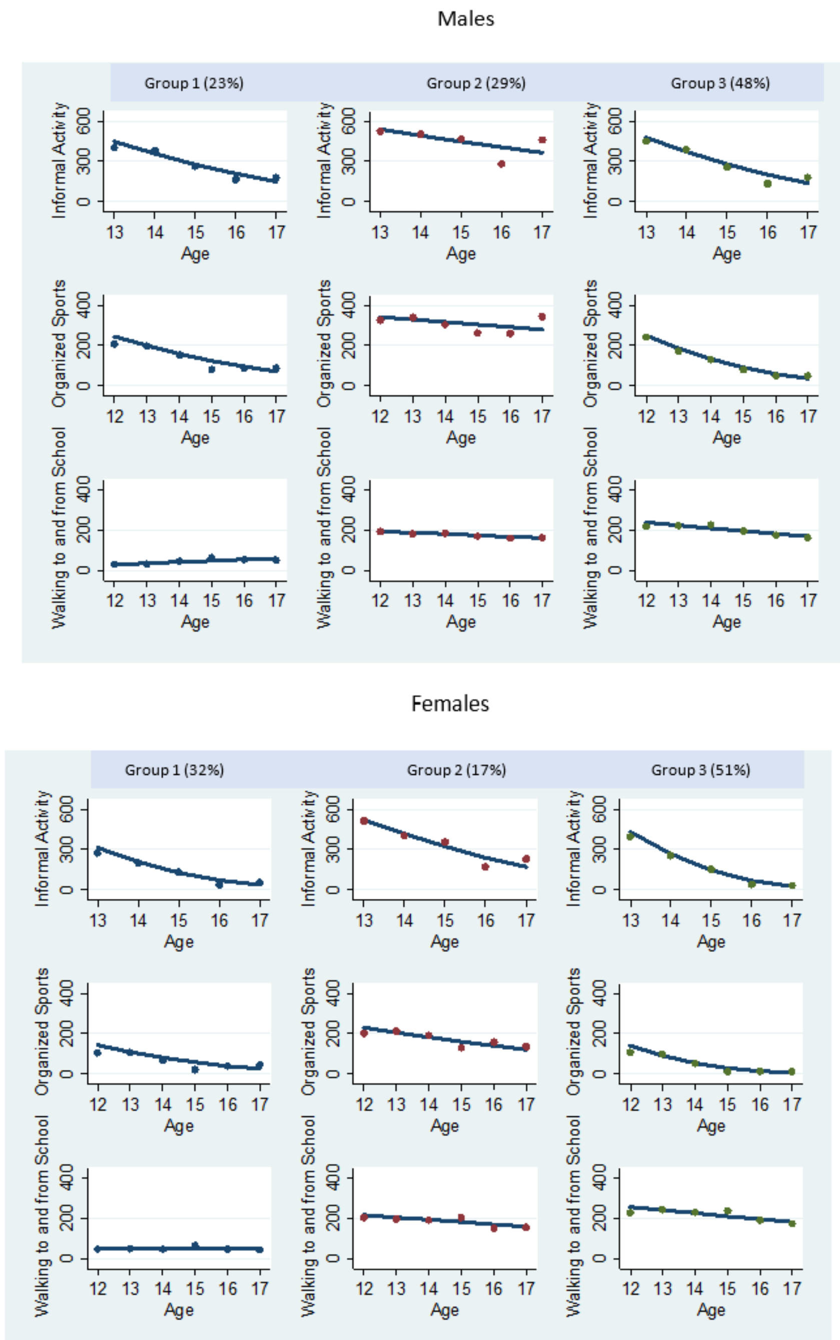
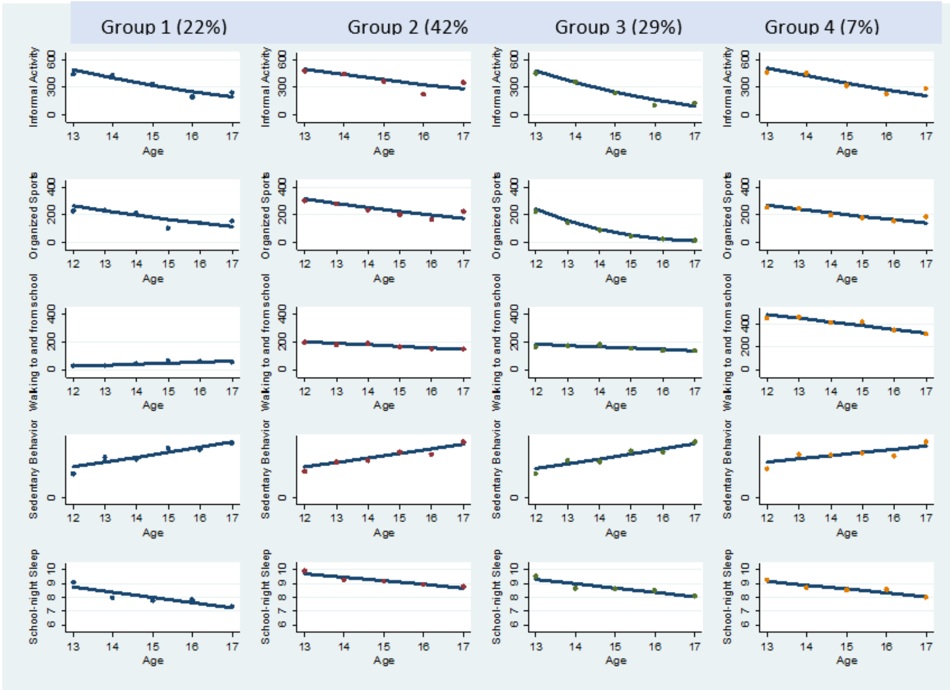


Figure 4.3. Multi-trajectory groups of physical activity domains through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa

Males



Female

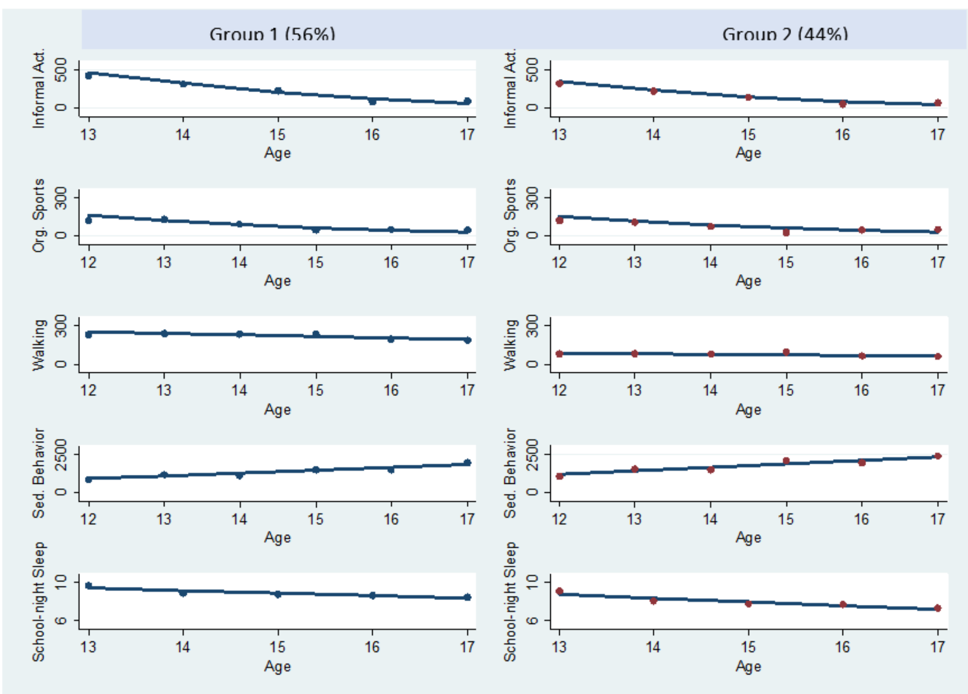


Figure 4.4. Multi-trajectory groups of movement behavior domains through adolescence, by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa

Supplemental Table 4.1. Latent Class Growth Analysis model fit for physical activity by domain and sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa [a]

Informal Activity

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4
Males	1	48344	N/A	N/A	Yes	N/A	-24149	7	100%			
	2	**48180**	**0.11**	**0.00**	**Yes**	**0.92**	**-24058**	**10**	**7%**	**93%**		
	3	48120	0.02	0.00	Yes	0.88	-24018	13	7%	87%	7%	
Females	1	51706	N/A	N/A	N/A	Yes	-25830	7	100%			
	2	**51285**	**0.23**	**0.24**	**Yes**	**0.99**	**-25610**	**10**	**5%**	**95%**		
	3	51035	0.49	0.00	Yes	0.99	-25474	13	92%	2%	6%	

Physical Education

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4
Males	**1**	**38424**	**N/A**	**N/A**	**Yes**	**N/A**	**-19186**	**8**	**100%**			
	2	38167	0.40	0.00	Yes	0.99	-19048	11	97%	3%		
	3	37992	0.24	0.00	Yes	0.99	-18950	14	3%	4%	93%	
Females	**1**	**41917**	**N/A**	**N/A**	**Yes**	**N/A**	**-20932**	**8**	**100%**			
	2	41646	0.00	0.00	Yes	0.99	-20787	11	3%	97%		
	3	41487	0.42	0.00	Yes	0.97	-20697	14	2%	91%	7%	

Organized Sports

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4
Males	1	55381	N/A	N/A	Yes	N/A	-27664	8	100%			
	2	55063	0.03	0.00	Yes	0.88	-27496	11	15%	85%		
	3	**55015**	**0.18**	**0.00**	**Yes**	**0.85**	**-27462**	**14**	**81%**	**11%**	**8%**	
	4	54991	0.09	0.00	Yes	0.90	-27440	17	7%	76%	3%	14%
Females	1	99432	N/A	N/A	Yes	N/A	-49687	8	100%			
	2	**98261**	**0.06**	**0.00**	**Yes**	**0.97**	**-49091**	**11**	**93%**	**7%**		
	3	97619	0.31	0.00	Yes	0.97	-48759	14	91%	7%	2%	

Walking to and from School

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4
Males	1	49286	N/A	N/A	Yes	N/A	-24617	8	100%			
	2	**48792**	**0.03**	**0.00**	**Yes**	**0.82**	**-24360**	**11**	**81%**	**19%**		
	3	48650	0.20	0.00	Yes	0.78	-24279	14	3%	31%	66%	
	4	48592	0.19	0.00	Yes	0.70	-24241	17	5%	44%	10%	41%
Females	1	55986	N/A	N/A	Yes	N/A	-27967	8	100%			
	2	**55406**	**0.36**	**0.00**	**Yes**	**0.79**	**-27667**	**11**	**75%**	**25%**		

3	55270	0.03	0.00	Yes	0.85	-27589	14	1%	72%	27%

[a] Bold text indicates selected model

Supplemental Table 4.2. Latent Class Growth Analysis model fit for sedentary behavior and sleep by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa [a]

Sedentary Behavior

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4	class 5
Males	1	59096	N/A	N/A	Yes	N/A	-29522	8	100%				
	2	58892	0.00	0.00	Yes	0.70	-29410	11	23%	77%			
	3	**58815**	**0.00**	**0.00**	**Yes**	**0.78**	**-29362**	**14**	**13%**	**76%**	**11%**		
	4	58818	0.56	0.05	Yes	0.73	-29354	17	4%	9%	18%	69%	
	5	58820	0.40	0.13	Yes	0.73	-29345	20	19%	4%	67%	9%	2%
Females	1	65539	N/A	N/A	Yes	N/A	-32743	8					
	2	**65361**	**0.05**	**0.00**	**Yes**	**0.90**	**-32644**	**11**	**91%**	**9%**			
	3	65242	0.00	0.00	Yes	0.66	-32574	14	59%	7%	34%		
	4	65233	0.74	0.00	Yes	0.68	-32560	17	5%	4%	54%	37%	
	5	65223	0.01	0.01	Yes	0.75	32546	20	8%	58%	2%	32%	0%

School-night Sleep

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4	class 5
Males	1	26288	N/A	N/A	Yes	N/A	-13121	7	100%				
	2	26125	0.000	0.000	Yes	0.56	-13030	10	60%	40%			
	3	26038	0.000	0.000	Yes	0.73	-12976	13	10%	25%	65%		
	4	**26024**	**0.032**	**0.000**	**Yes**	**0.72**	**-12960**	**16**	**5%**	**9%**	**54%**	**31%**	
	5	26032	0.035	0.000	Yes	0.76	-12954	19	8%	58%	5%	29%	
Females	1	28374	N/A	N/A	Yes	N/A	-14164	7	100%				
	2	28144	0.000	0.000	Yes	0.60	-14039	10	58%	42%			
	3	28074	0.087	0.000	Yes	0.69	-13994	13	8%	38%	54%		
	4	28054	0.280	0.000	Yes	0.67	-13974	16	21%	28%	3%	49%	

Weekend Sleep

Sex	Latent classes	BIC	LMR-LRT (p-value)	BLRT (p-value)	Convergence	Entropy value	Log likelihood	Number of parameters	class 1	class 2	class 3	class 4	class 5
Males	1	29625	N/A	N/A	Yes	N/A	-14790	7	100%				
	2	29512	0.02	0.00	Yes	0.46	-14723	10	47%	53%			
	3	**29456**	**0.34**	**0.00**	**Yes**	**0.72**	**-14686**	**13**	**19%**	**73%**	**8%**		
	4	29446	0.08	0.00	Yes	0.66	-14671	16	2%	10%	32%	56%	
Females	1	32787	N/A	N/A	Yes	N/A	-16371	7	100%				
	2	32652	0.00	0.00	Yes	0.48	-16293	10	47%	53%			
	3	32622	0.03	0.00	Yes	0.63	-16268	13	66%	19%	15%		
	4	**32627**	**0.40**	**0.00**	**Yes**	**0.62**	**-16261**	**16**	**37%**	**7%**	**47%**	**9%**	

[a] Bold text indicates selected model

Supplemental Table 4.3. Sedentary behavior trajectory class membership across physical activity trajectories in males, Birth to Twenty Plus Cohort, Johannesburg, South Africa

	Trajectory class	Sedentary behavior (%) 1	2	3	p-value
Informal activity (%)	1	79	12	10	
	2	70	14	16	0.38
Organized sports (%)	1	78	12	10	
	2	82	5	12	
	3	75	18	7	0.28
Walking to and from school (%)	1	77	12	11	
	2	81	10	9	0.77

Supplemental Table 4.4. Sedentary behavior trajectory class membership across physical activity trajectories in females, Birth to Twenty Plus Cohort, Johannesburg, South Africa

	Trajectory Class	Sedentary behavior (%)		
		1	2	p-value
Informal activity (%)	1	92	8	
	2	92	8	0.97
Organized sports (%)	1	92	8	
	2	89	11	0.28
Walking to and from school (%)	1	91	9	
	2	96	4	0.04

Supplemental Table 4.5. Sleep trajectory class membership across physical activity trajectories in males, Birth to Twenty Plus Cohort, Johannesburg, South Africa

		School-night sleep (%)					Weekend sleep (%)			
		1	2	3	4	p-value	1	2	3	p-value
Informal activity (%)	1	56	31	8	4		78	16	6	
	2	52	34	7	7	0.8	77	14	9	0.66
Organized sports (%)	1	55	32	9	4		78	16	6	
	2	63	29	5	3		77	16	3	
	3	59	25	9	7	0.74	70	16	16	0.21
Walking to and from school (%)	1	55	33	7	5		81	14	5	
	2	58	25	14	3	0.05	64	25	10	0.001
Sedentary behavior (%)	1	60	26	10	3		77	18	4	
	2	43	49	0	8		79	4	17	
	3	38	51	3	9	p<0.001	78	13	9	p<0.001

Supplemental Table 4.6. Sleep trajectory class membership across physical activity trajectories in females, Birth to Twenty Plus Cohort, Johannesburg, South Africa

		School-night sleep (%)				Weekend sleep (%)				
	Trajectory Class	1	2	3	p-value	1	2	3	4	p-value
Informal activity (%)	1	57	36	7		51	36	8	5	
	2	49	40	11	0.55	43	32	14	11	0.23
Organized sports (%)	1	57	35	7		51	36	8	6	
	2	49	44	7	0.3	54	35	7	4	0.87
Walking to and from school (%)	1	59	33	8		51	35	8	6	
	2	48	47	11	0.001	50	38	8	4	0.86
Sedentary behavior (%)	1	56	37	7		51	36	7	6	
	2	63	20	17	0.002	51	30	17	2	0.03

Supplemental Table 4.7. Multi-trajectory analysis model fit statistics for physical activity domains by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa
[a]

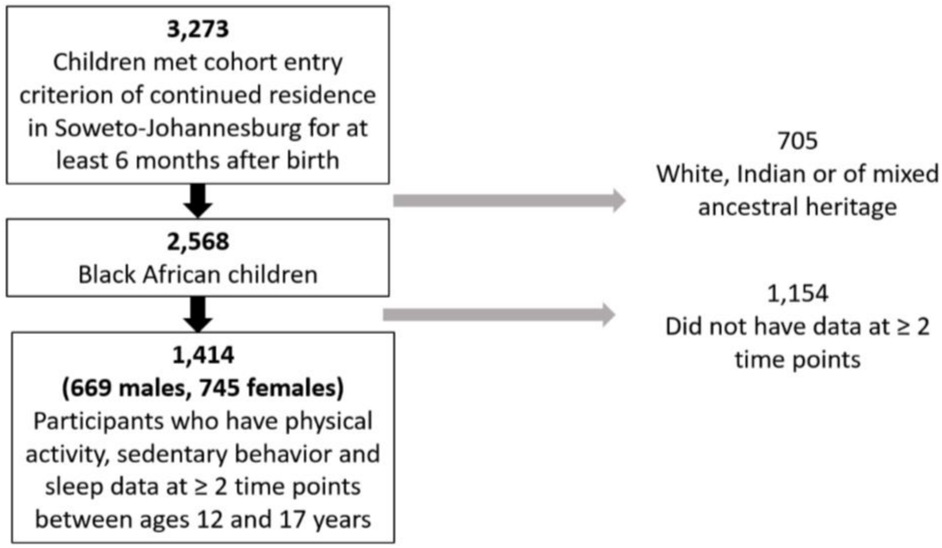
Sex	# of multi-trajectory groups	BIC	Group1	Group 2	Group 3	Group 4	Group 5
Males	1	-56262.97	100%				
	2	-56038.56	28%	72%			
	3	**-55898.43**	**23%**	**29%**	**49%**		
	4	variance matrix is nonsymmetric or highly singular					
	5	variance matrix is nonsymmetric or highly singular					
Females	1	-50231.71	100%				
	2	-49912.22	37%	63%			
	3	**-49783.08**	**31%**	**17%**	**51%**		
	4	variance matrix is nonsymmetric or highly singular					
	5	variance matrix is nonsymmetric or highly singular					

[a] Bold text indicates selected model

Supplemental Table 4.8. Multi-trajectory analysis model fit statistics for physical activity domains, sedentary behavior and sleep by sex, Birth to Twenty Plus Cohort, Johannesburg, South Africa[a]

Sex	# of multi-trajectory groups	BIC	Group 1	Group 2	Group 3	Group 4	Group 5
Male	1	-90615.82	100%				
	2	-90214.94	67%	33%			
	3	-90121.73	31%	62%	75%		
	4	**-90016.36**	**23%**	**42%**	**29%**	**7%**	
	5	variance matrix is nonsymmetric or highly singular					
Female	1	-88704.97	100%				
	2	**-88212.35**	**56%**	**44%**			
	3	variance matrix is nonsymmetric or highly singular					
	4	variance matrix is nonsymmetric or highly singular					
	5	variance matrix is nonsymmetric or highly singular					

[a] Bold text indicates selected model



Supplemental Figure 4.1. Flow chart depicting the final sample of eligible participants included in the analysis of physical activity patterns in adolescence, Birth to Twenty Plus Cohort, Johannesburg, South Africa

Empirical Chapter 2

Chapter 5

Adolescent Physical Activity, Sedentary Behavior and Sleep in Relation to Body Composition at Age 18 Years in Urban South Africa, Birth-To-Twenty Plus Cohort

Adolescent physical activity, sedentary behavior and sleep in relation to body composition at age 18 years in urban South Africa, Birth-to-Twenty+ Cohort

Sara K. Hanson[1,2], Lisa K. Micklesfield[2,] Felipe Lobelo3, Solveig A. Cunningham[3,4], Terryl J. Hartman[3,4,] Shane A. Norris[2,3], Aryeh D. Stein[3,4]

[1]Doctoral Program in Nutrition and Health Sciences, Laney Graduate School, Emory University, Atlanta, GA,

[2]MRC/Wits Developmental Pathways for Health Research Unit, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa,

[3]Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA

[4]Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA

Author email addresses: sara.hanson@emory.edu, lisa.micklesfied@wits.zc.za felipelobelo@emory.edu, sargese@emory.edu, tjhartm@emory.edu, shane.norris@wits.ac.za, Aryeh.stein@emory.edu

Corresponding author: Aryeh D Stein, Aryeh.stein@emory.edu

5.1 Abstract

Background

Adolescence is marked by a decline in physical activity, rapid physical growth and changes in body composition. Adolescent physical activity, sedentary behavior and sleep have been linked to body composition, but prospective data on these associations are rare, particularly in Africa.

Aim

The aim of this study is to examine the association of identified longitudinal patterns of adolescent physical activity, sedentary behavior and sleep with anthropometry and body composition at age 18 years in urban South Africa.

Methods

Participants for this study were part of the Birth-to-Twenty Plus Cohort (Bt20+), a longitudinal study of children born in 1990 in Soweto-Johannesburg, South Africa. Data were collected up to 21 times between birth and age 18 years. We used general linear models to investigate the association of adolescent (ages 12 to 18 years) longitudinal trends in physical activity, sedentary behavior and school-night sleep and overall physical activity patterns with BMI, waist circumference, fat mass index (FMI), lean mass index (LMI) and percent body fat at age 18 years.

Results

The final study sample included 1,337 participants with anthropometric measurements (52% female), and 958 participants with body composition measurements (53% female). After adjusting for covariates, males who decreased activity over adolescence but consistently walked to school had significantly lower FMI (B=-0.6, 95% CI: -1.0 to -0.1) and percent body fat (B=-1.9, 95% CI: -1.7 to -0.2) at age 18 years than those who decreased activity and did not walk to school. Males who were consistently more active and consistently walked to school over adolescence had lower waist circumference (B= -2.0, 95% CI: -3.9 to -0.2), FMI (B= -0.8, 95%: CI: -1.2 to -0.1) and percent body fat (B=-2.9, 95% CI: -4.9 to -0.9) at age 18 years than those who decreased activity and did not walk to school. Females who engaged in consistently high amounts of sedentary behavior over adolescence had higher waist circumference than those who engaged in initially low but increasing amounts of sedentary behavior (B=5.4, 95% CI: 0.2 to 10.6). Males who reported sleeping 9 hours or more per night on school-nights had significantly lower BMI (B=-1.0, 95% CI: -1.4 to- 0.5), waist circumference (B=-2.3, 95% CI -3.7 to -1.1), FMI (B=-0.4, 95% CI: -0.8 to -0.1) and percent body fat (B=-1.5, 95%CI -2.8 to -0.1) than those who reported sleeping 8 hours or less per night.

Conclusion

Adolescent physical activity, sedentary behavior and sleep are related to young-adult body composition in urban South Africa; the contribution of each behavior varies by sex. These behaviors are modifiable and may be paths for public health interventions to curb overweight and obesity in many low- and middle-income countries.

5.2 Background

Overweight and obesity have become major global health concerns, as both increase the risk of non-communicable diseases (NCD) such as cardiovascular disease, type II diabetes, some cancers, and pre-mature death [1]. South Africa, one of the wealthiest countries on the African continent, also has one of the highest rates of overweight and obesity, affecting 39% of men and 69% of women [2]. As the burden of overweight and obesity and related NCDs continues to rise in South Africa, there is a need for research on modifiable risk factors in early life that could be integrated into intervention strategies.

Adolescence is marked by rapid physical growth and changes in body composition triggered by the hormonal changes surrounding puberty [3, 4]. Behaviors adopted during adolescence can have both short and long-term effects on health [5]. The health-related behaviors that lead to overweight and obesity in adulthood usually begin or are reinforced during adolescence [6]. Adolescence is also known to be a time of physical activity decline, particularly in females, but most evidence of this is from high-income countries [7]. Until recently, little, if nothing, was known about longitudinal adolescent physical activity patterns in Africa. Our recent findings suggest that the majority of adolescents from an urban African population, like those from high-income countries, decrease physical activity as they age [8].

Adolescent physical activity [9], along with sedentary behavior [10] and sleep [11], are modifiable behaviors that have been linked to body composition. However, prospective longitudinal data on these behaviors and how they are associated with body composition in adulthood are rare, and in Africa, non-existent. The benefits of being physically active during adolescence are well documented [12]. Physical activity throughout adolescence has been inversely associated with fat mass and positively associated with lean mass [13]. Further, in the last decade, sedentary behavior has been recognized as a public health concern, independent of physical activity [14]. Adolescents who engage in more than 2 hours of sedentary behavior per day have higher risk of unfavorable body composition [15]. Adolescent sleep patterns have also been recognized as relevant for public health concern, with many countries reporting high levels of sleep disturbance among youth [16, 17]. While changes in sleep are a normal part of adolescence, many adolescents accumulate substantial sleep debt, especially during the school week [18]. Inadequate sleep can have consequences for numerous aspects of adolescent health, including risk of overweight and obesity [11].

Previously, we identified categories of distinct sex-specific trends in physical activity, sedentary behavior and sleep as well as overall physical activity patterns in urban South African adolescents [8]. The associations of these categories and overall patterns with later body composition remain unexplored [8]. The aim of this study was to assess the association of categories of longitudinal physical activity, sedentary behavior and sleep and overall physical activity patterns in adolescence with BMI, waist circumference, fat mass, lean mass and percent body fat at age 18 years in urban South Africa.

5.3 Methods

Study sample

Participants of this study were part of the Birth-to-Twenty Plus (Bt20+) Cohort, a longitudinal multidisciplinary study of children in Soweto-Johannesburg, South Africa [19]. All singleton children born between April and June 1990 and residing in the area for at least 6 months after birth were eligible for inclusion [20]. A total of 3,273 children of predominantly low SES were recruited to the study, of whom 78% were Black African and 51% were female [21]. Children were followed up 21 times between birth and age 18 years. Detailed information about the Bt20+ Cohort has been presented elsewhere [19-22]. Participants or their caregiver gave written informed consent; ethical approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects (approval ID #M010556).

Adolescent physical activity, sedentary behavior and sleep trajectories

Detailed methods for the assessment of adolescent behaviors and Latent Class Growth Analysis (LCGA) have been described previously [8]. In our preceding study, participants were grouped into distinct classes based on common longitudinal trajectories of self-reported informal activity (any physical activity outside of school and not part of a sports team or club), organized sports, walking to and from school, sedentary behavior (time spent before and after school watching TV; reading, drawing and homework; playing a musical instrument; playing video/computer games and internet surfing) and school-night sleep using data collected in annual surveys between ages 12 and 17/18 years, which are depicted graphically in Supplemental Figure 5.1.

Overall Physical Activity Patterns

Detailed methods for the assessment of overall physical activity patterns have been described previously [8]. In our prior study, individuals who followed similar trajectories of informal activity, organized sports and walking to and from school synchronously were categorized into an overall physical activity pattern using group-based multi-trajectory modeling.

Anthropometric Measures

Height was measured without shoes using a stadiometer (Holtain, UK) and recorded to the nearest millimeter. Weight was measured in light clothing using a digital scale (Dismed, USA) and recorded to the nearest 100g. Both devices were calibrated regularly throughout the study. Body mass index (BMI) was calculated as height (m) divided by weight (kg2). Waist circumference was measured at the midpoint between the iliac crest and the lowest rib with the participant standing erect and at the end of a normal expiration and recorded to the nearest millimeter. All measurements were taken by trained staff.

Body Composition Measures

Whole body fat mass, lean mass and percent body fat at age 18 years were measured using a Hologic QDR 4500A dual-energy x-ray absorptiometry (DXA) scanner and analyzed using Apex software version 4.0.2 (Hologic Inc., Bedford, USA). DXA scans were performed by trained technicians according to standard protocols and coefficients of variation for the study period remained below 1%. Fat mass and lean mass are directly associated with height [23]. To account for the association with height, we expressed these variables as fat-mass index (FMI) and lean-mass index (LMI). FMI and LMI were calculated by dividing fat mass and lean mass (in kilograms) by height (in meters) squared [23].

Selection of covariates

To adjust for potential confounding factors, we selected a series of covariates a priori based on previous findings from this cohort and evidence from the literature [8, 24-31]. These variables were birth order (firstborn/ not firstborn), SES asset quintile at child age 7/8 years, maternal schooling (matriculated/did not matriculate from secondary school) at child age 7/8 years, maternal marital/union status (in union/not in union) at child age 7/8 years and childhood BMIZ at child age 7/8 or 9 years. Childhood BMIZ was by converting BMI values to z-scores using the WHO reference [32]. If the participant had a BMI measurement at age 7/8 years, that data point was used to calculate childhood BMIZ. If the participant did not have a BMI measurement at age 7/8 years but had one at age 9 years, then the measurement at age 9 years was used to calculate childhood BMIZ. This allowed us to have childhood BMIZ data for 65% of participants. Co-linearity between these variables was examined using variance inflation factors and was not notable. Additional details on the selection and measurement of covariates can be found elsewhere [8].

Inclusion and exclusion

To be included in the present analyses, participants needed to have been included in the adolescent physical activity, sedentary behavior and sleep trajectories (which requires at least two data points over adolescence) and either anthropometric or body composition data at age 18 years. Due to low study numbers in the other ethnic groups, we restricted our analyses to Black African participants. A flow chart describing the final sample of eligible participants included in the analyses is provided in Supplemental Figure 5.2.

Statistical Analyses

We used general linear models to investigate the associations of categories of longitudinal adolescent physical activity, sedentary behavior and sleep and overall activity patterns with BMI, waist circumference, FMI, LMI and percent body fat at age 18 years. We stratified all analyses by sex due to previously observed sex-differences in patterns of adolescent physical activity, sedentary behavior and sleep, and overweight and obesity in this population [8, 33]. We adjusted models for birth order, maternal schooling at child age 7/8 years, maternal marital/union status at child age 7/8 years, SES quintile at child age 7/8 years and childhood BMIZ at ages 7/8 or 9 years. For analyses that included overall physical activity patterns, we also adjusted for adolescent sedentary behavior and school-night sleep trajectories. We conducted all analyses in Stata version 14 and set significance at $p<0.05$.

5.4 Results

The final study sample included 1,337 participants with anthropometric measurements (52% female), and 958 participants with body composition measurements (53% female). Black-African participants excluded from the analyses were similar to those included in the analyses, and participants who had both anthropometric and body composition data at age 18 years were similar to participants who had only anthropometric data (Supplemental Table 5.1). Characteristics of the study sample are provided in Table 1.

Physical Activity- males

93% of males decreased informal activity over adolescence. In unadjusted models, males who increased informal activity over adolescence had significantly lower BMI, FMI and percent body fat than those whose informal activity decreased (Table 5.2). These differences were attenuated following covariate adjustment (Table 5.3).

82% of males had consistently low sports participation over adolescence, while 11% decreased from adequate to low, and 7% increased from low to adequate. In unadjusted and adjusted models, there were no associations between trends in organized sports participation and any anthropometric or body composition outcome at age 18 years.

83% of males walked approximately 150 minutes per week to and from school over adolescence, while the remainder walked approximately 300 minutes per week. In both unadjusted and adjusted models, there were no associations between the amount of time spent walking to and from school during adolescence and any anthropometric or body composition outcome at age 18 years in males.

Physical Activity- females

95% of females decreased informal activity over adolescence. In both unadjusted and adjusted models, females who increased informal activity over adolescence had significantly higher waist circumference than females whose informal activity decreased. LMI was also higher among females whose informal activity increased, but only in the unadjusted models.

89% of adolescent females did not participate in organized sports. In unadjusted models, females who consistently participated in organized sports over adolescence had significantly lower waist circumference, FMI and percent body fat than those who did not participate in organized sports. These differences were attenuated following covariate adjustment.

75% of females walked approximately 150 minutes per week to and from school over adolescence, while the remainder walked approximately 300 minutes per week. In unadjusted models, there were no differences in any anthropometric or body composition outcome at age 18 years between these groups. However, after adjusting for covariates, females who walked approximately 300 minutes per week to and from school over adolescence had significantly higher LMI than those who walked approximately 150 minutes per week (B=0.4, 95% CI: 0.1 to 0.7).

<u>Overall Physical Activity</u>

22% of males decreased activity and did not walk to school over adolescence, 50% decreased activity and walked to school, and 28% were consistently more active and walked to school. In unadjusted models, trends in male overall adolescent physical activity were associated with BMI, waist circumference, FMI and percent body fat at age 18 years. After adjusting for childhood and maternal covariates (model 1), when compared to the reference (males who decreased physical activity and did not walk to school), the other two groups had lower BMI, waist circumference, FMI, and percent body fat at age 18 years. After also adjusting for adolescent sedentary behavior and sleep trajectories (model 2), when compared to the reference, males who decreased activity and walked to school over adolescence had significantly lower FMI (B=-0.6, 95% CI: -1.0 to -0.1) and percent body fat (B=-1.9, 95% CI: -1.7 to -0.2) and males who were consistently more active and walked to school over adolescence had significantly lower waist circumference (B= -2.0, 95% CI: -3.9 to -0.2), FMI (B= -0.8, 95%: CI: -1.2 to -0.1) and percent body fat (B=-2.9, 95% CI: -4.9 to -0.9) at age 18 years.

31% of females decreased activity and did not walk to school over adolescence, 54% decreased activity and walked to school, and 15% were consistently more active and walked to school. In unadjusted models, trends in female overall adolescent physical activity were associated with percent body fat at age 18 years. However, after adjusting for covariates, there were no significant differences in anthropometric or body composition outcomes at age 18 years between females who decreased activity but walked to school over adolescence and those who decreased activity and did not walk to school. In models adjusted for childhood and maternal covariates (model 1), and models also adjusted for sedentary behavior and school-night sleep trajectories (model 2), females who were consistently more active and consistently walked to school over adolescence had significantly higher waist circumference at age 18 years than females who decreased activity and did not walk to school over adolescence (B= 4.6, 95% CI: 0.5-8.6) and (B=4.8, 95% CI: 0.7-9.0).

Sedentary Behavior

78% of males engaged in consistently low amounts of sedentary behavior over adolescence, while 10% engaged in consistently high amounts, and 12% increased from low to high amounts. In unadjusted models, trends in male sedentary behavior over adolescence were associated with BMI and waist circumference at age 18 years with males whose sedentary behavior increases during adolescence having higher BMI and waist-circumference. These associations were attenuated following covariate adjustment.

In females, 92% engaged in initially low but increasing amounts of sedentary behavior and 8% engaged in consistently high amounts. In unadjusted models, trends in female sedentary behavior were associated with waist circumference and LMI. After adjusting for covariates, females who engaged in consistently high amounts of sedentary behavior over adolescence had significantly higher waist circumference than those who engaged in initially low but increasing amounts (B=5.4, 95% CI: 0.2 to 10.6).

Sleep

35% of males and 65% of females reported sleeping for 8 hours or less on school nights. In unadjusted models, males who reported sleeping 9 hours or more per night on school-nights over adolescence had significantly lower BMI and waist circumference at age 18 years than those who reported sleeping 8 hours or less per night. After adjusting for covariates, males who reported sleeping 9 hours or more per night on school-nights had significantly lower BMI (B=-1.0, 95% CI: -1.4 to- 0.5), waist circumference (B=-2.3, 95% CI -3.7 to -1.1), FMI (B=-0.4, 95% CI: -0.8 to -0.1) and percent body fat (B=-1.5, 95%CI -2.8 to -0.1) than those who reported sleeping 8 hours or less per night. In both unadjusted and adjusted models, there were no associations between school-night sleep in adolescent females and any anthropometric or body composition outcomes at age 18 years.

5.5 Discussion

This study related categories of longitudinal adolescent physical activity, sedentary behavior and sleep and overall adolescent physical activity patterns to young-adult body composition in an urban South African birth cohort. Given the high burden of overweight and obesity in South Africa, there is interest in modifiable behaviors. There were three main findings in this study. First, after controlling for covariates, being consistently more active throughout adolescence was associated with more favorable anthropometric measures and body composition at age 18 years in urban South African males. Second, engaging in consistently high amounts of sedentary behavior over adolescence was associated with higher waist circumference at age 18 years in females. Finally, sleeping 9 hours or more per night on school nights was associated with more favorable anthropometric measures and body composition at age 18 years in urban South African males.

Adolescence is a period of rapid growth and maturation characterized by significant changes in body composition [34]. While genetics, nutrition and hormones are the primary drivers of these changes, physical activity is an important ancillary determinant of body composition and may play an important role in increasing muscle mass and preventing overweight and obesity [35].

An age-related decline in physical activity throughout adolescence has been well established in high-income countries [7]. In our study population, the large majority of both males (72%) and females (85%) decreased their reported levels of physical activity over adolescence [8]. This decline is potentially a risk factor for adult overweight or obesity [36-38]. Until now, prospective evidence from Africa has been lacking. Our study found that Black-African males who were consistently more active over adolescence had significantly lower waist circumference, FMI and percent body fat in young-adulthood compared to Black-African males who decreased overall activity over adolescence. These results are consistent with findings from the Iowa Bone Development Study cohort, in which participants who were physically active as children but decreased activity with age were more likely to become obese in young-adulthood than participants who were consistently active [36]. In contrast, we found that being consistently more active during adolescence in Black-African females was not associated with more favorable body composition in young-adulthood, and to be associated with higher waist circumference, a proxy for abdominal obesity.

Due to hormonal changes, adolescence is a period of fat mass accretion in females [34]. Fat mass accretion, combined with the lower amount of, and likely less intense, physical activity may explain the differences in our finding among males and females. Qualitative research has discovered that particularly for girls, physical activity declines during the secondary school years as girls are more conscious of their appearance during puberty and cultural norms tend to favor fuller body shapes [39, 40]. The association between higher physical activity and higher waist circumference among females may be due to other factors, including diet, over-riding the influence of physical activity on abdominal obesity.

In a study from another low-middle income country, the 1993 Pelotas (Brazil) Birth Cohort Study, consistent moderate-to-vigorous intensity physical activity over adolescence was associated with higher lean mass at age 18 years in males and females [13]. In the present study, we considered organized sports a proxy for moderate-to-vigorous physical activity. In contrast to the Brazilian cohort, we found that trends in participation in organized sports were not associated with lean mass or any other measure of body composition at age 18 years, in either males or females. The inconsistency in findings between our study and the Brazilian cohort might be explained by low levels of activity in the South African cohort, as 82% of males and all females failed to meet the WHO recommendation of 60 minutes of moderate-to-vigorous intensity physical activity per day, as compared to 37% and 65% in the Pelotas cohort[41].

Informal activity, also known as active play, may make a significant contribution to an adolescent's daily energy expenditure [42]. While unstructured playtime is typically not very intense, the long duration of activity may lead to benefits [43]. In our study, we found no association between trends in informal activity over adolescence and any anthropometric or body composition outcome at age 18 years in males. However, we found females who increased informal activity over adolescence had significantly higher waist circumference at age 18 years than females who decreased informal activity over adolescence. The duration of male informal activity was likely not high enough to compensate for the low intensity. The association between trends in informal activity and waist circumference in females was not as hypothesized and may have been influenced by unmeasured variables.

Active transportation to school has been identified as an important source of physical activity in adolescents, but there is conflicting evidence regarding the association between active transportation to school and body composition [44, 45]. In our study, walking to and from school was a consistent source of physical activity over adolescence. While trends in walking to and from school over adolescence were not associated with anthropometric measures or body composition at age 18 years in males, we found that females who consistently spent more time walking to and from school over adolescence had significantly higher LMI at age 18 years than females who spent less time walking. This association, however, was only significant after adjusting for childhood BMIZ, indicating the possibility of negative confounding from an unmeasured variable. In the 1993 Pelotas Birth Cohort, active commuting to school throughout adolescence was associated with lower levels of central fatness at age 18 years in males [46]. It is possible that the intensity of walking to and from school was not high enough to have an impact on adiposity in our South African population. The Pelotas study included commuting via bicycle in their measure of active commuting, while we only included walking due to low prevalence of reported cycling.

Sedentary behavior, independent of physical activity, is a risk factor for overweight and obesity [14]. Sedentary behaviors, such as TV viewing, in childhood and adolescence have been prospectively linked to overweight and other adverse health outcomes in adulthood [47]. In our study, females who engaged in consistently high amounts of sedentary behavior throughout adolescence had significantly higher waist circumference at age 18 years than females who engaged in initially low but increasing amounts of sedentary behavior, but there was no association between trends in sedentary behavior and anthropometric measures and body composition at age 18 years in males. In an Australian birth cohort, males with lower screen time in childhood had lower percent body fat at age 20 years than males with consistently high screen time, and females with initially and consistently lower screen time had lower percent fat at age 20 years than females with consistently high screen time [10]. The Australian study focused on TV viewing whereas we examined total sedentary behavior and individual sedentary behaviors have been shown to have varying impacts on different health outcomes [48].

Reduced sleep is an independent risk factor for excess weight [49, 50]. Proposed mechanisms behind this relationship include metabolic and endocrine alterations, increased appetite leading to higher caloric consumption, increased systemic inflammation and decreased physical activity related to daytime sleepiness [51-53]. Most of the evidence on sleep duration and excess weight is cross-sectional, comes from high-income countries, or did not follow up into adulthood [11]. We found that males who reported consistently getting more sleep per night on school nights had significantly lower BMI, waist circumference, fat mass index and percent body fat at age 18 years than males who reported sleeping fewer hours per night. Trends in sleep duration over adolescence, however, were not associated with anthropometric measures or body composition at age 18 years in females. In support of our findings, several studies have found the association between short sleep duration and obesity to only exist in males [54]. The sex difference in this association may be attributed to different physiological mechanisms and hormones in males and females [54]. In contrast to our sex-specific findings, in the Pelotas Birth Cohort Study, females who increased from inadequate (<8 hours per day) to adequate (≥8 hours per day) sleep duration over adolescence had higher BMI, fat mass index and fat-free mass index at age 18 years than those who consistently got adequate sleep [55]. Differences in adolescent sleep trends between the South African and Brazilian cohorts and differences in how sleep duration was categorized may explain the differences in findings.

Strengths and Limitations

The main strength of our study was the use of longitudinal data with follow-up into late adolescence. We used longitudinal data from Africa, which is particularly scarce. Additionally, the use of detailed body composition data obtained via DXA allowed us to distinguish between fat mass and lean mass, providing a more accurate predictor of overweight and obesity than can be obtained from the use of BMI alone. The main limitation of our study was the use of self-reported physical activity, sedentary behavior and sleep data. Additionally, the LCGA and multi-trajectory modeling used previously to generate adolescent trajectories and overall physical activity patterns come with limitations, which have been discussed in detail elsewhere [8]. Also, this study cannot address the potential impact of dietary patterns on the relationship between movement behaviors and adiposity. Regardless of its limitations, this study contributes to the scarcity of prospective data on adolescent health behaviors and adult health in Africa.

5.6 Conclusion

Being consistently physically active and getting more sleep per night throughout adolescence was associated with more favorable body composition at age 18 years in urban South African males. Being more sedentary over adolescence was associated with less favorable anthropometric measurements in urban South African females. Adolescent physical activity, sedentary behavior and sleep are modifiable behaviors that may be contributing to the prevalence of overweight and obesity in urban South African adults.

5.7 References for Chapter 5

1. World Health Organization: **Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks.** 2009.
2. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany EC, Biryukov S, Abbafati C, Abera SF, et al**: Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013.** Lancet 2014, 384:766-781.
3. Dai S, Labarthe DR, Grunbaum JA, Harrist RB, Mueller WH**: Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years.** Project HeartBeat! Am J Epidemiol 2002, 156:720-729.
4. Chulani VL, Gordon LP: **Adolescent growth and development**. Primary care 2014, 41:465-487.
5. World Health Organization**: Health for the world's adolescents: a second chance in the second decade.** Geneva2014.
6. Dick B, Ferguson BJ**: Health for the world's adolescents: a second chance in the second decade.** The Journal of adolescent health: official publication of the Society for Adolescent Medicine 2015, 56:3-6.
7. Dumith SC, Gigante DP, Domingues MR, Kohl HW, 3rd**: Physical activity change during adolescence: a systematic review and a pooled analysis**. Int J Epidemiol 2011, 40:685-698.
8. Hanson SK, Munthali RJ, Micklesfield LK, Lobelo F, Cunningham SA, Hartman TJ, Norris SA, Stein AD: **Longitudinal patterns of physical activity, sedentary behavior and sleep in urban South African adolescents, Birth-To-Twenty Plus cohort**. BMC Pediatr 2019, 19:241.
9. Menschik D, Ahmed S, Alexander MH, Blum R: **Adolescent physical activities as predictors of young adult weight**. Archives of Pediatrics & Adolescent Medicine 2008, 162:29-33.
10. McVeigh J, Smith A, Howie E, Straker L: **Trajectories of Television Watching from Childhood to Early Adulthood and Their Association with Body Composition and Mental Health Outcomes in Young Adults**. PLoS One 2016, 11:e0152879.
11. Fatima Y, Doi SA, Mamun AA**: Longitudinal impact of sleep on overweight and obesity in children and adolescents: a systematic review and bias-adjusted meta-analysis.** Obes Rev 2015, 16:137-149.
12. Hallal PC, Victora CG, Azevedo MR, Wells JC: **Adolescent physical activity and health: a systematic review.** Sports Med 2006, 36:1019-1030.
13. Ramires VV, Dumith SC, Wehrmeister FC, Hallal PC, Menezes AM, Goncalves H**: Physical activity throughout adolescence and body composition at 18 years: 1993 Pelotas (Brazil) birth cohort study.** Int J Behav Nutr Phys Act 2016, 13:105.
14. Katzmarzyk PT**: Physical activity, sedentary behavior, and health: paradigm paralysis or paradigm shift?** Diabetes 2010, 59:2717-2725.
15. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, Goldfield G, Gorber SC: **Systematic review of sedentary behaviour and health indicators in school-aged children and youth**. Int J Behav Nutr Phys Act 2011, 8:1-22.
16. Gradisar M, Gardner G, Dohnt H: **Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep**. Sleep medicine 2011, 12:110-118.
17. Owens J**: Insufficient Sleep in Adolescents and Young Adults: An Update on Causes and Consequences**. Pediatrics 2014, 134:e921.
18. Carskadon MA: **Sleep in adolescents: the perfect storm.** Pediatric clinics of North America 2011, 58:637-647.

19. Richter L, Norris S, Pettifor J, Yach D, Cameron N**: Cohort Profile: Mandela's children: the 1990 Birth to Twenty study in South Africa**. Int J Epidemiol 2007, 36:504-511.
20. Richter LM, Yach D, Cameron N, Griesel RD, de Wet T: **Enrolment into Birth to Ten (BTT): population and sample characteristics.** Paediatr Perinat Epidemiol 1995, 9:109-120.
21. Richter LM, Panday S, Norris SA: **Factors influencing enrolment: A case study from Birth to Twenty, the 1990 birth cohort in Soweto–Johannesburg**. Eval Program Plann 2009, 32:197-203.
22. Richter LM, Norris SA, De Wet T: **Transition from Birth to Ten to Birth to Twenty: the South African cohort reaches 13 years of age.** Paediatr Perinat Epidemiol 2004, 18:290-301.
23. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA: **Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status**. Am J Clin Nutr 1990, 52:953-959.
24. Formisano A, Hunsberger M, Bammann K, Vanaelst B, Molnar D, Moreno LA, Tornaritis M, Veidebaum T, Lissner L, Barba G, Siani A: **Family structure and childhood obesity: results of the IDEFICS Project.** Public Health Nutr 2014, 17:2307-2315.
25. de Oliveira Meller F, Assuncao MC, Schafer AA, de Mola CL, Barros AJ, Dahly DL, Barros FC: **The influence of birth order and number of siblings on adolescent body composition: evidence from a Brazilian birth cohort study**. Br J Nutr 2015, 114:118-125.
26. Arkes J**: Longitudinal association between marital disruption and child BMI and obesity.** Obesity (Silver Spring) 2012, 20:1696-1702.
27. Biehl A, Hovengen R, Groholt EK, Hjelmesaeth J, Strand BH, Meyer HE: **Parental marital status and childhood overweight and obesity in Norway: a nationally representative cross-sectional study.** BMJ Open 2014, 4:e004502.
28. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW: **Correlates of physical activity: why are some people physically active and others not?** Lancet 2012, 380:258-271.
29. F. Sallis J, Owen N, Fisher E: Ecological Models of Health Behavior.2008.
30. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman S, Norris SA: **Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates.** BMC Public Health 2014, 14:40.
31. McVeigh J, Norris S, de Wet T: **The relationship between socio-economic status and physical activity patterns in South African children.** Acta Paediactr 2004, 93:982-988.
32. WHO Multicentre Growth Reference Study Group. **WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development**. (Organization WH ed. Geneva2006.
33. Lundeen EA, Norris SA, Adair LS, Richter LM, Stein AD: **Sex differences in obesity incidence: 20-year prospective cohort in South Africa**. Pediatr Obes 2016, 11:75-80.
34. Rogol AD, Roemmich JN, Clark PA**: Growth at puberty**. Journal of Adolescent Health 2002, 31:192-200.
35. Strasser B: **Physical activity in obesity and metabolic syndrome**. Ann N Y Acad Sci 2013, 1281:141-159.
36. Kwon S, Janz KF, Letuchy EM, Burns TL, Levy SM**: Active lifestyle in childhood and adolescence prevents obesity development in young adulthood**. Obesity (Silver Spring) 2015, 23:2462-2469.
37. Yang X, Telama R, Viikari J, Raitakari OT: **Risk of obesity in relation to physical activity tracking from youth to adulthood.** Med Sci Sports Exerc 2006, 38:919-925.
38. Tammelin T, Laitinen J, Nayha S: **Change in the level of physical activity from adolescence into adulthood and obesity at the age of 31 years**. Int J Obes Relat Metab Disord 2004, 28:775-782.

39. Gitau TM, Micklesfield LK, Pettifor JM, Norris SA**: Changes in eating attitudes, body esteem and weight control behaviours during adolescence in a South African cohort**. PloS one 2014, 9:e109709-e109709.
40. Gitau TM ML, Pettifor JM, Norris SA: **Ethnic differences in eating attitudes, body image and self-esteem among adolescent females living in urban South Africa**. J Psychiatry 2014, 17:468-474.
41. **WHO recommendation on adolescent health: guidelines approved by the WHO Guidelines Review Committee.** Geneva: World Health Organization; 2017.
42. Janssen I: **Active play: an important physical activity strategy in the fight against childhood obesity**. Can J Public Health 2014, 105:e22-27.
43. Vogel L**: Active play key to curbing child obesity**. Cmaj 2015, 187:E269-270.
44. Larouche R, Saunders TJ, Faulkner G, Colley R, Tremblay M**: Associations between active school transport and physical activity, body composition, and cardiovascular fitness: a systematic review of 68 studies.** J Phys Act Health 2014, 11:206-227.
45. Lubans DR, Boreham CA, Kelly P, Foster CE: **The relationship between active travel to school and health-related fitness in children and adolescents: a systematic review**. Int J Behav Nutr Phys Act 2011, 8:5.
46. Martinez-Gomez D, Mielke GI, Menezes AM, Goncalves H, Barros FC, Hallal PC: **Active commuting throughout adolescence and central fatness before adulthood: prospective birth cohort study.** PLoS One 2014, 9:e96634.
47. Hancox RJ, Milne BJ, Poulton R: **Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study.** Lancet 2004, 364:257-262.
48. Carson V, Hunter S, Kuzik N, Gray CE, Poitras VJ, Chaput JP, Saunders TJ, Katzmarzyk PT, Okely AD, Connor Gorber S, et al: **Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update.** Appl Physiol Nutr Metab 2016, 41:S240-265.
49. Patel SR: **Reduced sleep as an obesity risk factor**. Obes Rev 2009, 10 Suppl 2:61-68.
50. Miller MA, Kruisbrink M, Wallace J, Ji C, Cappuccio FP: **Sleep Duration and Incidence of Obesity in Infants, Children and Adolescents: A Systematic Review and Meta-Analysis of Prospective Studies.** Sleep 2018.
51. Knutson KL, Van Cauter E: **Associations between sleep loss and increased risk of obesity and diabetes**. Ann N Y Acad Sci 2008, 1129:287-304.
52. Leproult R, Van Cauter E: **Role of sleep and sleep loss in hormonal release and metabolism.** Endocr Dev 2010, 17:11-21.
53. Van Cauter E, Knutson KL: **Sleep and the epidemic of obesity in children and adults**. Eur J Endocrinol 2008, 159 Suppl 1:S59-66.
54. Knutson KL: **Sex differences in the association between sleep and body mass index in adolescents**. J Pediatr 2005, 147:830-834.
55. Schafer AA, Domingues MR, Dahly DL, Meller FO, Goncalves H, Wehrmeister FC, Assuncao MC: **Sleep Duration Trajectories and Body Composition in Adolescents: Prospective Birth Cohort Study**. PLoS One 2016, 11:e0152348.

5.8 Chapter 5 Tables and Figures

Table 5.1. Characteristics of participants by sex, Bt20+

	Males	Females
N	638	699
Childhood characteristics		
Birth order, %		
First born	38	41
BMIZ at age 7/8 or 9 y	0.0 (0.9)	0.0 (1.0)
Maternal characteristics		
Schooling at child age 7/8 y, %		
Matriculated	29	31
Household characteristics		
SES asset quintile at child age 7/8 y, %		
1 (lowest)	16	22
2	21	17
3	30	29
4	23	19
5 (highest)	10	13
Adolescent trajectories		
informal activity, %		
Decreasing over time	93	95
Increasing over time	7	5
Organized sports participation, %		
Males		
Consistently low	82	
Decreasing from adequate to low	11	
Increasing from low to adequate	7	
Females		
No sports participation		89
Some sports participation		11
Walking to and from school, %		
Consistently 150 min/week	83	75
Consistently 300 min/week	17	25
Overall physical activity, %		
Decreasing activity over time and do not walk to school	22	31
Decreasing activity over time but consistently walk to school	50	54
Consistently more active and consistently walk to school	28	15
Sedentary behavior, %		
Males		
Consistently low	78	
Consistently high	12	
Increasing from low to high	10	
Females		
Initially low		92
Consistently high		8
School-night sleep, %		
≤ 8 hours/night	35	65
≥ 9 hours/night	65	35

<u>Young-adult characteristics (18 y)</u>		
Height, cm	170.7 (6.5)	159.6 (6.1)
BMI, kg/m2	20.3 (3.2)	23.2 (4.6)
Waist-circumference	72.0 (7.2)	75.6 (12.9)
Fat mass index, kg/m2	2.5 (1.5)	7.3 (3.0)
Lean mass index, kg/m2	15.0 (1.5)	13.1 (1.6)
Body fat, %	13.2 (5.5)	33.6 (6.7)

[a] Expressed as mean (standard deviation).
[b] data collected from only 958 participants (449 males and 509 females)

Table 5.2. Mean anthropometric and body composition measures at 18y by adolescent movement behavior trajectories, Bt20+

	BMI (kg/m²)	Waist circumference (cm)	Fat Mass Index [a] (kg/m²)	Lean Mass[b] Index [c] (kg/m²)	Body fat (%)	BMI (kg/m²)	Waist circumference (cm)	Fat Mass Index (kg/m²)	Lean Mass Index (kg/m²)	Body fat (%)
	Males					**Females**				
N	638	638	449	449	449	699	699	509	509	509
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Informal activity										
Decreasing over time	20.4 (3.1)	72.1 (7.3)	2.5 (1.6)	15.7 (1.5)	13.4 (5.6)	23.1 (4.6)	75.4 (11.0)	7.2 (3.0)	13.1 (1.6)	33.5 (7.0)
Increasing over time	19.4 (2.1)	69.9 (5.1)	1.9 (0.7)	14.7 (1.0)	11.1 (3.4)	23.9 (4.3)	80.1 (31.1)	8.4 (2.8)	13.8 (1.5)	35.8 (6.5)
P-value	0.04	0.05	0.04	0.21	0.03	0.3	0.03	0.08	0.03	0.12
Organized sports participation										
Males										
Consistently low	30.4 (3.2)	72.1 (7.5)	2.5 (1.6)	15.0 (1.5)	13.4 (5.6)					
Decreasing from adequate to low	19.8 (2.3)	71.5 (6.4)	2.3 (1.7)	14.7 (1.1)	12.6 (6.1)					
Increasing from low to adequate	20.1 (1.9)	71.2 (5.0)	2.2 (0.9)	15.3 (1.4)	12.1 (4.0)					
P-value	0.4	0.6	0.3	0.3	0.3					
Females										
None						23.3 (4.7)	76.0 (13.2)	7.4 (3.01)	13.1 (1.7)	33.9 (6.9)
Consistently some						22.3 (3.4)	72.8 (9.1)	6.5 (2.7)	13.1 (1.2)	31.1 (7.5)
P-value						0.1	0.04	0.04	0.9	0.005
Walking to and from school										
Consistently 150 min/week	20.4 (3.1)	72.2 (7.4)	2.6 (1.6)	15.1(1.5)	13.4 (5.7)	23.2 (4.8)	75.8 (13.6)	7.4 (3.2)	13.1 (1.7)	33.7 (7.3)
Consistently 300 min/week	19.9 (2.6)	71.0 (6.1)	2.2 (1.0)	14.9 (1.5)	12.1 (4.1)	23.0 (3.7)	75.2 (10.6)	7.1 (2.5)	13.2 (1.4)	33.2 (6.2)
P-value	0.2	0.1	0.07	0.3	0.07	0.7	0.6	0.5	0.4	0.4
Overall physical activity [d]										
Decreasing activity over time and do not walk to school	20.9 (3.6)	72.3 (7.4)	3.0 (2.2)	15.1 (1.4)	14.9 (7.4)	23.6 (5.2)	75.6 (11.7)	7.7 (3.3)	13.1 (1.7)	34.7 (7.2)
Decreasing activity over time but consistently walk to school	20.4 (3.1)	72.3 (7.3)	2.5 (1.3)	15.0 (1.6)	13.2 (4.9)	23.0 (4.3)	75.7 (11.0)	7.2 (3.0)	13.1 (1.6)	33.4 (6.8)
Consistently more active and consistently walk to school	19.3 (2.0)	70.1 (6.0)	2.1 (1.1)	15.1 (1.2)	11.7 (4.3)	22.8 (3.9)	75.5 (20.0)	6.8 (2.7)	13.2 (1.4)	32.1 (7.1)
P-value	0.001	0.03	0.0002	0.7	0.0001	0.2	0.9	0.1	0.8	0.03
Sedentary behavior										
Males										
Consistently low	20.1 (2.6)	71.5 (6.5)	2.5 (1.5)	15.0 (1.5)	13.2 (5.5)					
Consistently high	20.7 (4.4)	72.6 (9.2)	2.1 (0.9)	14.7 (1.4)	12.0 (4.4)					

Increasing from low to high	21.2 (3.8)	74.6 (8.8)	2.8 (1.8)	15.3 (1.4)	14.1 (6.3)					
P-value	0.004	0.001	0.2	0.3	0.3					
<u>Females</u>										
Initially low						23.1 (4.5)	75.2 (10.9)	7.3 (3.0)	13.1 (1.6)	33.6 (6.9)
Consistently high						24.3 (5.0)	81.3 (26.7)	7.8 (3.6)	13.7 (1.7)	33.9 (8.4)
P-value						0.05	0.0008	0.4	0.04	0.8
<u>School-night sleep</u>										
≤ 8 hours/night	20.9 (3.7)	73.3 (8.5)	2.7 (1.7)	15.1 (1.6)	13.9 (5.9)	23.3 (4.6)	75.7 (14.0)	7.4 (2.9)	13.2 (1.6)	33.8 (6.9)
≥ 9 hours/night	20.0 (2.5)	71.2 (6.2)	2.4 (1.4)	15.0 (1.4)	12.9 (5.3)	22.8 (4.5)	75.4 (10.6)	7.1 (3.2)	13.0 (1.7)	33.1 (7.2)
P-value	0.0001	0.0007	0.06	0.3	0.06	0.1	0.8	0.3	0.2	0.3

[a] Fat mass index, calculated by dividing fat mass (in kg) by height (in meters) squared.
[b] Lean mass does not include bone mineral content.
[c] Lean mass index, calculated by dividing lean mass (in kg) by height (in meters) squared.
[d] Multi-trajectory groups made up of informal activity, organized sports and walking to and from school trajectories, representing overall physical activity pattern.

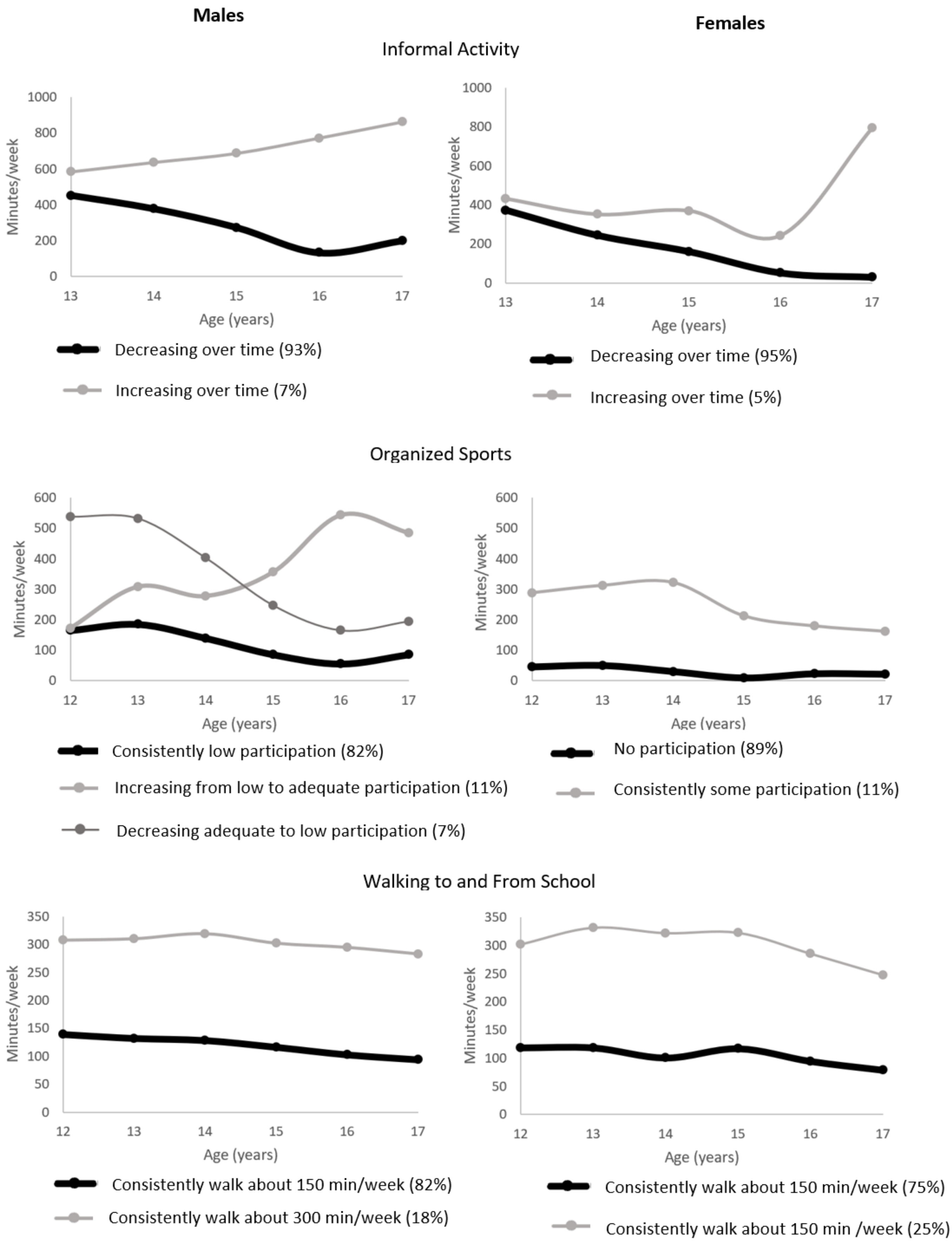
Table 5.3. Regression coefficients (B) and 95% CI for anthropometric and body composition measures at 18y, adjusted, Bt20+

	BMI (kg/m2)		Waist circumference (cm)		Fat mass index [a] (kg/m2)		Lean mass [b] index [c] (kg/m2)		Body fat (%)	
	Males									
N	638		638		449		449		449	
	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value
Informal activity [d]										
Decreasing over time	ref	0.7	ref	0.9	ref	0.5	ref	0.7	ref	0.4
Increasing over time	-0.2(-1.1-0.68)		0.0 (-2.4-2.4)		-0.2 (-0.8-0.4)		0.1 (-0.5-0.7)		-0.9 (-3.3-1.4)	
Organized Sports Participation [d]										
Consistently low	ref	0.4	ref	0.2	ref	0.5	ref	0.5	ref	0.4
Decreasing from adequate to low	0.02 (-0.9-0.8)		0.8 (-1.-3.0)	0.5	0.1 (-0.5-0.8)		-0.2 (-0.8-0.3)		0.4 (-2.0-2.8)	
Increasing from low to adequate	-0.2 (-1.1-0.7)		-1.6 (-3.7-0.4)	0.1	-0.3 (-0.9-0.3)		0.1 (-0.4-0.7)		-1.4 (-3.6-0.8)	
Walking to and from school [d]										
Consistently 150 min/week	ref	0.7	ref	0.8	ref	0.4	ref	0.8	ref	0.3
Consistently 300 min/week	-0.1 (-0.7-0.5)		-0.2 (-1.9-1.5)		-0.2 (-0.7-0.3)		0.0 (-0.4-0.5)		-0.9 (-2.7-0.9)	
Overall physical activity [e]										
model 1 [d]										
Decreasing activity over time and do not walk to school	ref	0.02	ref	0.01	ref	0.01	ref	0.5	ref	0.004
Decreasing activity over time but consistently walk to school	-0.8 (-1.4--0.2)		-2.1 (-3.7--0.4)		-0.7 (-1.1-0.2)		-0.2 (-0.6-0.2)		-2.2 (-3.8--0.6)	
Consistently more active and consistently walk to school	-0.8 (-1.5--0.2)		-2.7 (-4.5--0.8)		-0.8 (-1.3--0.3)		0.0 (-0.5-0.4)		-3.2 (-5.1--1.3)	
model 2 [f]										
Decreasing activity over time and do not walk to school	ref	0.1	ref	0.1	ref	0.02	ref	0.6	ref	0.008

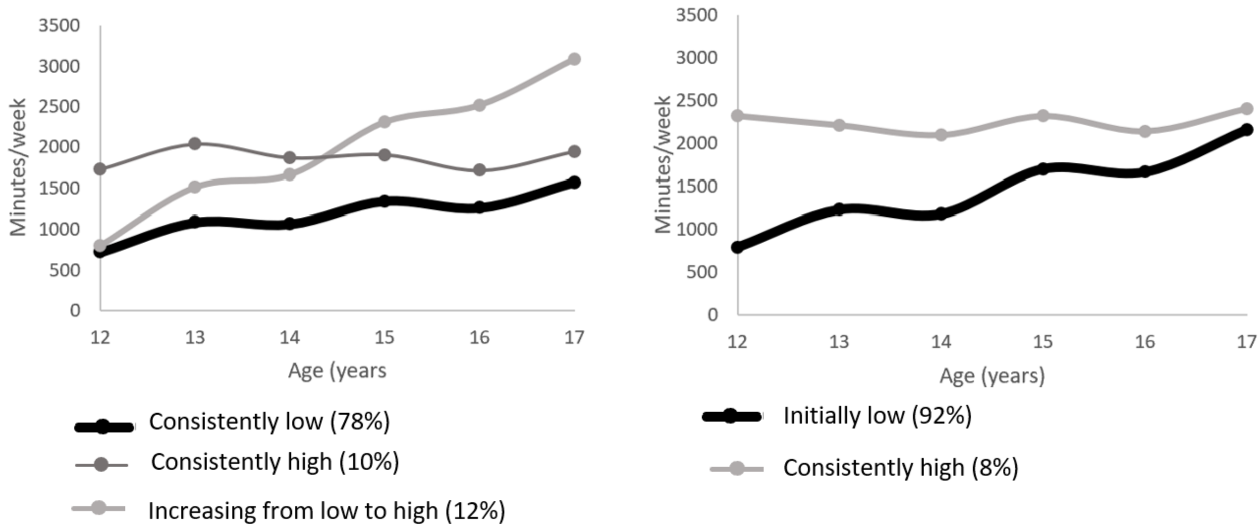
Decreasing activity over time but consistently walk to school	-0.6 (-1.2-0.1)		-1.4 (-3.1-0.3)		-0.56(-1.0--0.1)		-0.1 (-0.5-0.3)		-1.9 (-1.7--0.2)	
Consistently more active and consistently walk to school	-0.6 (-1.3-0.0)		-2.0 (-3.9--0.2)		-0.8 (-1.2--0.1)		0.1 (-0.4-0.6)		-2.9 (-4.9--0.9)	
Sedentary behavior [d]										
Consistently low	ref	0.1	ref	0.2	ref	0.2	ref	0.4	ref	0.2
Consistently high	0.6 (-1.3-1.4)		0.1 (-2.1-2.2)		-0.7 (-1.5-0.2)		-0.2 (-0.9-0.6)		-2.7 (-5.8-0.5)	
Increasing from low to high	0.5 (-0.2-1.2)		1.8 (-0.1-3.8)		0.3 (-0.2-0.8)		0.3 (-0.2-0.8)		0.6 (-1.3-2.5)	
School-night sleep [d]										
≤ 8 hours/night	ref		ref		ref		ref		ref	
≥ 9 hours/night	-1.0 (-1.4--0.5)	<0.0001	-2.3 (-3.7--1.1)	<0.0001	-0.4 (-0.8--0.1)	0.02	0.1 (-0.2-0.5)	0.5	-1.5 (-2.8--0.1)	0.04
Females										
N	699		699		509		509		509	
	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value
Informal activity [d]										
Decreasing over time	ref	0.2	ref	0.02	ref	0.2	ref	0.2	ref	0.2
Increasing over time	0.9 (-0.4-2.1)		6.0 (0.9-11.1)		0.8 (-0.5-2.0)		0.4 (-0.2- 1.1)		2.1 (-1.1-5.3)	
Organized sports participation [d]										
None	ref	0.8	ref	0.6	ref	0.9	ref	0.05	ref	0.6
Consistently some	0.4 (-0.6-1.4)		-1.4 (-5.0-2.7)		0.1 (-0.9 1.0)		0.5 (0.0- 1.0)		-0.7 (-3.0-1.67	
Walking to and from school [d]										
Consistently 150 min/week	ref	0.3	ref	0.8	ref	0.7	ref	0.02	ref	0.9
Consistently 300 min/week	0.4 (-0.3- 1.1)		0.4 (-3.4-2.6)		0.1 (-0.5-0.8)		0.4 (0.1-0.7)		0.1 (-1.5-1.7)	
Overall physical activity [e]										
model 1 [d]										
Decreasing activity over time and do not walk to school	ref	0.2	ref	0.09	ref	0.5	ref	0.2	ref	0.6
Decreasing activity over time but consistently walk to school	0.5 (-0.3-1.3)		2.6 (-0.6-5.8)		0.5 (-0.3-1.2)		0.3 (-0.1-0.7)		0.9 (-1.0-2.7)	
Consistently more active and consistently walk to school	0.9 (-0.1-1.9)		4.6 (0.5-8.6)		0.4 (-0.6-1.3)		0.4 (-0.1-0.9)		0.1 (-2.3-2.6)	
model 2 [f]										

Decreasing activity over time and do not walk to school	ref	0.2	ref	0.07	ref	0.5	ref	0.2	ref	0.6
Decreasing activity over time but consistently walk to school	0.5 (-0.3-1.4)		2.9 (-0.4-6.1)		0.4 (-0.3-1.2)		0.3 (-0.1-0.7)		0.8 (-1.1-2.7)	
Consistently more active and consistently walk to school	0.9 (-0.1-2.0)		4.8 (0.7-9.0)		04 (-0.6-1.3)		0.5 (0.0-0.1)		0.1 (-2.3-2.6)	
<u>Sedentary behavior [d]</u>										
Initially low	ref	0.08	ref	0.04	ref	0.1	ref	0.7	ref	0.06
Consistently high	-1.1 (-2.4-0.1)	0.08	5.4 (0.2-10.6)		-1.2 (-2.6-0.2)		-0.2 (-0.9-0.6)		-3.5 (-7.0-0.1)	
<u>School-night sleep [d]</u>										
≤ 8 hours/night	ref	0.8	ref	0.6	ref	0.3	ref	0.7	ref	0.7
≥ 9 hours/night	0.1 (-0.6-0.8)		0.6 (-2.2-3.3)		0.3 (-0.3-0.9)		-0.1 (-0.4-0.2)		0.3 (-1.2-1.8)	

[a] Fat mass index, calculated by dividing fat mass (in kg) by height (in meters) squared. [b] Lean mass does not include bone mineral content.
[c] Lean mass index, calculated by dividing lean mass (in kg) by height (in meters) squared.
[d] Adjusted for childhood BMIZ at age 7/ 8 or 9 years, birth order, maternal schooling, maternal marital status and SES asset quintile at child age 7/8 years.
[e] Multi-trajectory groups made up of informal activity, organized sports and walking to and from school trajectories representing overall physical activity pattern.
[f] Adjusted for childhood BMIZ at age 7/ 8 or 9 years, birth order, maternal schooling, maternal marital status and SES asset quintile at child age 7/8 years, and sedentary behavior and sleep trajectories.

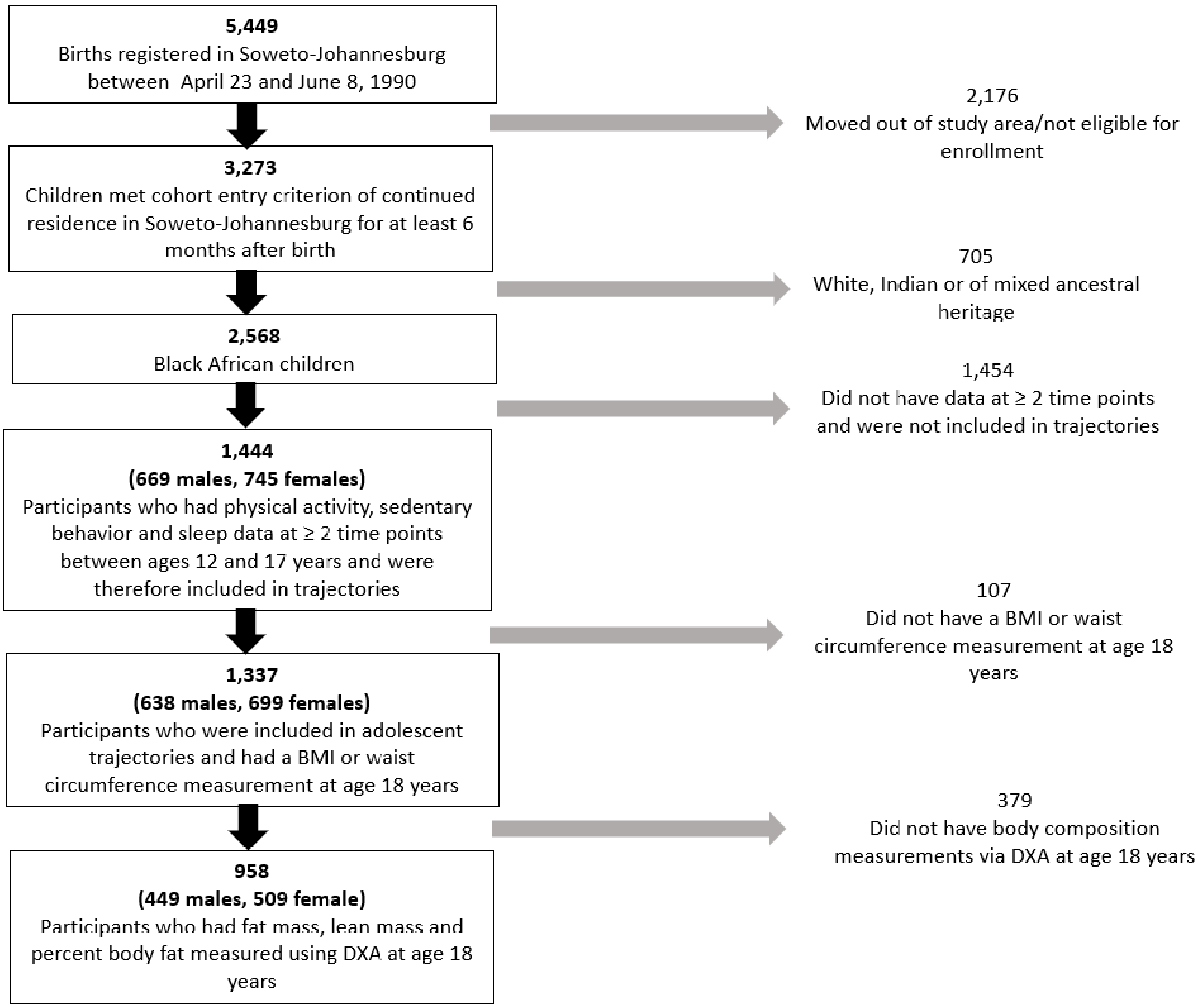

Males
Females
Informal Activity
Minutes/week
Age (years)
Decreasing over time (93%)
Increasing over time (7%)
Decreasing over time (95%)
Increasing over time (5%)
Organized Sports
Consistently low participation (82%)
Increasing from low to adequate participation (11%)
Decreasing adequate to low participation (7%)
No participation (89%)
Consistently some participation (11%)
Walking to and From School
Consistently walk about 150 min/week (82%)
Consistently walk about 300 min/week (18%)
Consistently walk about 150 min/week (75%)
Consistently walk about 150 min /week (25%)

Sedentary Behavior



[a] Figure has been adapted from previously published work and is intended to provide necessary background information for the present study [8]. The use of this figure is goverend by the copyright release in the original manuscript.

Supplemental Figure 5.1. Trajectories of physical activity and sedentary behavior from Latent Class Growth Analysis, Bt20+



Supplemental Figure 5.2. Flow chart depicting the final sample of eligible participants included in the analysis, Bt20+

Supplemental table 5.1. Comparison of characteristics of the study sample by data available and sex, Bt20+

	Males					Females				
	Black-Africans Excluded [a]	P-value [b]	Anthro Only [c]	Anthro + DXA [d]	P-value	Black-Africans Excluded	P-value	Anthro Only	Anthro + DXA	P-value
N	608		189	449		623		190	509	
Childhood characteristics										
Birth order, %										
First born	33	0.04	41	37	0.4	32	0.001	44	40	0.8
BMIZ at age 7/8 or 9 y	--	--	0.1 (0.9)	0.0 (0.9)	0.1	--	--	0.0 (0.9)	-0.1 (1.0)	0.6
Maternal characteristics										
Schooling at child age 7/8 y, %										
Matriculated	27	0.5	30	28	0.7	31	0.9	35	30	0.2
Marriage/union status, %										
In union	36	0.3	41	39	0.4	43	0.03	35	35	0.9
Household characteristics										
SES asset quintile at child age 7/8 y, %										
1 (lowest)	23	0.07	12	18	0.09	26	0.1	24	24	0.007
2	19		20	21		23		17	18	
3	29		32	29		24		32	28	
4	16		22	23		17		14	20	
5 (highest)	13		14	8		10		19	10	
Adolescent Trajectories										
informal activity, %										
Decreasing over time			92	93	0.5			92	95	0.1
Increasing over time			8	7				7	5	
Organized sports participation, %										
Males										
Consistently low			82	82	0.7					
Decreasing from adequate to low			7	6						
Increasing from low to adequate			10	12						
Females										
None								89	89	0.9
Consistently some								11	11	
Walking to and from school, %										
Consistently 150 min/week			79	84	0.1			79	73	0.09

Consistently 300 min/week	21	16			21	27	
Overall physical activity [e], %							
Decreasing activity over time and do not walk to school	21	22	0.7		36	29	
Decreasing activity over time but consistently walk to school	50	51			48	56	
Consistently more active and consistently walk to school	30	27			16	15	
Sedentary behavior, %							
Males							
Consistently low	66	83					
Consistently high	15	6					
Increasing from low to high	19	11					
Females							
Initially low					88	94	0.01
Consistently high					12	6	
School-night sleep, %							
≤ 8 hours/night	69	69	0.9		68	64	0.3
≥ 9 hours/night	31	31			32	36	
Young-adult characteristics (18 y)							
BMI, kg/m2	20.7 (3.8)	20.1 (2.6)	0.02		23.5 (4.9)	23.2 (4.4)	0.2
Waist- circumference	71.2 (8.3)	72.3 (6.6)	0.09		75.4 (17.0)	75.7 (10.9)	0.8

[a] Black-African participants who did not have movement behavior data at ≥2 timepoints and were therefore not included in adolescent trajectories and excluded from the analysis.
[b] P-value for comparison of Black-African participants excluded from analysis to the participants (638 male and 699 female) who were included in adolescent trajectories and had a BMI or waist circumference data at age 18 years.
[c] Participants who had anthropometric data (BMI, waist circumference) at age 18 years, but not DXA body composition data (lean mass, fat mass, percent fat).
[d] Participants who had both anthropometric data and DXA body composition data at age 18 years).
[e] Multi-trajectory groups made up of informal activity, organized sports and walking to and from school trajectories representing overall physical activity pattern.

Part 3

Discussion and Implications

Chapter 6: Discussion

Preface

Extensive discussion of key findings in the context of current research can be found in empirical chapters 1 and 2. Here, I will focus on summarizing key findings and discussing the overall story, public health implications, strengths and limitations, and future directions of this research.

6.1 Summary of Study Findings

There were two main aims to this dissertation. First, to add to the paucity of longitudinal data on physical activity, sedentary behavior and sleep change over time from adolescents living in Africa. Second, to offer new insights into the current adult overweight and obesity epidemic in South Africa by examining the association of adolescent physical activity, sedentary behavior and sleep with anthropometry and body composition at age 18 years. The consolidated findings from the empirical chapters are summarized in table 6.1.

Table 6.1 Consolidated findings

Chapter		Objective	Key Findings
3	1a.	Identify physical activity, sedentary behavior and sleep trajectories from ages 12-17/18y	• Using latent class growth analysis (LCGA), I identified: - 2 informal activity trajectories each for males and females (*increasing over time, decreasing over time*). -3 organized sport trajectories for males (*consistently low, decreasing from adequate to low, increasing from low to adequate*) and 2 for females (*none, some*). - 2 walking to and from school trajectories each for males and females (*approx. 150 min/week, approx. 300 min/week*). - 3 sedentary behavior trajectories in males *(consistently low, consistently high, increasing from high to low)* and 2 in females *(initially low but increasing, consistently high*) - 4 school-night sleep trajectories in males *(consistent 7, 8, 9, 10 h /night*) and 3 in females *(consistent 6.5, 8, 9 h/night)* -3 weekend sleep trajectories in males *(consistent 7.5, 9.5, 11 h/night*) and 4 for females *(consistent 8, 9, 10, 11.5 h/night).* • 82% of males and 100% of females failed to meet the WHO recommendation of 60 min per day of moderate-to-vigorous physical activity throughout adolescence (indicated by the organized sports trajectories). • By age 13 years, 100% of both males and females engaged in more than 2 hours per day of sedentary behavior, which persisted throughout adolescence. • 95% of males and 92% of females reported sleeping between 8 and 10 hours per night on school-nights through, which meets the American Academy of Sleep recommendation for this age group.

3	1b.	Identify overall adolescent physical activity patterns	• Using group-based multi-trajectory modeling with 3 physical activity domains, I identified 3 distinct overall physical activity patterns that were similar in males and females: "*Decreasing activity over time and do not walk to school*", "*Decreasing activity over time and consistently walk to school*" and "*Consistently more active and consistently walk to school*." • 71% of males and 82% of females decreased overall physical activity throughout adolescence.
3	1c.	See if physical activity, sedentary behavior and sleep track together over time in adolescence	• Using group-based multi-trajectory modeling with physical activity, sedentary behavior and sleep together did not result in distinct groups. There was not enough heterogeneity in the linkages between these behaviors to identify clusters of individuals following similar patterns.
3	1d.	Examine associations between maternal and childhood socio-ecological variables and adolescent trajectories/multi-trajectory groups	• <u>SES:</u> Higher SES was associated with: -higher likelihood of increasing informal activity over time (versus decreasing over time) in males -higher likelihood of walking 150 min/week to and from school (versus 300 min/week) in males and females. -Not associated with organized sports trajectories in males or females <u>Maternal schooling:</u> Higher maternal schooling was associated with: -higher likelihood of walking 150 min/week to and from school (versus 300 min/week) in males and females -higher likelihood of engaging in consistently high amounts of sedentary behavior (versus consistently low) in males -Not associated with organized sports trajectories in males or females
4	2a.	Assess associations of categories of longitudinal adolescent physical activity, sedentary behavior and sleep with anthropometry and body composition at age 18 y.	*After adjusting for covariates:* • Females who increased informal activity over adolescence had significantly higher waist circumference than females whose informal activity decreased. • Females who walked approximately 300 minutes per week to and from school over adolescence had significantly higher LMI than those who walked approximately 150 minutes per week. • Females who engaged in consistently high amounts of sedentary behavior over adolescence had significantly higher waist circumference than those who engaged in initially low but increasing amounts. • Males who reported sleeping 9 hours or more per night on school-nights had significantly lower BMI, waist circumference, FMI and percent body fat than those who reported sleeping 8 hours or more per night.
4	2b.	Assess associations of overall adolescent physical activity patterns with anthropometry and body composition at age 18y	*After adjusting for covariates:* • Males who decreased activity and walked to school over adolescence had significantly lower FMI and percent body fat and males who were consistently more active and walked to school over adolescence had significantly lower waist circumference FMI, and percent body fat at age 18 years

	when compared to males who decreased activity and did not walk to school. • Females who were consistently more active and consistently walked to school over adolescence had significantly higher waist circumference at age 18 years than females who decreased activity and did not walk to school over adolescence

6.2 Overall story

Since South Africa's political transformation with the first democratic election in 1994, the nation has experienced rapid urbanization, globalization and other socioeconomic changes [1]. Like other LMICs, these socioeconomic changes have led to an epidemiologic transition, where the burden of disease is shifting from infectious to non-communicable diseases [2]. Now South Africa faces a high burden of overweight and obesity, affecting 69% of women and 39% of men [3]. Given this high disease burden, identifying and understanding modifiable factors contributing overweight and obesity are critically important.

Physical activity, sedentary behavior and sleep are modifiable risk factors that have been shown to contribute to overweight and obesity in high-income countries [4-6]. However, until now, there have been no longitudinal studies on these modifiable behaviors in adolescents from Africa. This dissertation focuses on these modifiable risk factors in adolescence, an age group that, until recently, has been overlooked in public health research and policy, and largely ignored in Africa [7]. Most research on physical activity, sedentary behavior and sleep take a one size fits all approach and assume that all individuals in the population follow the same behavior pattern over time. However, adolescence is a dynamic phase of life influenced by a wide range of biological, social and environmental factors, and behaviors among individuals likely vary [8].

Using LCGA, I was able explore the variation in how physical activity, sedentary and sleep behaviors develop over 6 years of adolescence in both males and females. LCGA generates categories, or trajectories, of longitudinally observed variables. This method takes a "person-centered" rather than "variable-centered" approach to the analyses which allowed me to identify subsets of individuals whose behaviors differed from the population norm [9]. For example, while 89% of females did not participate in organized sports at all over adolescence, LCGA identified a small sub-set of 11% who did. In males, 89% decreased participation in organized sports over adolescence, but 11% increased. Standard longitudinal methods would have generated a single growth curve, failed to distinguish these sub-sets, and would not have described the behaviors in this population adequately.

While examining individual domains of physical activity is important, I was also interested in seeing if, and how, the domains tracked together over time. Doing so would allow me to recognize "overall physical activity" patterns in this population. Using group-based multi-trajectory modeling, I was able to identify clusters of individuals who followed similar groupings of informal activity, organized sports and walking to and from school over time. I found three distinct patterns of overall physical activity among males and females in this population; two that concurrently decreased informal activity and organized sport participation and varied only by level of walking to and from school, and one that maintained higher levels of all three domains. By using this methodological approach, I discovered that while most adolescents in the population experienced the age-related decline in overall physical activity seen in other populations [10], 28% of males and 15% of females were consistently active throughout adolescence.

Recently, there has been a paradigm shift from looking at the associations of physical activity, sedentary behavior and sleep with overweight and obesity in isolation, to looking at them together [11]. Because my data were questionnaire based, I was unable to take a compositional data analysis approach that is often used with objectively measured data. To overcome this, and make use of the strong longitudinal data, I took a novel approach and used group-based multi-trajectory modeling to identify "overall movement behavior" patterns. This approach however, had limited success. While I able to create groupings of trajectories, much of the information form the single trajectory analysis was lost, and there was little distinction between groups. There was not enough heterogeneity in the linkages between the physical activity, sedentary behavior and sleep trajectories to create meaningful groupings of the trajectories together, suggesting these adolescent behaviors have different etiologies. Because of this, I decided to not include the “overall movement behavior” patterns in the subsequent analyses of this dissertation.

Once I identified the trajectories for each physical activity domain, sedentary behavior and sleep and the overall physical activity patterns, I was able to examine what were and were not predictors of each. Understanding the factors that influence changes in behavior as adolescents age and develop is necessary for informing public health efforts and interventions. For example, an intervention aiming to increase the exceedingly low female organized sports participation in urban South Africa, may find it useful to know that SES during childhood does not predict whether or not a female participates in organized sports during adolescence, which would allow efforts to focus on other potential barriers to female sports participation.

The socioecological predictors I selected *a priori* based on literature review and previous finding is this population did not explain much of the variability in adolescent physical activity, sedentary behavior and sleep trajectories or overall physical activity patterns. Adolescent behaviors that develop over time are complex and therefore likely have a complex causal web [12]. Environmental and psychosocial factors potentially play a greater role in the development of these behaviors over adolescence and should be a focus of future research.

In Empirical Chapter 1, I wanted to identify groups of adolescents whose behaviors stood out from the norm and examine what set them apart from the majority of this urban South African population. Therefore, in the analyses for Empirical Chapter 1, I set the trajectory that included the highest percentage of participants for each behavior as the referent group and compared the smaller trajectories to it. This method led to difficulties in interpretation and comparability of results with other populations. To address this, for Empirical Chapter 2, I made the trajectory with the lowest duration of each behavior as the referent group. This allowed me to examine if higher levels of physical activity, sedentary behavior and sleep throughout adolescence were associated with more favorable body composition at age 18 years.

The results of Empirical Chapter 2 showed that adolescent physical activity, sedentary behavior and sleep were all related to young-adult body composition in urban South Africa, but that the contribution of each behavior varies by sex. Being consistently physically active and getting more sleep per night throughout adolescence was associated with more favorable body composition at age 18 years among males. Being more sedentary over adolescence was associated with less favorable anthropometric measurements among females. These findings suggest that adolescent physical activity, sedentary behavior and sleep may be contributing to the high prevalence of overweight and obesity in urban South Africa.

The first step in tackling the overweight and obesity epidemic in South Africa should be prevention. Adolescence is a critical time to shape learning and behaviors, making it an ideal time for behavioral interventions [8]. Healthy patterns of physical activity, sedentary behavior and sleep are usually established and reinforced during adolescence [13]. These behaviors are modifiable risk factors that can be targeted by public health interventions early in life. The findings from this dissertation suggest that increasing physical activity, reducing sedentary behavior and maintaining adequate sleep duration throughout adolescence are effective means to curb overweight and obesity in urban South Africa. Public health efforts and interventions aimed at reducing overweight and obesity in this population should focus on improving these behaviors in adolescence.

6.3 Strengths and Limitations

The overarching strength of this dissertation is that it is the first longitudinal study of adolescent physical activity, sedentary behavior and sleep in an African population. The data used for this research covered six years of adolescence and followed up to age 18 years, covering multiple domains of physical activity, sedentary behaviors and both weekday and weekend sleep. Another strength of this dissertation is the use detailed body composition data obtained via DXA, the gold standard in body composition measurement, in addition to anthropometric measurements. The use of DXA data allowed for the distinction between fat mass and lean mass, providing a more accurate measure of overweight and obesity than BMI. The main limitation of this dissertation was the use of self-reported physical activity, sedentary behavior and sleep data, which is less reliable than objectively measured data. Additionally, this dissertation did not include dietary data, and was therefore unable to address the potential impact of adolescent dietary patterns on the relationship between movement behaviors and body composition.

A methodological strength of this dissertation was the use of LCGA to model changes in physical activity sedentary behavior and sleep over time. This approach identified subsets of individuals whose behaviors differed from the population norm, allowing a more complete picture of these behaviors over time in this population. The use of LCGA presented some limitations, as validity of LCGA is occasionally questioned [14]. In LCGA, model fit statistics may not adequately differentiate between a model with multiple latent classes and a single-class model with non-normal outcomes [14]. Further, trajectory class membership is based on estimated posterior probabilities from a maximum likelihood analysis and not all participants follow a trajectory perfectly [9]. An additional methodological strength of this dissertation was the use of a novel approach in describing an overall physical activity pattern covering multiple domains of physical activity. This approach was also used to identify an overall pattern of all movement behaviors over time but was not as successful.

Despite its limitations, this dissertation contributes prospective data on adolescent physical activity, sedentary behavior and sleep from Africa. Further, the results of this dissertation offer new insights into the role of these adolescent behaviors on the overweight and obesity epidemic engulfing South Africa and other LMICs.

6.4 Directions for Future Research

This dissertation has unearthed the following research gaps:

1. This research was unable to address the potential impact of dietary patterns on the association between adolescent movement behaviors and later adiposity. Future research should model longitudinal adolescent dietary patterns alongside the movement behavior patterns and examine their concurrent influence on body composition at age 18 years.
2. I conducted sex-stratified analyses but did not directly compare males and females. Additional research is needed to see if sex mediates the associations between adolescent trajectories and adult outcomes. This research may help in understanding the vast sex-differences in overweight and obesity prevalence in South Africa.
3. This study had limited success identifying overall “movement behavior” patterns using group-based multi-trajectory modeling. This approach may still provide a novel way of summarizing these behaviors over time, but more methodological testing is needed.
4. Socioecological factors in childhood did not predict much of the variability in adolescent physical activity, sedentary behavior or sleep trajectories. Future studies should explore the associations of environmental and psychosocial variables with adolescent physical activity, sedentary behavior and sleep, as these variables may be more easily targeted by interventions and policy changes.

5. This research examined the association of adolescent physical activity, sedentary behavior and sleep with indicators of overweight and obesity at age 18 years. It is still unknown if and how these behaviors are associated with outcomes later in adulthood. Future research in this cohort should explore the prospective association of adolescent physical activity, sedentary behavior and sleep, and cross-sectional association of current adult behaviors, with overweight and obesity in later adulthood.
6. This research was conducted in an urban South African population and may not be generalizable to more rural populations. Additional research is needed on the associations between adolescent physical activity, sedentary behavior and sleep and young-adult overweight and obesity in rural South Africa.
7. Household and family patterns may influence adolescent behaviors and young-adult body composition. The intergenerational effects of household and family patterns are worth examining in future research.

6.5 Public Health Implications

The findings from this dissertation can be used by public health researchers to design interventions, prevention strategies and educational material aimed at reducing the burden of overweight and obesity in South Africa. Taking a life-course approach to this research enabled the identification of risk factors and higher-risk groups earlier in life, supporting current efforts for prevention and control of NCDs before disease occurrence. Understanding how these modifiable risk factors develop over time and which patterns are related to unfavorable body composition will ensure the concentration of intervention resources and efforts where they will have the most impact. Starting public health interventions earlier in adolescence or pre-adolescence will set up healthier lifestyle trajectories that carry into and through adulthood. This research shows that addressing physical activity, sedentary and sleep behaviors earlier in adolescence is important in urban South Africa, as prevention of weight gain may be more effective than weight loss in reducing obesity rates. Addressing these behaviors earlier in adolescence has the potential to promote health in future adults as well as the next generation.

6.6 Conclusions

In conclusion, this dissertation has added to the considerable lack of longitudinal adolescent physical activity, sedentary behavior and sleep data from Africa. The majority of this urban South African study population failed to meet the WHO recommendation for physical activity and engaged in high amounts of sedentary behavior, but reported receiving adequate amounts of sleep over adolescence.

This research has demonstrated the importance of allowing for heterogeneity when examining adolescent physical activity, sedentary behavior and sleep longitudinally. It has shown that there are subsets of individual adolescents in urban South Africa whose behaviors differ from those of the population norm, and who may be at greater/reduced risk of overweight or obesity in young adulthood.

Being consistently physically active and getting more sleep per night throughout adolescence was associated with more favorable young adult body composition in urban South African males. Being more sedentary over adolescence was associated with less favorable anthropometric measurements in urban South African females. These findings suggest that adolescent physical activity, sedentary behavior and sleep are modifiable behaviors that may be contributing to the prevalence of overweight and obesity in urban South African adults. These behaviors are modifiable and may be paths for public health interventions to curb overweight and obesity in South Africa and other LMICs.

References for Chapter 6

1. Chopra M, Lawn JE, Sanders D, Barron P, Abdool Karim SS, Bradshaw D, Jewkes R, Abdool Karim Q, Flisher AJ, Mayosi BM, et al: **Achieving the health Millennium Development Goals for South Africa: challenges and priorities.** *Lancet* 2009, **374:**1023-1031.
2. Pisa PT, Pisa NM: **Economic growth and obesity in South African adults: an ecological analysis between 1994 and 2014.** *Eur J Public Health* 2017, **27:**404-409.
3. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany EC, Biryukov S, Abbafati C, Abera SF, et al: **Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013.** *Lancet* 2014, **384:**766-781.
4. Menschik D, Ahmed S, Alexander MH, Blum R: **Adolescent physical activities as predictors of young adult weight.** *Archives of Pediatrics & Adolescent Medicine* 2008, **162:**29-33.
5. McVeigh J, Smith A, Howie E, Straker L: **Trajectories of Television Watching from Childhood to Early Adulthood and Their Association with Body Composition and Mental Health Outcomes in Young Adults.** *PLoS One* 2016, **11:**e0152879.
6. Fatima Y, Doi SA, Mamun AA: **Longitudinal impact of sleep on overweight and obesity in children and adolescents: a systematic review and bias-adjusted meta-analysis.** *Obes Rev* 2015, **16:**137-149.
7. Dick B, Ferguson BJ: **Health for the world's adolescents: a second chance in the second decade.** *J Adolesc Health* 2015, **56:**3-6.
8. Resnick MD, Catalano RF, Sawyer SM, Viner R, Patton GC: **Seizing the opportunities of adolescent health.** *Lancet* 2012, **379:**1564-1567.
9. Jung T, Wickrama KAS: **An introduction to latent class growth analysis and growth mixture modeling.** *Social and Personality Psych Compass* 2008, **2:**302-317.
10. Dumith S, Hallal P, Reis R, 3rd KH: **Worldwide prevalence of physical inactivity and its association with human development index in 76 countries.** *Prev Med* 2011, **53:**24-28.
11. Katzmarzyk PT: **Physical activity, sedentary behavior, and health: paradigm paralysis or paradigm shift?** *Diabetes* 2010, **59:**2717-2725.
12. Sallis JF, Owen N, Fisher EB: *Ecological models of health behavior and education; theory, research and practice, 4th edn.* San Francisco, CA: Jossey-Bass; 2008.
13. Organization WH: **Health for the world's adolescents: a second chance in the second decade.** Geneva2014.
14. Bauer DJ CP: **Overextraction of latent trajectory classes: much ado about nothing? Reply to Rindskopf (2003), Muthén (2003), and Cudeck and Henly (2003).** *Psychol Methods* 2003, **8:**384–393.